FLORIDA SEA GRANT COLLEGE PROGRAM
SGEP-13 FLSGP-W-01-005 C2



Proceedings of the

FIFTY-FOURTH ANNUAL Gulf and Caribbean Fisheries Institute

PROVIDENCIALES, TURKS & CAICOS ISLANDS

NOVEMBER 2001

HOSTED BY:

THE GOVERNMENT OF THE TURKS & CAICOS ISLANDS

FORT PIERCE, FLORIDA 2003

Gulf and Caribbean Fisheries Institute, Inc.

(A South Carolina Non-Profit Corporation)

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FIFTY- FOURTH ANNUAL

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Turks & Caicos Islands

NOVEMBER 2001

Library of Congress Catalog Card Number
52-033783

Edited by:
R. LeRoy Creswell

FORT PIERCE, FLORIDA 2003

We would like to extend our grateful appreciation to the following sponsors of the 54th Gulf and Caribbean Fisheries Institute

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And to the tireless efforts of the staff of the Turks & Caicos Department of Environmental and Coastal Resources that served as our host.

Opening Remarks

54th Gulf and Caribbean Fisheries Institute
November 12 - 17, 2001
Providenciales, Turks & Caicos Islands, BWI

Bob Glazer, Chairman

Good morning and welcome to the 54th annual Gulf and Caribbean Fisheries Institute. I am very pleased to see so many familiar faces and so many new ones, and I truly appreciate all your efforts to make it here so soon after the tragic events of September 11th.

In many ways this is a homecoming for me. I first cut my teeth in the tropics over 15 years ago no more than five kilometers up the street from where we now sit. Back then it was rare to see even a palm tree on this island – what a difference 15 years makes. But in many ways, it is entirely fitting that this meeting be held in the Turks and Caicos Islands. There are few better examples in the region of visionary planning relative to marine conservation – a good part of the island where we now sit is bordered by marine parks. Later in the week we will all have the opportunity to visit a marine park.

Last year we promised you many new and exciting initiatives for GCFI. This year we have begun to make good on that promise. On Monday, we have a session dealing in-part with the Lacey Act, a mechanism by which nations throughout the region can ensure that their fisheries laws are enforced in the U.S. even when the fisheries products have left the original jurisdiction. Another session will deal with fish spawning aggregations. This special session is a warm-up for a comprehensive symposium on the same topic for the 2002 meeting. And this year, together with many partners, we are hosting the most comprehensive symposium in the region dedicated to Marine Protected Areas. From this two-day symposium, a peer-reviewed publication will be produced in association with the journal Gulf and Caribbean Research, published at the University of Southern Mississippi. It will be distributed to all members of GCFI. Of course, the membership will also receive the proceedings of this meeting.

But we will not rest on our laurels. The Board of Directors of GCFI recognizes that there are many more services that will be helpful to our membership. We are actively developing initiatives that will provide enhanced opportunities to you in the upcoming years. As I did last year, I encourage each of you to provide feedback to the Board of Directors so we may know your needs and concerns so we may make a better GCFI. Even better, I encourage each of you to become more active in your GCFI.

Finally, I wish each of you a productive meeting and hope you renew friendships, make new acquaintances, develop partnerships and collaborations, learn new science, and return home the richer for it.

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The Effects of Trap Fishing in Coralline Habitats: What Do We Know? How Do We Learn More?

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ABSTRACT

Trap fishing in United States waters occurs in coral habitats in the Florida Keys, Puerto Rico, and the Virgin Islands. Although the numbers of traps fished and the general placement areas of traps are known, there is little information on the exact placement of traps by habitat type, seasonal movement of traps among habitats, and potential for gear impacts to various habitats such as seagrasses, macroalgae, sponges, and hard and soft corals. We are beginning to examine the placement of traps in relation to habitat types and, in the future, will be conducting underwater surveys of traps and fishing techniques in all three locales to determine potential for habitat damage and for gear or method modifications, if necessary.

KEYWORDS: Coral reef ecosystem, gear impacts, traps

INTRODUCTION

The effects of trap fishing on essential fish habitats, particularly coral reefs and reef-associated habitats, are largely unstudied. The U. S. Department of Commerce's NOAA Fisheries has identified traps as one of five types of fishing gear with the highest potential for impacting essential fish habitat (Hamilton 2000). Trap fishing occurs in coralline habitats under the jurisdiction of all three federal fishery management councils in the southeast U. S. and in state, territory, and commonwealth waters. Traps are used to capture spiny lobster *Panulirus argus* in Florida (Matthews and Williams 2000) and spiny lobster plus various reef fishes in Puerto Rico (Matos-Caraballo 2000a,b) and the U. S. Virgin Islands (Garrison et al. 1998).

We are building on preliminary investigations conducted in Puerto Rico (Appeldoorn et al. 2000) to compare and contrast the distribution and potential habitat effects of trap fishing in the Florida Keys, Puerto Rico, and the U.S. Virgin Islands. Our objectives are:

i) To review the known distributions of fishing effort and habitats and to suggest refinements,
ii) To develop methods for rapid, large scale surveys of the distribution of traps and potential for habitat damage in both shallow and deep waters, and

iii) To document gear effects on habitat and to suggest less destructive fishing methods, if needed.

WHAT WE KNOW

Florida Keys

The Florida Marine Research Institute (FMRI) employs a ticket system wherein fishers record a variety of data for each trip completed during the spiny lobster fishing season (August - March). Data include biomass landed, number of traps fished, soak times, coastal area, and whether traps were fished inshore / bay, offshore, or in federal waters. Landings generally are highest in August and decline through March. During 2000, most landings were recorded from the vicinities of the Dry Tortugas, Key West, and Marathon (83% of the 1.93 million kg total; NOAA Fisheries, Miami, FL unpublished data). Approximately 20% of the total landings came from inshore or bay waters (mostly from the Florida Bay region near Marathon), while the remaining 80% came from offshore state and federal waters. Over 500,000 lobster traps were permitted for the 2000 - 2001 fishing season, approximately 90% of the traps were fished as singles, and traps were fished as deep as 45 - 60 m (T. Matthews, FMRI, Marathon, FL pers. comm.).

Commercial fishers are requested to participate in an annual FMRI questionnaire that asks them to indicate on a map where they fished relative to a series of coastal markers (reefs, shallows, and lights differing from the aforementioned coastal areas) and how many traps they deployed each month. We used data collected after the 2000 - 2001 season to generate a finer-scale picture of the distribution of effort in relation to available habitat maps. Trap effort was expended on both Atlantic and Gulf of Mexico sides of the Florida Keys and the Dry Tortugas and extended along the southeastern mainland north of Biscayne Bay and Fowey Rocks (Figure 1). Effort was highest in the central Keys (particularly Bullard Light in the Gulf and Looe and Sombrero Keys in the Atlantic) and lowest at the extremes (northeast around Fowey Rocks, and southwest around Smith Shoal, Ellis Rock, and Cosgrove Shoal). There appeared to be little difference in proportional allocation of effort among areas between start (August 2000) and end (March 2001) of the fishing season, although the total number of traps in use decreased by 30%.

There have been several cooperative characterizations of south Florida benthic habitats (available from FMRI, St. Petersburg, FL, and NOAA, National Ocean Service, Silver Spring, MD). We have assembled these data in a geographical information system (GIS) format in order to overlay apparent fishing effort on habitat characteristics. Habitat categories have been combined to reflect three dominant features: coral reef, seagrass, and unknown or uninterpreted substrates due to poor water clarity (Figure 2). Corals are found primarily on the Atlantic side of the islands and around the Dry Tortugas and Marquesas. Seagrasses are the primary live bottom habitat inshore and are found in shallower waters inshore of reefs. Other live bottom and bare substrates (not pictured) are scattered throughout. Characterizations, however, have been depth-limited (< 30 m).

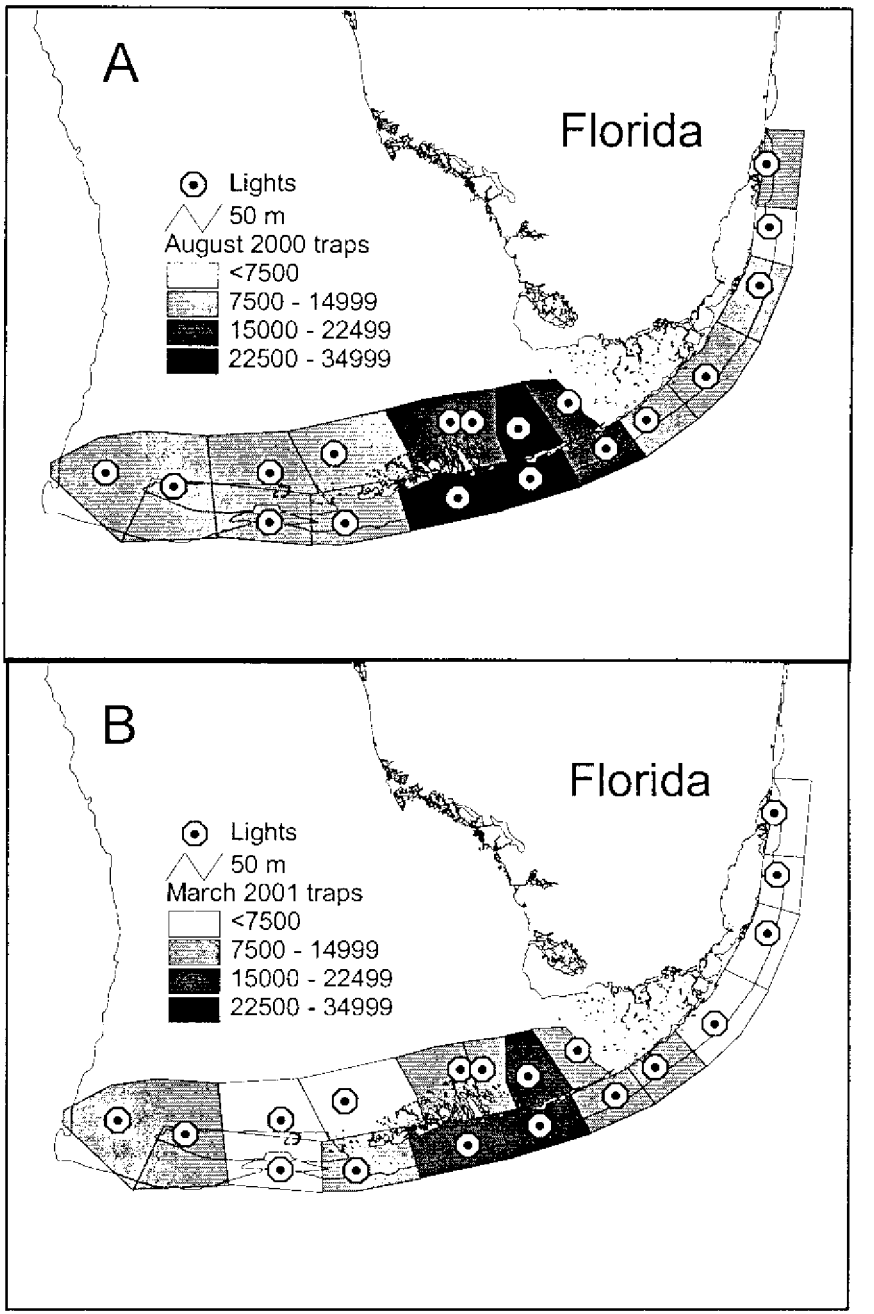


Figure 1. Distribution of lobster traps fished in 18 sections of the Florida Keys during August 2000 (A) and March 2001 (B). Lights refer to named shoals.

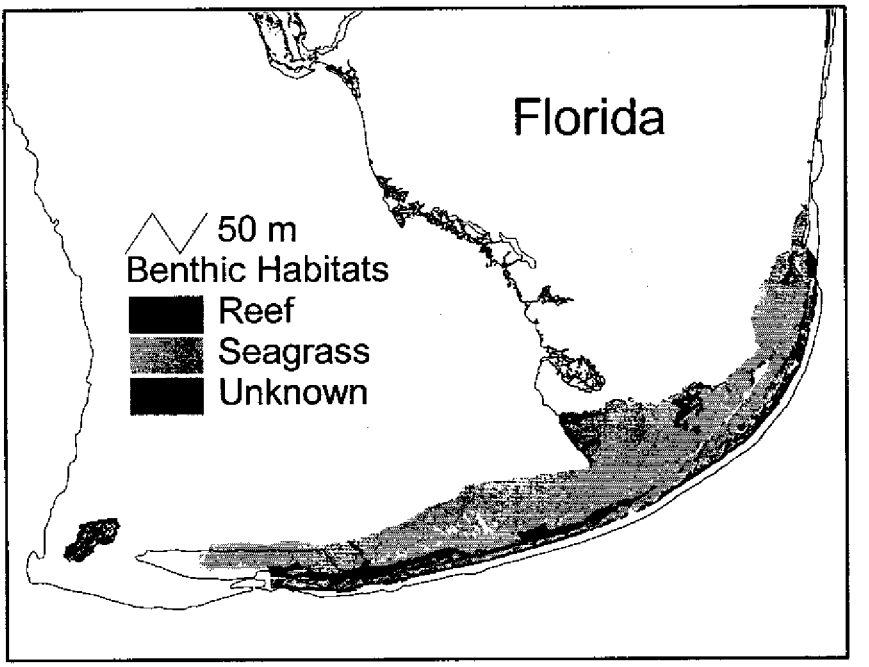


Figure 2. Dominant benthic habitats of the Florida Keys.

If we assume as a null hypothesis that fishing effort was spread evenly over all habitat types within each section of the coast, then we can get a first approximation of which habitat types could be impacted by trap fishing in each region. Most effort in inshore and bay waters appears to be placed in seagrass habitats, but offshore effort appears to have a high potential for being placed in coral habitats. Deeper water habitats have not been characterized, and thus there is some effort expended over unknown bottom types, presumably coralline in nature.

Puerto Rico

The Puerto Rico Department of Natural and Environmental Resources (PRDNER) employs a ticket system wherein fishers record a variety of data for each trip completed during the year (Matos-Caraballo 2000a). Data include species biomass landed, number of traps, hours fished, and municipality landing areas. Fish traps are employed in almost every municipality but are most numerous in the southwest (Cabo Rojo, Lajas), south central (Guayama), and east coasts (Culebra and Naguabo; 44% of the 11,213 total traps reported), whereas spiny lobster traps are almost all found on the east (Vieques and Culebra) and south (Juana Diaz; 52% of the 4,268 total traps reported; Matos-Caraballo 2000b). Trap fishery landings during 2000 included 223,000 kg of fish (primarily snappers, boxfish, grunts and groupers) and 50,700 kg of spiny lobster, and most landings were recorded from the

aforementioned municipalities (Figure 3; NOAA Fisheries unpublished data). Examination of the distribution of traps and landings for 2000 indicates similar areas of concentration (Figure 3), however, there appeared to be under-reporting of traps in the southwest municipalities. Most traps are fished singly, at least in the southwest (Valdéz-Pizzini et al. 1997, Jean-Baptiste 1999, Appeldoorn et al. 2000).

Cooperative habitat characterization of shallow Puerto Rico benthic habitats by the University of Puerto Rico, PRDNER, and NOAA is still in progress (J. Christensen, U. S. Department of Commerce, NOAA, National Ocean Service, Silver Spring, MD, pers. comm.). Preliminary habitat data for the La Parguera (Lajas) area of southwestern Puerto Rico were available to estimate potential for habitat disturbance (Figure 4). Major habitat categories included coral reef, seagrass, bare sand or mud, and unknown or uninterpreted habitats. Corals dominate the offshore area, while seagrasses are primary in shallow inshore waters and around reefs. Bare substrates are scattered in the eastern section, and a large area of unknown habitat dominates the central section. Again, habitat characterizations have been depth-limited (< 30 m), and fishing may extend beyond these depths over unknown habitat types.

Assuming that fishing effort was spread evenly over all habitat types within the Lajas area, then the largest amount of effort would likely be placed in coral habitats. Preliminary observations by Appeldoorn et al. (2000) indicated that 57 of 100 traps were placed over or adjacent to coral. Given the position and extent of reefs, offshore effort occurring deeper than the mapped areas appears to have a high potential for being placed in coral habitats.

U. S. Virgin Islands

The Virgin Islands Department of Planning and Natural Resources (VIDPNR) employs a monthly log book wherein fishers record a variety of data for each day fished during the year. Data include biomass landed by major family groups (such as groupers, parrotfishes, or lobsters), number and type of traps fished, and area fished around each island. Landings vary by season, location, and species groups. During 1998 (the latest complete data set), fish trap landings were highest during January - March and lowest during May - June, whereas lobster trap landings were highest during January - February and lowest during July-August (NOAA Fisheries unpublished data). Landings for 1998 included 161,000 kg of fishes (dominated by parrotfishes, triggerfishes, and grunts) and 16,800 kg of spiny lobsters. Approximately 8,500 traps are permitted (1,500 in St. Croix and 7,000 in St. Thomas and St. John), with about half of the fishers using single traps and half using strings that may include hundreds of traps (B. Kojis, VIDPNR, St. Thomas, USVI, pers. comm.). Traps were most often placed off southwestern St. Croix and southern and western St. Thomas and St. John (Figure 5; NOAA Fisheries unpublished data).

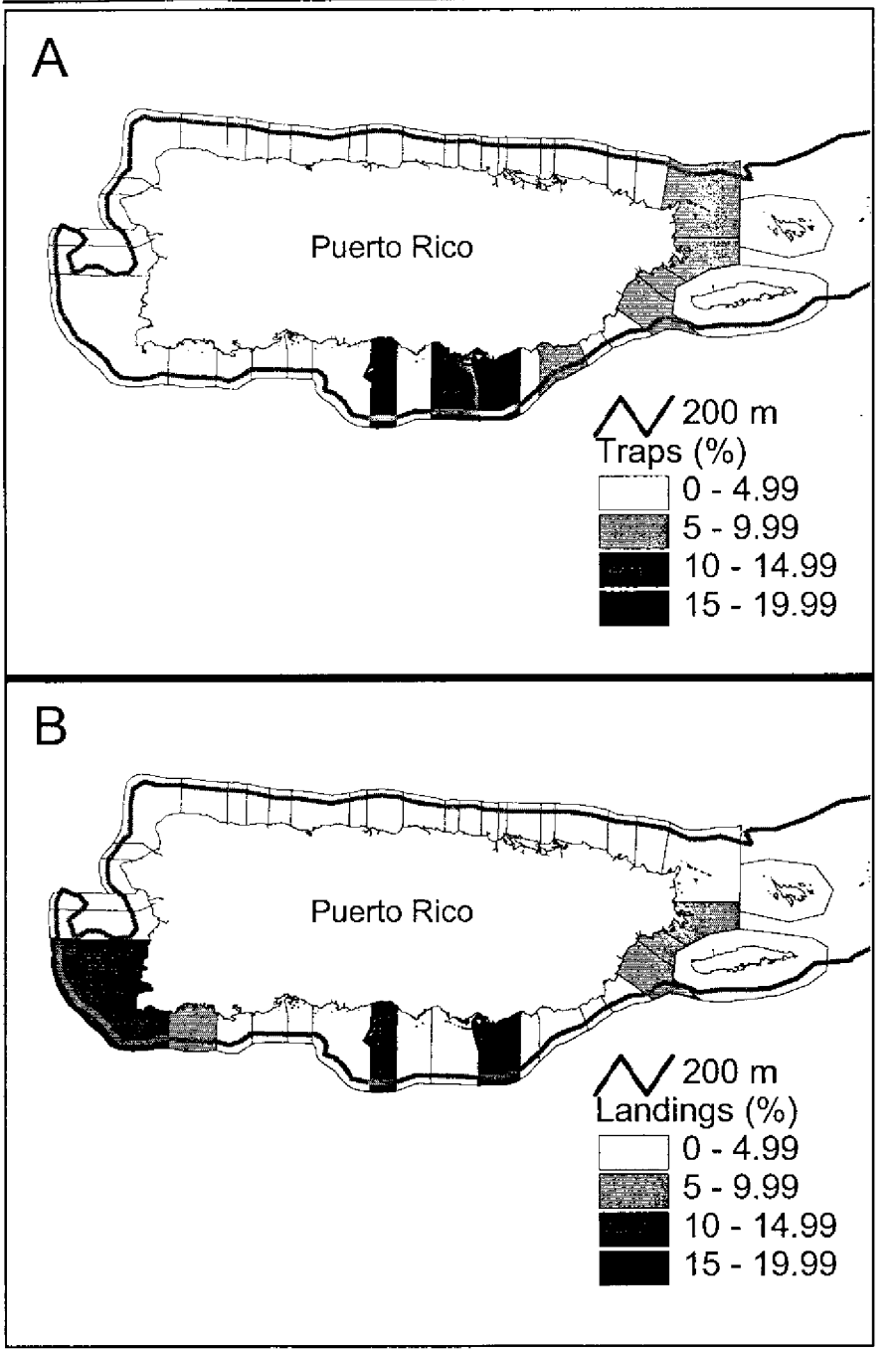


Figure 3. Proportional distribution of all traps fished (A) and all landings (B) off 42 municipalities in Puerto Rico during 2000.

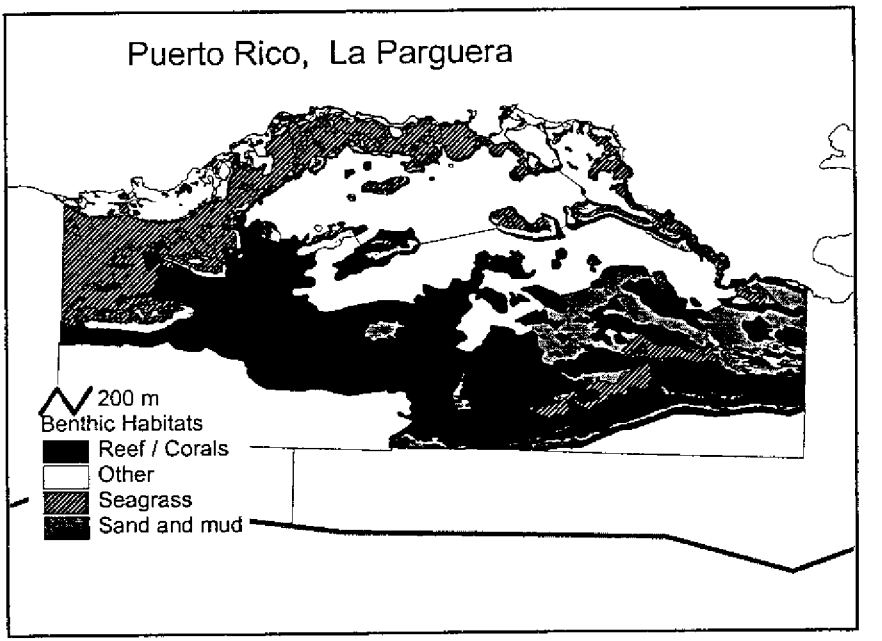


Figure 4. Dominant benthic habitats off La Parguera, Lajas, Puerto Rico.

Characterization of shallow benthic habitats has been completed recently (cooperators include University of the Virgin Islands, VIDPNR, U. S. Geological Survey, National Park Service, and NOAA; available from U. S. Department of Commerce, NOAA, National Ocean Service, Silver Spring, MD). Habitat categories have been combined to reflect system dominants such as coral reef, seagrass, macroalgae, and unknown or uninterpreted substrates (Figure 6). Coral and seagrass dominate the fishable area of St. Croix, while extensive algal plains are prominent in the reef systems of St. Thomas and St. John. Again, deeper waters are of unknown habitat type but they may not all be coral reefs. Much of the trap fishing effort is offshore and in waters deeper than those included in the mapping effort (B. Kojis, VIDPNR, St. Thomas, USVI, pers. comm.).

Gear Impacts

Traps may impact coralline habitat types during setting or hauling, while fishing, during storms, or if lost. When set or hauled, traps may physically damage hard and soft corals, sponges, seagrasses, and macroalgae. While in place, traps may flatten structural components of corals as well as plants, leading to injury and reduced growth or death. If traps are set in strings or lines, the connecting lines may abrade or shear structures surrounding them. Grapples used for retrieval of traps or trap lines potentially add another source of damage. Storms may cause damage by dragging traps and trap lines over the bottom. Lost traps could cause continuous habitat damage until they degrade.

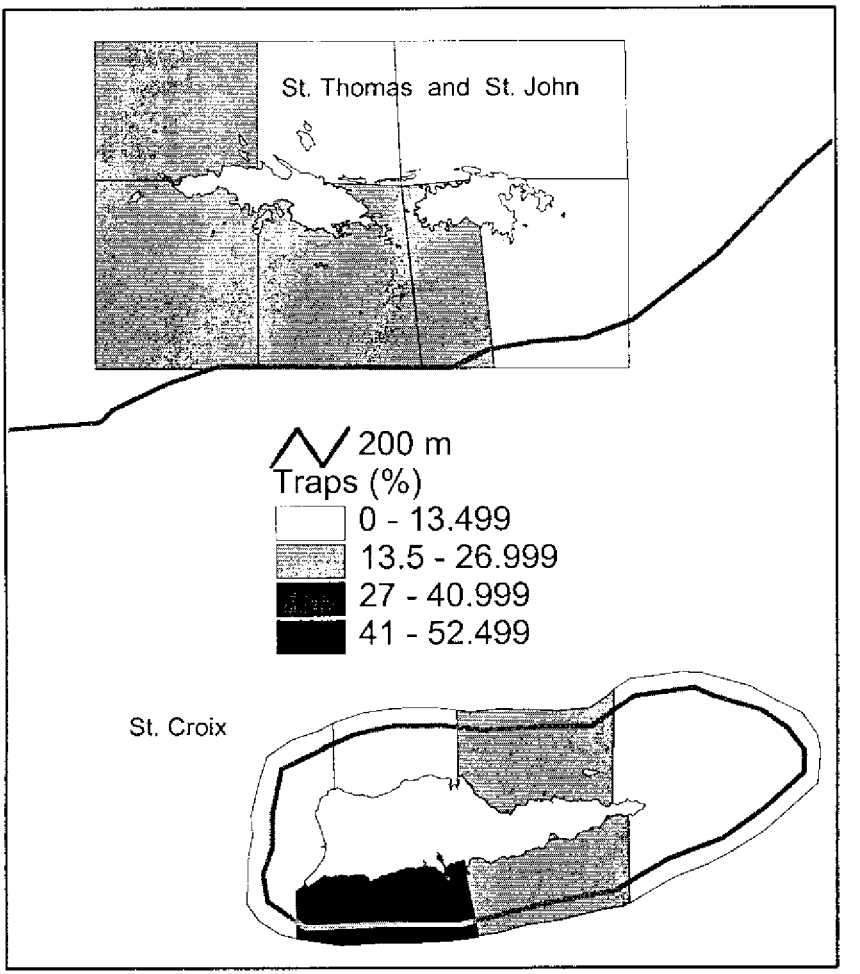


Figure 5. Proportional distribution of all traps fished in the U. S. Virgin Islands during 1998 (sum to 100% each for St. Croix and for St. Thomas + St. John).

Few studies have been conducted to assess the potential for trap-induced injuries to coralline habitats. One inshore study indicated that lobster traps were placed primarily on turtlegrass *Thalassia testudinum* habitats in Biscayne Bay, Florida (Ault et al. 1997). Traps were responsible for a 7% loss of turtlegrass cover after one week (typical soak time) and 26% cover after one month (simulating a lost trap). One of the more well-studied offshore areas is Lajas, southwestern Puerto Rico. Valdéz-Pizzini et al. (1997) and Jean-Baptiste (1999) examined the distribution of traps off Lajas and found that the majority of traps were located over algal plains or sand substrates. Appeldoorn et al. (2000) noted that while 45 of 100 of traps examined in this area were placed in sand / mud habitats, another 44 were

placed in hard bottom and reef habitats. Other studies have examined trap placement near St. Thomas and St. John, U. S. Virgin Islands. Quandt (1999) noted that 18 traps were almost evenly split between sand or rubble and reef around St. Thomas. Garrison et al. (in prep.) checked 295 traps, noting that the largest portion were set in algal plains around St. John but that relatively large numbers of traps were found in octocoral and hard coral substrates. Three studies have attempted to quantify damage to coralline habitats from trap fishing. Both Quandt (1999) and Appeldoorn et al. (2000) found the actual areas of damage to corals, sponges, and gorgonians was low (2 - 5%), but the proportions of colonies damaged was high (up to 50%). Eno et al. (2001) noted that lobster and crab traps in Great Britain bent and uprooted sea pens, bent but did not damage sea fans, and damaged some hard coral colonies.

HOW WE PROPOSE TO LEARN MORE

One aspect we have little knowledge of in most of the trap fishing areas is where the traps are actually placed in relation to the habitats under and adjoining them. In the near future, we will be mapping the distribution of trap effort in selected areas of the Florida Keys, Puerto Rico, and the U. S. Virgin Islands using small boat transects and GPS systems. We will compare these data to available benthic habitat maps in a GIS system, assessing seasonal and spatial variations in effort data collected by local partners with local knowledge (e.g., FMRI, VIDPNR, University of Puerto Rico). We will compare aerial transects versus boat transects of trap locations in an attempt to collect more synoptic trap distribution patterns. We will compare these data against fishery-dependent data to determine whether these alternative methods could enhance local fishery management.

There is a need to examine the underwater placement of a large number of traps using standard methods in all locations, in order to have a more synoptic determination of potential habitat damage. We intend to dive on hundreds of traps in each area to verify habitat placement and to quantify damage beneath and adjacent to traps. However, the process of diving on a large number of traps is limited by bottom time, especially if one has few divers and traps are fished beyond 40 m depths. We will develop underwater video techniques (using a remotely operated vehicle) for benthic assessment of habitat damage in deeper waters that are comparable to shallow water diver techniques used in Puerto Rico (Appeldoorn et al. 2000). We intend to compare diver and underwater video observations in both trapped and non-trapped locations.

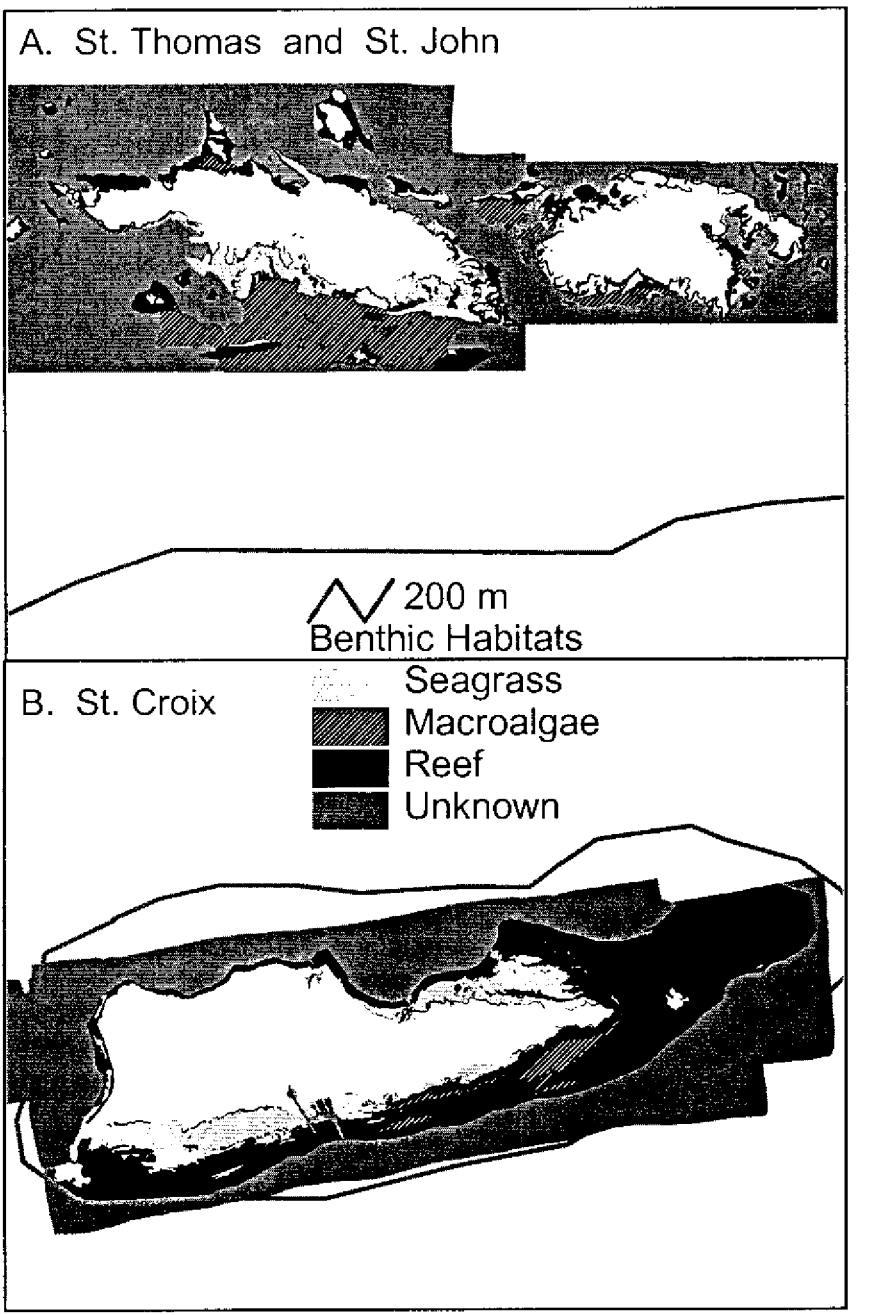


Figure 6. Dominant benthic habitats for the U. S. Virgin Islands.

Appeldoorn et al. (2000) noted that the process of trap hauling may inflict extra damage to the substrate. We will work with local fishers to study their trap fishing techniques, using underwater video to examine trap setting, trap hauling, grappling, and anchoring, in order to quantify and differentiate among habitat effects. Permanent locations for long term monitoring of habitat damage and recovery will be established in representative habitats with emphasis on marine reserve areas as controls. Trapping gear and techniques vary significantly in each of the three geographic locations, and inter-regional comparisons will allow identification of more habitat-friendly gear or techniques that can be recommended for fisher and management agency consideration.

ACKNOWLEDGMENTS

This project was funded by the NOAA Coral Reef Initiative. B. Kojis and R. Uwate (Virgin Islands Department of Planning and Natural Resources) and T. Matthews (Florida Marine Research Institute) provided unpublished data and information. J. Bennett (NOAA Fisheries Miami) provided landings data.

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Potential Impacts of Industrial Development on Coastal Fisheries in the Gulf of Paria, Trinidad

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ABSTRACT

Four fish landing sites on the west coast of Trinidad lie within the area for proposed expansion of an industrial complex. This would increase the complement of industries such as ammonia, methanol, urea, iron, and steel production plants. Such development has the potential to change the present fishery related activities of the four sites. In Trinidad and Tobago tourism, industrial development, conservation, recreational and traditional uses including fishing, all compete for access to the coastal zone often leading to user conflicts. The importance of the fisheries sector needs to be better represented in the broader context of coastal area management.

The fishery related activities at these landing sites were characterised through the use of interviews, trawl surveys, and secondary data from the Fisheries Division and a fishing association. Potential impacts of the proposed development on fishing activities were evaluated based on a programmatic environmental impact assessment conducted by the Institute of Marine Affairs (IMA). Two hundred and forty four fisherfolk using seventy-seven fishing boats operate from these landing sites exploiting fish resources mainly in the nearshore and offshore areas of the coastal zone of the Gulf of Paria. Changes in the terrestrial and nearshore areas of the coastal zone will result in changes of varying degrees to fishing activities at all landing sites. A major perception by the fisherfolk is the negative impact of increased pollution by this industrial complex on their livelihoods. It is recommended that prior to development any resultant changes, particularly those that cannot be mitigated, be discussed with fisherfolk through consultative workshops and meetings. The final design of the expansion of the industrial estate should accommodate fishery related activities resulting in the least disruption to the landing sites.

KEYWORDS: Coastal area management, fisheries, Trinidad

INTRODUCTION

In Trinidad and Tobago industrial development, tourism, conservation, recreational and traditional uses including fishing, all compete for access to the coastal area often leading to user conflicts. This coastal area is a transitional region where land meets the sea – a region encompassing watershed, floodplains, shorelands, beaches, mangroves, estuaries, bays, offshore waters, and the continental

shelf. In Small Island Developing States (SIDS) such as Trinidad and Tobago, the whole island can be considered a coastal area for land use control purposes (McShine 1996). The fisheries sector depends on the coastal area both directly in terms of resources and space and indirectly by factors affecting biological productivity (FAO 1998). This makes the sector particularly susceptible to land- and sea-based activities that have an impact on coastal environment.

The economy of Trinidad and Tobago is dependent on the energy sector, which is the most significant contributor to foreign exchange earnings of the country. Export data for 1994 listed crude oil and refined products as accounting for about 45% (TT$ 5.6 B; US$ 1= TT$6.0) of total export earnings while petrochemical exports account for around 30% of export earnings. Fish and fish products exported in 1994 rank twentieth (TT$ 53M) (Trade Point, 2001). The relative importance of the industrial sector is a significant factor for prioritising access to the coast area of Trinidad. This is often to the detriment of the fisheries sector, and the current legislative framework cannot facilitate changes to the fisheries sector that result from this demand for use of the coastal area.

The Fisheries Division of Trinidad and Tobago in conjunction with the Food and Agricultural Organisation of the United Nations (FAO) developed a draft formal policy for the fisheries sector (Fisheries Division 1997). However, the fisheries sector is still governed by the Fisheries Act (1916) and the Archipelagic Waters and Exclusive Economic Zone (EEZ) Act (1986) which regulate fishing activities in Trinidad and Tobago (IMA 1999a). The Fisheries Act regulates the size of mesh, form, and dimensions of nets or appliances for fishing.

An expansion of an industrial estate and port facilities at Point Lisas on the west coast of Trinidad is earmarked for development, Figure 1. This estate, established in the 1960s, now occupies an area of approximately 900 ha and accommodates about 90 companies including three ammonia/nitrogen plants, five methanol plants, three iron and steel plants, power generation plant and downstream industries (IMA 1998a). The port facilities have docking bays, navigational channels and turning basins and dedicated facilities for steel, ammonia, urea, base oil, methanol and additives for lube oil manufacturers. It also handles general cargo and minor dry bulk operations. The area proposed for expansion consists of approximately 400ha of sugarcane cultivation, wetlands and residential communities. Included in the Estate developmental plans is the reclamation of 200 ha extending from the western portion of the proposed expansion.

Four fish landing sites at Carli Bay, Orange Valley, Waterloo and Brickfield are located within this expansion Figure 1. Carli Bay has a history of impacts on its fishing activities, in the 1980's the main river, which received much of the effluents from the estate, was earmarked to be diverted into Carli Bay and the subsequent dredge spoil was dumped on a herbaceous swamp. The diversion was to accommodate large volumes of hot water entering the river, to increase the circulation path into Carli Bay and the adjacent bay, and to increase land space for a housing complex associated with the estate (McShine-Mutunhu 1985). In anticipation, fishing facilities with slipways and vending facilities were constructed

for the fisherfolk on the banks of this channel. Although the diversion was never completed, the fisherfolk still used the channel for a few years before it silted up and the fishing facilities was later abandoned. The fisherfolk now operate from the beach with no facilities.

This paper describes the baseline conditions of the fishing activities of four fish landing sites at Carli Bay, Orange Valley, Waterloo and Brickfield on the west coast of Trinidad and examines the potential impacts such an expansion might have on the fishing activities.

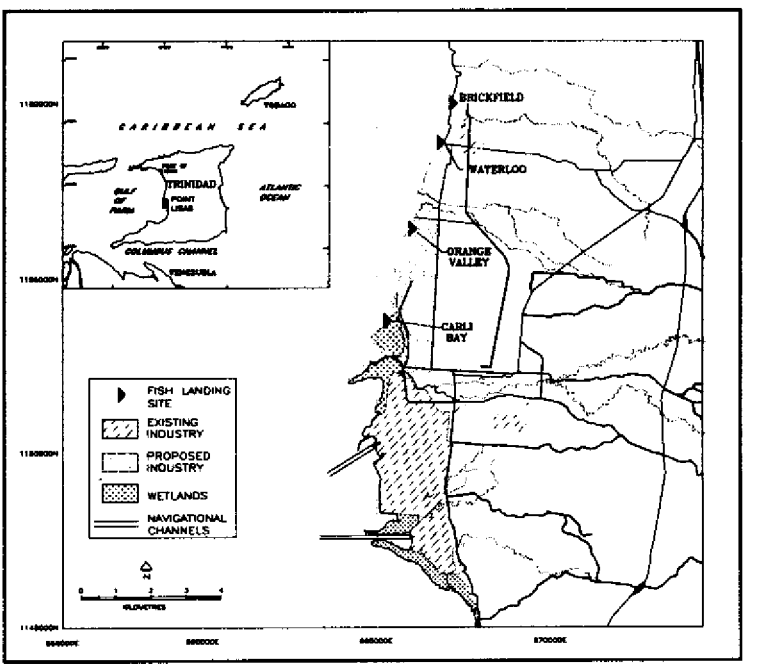


Figure 1. Location of fish landing sites adjacent to industrial estate, Pt. Lisas, Trinidad

METHODOLOGY

Trawl surveys were used to determine the demersal species composition of the nearshore environment. The nearshore marine area was defined as the region extending to approximately five (5) metre water depth. Six trawl surveys were undertaken between May and July 1998 at 1.5 – 2.0 m, 3.0 - 3.5 m and 4.0 - 5.75 m using a Type II trawler. This trawler was a 9.4 m wooden/fibreglass pirogue with an inboard engine. It was equipped with a single otter trawl with a headrope length of 8.96m and a cod end stretched mesh size of 4cm. Entire catches were sorted and

species identified using (Fischer 1978, Cervigón et al. 1993). Species diversity was calculated using the Shannon-Wiener Index.

A Frame Survey was conducted in September 1998 to characterize the fishing activities at each of the landing sites using a questionnaire and maps to identify fishing areas. The survey was administered over one week and targeted vessel owners and captains. The data was incorporated into a Microsoft Access database and analyzed to yield information on fishing units by home port, fishing gear by home port, fishers involved in primary gear fisheries, species caught by primary gear, catches by primary gear and problems and impacts that the fisherfolk held regarding the proposed expansion.

Responses on problems in the fishing industry were grouped into the following categories; conflict with other fishers, damage to vessel/gear, dumping of garbage, fishery economic factors, lack of facilities, loss of fishing grounds, pollution by the industrial estate, safety hazards, siltation and others. Perceptions of impacts of the proposed expansion were grouped into the following categories; relocation/compensation, pollution, loss of fishing grounds, improved facilities, safety hazard, unemployment and other. Potential impacts from the proposed Industrial Estate expansion were adapted from a matrix developed from a programmatic environmental impact assessment conducted by the Institute of Marine Affairs (1999a).

The resulting impacts on the fisheries were categorised into terrestrial, nearshore and offshore environments of the coastal area. The impacts were further classified based on effects on the fisheries ecosystem and social and economic benefits of the fisherfolk. The linkages as well as causal relationships between the different groups of potential impacts were identified and expressed in the form of primary, secondary and tertiary potential impacts.

RESULTS

Fish Resources of the Nearshore Area

The species composition of the nearshore area in the region of the proposed expansion is diverse comprising 100 species from 56 families. The fish group consists of 68 species from 34 families. It was dominated by clupeoids, scianids, haemulids, carangids and plueronectids. There were five penaeid shrimp species; white shrimp *Penaeus schmitti*, pink shrimp *Penaeus notialis*, brown schrimp *Penaeus subtilis*, red-spotted shrimp, *Penaeus brasiliensis, and* sea-bob *Xyphopenaeus kroyeri*, and four species of portunid crab. The Shannon-Weiner diversity indices for the six trawls ranged from 2.02 – 2.67, indicating a high diversity. Juveniles of many species of fish, shrimp and crabs were present (IMA 1998b) as well as gravid females of the white shrimp and portunid crabs.

Fishing Facilities

Orange Valley is the largest landing site of the four sites with two slipways, two net and boat repair sheds, an engine repair area and an 80-locker building. The adjacent wholesale market consists of a tiled building with aluminum tables. Cold storage facilities in the market are no longer operational and are used for general storage. This market is one of the three largest fish markets in Trinidad. At Brickfield there is a slipway, locker building with storage for approximately 45 lockers, and a net and boat repair shed. There are no useable facilities for fisherfolk at Carli Bay, and the fish are landed on the beach and the boats are anchored in the Bay. At Waterloo, the fisherfolk have constructed makeshift storage areas for their engines and gear, and to repair nets. More permanent concrete storage buildings are replacing some of these temporary structures and a slipway is presently under construction by the fisherfolk. There are a few stalls for selling catches, and there is neither electricity nor pipe-borne water supply. With the exception of Carli Bay, all the sites are easily accessible by roads.

Fishing Methods

The fish resources are exploited by a variety of fishing methods and the resulting fisheries are categorised by gear type (Table I). There are the gillnet, line, trawl and Italian seine or tuck seine fisheries. The trawl fishery comprises four fleets based on the size of vessel and degree of mechanisation (Kuruvilla et al. 2000). Type I and Type II fleets are artisanal with a single otter trawl, the Type III is semi-industrial with a larger stern trawl and the Type IV are the industrial gulf of Mexico design vessels. The trawl fishery is restricted to Orange Valley and Waterloo (Table 1). At Waterloo however all the trawlers are Type II whereas at Orange Valley the entire Type III semi-industrial fleet is based. The gillnet fishery comprise both braided cotton multifilament and nylon monofilament nets. This is the dominant fishery at Carli Bay (Table 1). In the line fishery the primary fishing method is the bottom-set long-line locally called "palangue" which has about 2000 – 5000 hooks per line. A boat may have 1 to 3 palangues. Other secondary methods used by the line fishery include banking, towing, and "a-la-vive". Found only at Carli Bay, the Italian seine or Tuck seine is made of a much heavier braided cotton and use like a purse to catch schooling pelagics.

Fishing Areas

The fisherfolk from the four landing sites exploit fishing areas throughout the Gulf of Paria, the south coast and north coast of Trinidad. The fishing areas are dependent on the type of vessel, engine size and time of year. They predominantly fish in the Gulf of Paria, but industrial trawlers extend to the north and south coast. Artisanal Type I and II trawlers concentrate their fishing around Point Lisas.

Table 1. Summary of fishing methods, boats and fishermen at four landing sites on the west coast of Trinidad

Landing Site	Fishing Methods		No. of Boats	No. of fishermen
Carli Bay	Gillnet	Monofilament (P)	9	26
		Multifilament (P)	2	8
		Multi/monofilament (P)	2	2
	Line fishing	Banking (P)	1	1
	Italian Seine (P)		4	32
			18	69
Orange Valley	Gillnet	Multifilament (P)	1	3
		Monofilament (P)	4	11
	Line fishing	Bottom set long-line (S)		
		Banking (S)		
	Trawling	Type I (P)	1	2
		Type II (P)	5	22
		Type III (P)	10	15
		Type IV (P)	5	22
			26	75
Waterloo	Gillnet	Monofilament (P)	1	2
	Line fishing	Bottom set long-line (P)	4	11
		Banking (S)		
	Trawling	Type II (P)	8	27
			13	40
Brickfield	Gillnet	Monofilament (P)	3	9
	Line fishing	Bottom set long-line (P)	17	51
		Banking (S)		
		A-la-vive (S)		
		Towing (S)		
			20	60
		TOTAL	77	244

(P) - Primary fishing method
(S) - Secondary fishing method
Type I - Artisanal otter trawl
Type II - Artisanal otter trawl
Type III - (semi-industrial) Stern trawl
Type IV - (industrial) Gulf-of-Mexico trawl

Catch Data

Monofilament gillnets are usually bottom-set for demersal species mainly sciaenids and lutjanids. At Carli Bay the target species is the yellow mouth croaker, *Micropogonias furnieri*. The multifilament nets are generally set at the surface for pelagics mainly scombrids such the Spanish mackerel *Scomberomorus brasiliensis*

and the kingfish, *S. cavalla* and carangids. Daily records from the Carli Bay Fishing Co-operative Society Limited showed that 260 metric tons (mt) of fish were landed valued. This was locally valued at TT$ 1.45 million. This value is the ex-vessel value and does not take into account the added value of the catch. Of this landed catch, *M. furnieri* accounted for 213 mt locally valued at TT$ 1.07 million. Estimates from the Frame Survey suggest that for Orange Valley, Waterloo and Brickfield, this fishery landed approximately 82 mt, 8 mt and 49 mt, respectively. Trawling is the most important fishery both in terms of landed weight and value. The target species for the trawl fishery are five penaeid shrimp species. Important fish species caught include *M. furnieri*, and *Cynoscion* spp. The artisanal trawl fishery for Orange Valley and Waterloo were estimated to have landed 138mt and 141mt annually. No estimates for the Type III trawlers were available from the Frame Survey. Estimates from the Frame Survey suggested that 282mt for the Type IV trawlers were landed annually. The line fishery targets both pelagic and demersal species depending on the geartype employed. Species include *S. brasiliensis*, *S cavalla*, *Caranx hippos*, crevalle jack, *Cynocion* spp. lutjanids, and carcharhinid sharks. Based on the Frame Survey 588mt of fish were landed for Brickfield. The Italian seine targets schooling pelagics such *S. brasiliensis* and *S. cavalla* and herrings. No verifiable catch data were available for this fishery.

Markets

The three wholesale markets are located on the west coast of Trinidad, including the Orange Valley fish market. Despite this, most of the catch is landed at the homeports of vessels. Catch is purchased by wholesale vendors and retailed to processing plants, smaller buyers, restaurants and supermarkets. Fish is also sold in the communities by other vendors. The fish from the gillnet fishery landed at Carli Bay is exported to Canada, the Unites States and occasionally the United Kingdom. The Type IV vessels are the only exception in landing their catch at all the major wholesale markets, predominantly at Port of Spain and Orange Valley. Most of the shrimp from the semi-industrial and industrial fleets are exported to the United States and other Caribbean countries.

Socio-economic Profiles

Fishing is an all-male occupation providing employment for fisherfolk in Carli Bay, Brickfield, and Waterloo. More than 75% of the boat owners and captains are engaged full-time in the fishing industry. Other occupations include, truckers, masons, and workers in the sugarcane industry. Most of the boat owners and captains fall within the 30-59 age group. The most common primary reason for choosing fishing as an occupation was family tradition and a lack of an alternative employment option.

Problems in the Fishing Industry as Identified by the Fisherfolk

The major problems identified by the boat owners and captains at the four landing sites were conflict with other fisherfolk (20.1 %), perceived pollution from

the Point Lisas Industrial Complex (16.5%) and siltation (15.8%) (Figure 2). Other problems include lack of facilities (11.4%), fishery economic factors (10.8%) and damage to vessel or gear (9.1%). Conflict among the fisherfolk is largely related to the trawlers, with fishers from the line and gillnets fisheries at Brickfield and Carli Bay having the highest percentage of conflict with them.

Some problems are specific to a landing site. For example, siltation was highest for Orange Valley and Brickfield. At these sites, the mudflats can be completed exposed for about 200-300 m from the shoreline at low tide. Loss of fishing grounds is closely related to the trawlers who indicated that areas outside of the existing Point Lisas Industrial Estate was once prime trawling grounds. The close proximity of Carli Bay to the Industrial Estate is also related to the loss of fishing grounds. Safety hazards mainly related to theft and piracy has affected the Carli Bay fisherfolk and their practice of operating at night makes them particularly vulnerable.

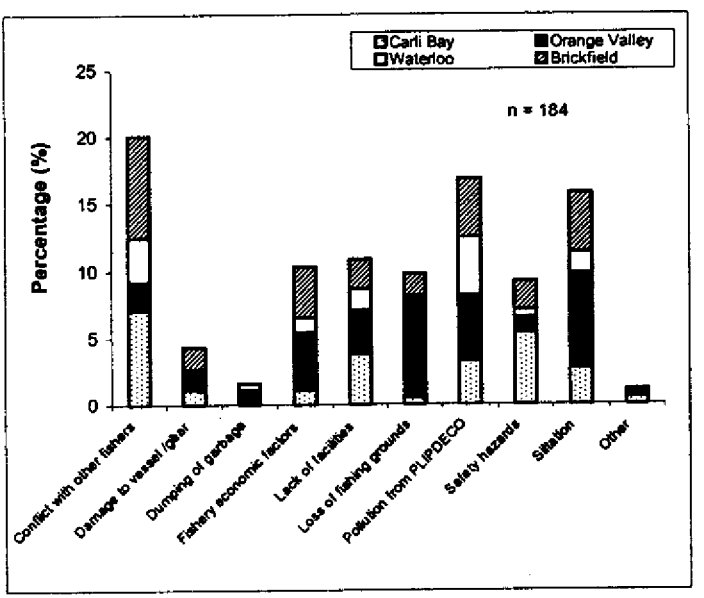


Figure 2. Perceived problems in the fishing industry by fisherfolk at four landing sites on the west coast of Trinidad

Perceived Impacts of the Industrial Expansion

The major concerns expressed by fisherfolk are increased loss of fishing grounds (29.4%) and pollution (28.7%) (Figure 3). About 50% of the responses for these two issues were from trawlers who concentrate their fishing effort for shrimp in the vicinity of the Point Lisas area. Unemployment (11.8%) was considered by some

to impact negatively on them as result of the expected decrease in catch associated with pollution and loss of fishing grounds.
Only 7% of the fisherfolk perceived the issue of relocation of their fish landing site and the possibility of compensation. Most of these responses were from fisherfolk in Brickfield which is outside of the industrial expansion area. One positive impact that the expansion was perceived as bringing was improved facilities for the fisherfolk.

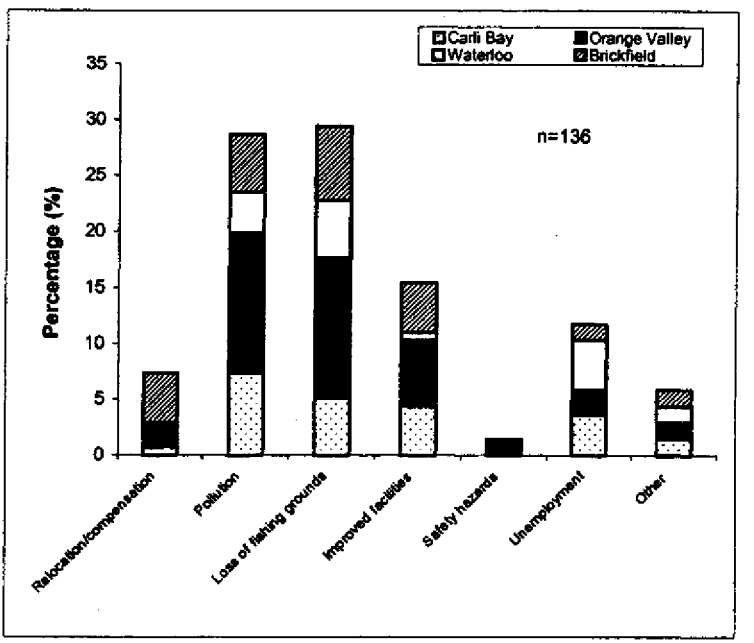


Figure 3. Perceived impacts to the fishing industry by an expansion of an industrial estate at four landing sites on the west coast of Trinidad

Potential Impacts

The potential impacts of the proposed expansion inclusive of the port facilities are summarised in Figure 4. The negative effect on the fisheries ecosystem has the potential to reduce the livelihood of the fisherfolk and disrupt the social cohesion of the communities. In the terrestrial region of the coastal area where the fishing facilities are located and the point from which fishing activities are launched, the main issues revolve around the possible physical loss of the landing site. This is a greater threat at Carli Bay and Orange Valley since both sites are well within the proposed expansion. The presence of a fueling facility at Orange Valley may pose a hazard to the industrial development.

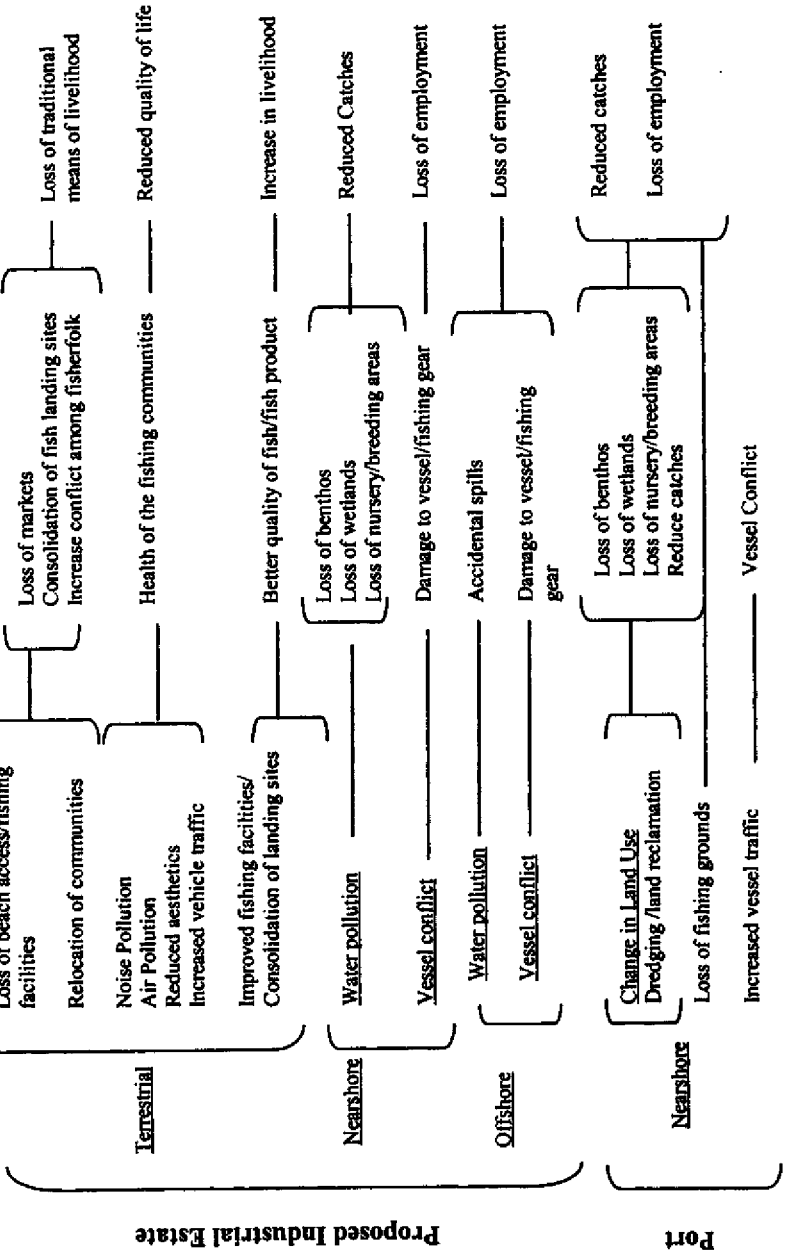


Figure 4. Potential impacts of the proposed industrial estate and port development on the fishing activities at Carli Bay, Orange Valley, Waterloo, and Brickfield, Trinidad

The possibility of a consolidation of all the landing sites will most likely cause problems because of the existing conflicts among the fisherfolk. However interviews with fisherfolk suggest that these conflicts may be mitigated if the expansion accommodated sufficient berthing facilities and increased marketing facilities. Since Orange Valley is also the third largest wholesale market on the west coast, disruption to its activities or existence will affect not only local distribution but also shrimp exports.

The environmental quality of the habitats in which the fish resources are exploited are of prime concern because of the threats of heavy metal, inorganic and organic pollution from effluents discharges into the environment. The most important environmental problem in the coastal areas of the Gulf of Paria is the nutrient load to coastal waters (UNEP 1999). Levels of petroleum hydrocarbons in marine sediments in the Gulf is also high (Ibid.). This pollution threat was one of the major concerns of the fisherfolk. Additionally, the loss of wetlands concomitant with reclamation of land for port and estate development will reduce the size as well as the productivity of the nearshore area. This area acts as nursery and breeding grounds for the exploited penaeid shrimps and some crabs and fish species. While most shrimp larvae may arrive in the plankton from the South American shelf, the local abundance of adult shrimp stocks is dependent upon the quantity of juveniles inhabiting the nearshore area (Morton and Talbot 1996). The availability of suitable habitat is an important factor affecting the local abundance of shrimp. This may affect both the artisanal trawl, the semi-industrial and industrial trawl fisheries. One shrimp species, *Xiphopenaeus kroyeri*, because of its absence in catches from semi-industrial vessels in the Gulf of Paria is thought to complete its entire life cycle within the nearshore area (Amos 1990).

Loss of fishing grounds of non-trawlers was considered as a potential impact due to the possibility of increased vessel traffic and restricted access by companies in the expanded industrial estate. Loss of fishing grounds by trawlers in the nearshore areas was not considered an impact of the proposed expansion because of the Fisheries Regulation (1998), which created a no trawl zone in the Gulf of Paria extending one nautical mile from the coastline. Although this Regulation was in effect at the time of the Frame Survey, the fisherfolk continued to fish in these waters, their previous fishing grounds, because of a lack of enforcement.

Decrease in catches as a result of environmental degradation, loss of the landing site, or marketing of their product will lead to loss of income and loss of livelihood to the fisherfolk. For those with fishing as their only source of employment, it would be difficult to find alternative jobs. Capital-intensive developments demand relatively small amounts of skilled labour, which is not available in the communities (IMA 1998a). Statistics for 1990, showed that only 409 jobs or 7% of the work force at the existing industrial estate came from within the communities (Manwaring and McShine 1991). Many of the fisherfolk chose fishing because of family tradition and several of them at a landing site are related, therefore loss of earnings and jobs can also affect the social structure of the communities. While 244 fisherfolk directly

fished, this does not include the retail and wholesale vendors, processors and their employers, net repairers and boat builders, marine equipment suppliers and exporters, who may also be affected in varying degrees depending on the severity of the impacts, affecting the social cohesion of a much wider community.

DISCUSSION

The fish landing sites at Carli Bay, Orange Valley, Waterloo and Orange Valley land more than 1,500 mt of fish and shrimp, but no accurate value of these resources is available. This value is an approximation based on results from the Frame Survey and secondary data from the Fisheries Division and the Carli Bay Fishing Co-Corporative Society Limited. The quality and quantity of the fish resources exploited is dependent on the quality of the natural environment. The described fishing activities of the landing sites show that if these activities are presented as a system representing the fisheries ecosystem, the social and economic considerations as well as the fisheries management regimes as components then the likelihood of predicting impacts are clearer when the linkages between these components are highlighted. The numerous concerns expressed by the fisherfolk indicated that this group of stakeholders has concerns about the proposed expansion, which has the potential to affect their livelihood. When these potential impacts are taken into consideration with the changes already taking place within the fisheries sector, it demonstrates a differential vulnerability of the landing sites and a similar ability to cope with such changes. The concerns and needs expressed by the fisherfolk need to be taken into consideration into any developmental plans of the estate. There must be continuous dialogue between the developer and the fisherfolk, possibly through consultative workshops and meetings with representatives from government fisheries agencies also in attendance. One such example is the consolidation of landing sites, because of the siltation problem on the west coast and the need to provide cost effective facilities to meet export standards (Kishore et al. 1999). Dialogue between the fisheries sector and the energy sector should be encouraged so that the final design of the expansion of the industrial estate can accommodate fishery related activities resulting in least disruption to the landing sites.

The issues of resource allocation and conflict resolution among the multiple users of the coastal area can be dealt with in the context of coastal area management (FAO 1998). However, after a thirty year history of such initiatives towards this goal (McShine 1996), there is no legislative framework for coastal area management. Many of the issues are dealt by existing planning, research and administrative machinery (Clark 1998). The establishment of an Environmental Management Authority in 1995 and the development of a national environmental policy to regulate pollution provide some means of consolidating and addressing issues from a fisheries perspective. Of particular importance is the environmental impact assessment (EIA) process that is now mandatory for certain types of development including industrial development, in obtaining certificate of clearance approval. However, perusal of available environmental impact assessments reveals

that the fishing activities of the targeted area is poorly characterized and the linkages between the environmental quality of the habitat fished, fish resources, gear used, and their contribution to the economy both at community and nationally levels is weakly articulated. In addition, the creation of jobs and the traditions of the fisherfolk should also be reviewed for their contribution to social cohesion of these coastal communities. A large part of this under-representation is due to the low contribution of the fisheries sector to the economy. Statistics for fisheries generally never reflect a true economic value of the fisheries, as the added value is not evaluated. This is one of the weaknesses in the fisheries sector that is reflected in the EIA.

The fisheries sector needs to take the responsibility for being recognised and included in coastal area planning. As part of the consultative process and to correct existing inadequacies, the fisheries sector can take the initiative in the development of standards for the manner in which the sector is represented in environmental impact assessments. This scenario presented in this study is not isolated and is taking place in other locations in Trinidad and Tobago. One output of such standards for the fisheries sector can be a vulnerability index of the fish landing sites to potential impacting activities due the multiple uses of the coastal areas.

ACKNOWLEDGEMENTS

The authors would like to express their sincere appreciation to the Ministry of Environment and the Institute of Marine Affairs for funding as well as P. Gabbadon and H. McShine for providing a critical review of this manuscript. Also H. Baptiste for assistance with map reproduction.

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Escape Gaps: An Option for the Management of Caribbean Trap Fisheries

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ABSTRACT

The use of escape gaps set in the corners of Antillean fish traps is suggested as a management mechanism for the intensive trap fisheries of the Caribbean. Escape gaps could be rectangular or diamond-shaped. Rectangular apertures provide two dimensions (width and the diagonal) that can be adjusted to permit the escape of deep-bodied slender fishes while retaining round-bodied fishes and crustaceans. Diamond-shaped escape gaps provide height, width and, to a degree, body shape as controlling dimensions.

Previous investigations have suggested that the effectiveness or fishing power of traps might decrease when mesh size is increased. Preliminary indications from a series of tests with rectangular escape gaps are that appropriately sized escape gaps are effective in releasing undersized fish but do not significantly decrease the catchability of target species.

Yields of deep-bodied fishes such as surgeonfish, triggerfish, hogfish, angelfish, spadefish, porgies and some of the grunts and jacks would be increased, because such fishes are invariably harvested at extremely small sizes by the hexagonal wire meshes commonly used in Caribbean trap fisheries. Morphometric information is presented for twenty-one species to estimate size at first capture with various escape gap sizes, and to calculate potential improvements in yield-per-recruit when using escape gaps.

For severely depleted fisheries, the dimensions of the escape gap would need to be progressively changed as stocks of key fishery species recovered and the composition of the fish communities changed.

KEY WORDS: Fish traps, escape gaps, management, mesh size.

INTRODUCTION

Antillean fish traps or "pots" are the principal fishing gears in most countries in the Caribbean. A wide variety of trap designs are used, ranging from rectangular box traps with a single straight entrance funnel, to more complex designs such as the single-entrance arrowhead trap or the Z or S traps that have two entrances, usually with a down turned entrance funnel (Munro et al. 1971). The arrowhead trap is historically important, having been the main trap design used in the past and one still

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used extensively in Africa and the Middle East. Most modern traps use wire mesh but the original traps were of woven cane.

Some designs of traps might be better than others but they are all exceedingly efficient passive fishing gears. They maintain the catch in good condition until the trap is hauled and do not have to be hauled if the weather is unfavorable. They are relatively inexpensive to construct and, with the advent of plastic coated mesh, quite durable. Almost all species of Caribbean reef fishes will enter traps but catchability (the average fishing mortality caused by one unit of effort) is variable and predatory species tend to be more catchable than herbivores because they often enter traps to prey on the catch (Munro 1999a).

Trap fishing was banned in Bermuda in 1990 (Burnett-Herkes and Barnes 1996) but is largely unregulated elsewhere. Some countries stipulate minimum mesh sizes, ranging from 31 mm to 48 mm and in others a biodegradable panel is mandatory, to ensure that the trap will become inoperable if it is lost. However, there are no limits to the number of traps that can be deployed. This has generally led to a situation in which reef fish stocks suffer from growth and recruitment overfishing in most countries. Deep-bodied species such as surgeonfish, triggerfish, angelfish, hogfish, spadefish, porgies and some species of grunts and jacks are particularly badly affected.

The idea of using escape gaps in traps dates back to the 1950s (Templeman 1958), at which time escape gaps were mandatory in Newfoundland lobster traps. Their use has been investigated in British lobster and crab fisheries (Brown 1982) and in spiny lobster fisheries in Australia (Bowen 1963), Florida (Lyons and Hunt 1991) and Hawaii (Polovina et al. 1991). Escape gaps in lobster and crab traps are now required by law in a number of countries. However, it appears that the concept has never been applied to multi-species trap fisheries, such as those of the Caribbean, in which a wide array of fish and invertebrates are concurrently harvested.

Clearly, the ability of a fish or invertebrate to pass through a gap of a given size and shape depends its relative body proportions. With a rigid circular, hexagonal or square mesh, only one dimension, usually body depth, determines whether of not escapement is possible. In contrast, rectangular or diamond-shaped escape gaps offer more possibilities. Rectangular apertures provide two dimensions (width and the diagonal) that can be adjusted to permit the escape of deep-bodied, slender, fishes while retaining round-bodied fishes and crustaceans. Diamond-shaped escape gaps provide height, width and, to a degree, body shape as controlling dimensions.

In the context of Antillean fish traps, several studies (Olsen et al. 1978, Stevenson and Stuart-Sharkey 1980, Ward 1988, Rosario and Sadovy 1996, Robichaud et al. 1999) have found that increasing mesh sizes appeared to decrease the total catch, including that of fish that should have been retained by the larger mesh. Thus, the catchability of retainable fish appeared to be reduced. This might be attributable to decreased ingress of larger fish as a result of reduced conspecific attraction or because small fishes captured in the trap act as bait for larger fish. Alternatively, it has been suggested that large-meshed traps have a weaker visual impact (Munro 1974), look less like a refuge and therefore attract fewer fish.

Bohnsack et al. (1989) tested this by covering the sides of traps with a standard small mesh and only varied the mesh size of the upper and lower panels. The weight-frequency distributions of fully retainable fish did not differ markedly in 11 different mesh sizes, suggesting that catchability might not be reduced. Ward (1988) compared the frequency distributions of body depth in the total catches (excluding trunkfish and cowfish) of three different mesh sizes in inshore waters at Bermuda, all fished equal amounts. There was no evidence of reduced catching power for fully retainable fish.

Current evidence, therefore, suggests that escape gaps would not reduce catchability. That is, the numbers of fish captured in each size group, above the minimum size expected, would not be significantly decreased. However, there is sufficient ambiguity in available reports to warrant further examination of this aspect.

Escape gaps would be ineffective if fish were simply unwilling to pass through the gaps. The effectiveness of escape gaps would also be reduced if undersized fish used the trap as a refuge and were unable to rapidly discern the escape gap and make an exit when the trap was hauled.

METHODS

This study was undertaken at Hans Creek, located on the south coast of Beef Island, adjacent to Tortola, British Virgin Islands (BVI) and in Discovery Bay, on the north coast of Jamaica. We used non-standard double-arrowhead (AA) Antillean fish traps constructed of sticks and 25 mm (1") plastic-coated wire mesh. The wire mesh has a maximum aperture of 33 mm. These AA traps have an outer chamber (sometimes called a parlor) and a second, internal, entrance funnel leading to the inner chamber (Figure 1). In theory, such a trap should have reduced escapement rates. The traps are 120 cm across, 150 cm along the side and 60 cm high. The horse neck entrance funnel protrudes 50 cm into the trap and terminates in a downward facing pear-shaped aperture 60 cm in circumference and 12 cm wide. The internal funnel is identical. Escape gaps were made of from rectangles of plexiglass (in Jamaica) or galvanized metal (in BVI), with rectangular apertures cut out of them.

As a preliminary experiment, undertaken at Hans Creek, nine traps were fitted with escape gaps between the parlor and the inner chamber but not in the outer walls of the trap. The inner entrance funnel was blocked. If undersized fish passed freely through the gaps, then the average number in each chamber should be equal, provided that no large predator was concurrently trapped in the parlor. The traps were checked by divers and the fishes in each chamber were identified, counted and their sizes estimated.

After that, escape gaps were located in the outer walls of the traps, close to the floor in the acute corners furthest from the apex of the trap. Traps were hauled with a rope attached above the entrance funnel so that any fish in the outer parlor would descend through the inner funnel as the trap was being hauled.

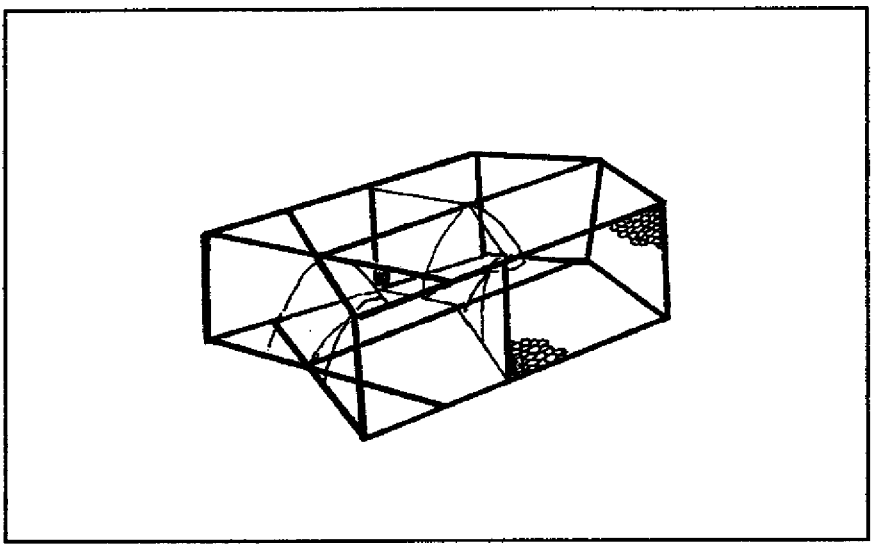


Figure 1. Double arrowhead fish trap fitted with escape gaps. Dimensions are 150 mm along the side, 120 cm wide and 60 cm deep. Plastic-coated hexagonal wire mesh measures 33x25 mm. Wooden poles, fitted externally, support the structure.

Divers inspected traps fitted with escape gaps to count the numbers of fish in the traps, for comparison with the numbers actually caught. Traps were then hauled and reset, once weekly (in BVI) or twice weekly (in Jamaica). All fish were identified and measured for length (to the end of the middle caudal ray), maximum body depth and body width and then returned to the sea. Traps were set in shallow, 2 m, back reef seagrass and patch reef areas in Jamaica and in 5-8 m at the base of the fore reef at Hans Creek. Traps were unbaited. Catch data were supplemented by diver observations of behavior of fish in the traps. The traps in Hans Creek were frequently attacked and damaged by nurse sharks.

We made one series of observations at each site of the catch rates, catch composition and size frequencies in control traps and traps with escape gaps. These are summarized in Table 1.

The morphometric data gathered during our experiments were compiled in a database, supplemented where necessary by information from the literature and measurements made at the BVI Fisheries Complex in Tortola. From these morphometric data we are able to compile a basic analysis of the comparative catch rates of the control traps and of the traps fitted with escape gaps for each of the data sets. This was done by calculating the average catch (numbers and weights of all species) per control trap hauled and, from the size frequency data for the control traps, calculating the proportion of that catch that would have been retained by each of the escape gaps used in that series of observations. This is then repeated for the

catch in the trap with the smallest escape gap and then for the next largest. Only one size of escape gap was used at Discovery Bay. If the parts of the catches in the control traps that would have been retained by traps fitted with escape gaps are similar in magnitude to the catches actually taken in the traps with gaps, then the escape gaps can be deemed to not reduce catchability overall.

Table 1. Summary of locations, dates, depths, soak times and numbers of traps with escape gaps and control traps.

Location	Dates	Depth	Soak	Hauls of control AA traps	Hauls of traps with gaps (mm)
Hans Creek	Mar-Sep 2001	6-9 m	7 d	53 with 33x25 mm mesh	58 with 70x28, 63 with 80x30, 30 with 90x33
Discovery Bay	Feb-May 2000	2-8 m	3-4 d	166 with 33x25 mm mesh	78 with 90x25

Twenty-one species make up 78% of the current catch in traps in the Discovery Bay area (Sary 2001). An additional 11.4% of the catch is made up of small catches of spiny lobster (1.2%) and Caribbean king crab (0.8%), various eels (3.5%) and occasional catches of groups of large yellowfin grouper (3.2%), Nassau grouper (1.7%), and red hind (1%) that still survive in the area. However, we have not observed juveniles of the large species of groupers in six years of work in the area, and it seems likely that they will eventually become locally extinct. Escape gaps would have little effect on the larger species. A further 10.6% of the catch is made of assorted uncommon fish and invertebrates.

Morphometric data for these 21 most commonly caught species are shown in Table 2. Published values of length at maturity, L_m, are included in Table 2, together with estimates of growth parameters that are required for some of our computations. In order to assess the effect that escape gaps might have on the harvest of fish from the intensively fished north coast of Jamaica we effected simple yield per recruit analyses for each species. The total landings of each species in traps in the Discovery Bay area, derived from Sary (2001), was weighted by the calculated yield per recruit in the predominant 43 x 32 mm wire mesh and then recalculated for the three escape gap sizes that we had used in most of our experimental work (70 x 28 mm, 80 x 30 mm and 90 x 33 mm) plus an additional hypothetical size of 100 x 40 mm. For each of the species considered the length at first capture (l_c) was determined either by body width or depth.

Table 2. Morphometric characteristics of the 21 species of reef fish that yield 78% of the trap catch in the Discovery Bay area in Jamaica. All dimensions are in mm. L = length (either TL = total length or FL = fork length), BD = body depth, BW = body width, L_c = length at first capture in traps with 43x32 mm mesh, L_m = length at maturity, L_∞ = asymptotic length, a and b = values of the length-weight equation ($W = aL^b$), W_∞ = asymptotic weight in g, K = growth coefficient, Z = total mortality rate (calculated from the mean weight of individuals in the catch and the growth parameters). Growth parameters from Munro (1983) and Munro (1999b).

Family	Species		BD:L	BW:L	Lc	Lm	Loo	a	b	Woo	K	Z
Acanthuridae	*Acanthurus bahianus*	FL	0.477	0.113	95	155	280	0.0191	3.08	547	0.36	1.1
	A. chirurgus	FL	0.428	0.107	101	210	313	0.0221	3.01	701	0.56	1.3
	A. coeruleus	FL	0.518	0.144	81	130	333	0.0278	3.02	1101	0.24	0.8
Balistidae	*Balistes vetula*	FL	0.468	0.144	92	175	496	0.0516	2.88	3941	0.28	0.4
Carangidae	*Caranx ruber*	FL	0.289	0.113	149	240	540	0.0180	2.99	2724	0.19	0.9
Holocentridae	*Holocentrus ascensionis*	FL	0.30	0.124	145	145	261	0.0198	3.00	352	0.23	0.5
	H. rufus	FL	0.265	0.121	168	135	188	0.0131	3.06	104	0.48	1.0
Haemulidae	*Haemulon flavolineatum*	FL	0.305	0.132	144	155	287	0.0111	3.23	568	0.25	3.1
	H. plumieri	FL	0.328	0.147	130	220	400	0.0238	2.93	1177	0.26	0.8
	H. sciurus	FL	0.313	0.137	137	180	370	0.0200	3.01	1050	0.26	0.4
Lutjanidae	*Lutjanus apodus*	FL	0.305	0.130	138	250	349	0.0089	3.20	770	0.35	0.3
	Ocyurus chrysurus	FL	0.268	0.120	148	300	525	0.0145	3.03	2363	0.18	0.6
Mullidae	*Mulloidichthys martinicus*	FL	0.223	0.132	201	180	250	0.0207	3.00	323	1.07	>10
	Pseudopeneus maculatus	FL	0.222	0.127	199	185	244	0.0229	2.96	293	1.14	>10
Scaridae	*Scarus iserti/taeniopterus*	TL	0.23	0.122	182	155	223	0.0166	3.02	196	0.46	>10
	Sparisoma aurofrenatum	TL	0.287	0.138	155	150	260	0.0129	3.11	324	1.10	6.4
	S. chrysopterum	TL	0.291	0.141	161	240	418	0.0199	3.00	1453	0.78	4.5
	S. rupripinne	TL	0.291	0.146	158	160	465	0.0194	3.00	1951	0.58	1.6
	S. viride	TL	0.325	0.140	140	180	549	0.0370	3.12	9901	0.27	7.8
Serranidae	*Cephalopholis fulva*	TL	0.26	0.142	165	160	325	0.0174	3.00	597	0.30	1.2
	C. cruentata	TL	0.266	0.136	161	160	365	0.0121	3.08	785	0.26	1.2

Total mortality rates, Z, prevailing in the Jamaica fishery were calculated from the mean weight of individuals in the catch (Sary 2001) using the formulation of Gulland (1969), which states that,

$$W_c = W_\infty \sum_0^3 \frac{Un\, Ze^{-nK(tc-to)}}{Z - nK}$$

in which W_c is a function of the asymptotic weight, W_∞, the growth rate, K, the total mortality rate, Z, and the age at entry to the exploited phase, t_c. The theoretical point of origin of the growth curve, to, can be set at zero. U_n is the summation variable in which $U_0 = 1$, $U_1 = -3$, $U_2 = 3$ and $U_3 = -1$.

Natural mortality rates, M, are unknown and in an environment in which predators are extremely scarce, natural mortality rates of adult and sub-adult fish are expected to be very low (Munro 1980). We therefore assumed a exploitation rate, E, of 0.9 and estimated natural mortality as

$$M = Z - EZ$$

RESULTS

Our preliminary observations by divers confirmed that on average nearly equal numbers of undersized fish of all families and genera were found in the inner and outer chambers of the traps that were fitted with internal escape gaps and in which the inner funnel was blocked. This showed that fish would move freely through the escape gaps if they were small enough to do so. There were no instances of fish becoming stuck in the escape gap. Secondly, when traps were fitted with escape gaps in the external walls very few undersized fish were observed to be lingering in the trap. The very few that were observed in the traps usually left by the escape gaps when the traps were being hauled.

Tables 3a and b show the results of the comparisons between control traps and traps with escape gaps in Jamaica and BVI. Table 3b shows, for example, that the control traps captured an average of 1,214 g of fish and invertebrates, including 382 g that were large enough in body width or depth to be retained in a trap with a 90 x 33 mm escape gap and, reading vertically, that there is no pattern of decrease in average catch rates in traps with escape gaps.

The yield per recruit estimates are shown in Figure 2a-d. All combinations of gap height and width will produce increases in the total harvests, ranging from about 18% with the 70 x 28 mm gaps, 19% with the 80 x 30 mm gaps, 22% with the 90 x 33 mm gaps and 42% with the 100 x 40 mm gaps. The value of the catch would increase by somewhat greater amounts owing to the increased catches of snappers and also because larger fish attract better prices, irrespective of species.

Table 3a. Average numbers and weight of all species of fish, spiny lobsters, crabs and octopus caught in Discovery Bay, Jamaica, in control traps (33 x 25 mm mesh) and traps with 90 x 25 mm escape gaps. The upper row shows (in boldface) the numbers and weight of fish and invertebrates caught in the control traps and the numbers and weights that would have been retained in traps with 90 x 25 mm escape gaps. The lower row shows the number and weight (in boldface) actually taken in the traps with 90 x 25 mm escape gaps.

	Numbers/trap		Weight (g)/trap	
	Control	90 x 25	Control	90 x 25 mm
Control	**10.2**	1.8	**794**	241
90 x25		**4.2**		**336**

Table 3b. Average numbers and weight of all species of fish, spiny lobsters, crabs and octopus caught in Hans Creek, BVI, in control traps (33 x 25 mm mesh) and in traps with 70 x 28, 80 x 30 and 90 x 33 mm escape gaps. Each row shows the numbers and weight of fish and invertebrates actually caught (in boldface) and the numbers and weights in that catch that would have been retained in traps with successively larger gap sizes.

	Numbers/trap				Weight (g)/trap			
	Control	70x28	80x30	90x33	Control	70x28	80x30	90x33
Control	**10.0**	2.6	1.7	1.0	**1214**	615	507	382
70 x 28		**2.3**	1.4	0.8		**496**	376	273
80 x 30			**1.4**	1.0			**647**	598
90 x 33				**0.7**				**224**

In these calculations it has been assumed that the catches of the larger groupers would be unchanged but that is a rather optimistic view in the absence of any significant spawning stock biomass. The crabs and spiny lobsters would be unaffected by any gaps as they become catchable in traps when body depths exceed the largest gap sizes considered here. Harvests of eels would be expected to increase by an unknown amount in response to the gaps but as they have no market value they are discounted from the calculations. Note, however, that "trash" fish such as eels are landed, given away, and consumed.

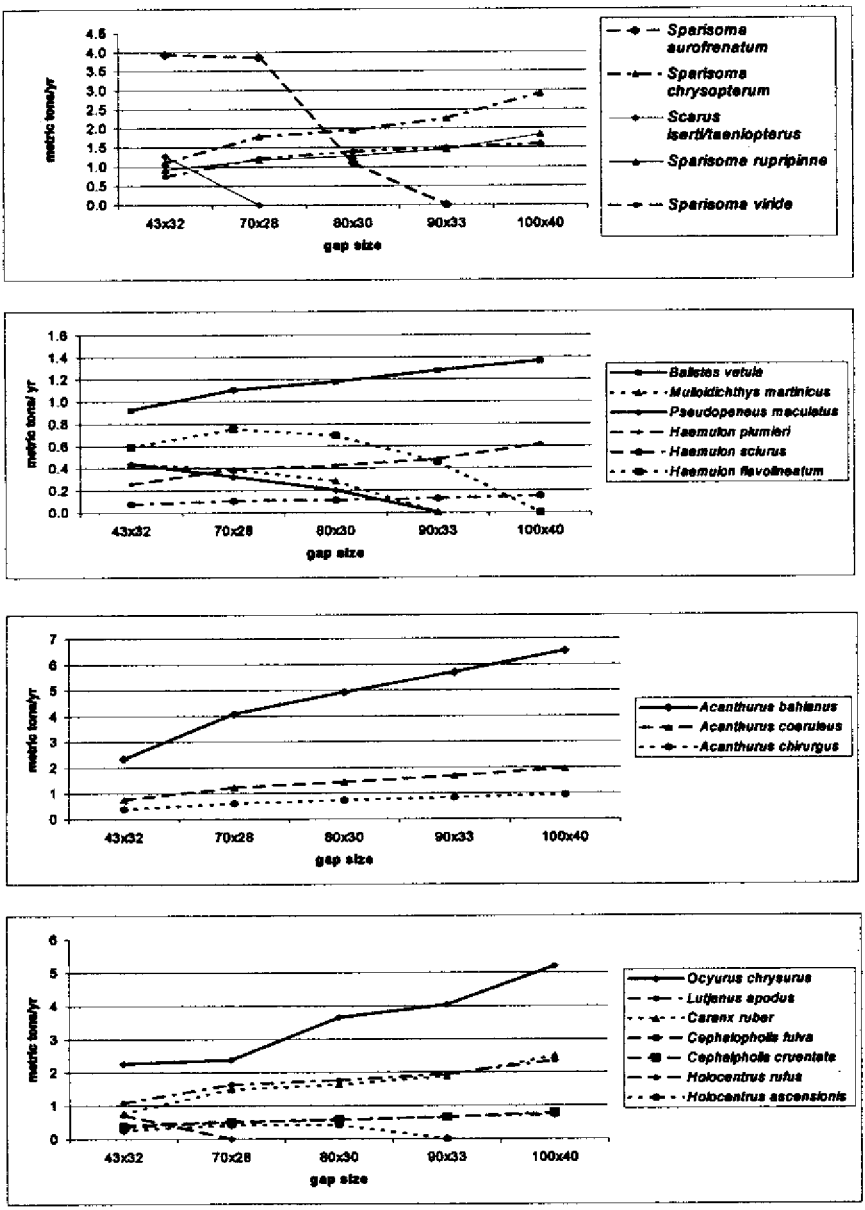


Figure 2. Calculated responses of the 21 species that comprise nearly 80% of the catch in the vicinity of Discovery Bay, Jamaica, to the introduction of escape gaps of various sizes.

DISCUSSION

The yield per recruit estimates (Figure 2) showed that all of the tested gap sizes and the hypothetical 100 x 40 mm gap would produce increases in harvests if they were introduced. The calculated increase would be in the order of 42% if 100 x 40 mm escape gaps were introduced. However, the immediate effect would be to completely eliminate catches of the small parrotfish (*Scarus iserti/taeniopterus* and *Sparisoma aurofrenatum*), goatfish (*Pseudupeneus maculatus* and *Mulloidichthys martinicus*) squirrelfish (*Holocentrus asencionus* and *H. rufus*), and a number of minor species, none of which attain a body width much greater than 28 mm. This would be accompanied by an increase in value because larger fish fetch higher prices per unit weight. Additionally, as most deep bodied species other than acanthurids have been virtually exterminated, we can anticipate some recovery of the other deep-bodied species.

However, it would take several years before the current fish stock grew to sizes at which they would be retained in a 100 x 40 mm gap. The obvious alternative is to progressively increase the gap sizes over a number of years, starting with 70 x 28 mm and making increases in gap sizes in response to changes in the composition of the catches. Figure 3 shows the likely outcome of a possible conservative strategy in which a gap size of 70 x 28 mm is initially adopted, then 80 x 30 mm, after which the gap width is held at 30 mm while gap depth is progressively increased. This would enable catches of small parrotfish, goatfish, and squirrelfish to be maintained at reasonable levels while catches of surgeonfish would treble. Thereafter, gap width could be progressively increased, particularly with a view to improving harvests of snappers, jacks, larger species of grunts, and the smaller groupers.

The calculations are also based upon the current harvests, which are in turn related to recruitment rates and these have been shown to be massively depleted (Watson and Munro in review). Table 2 shows the mean sizes at maturity and the sizes at which fish are currently captured in the Jamaican fishery in pots with a mesh size of 43 mm maximum aperture. Most species are captured well before maturity, and the spawning stock biomasses of all but the smallest species are extremely small and will remain so unless management measures are adopted throughout the country. Table 2 shows that the surgeonfish, that presently comprise 12.5% of the catch, would reach maturity before recruitment if escape gaps were adopted. This presumably would lead to improved recruitment rates and commensurate increases in harvests. However, many of the important jacks, angelfish, porgies, spadefish, and deep-bodied grunts, all of which will be taken by small meshed fish traps well before they reach maturity, have virtually disappeared from the north coast of Jamaica.

Changes in the recruitment rates and community composition would probably have positive effects on the spear, handline and net fisheries (Sary 2001) by making larger fish available to these fishing gears.

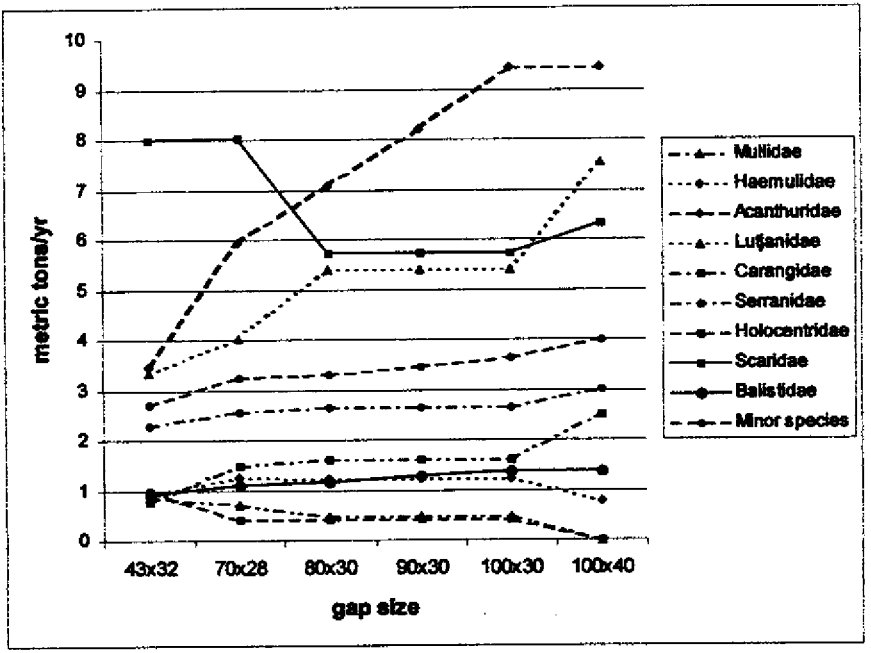


Figure 3. Suggested strategy for the introduction of escape gaps to the Discovery Bay fishery, in which a gap size of 70 x 28 mm is initially introduced, followed by 80 x 30 mm. Thereafter, gap width is held at 30 mm while gap heights are progressively increased to 100 mm. Thereafter gap width could be progressively increased to 40 mm.

We believe that the adoption of escape gaps that are progressively increased in size as catch rates improve and catch compositions change offers a partial solution to the management of Caribbean trap fisheries. Such an undertaking would have to be done in close consultation with the fishing community. It would be a difficult task. However, Parchment (1998) recorded a very widespread acceptance of the need to protect juvenile fish, and this gives some hope that the fishers might be quite receptive to the idea of escape gaps.

Although we have worked with rectangular escape gaps, because the controlling dimensions are easily measured, we recognize that diamond-shaped gaps might give better results by adding body shape as an additional controlling factor.

ACKNOWLEDGEMENTS

This study was part of the work of the Caribbean Marine Protected Areas Project, funded by the United Kingdom Department for International Development. Robert Power, Ivor Williams, Annalie Morris, Vanessa Bertenshaw, Karen Bech and Patsy Leonard assisted with field work in the BVI and Moana Murray and John Samuels with field work in Jamaica. We thank the management and staff of the BVI Fisheries Complex in Tortola for permitting us to gather morphometric data at their facility.

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Catch Per Trip Variability Analysis Related to Several Fishing Effort Components in the Small-scale, Large Pelagic Fishery in Martinique (FWI): An Attempt to Define More Accurate Fishing Effort Units Function of the Different Types of Fish "Aggregators"

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ABSTRACT

As in most of the islands of the Lesser Antilles, the small-scale large pelagic fishery in Martinique (FWI) is based on the exploitation of fishes concentrated around three types of "aggregators": flotsams, seamounts and Fish Aggregating Devices (FADs). The technical and human means implemented by the small scale fishermen to catch the fishes are the same whatever aggregator they target.

Due to the lack of consistent data series, CPUEs are commonly expressed as "catches by trip". The influence of several other fishing effort components on the catches per trip data issued from the small scale large pelagic fishery in Martinique was modelled using General Linear Models. The aim of the analysis is not to get a predictive model but to identify the variables explaining most of the catch per trip variability so as to evaluate the fishing effort more accurately.

At the scale of the global large pelagic fishery, the most influent variables were the type of aggregator exploited during the trip ("type of fishing") and the depth layer prospected with the fishing gears. The same analysis was conducted within the strata defined by the types of fishing. Most of the catch per trip variability of the moored FAD fishery was explained by the use or not of drifting longlines allowing to catch large adult pelagics (essentially Thunnus albacares and Makaira nigricans. The fishing effort components available seemed to be inefficient to explain the catch per trip variability of the very random offshore trolling fishery. The catch per trip variability of the coastal trolling fishery depended mainly on the trip length.

Generalized Linear Models appeared to be efficient to process the data issued from the small skewed data sets often encountered in the insular context. The results suggest several fisheries should be defined within the large pelagic fishery so as to better assess the catch per trip variability but also the age structure of the catches. The fisheries should be classically defined by the fishing area, the species targeted, the fishing gears but also by the type of aggregator prospected. The moored FAD fishing seems to substitute effective fishing time (local fishing efficiency) to costly travelling time (local searching efficiency) compared to the traditional coastal trolling fishery.

KEY WORDS: FAD, Martinique, GLM

INTRODUCTION

In Martinique as in most of the Lesser Antilles islands, pelagic resources are traditionally exploited by small scale fishermen aboard 6 to 7 m undecked boats. Fishermen stay at sea in the daytime and use mainly trolling lines. The main traditional fishery is the offshore trolling under drifting flotsams which occurs from January to June, when flotsams are numerous enough on the Atlantic Coast of the island. The main specie targeted is *Coryphaena hippurus* but *Acanthocybium solandri* and juveniles tunas (Thunnini) are also commonly caught. Fishermen also troll over seamounts near the shore for *Thunnus atlanticus*, *Sphyraena barracuda* and *Scomberomorus* sp. all year long in some harbors.

Moored FADs were first introduced in early 1980s to retarget the intense fishing effort deployed on the coastal resources toward large pelagic stocks. The moored FAD fishery has been developing since mid-1990s in Martinique, both on the Caribbean and Atlantic coasts and currently produces around 2000 metric ton per year. The main species targeted are *Makaira nigricans*, *Thunnus albacares* and *Thunnus atlanticus*.

Assessing the real impact of this new fishery is difficult because of the lack of an exhaustive data collection system. The fishermen sell directly their catches to the consumers in the 150 landing sites recorded around Martinique and monitoring the fisheries is very uneasy. However, IFREMER has gathered very detailed information on catches and fishing effort of a little sample of trips targeting large pelagics.

Assessing the evolution of the exploitation of large pelagic fishes and evaluating the impact of the development of the moored FAD fishery is also difficult because of the necessity of both evaluating the exploitable living resources and the impact of fishing on these resources: that is drawing relations between catches, fishing effort, and abundance. A useful theoretical frame on fishing effort and power is provided by Gascuel (Gascuel et al. 1995).

Traditionally, the yield at a given time t (Y(t)) is related to the average available biomass at t (Bm(t)) and to the fishing mortality (F) following:

$$Y(t)=Bm(t)*F(t)$$

The fishing mortality F is related to the fishing effort (f) and the catchability at t (q(t)) following :

$$F(t)=q(t)*f$$

Catchability can be divided into two components: one related to the availability and vulnerability of the fishes ("availability" = d) and the other to the fishermen ability to find and catch the fishes ("global fishing power" = Pg). In this case we assume that the fishing effort is "nominal" (fn) i.e. represents the fishing effort directly measurable by fishery managers.

The yield at t is:

$$Y(t)=Bm(t)*d(t)*Pg(t)*fn$$

However, if we assume that the fishing effort represents the real fishing pressure applied to the stock by fishermen, the fishing effort is "effective" (fe). Y becomes:

$$Y(t)=Bm(t)*d(t)*fe$$

All the parameters describing the fishing trip shall be considered as effective fishing effort parameters.

Nevertheless, these theoretical formulas cannot be used to asses the large pelagic fishery in Martinique because the available data are very limited (no abundance data and no long series of catch and effort to evaluate the fishing power).

However, Generalised Linear Models (GLM) can be used to establish a linear relation between our basic "CPUE" (the catches per trip (Y(trip)) and the explanatory variables available (Xi), namely the fishing effort parameters:

$$g(avg(Y(trip)))=a_1X_1+a_2X_2+....+a_nX_n$$

OR

$$g(avg(CPUE))=a_1X_1+a_2X_2+....+a_nX_n$$

avg is the average and the g is the link function used in the Generalised Linear Model.

The aim of the study is not to get a predictive model of the catches per trip function of the values of Xi but to assess and compare statistically the influence on the variability of the catches of each of the fishing effort parameter that have been collected. Hence we will try to isolate the more accurate information to collect for monitoring accurately the fisheries.

The second major advantage of generalized linear models is to handle non normally distributed data. This property is very important in the case of CPUEs which generally follows non normal distribution and, in our case, cannot be easily normalized.

MATERIAL AND METHODS

Data

The data have been collected by Ifremer during landing road surveys in three landing areas in Martinique: one on the Southern Atlantic Coast (Le François), one on the Northern Caribbean Coast (Le Prêcheur, St-Pierre and Le Carbet) since May,

1998 and one on the Southern Coast (Ste-Luce) since March, 2000. The two investigators have been surveying the three areas every week. The sampling plan is not a simple random one so data recorded cannot be extrapolated to the whole fishery.

The investigators identified all the fishes landed and measured the fork length (FL) and the weight at each site for half a day, until all the boats at sea were returned. They also recorded detailed information on the fishing trip gathered in Table 1. The boats surveyed were not identified and fishermen willingly answered the questions. The data processed are issued from 1026 fishing trips surveyed from May, 1998 to May, 2001 (301 in 98/99, 259 in 99/00 and 424 in 00/01).

Table 1. Fishing trip parameters gathered during Ifremer road surveys

Date
Sampling site
Time of departure
Time of arrival
Type of boat
Number of engines
Engine power
Crew size
Gas consumption
Fishing area: Island coast (N/S/E/W)
Trolling during the whole trip (Y/N)
Type of fishing (type of aggregator)
Fishing area(s): name of FAD or seamount
Time of arrival and departure in each fishing area
Type and number of fishing gears used in each fishing area
Type of offshore trolling aggregation (flight and/or flotsam)
Type of flotsam if any
Time of fishing on each offshore trolling aggregation
Type and number of fishing gears used on each aggregation

Model Development

The dependent variable studied is the total catches aggregated by fishing trip (Y). The total catch per trip can be assimilated to a Catch per Unit of Effort (CPUE). The Y variable distribution seems to be log linear or Gamma distributed (Figure 1). Attempts to normalize Y into log(Y+b) (with b a positive parameter) failed because of the presence of fishing trips with zero catch that skewed the transformed Y distribution. Hence classical linear models and analysis of variance could not be used to assess the effect of the fishing trip parameters on Y that is why Generalized Linear Models were used. Moreover, the surveys depending on the availability of the investigators (holidays...) and the sampling plan having slightly evolved over the years, the sample is not rigorously balanced and the use of GLM allow to rebalance it through the marginal means calculation (Gascuel 1994).

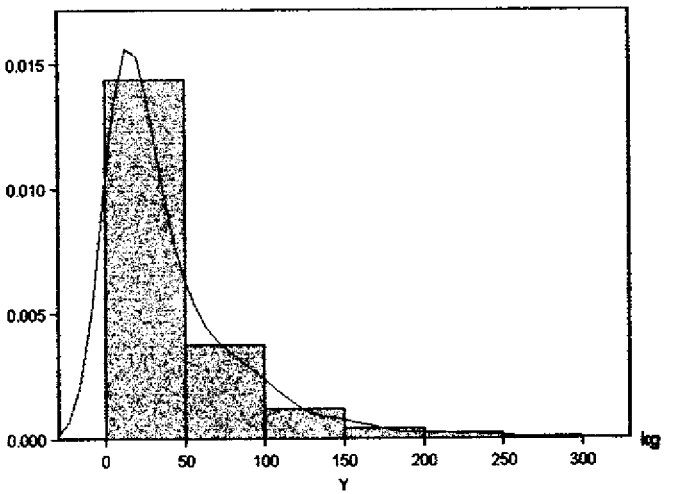


Figure 1. Total catch per trip frequency distribution

Generalized Linear Models (GLMs) extend linear models to accommodate both non-normal response distribution and transformation to linearity (Venables and Ripley 1999). According to Venables and Ripley (1999), the comprehensive reference on GLM is Mc Cullagh and Nelder (1989) and a generalized linear model can be described by the following assumptions:

i) a random dependent variable y observed independently at fixed values of explicative variables $x_1, x_2, \ldots, x_p$

ii) the explicative variables may only influence the distribution of y through a single linear function called the linear predictor $\eta = a_1x_1+a_2x_2+\ldots+a_px_p$

iii) the distribution of y belongs to the exponential family (see Lindsey, 1997, p.10)

iv) The mean μ of y is a smooth invertible function of the linear predictor: $\eta = m(\mu)$, $\mu = m^{-1}(\eta)$, with m is the "link function"

Here, from the shape of the distribution of the dependent variable Y we assume it belongs to the Gamma family which belongs itself to the exponential family. In fact, in fishing science, the Gamma distribution is commonly used to describe CPUEs (Mahevas, 2000). The explicative variables (X_i)selected to model Y variability are listed in Table 2.

The inverse, identity and log functions were tested as link function and the best fits were obtained with $m(\mu) = \log(\mu)$. Actually the linear predictor may be written:

$$\eta = \log(\mu) = a_1X_1+a_2X_2+\ldots+a_pX_p$$

Table 2. Fishing trip parameters selected as explicative variables in GLM modelling

Name	Decription	Type	Category
eq	Crew size	Continuous	Fishing effort
tsnum	Trip length (h)	Continuous	Fishing effort
nbBl	Number of vertical longlines used	Continuous	Fishing effort
conso	Gas consumption	Continuous	Fishing effort
cP	Engine power class (1 to 4)	Factor	Fishing effort
Bl	Use of longline (T/F)	Factor	Fishing effort
nbT	Number of trolling lines used	Continuous	Fishing effort
codehf	Name of the seamount fished	Factor	Fishing effort
fm	Fishing area: Island coast (N/S/E/W)	Factor	Geographic (Fishing area)
zone	Site location	Factor	Geographic (Landing point)
site	Sampling site	Factor	Geographic (Landing point)
anech	Year	Factor	Time
Ysaison	High production season (T/F)	Factor	Time period
saison	Offshore trolling season (T/F)	Factor	Time period
mois	Month	Factor	Time period

Variable Selection

The parameters issued from Table 1 were sorted and some categorised (cP, zone) to get the explicative variables (Table 2). The effective fishing time on each fishing area was not selected because this information has only been recorded since the end of 2000. The names of the FADs were also not selected because one FAD can be called with different names and their precise location is very bad known. Data on gears were summarized into the Bl variable: use or not of single vertical longline during the trip.

Model Selection

All the calculations were performed with S PLUS 2000 for Windows using the glm related functions.

> "Statistical models contain both elements (...) *systematic effects* and *random effects*. The value of a model is that often it suggests a simple summary of the data in terms of the major systematic effects together with a summary of the nature and magnitude of the unexplained or random variation." (Mc Cullagh and Nelder 1989).

Hence, the building model consists of selecting the combination of explicative variables which better fit the observations with less estimated parameters as possible (systematic effect) and then to check if the residuals produced by the model are randomly distributed (random effect). The variables can be considered either alone (main effects) or combinated (interaction effects).

The candidate model must reach a trade-off between underfitting the data that is narrowing the null model (no parameter, largest variance) and overfitting the data that is tending to the saturated model (as many parameters as observations, null variance). So for one model, once must assess the variability (called deviance in this case) explained by the model but also the number of degree of freedom of the model, that is the number of parameter that must be estimated for using it.

Following Gaertner et al.(1999), we did not use the stepwise selection procedure to build our models but the Akaikes's Information Criterion (AIC) which allows to compare different models based on the same set of observations and to emphasize the parsimony (reducing the number of estimated parameters): AIC=-2(log-likelihood)+2K=D+2K with K is the number of parameters in the model and D the deviance. The model with the smallest AIC is defined as the parsimonious model (Gaertner et al. 1999).

Mahevas (2000) provided a comprehensive method to study the structure of the residuals:

The structure of the residuals was assessed using the standardised residuals of deviance(rDi):

$$_{Rdi}=\text{sign}(y_i-\text{est}(y_i))\ddot{O}(2y_i\log(y_i/\text{est}(y_i))+2(n_i-y_i)\log((n_i-y_i)/n_i-\text{est}(y_i)))$$

where $\text{est}(y_i)$ is the estimated value of y_i

$$rD_i=Rd_i/\ddot{O}(1-h_i)$$

where h_i (leverage)is the ith element of the diagonal of the H matrix

If the model is correct, the standardised residuals of deviance are asymptotically distributed following a centered reduced normal distribution function. The squared residuals of deviance were also used to detect the observations which had the biggest influence on the fit of the model.

Actually the Cook's distance was used to detect the observations which had the biggest influence on the estimation of the parameters of the model: Cook's distance $= R^2_{Pi}.hi/k(1-hi)^2$ where R^2_{Pi}.are the partial residuals.

The most influent observations were systematically studied, being sometimes doubtful and then deleted. Nevertheless, they were also systematically deleted and the model readjusted on the new data set to assess if the residual deviance decreased.

Modelling Strategy

In the case of our analysis, the explicative variables can be grouped into 5 categories: fishing effort (FE), geographic (fishing area) (FA), geographic (landing point) (LP), time (T), time period (TP).

$$\mathbf{FE = tsnum+cP+eq+tp+BI+conso}$$
$$\mathbf{FA = fm}$$

LP = site OR zone
T = anech
TP = mois OR saison OR Ysaison

The first step consisted in selecting a subset of variables among the list of the explicative ones. Each candidate variable was modelled alone as the only explicative variable and the hypothesis that the GLM slope coefficient was zero was tested with the use of the Wald test.

The basic multivariate model tested according to the AIC criterion ("AIC" function in S PLUS 2000) was: Y~FE+FA+LP+T+TP
For LP and TP, the different modalities were tested successively and the model with the smallest AIC selected.

Then all the interaction effects between all the variables in the best model were tested with the "step" function which selects the model with the smallest AIC. The "step" function was repeated until no new term is selected in the model. Only interactions "which make biologic sense "were retained (Hosmer and Lemeshow, 1989 in Gaertner et al. 1999).

The variance of Y was modelled for the whole large pelagic fishery in Martinique and the more significant and explicative variable was used to stratify the sample. Then similar modelling was performed within each strata.
Some particular explanative variables were add to the basic model to try to better fit observations in the case of the FAD fishery (nbBI) and of the coastal fishery (nbT, codehf). The model selection was performed in the same way.

Explanative Variable Effects Assessment

The aim of the study is to analyse the compared effects of the explanative variables on the variability of the catches per trip. When the best model is defined, the influence of the variables on the variability of Y can be assessed with different tools:

i) The Wald's test for nullity of the a_i coefficient of each single degree of freedom variable: if the estimated coefficient of the variable is significantly not null, the variable influences the model. A variable is usually considered as significant for $t \geq 1.96$.

ii) The deviance explained by the variable: terms are added successively in the model and the new deviance explained by the new term is calculated in relation to the terms previously added. The intrinsic deviance explained by a variable without relation with the other variables is obtained while adjusting the model with the considered term in the last position. This is the way chosen to compare the deviance explained by each term. The intrinsic deviance explained by degree of freedom of the variable was also used to compare the parsimony of the terms. A Fisher's test is used to test the significativity of the explained deviance of each term.

RESULTS

Variable Selection

All the candidate variables were significant ($p < 0.05$) and the use or not of longline (BI), the type of fishing (tp), the engine power (cP), the trip length (tsnum), the gas consumption (conso), the high yield season (Ysaison) and the offshore trolling season were highly significant ($p < 0.001$).

Variables Explaining the Variability of the Catches Per Trip of the Whole Large Pelagic Fishery

Data issued from 1026 fishing trips were processed and the smallest AIC statistic was reached for:

$$\log(\mu) = \mathbf{BI + tp + tsnum + conso + eq + site + saison + anech + fm + BI{:}tsnum + conso{:}anech}$$

This model explains a large part (33%) of the total deviance of Y for 48 parameters estimated. The standardised residuals of deviance are roughly normally distributed (Figure 2). We can notice that the fit is less accurate for short FAD fishing trips with big catches. Five observations with big Cook's distances were deleted to improve the fit. Squared residuals of deviance and Cook's distances show no particularly influent observation. (Figure 3). The values plotted on figure 3 are the yields per trip showing the most influent observations are those corresponding to the higher catches.

The variables explaining the biggest part of total deviance and the highest explained deviance per degree of freedom are the type of fishing (tp) and the use of or not of single vertical longline (BI) (Table 3). tp explains the biggest part of the overall deviance whereas BI explains the highest deviance per degree of freedom. Both of the variables are significant regarding Wald's test and the explained deviance. The crew size (eq) and the season for offshore trolling (saison) are also significant for both tests and explains a smaller part of Y variability. The site and the year effects explain substantial total deviance but are not significant regarding to Wald's test.

The "type of fishing" effect explains the biggest overall catch per trip variability for three degrees of freedom. Moreover, the "BI" effect explains the other big part of catch variability and is closely related to the "tp" effect because the single drifting longline is only used in one type of fishing: the moored FAD fishing.. Hence the "tp" effect was chosen to stratify the sample. Similar modelling was conducted successively for the FAD fishing trips, offshore trolling and coastal trolling trips to assess the more explicative factors of the catches within each fishery.

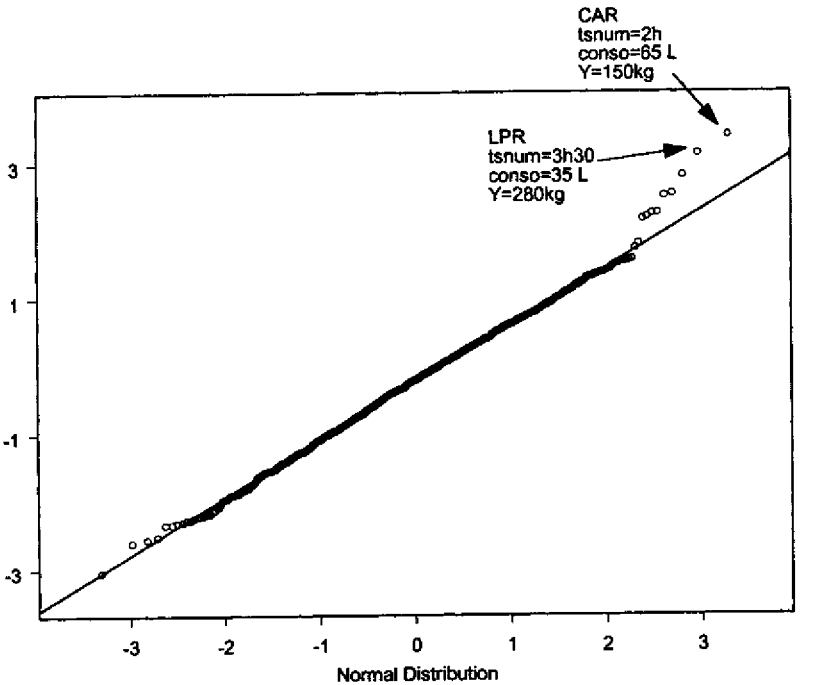


Figure 2. Half normal plot of the standardized residuals of deviance

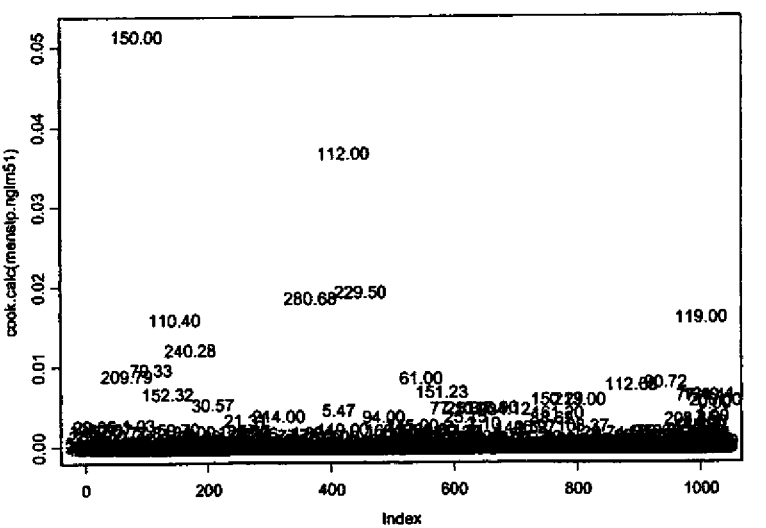


Figure 3. Cook's distance against observations

Table 3. Factors explaining the deviance of the catch per trip in the whole large pelagic fishery in Martinique

	Df	Deviance	Dev/Df	Res.Df	Resid. Dev	F Value	Pr(F)
BI	1	37.3292	37.3	1003	855.231	46.80022	0.00000000
tp	3	40.39884	13.4	1003	855.231	16.88291	0.00000000
eq	1	9.72325	9.7	1003	855.231	12.1902	0.00050186
saison	1	8.10957	8.1	1003	855.231	10.16711	0.00147506
tsnum:eq	1	5.8531	5.9	991	822.105	7.33819	0.00686830
site	7	37.65182	5.4	1003	855.231	6.7435	0.00000008
BI:tsnum	1	4.9094	4.9	982	799.584	6.15495	0.01327154
conso:anech	3	6.4957	2.1	979	793.088	2.71461	0.04370791
BI:fm	4	7.8324	1.9	983	804.493	2.45492	0.04428787
conso	*1*	*3.36778*	*3.4*	*1003*	*855.231*	*4.2473*	*0.03957608*
site:anech	*11*	*27.2730*	*2.5*	*992*	*827.958*	*3.10842*	*0.00039542*
tsnum:fm	*4*	*9.7790*	*2.4*	*987*	*812.326*	*3.06501*	*0.01594935*
anech	*3*	*6.54533*	*2.2*	*1003*	*855.231*	*2.7353*	*0.04251162*
tsnum	*1*	*1.5545*	*1.5*	*1003*	*855.231*	*1.9489*	*0.1630220*
fm	*4*	*7.4332*	*1.9*	*1003*	*855.231*	*2.32980*	*0.05436714*

Non significant effects italicised

Variables Explaining the Variability of the Catches Per Trip in the Moored FAD Fishery

The crew size (eq) and the offshore trolling season (saison) variables were not significant regarding the univariate Wald's test. They have not been retained for the multivariate model selection process.

The smallest AIC statistic was reached for:

$$\log(\mu) = \text{BI} + \text{conso} + \text{site} + \text{Ysaison} + \text{anech} + \text{site:anech}$$

This model explains a large part (29%) of the total deviance of Y for 26 parameters estimated. The data issued from 490 fishing trips were processed.

The standardized residuals of deviance are roughly normally distributed. Two observations with big Cook's distances were deleted to improve the fit. Squared residuals of deviance and Cook's distances show no particularly influent observation. The most influent observations are also those with the bigger catches.

The variable explaining the biggest part of total deviance and the highest explained deviance per degree of freedom is the use of, or not of, single vertical longline (BI) (Table 4). BI is highly significant for both tests. The FAD high yields/low yields season is also significant for both tests and explains a substantial part of deviance for only one degree of freedom. The other effects are not significant regarding the Wald's test and explain less deviance. The most explanative and significant variable is so the use or not of single vertical longline

Table 4. Factors explaining the deviance of the catch per trip in the moored FAD fishery in Martinique

	Df	Deviance	Dev/Df	Res.Df	Resid.Dev	F Value	Pr(F)
BI	1	21.48771	21.5	476	494.3337	21.95134	0.000003673
Ysaison	1	8.88716	8.8	476	494.3337	9.07891	0.002726253
conso	*1*	*4.94093*	*4.9*	*476*	*494.3337*	*5.04753*	*0.02512745*
site	*9*	*25.02345*	*2.7*	*476*	*494.3337*	*2.84037*	*0.002890876*
site:anech	*9*	*24.40199*	*2.7*	*467*	*469.9317*	*2.76983*	*0.003621247*
anech	*3*	*4.85513*	*1.6*	*476*	*494.3337*	*1.65330*	*0.1763182*

Non significant effects italicised

Variables Explaining the Variability of the Catches Per Trip in the Offshore Trolling Fishery

The crew size (eq) and the high yields season (Ysaison), the island coast (fm) and the trip length (tsnum) variables were not significant regarding the univariate Wald's test (Table 5). They have not been retained for the multivariate model selection process.

The offshore trolling essentially occurs from January to June and only the 183 trips recorded during this period have been taken into account in the model. The smallest AIC statistic was reached for:

$$\log(\mu) = \text{zone} + \text{anech}$$

This very simple model only explains (13%) of the total deviance of Y for eight parameters estimated. The standardised residuals of deviance are roughly normally distributed.. Squared residuals of deviance and Cook's distances show no particularly influent observation. The area where the landing point is located (zone) and the year (anech) are significant for both tests but explain very few deviance. No fishing effort related variables have been retained in this model.

Table 5. Factors explaining the deviance of the catch per trip in the offshore trolling fishery in Martinique

	Df	Deviance	Dev/Df	Res.Df	Resid.Dev	F Value	Pr(F)
zone	3	12,97765	4,3	177	124,492	8,04851	0,00004669
anech	3	8,660421	2,9	177	124,492	5,371042	0,00145979

Non significant effects italicised

Variables Explaining the Variability of the Catches Per Trip in the Coastal Trolling Fishery

The crew size (eq) and the high yields season (Ysaison), the offshore trolling season (saison) and the number of trolling lines used (nbT) variables were not significant regarding the univariate Wald's test (Table 6). They have not been retained for the multivariate model selection process. The smallest AIC statistic was reached for:

$$\log(\mu) = \text{tsnum} + \text{fm} + \text{tsnum:fm}$$

This model explains 22% of the total deviance of Y for 10 parameters estimated.. The data issued from 254 fishing trips were processed. The standardised residuals of deviance are roughly normally distributed. One observation with big Cook's distances were deleted to improve the fit. The trip length (tsnum) and the island coast (fm) are significant for both tests and explain most of the global deviance and of the deviance per degree of freedom.
Another model was tested including the precise fishing area (seamounts). The new effect was not retained through the model selecting process.

Table 6. Factors explaining the deviance of the catch per trip in the coastal trolling fishery in Martinique

	Df	Deviance	Dev/Df	Res.Df	Resid.Dev	F Value	Pr(F)
tsnum	1	5.47595	5,5	249	120.3008	11.65535	0.00074856
fm	3	9.05218	3	249	120.3008	6.42241	0.00033272
fm:tsnum	*3*	*3.51250*	*1*	*246*	*116.7883*	*2.49208*	*0.06072916*

Non significant effects italicised

DISCUSSION

Representativity of Data

As mentioned above, the data sample used for this study is not representative of the whole fishery in Martinique. The only other available catch per trip data are issued from logbooks collected both in Martinique and Guadeloupe but without simple random sampling plan. This dataset is also not representative of the whole fishery. However, this data set is bigger which allows a wider coverage of the fishery (11,678 fishing trips recorded over five years). The yearly coefficient of variation of Y in the sample used for this study ranges from 1.06 to 1.14 for the moored FAD fishery. It is comparable to the same coefficient for the same fishery in Guadeloupe between 1992 and 1995 (0.97 to 1.41). The yearly coefficient of variation of Y in the sample ranges from 0.62 to 0.87 for the offshore trolling fishery. It is comparable to the same coefficient for the same fishery in Martinique between 1994 and 1995 (0.76 to 0.83). So we can suppose that the size of the data sample used in this study is not too small to be compared to bigger samples with wider coverage of the fishery.

Variables Explaining the Variability of the Catches Per Trip of the Whole Large Pelagic Fishery

The type of fishing (tp) and the use of longline (BI) explain most of the deviance in the model. It implies that, in this sample issued from Martinique, different fisheries must be distinguished within the large pelagic fishery regarding to the catch per trip variability patterns. A fishery is commonly defined by:

i) A fishing area,
ii) One or several target species,

iii) A fishing gear,
iv) A "fishing practice".

In this case, the "fishing practice" corresponds to the type(s) of fish "aggregator(s)" that is (are) exploited by the fishermen during the trip. In fact, the absence in the Lesser Antilles of big hydrological fronts related to areas of high trophic interest for large pelagics does not allow the fishes to gather into large schools. The only way for the small scale fishermen to exploit these pelagic resources is to take advantage of local concentrations around different types of "aggregators" to catch fishes that would either be "virtually nonexistent" (Sharp, 1978 in Bertrand 1999) due to their very low global density. In Martinique, the aggregators exploited by the fishermen are the drifting flotsams, the seamounts and more recently, the Fish Aggregating Devices (FADs).

The large part of variability of Y explained by the "BI" effect highlights the fact that the concentrations of fishes found around the aggregators are only partially exploited by the small scale fishermen which only prospect the sub-surface layer. The use of the vertical drifting longline deeply influence the catch per trip variability patterns in our sample. This technique was introduced in 1994 in Martinique and allowed to increase the average production per trip by catching big adults pelagic under the moored FADs (Figure 4). This statement was confirmed by testing the GLM model: $Y \sim Ysp_1 + Ysp_2 + \ldots + Ysp_n$ where Yspi are the catches per trip per species i. The biggest part of the deviance of Y was explained by the catches of big pelagics (YGP), namely adult *Thunnus albacares* and *Makaira nigricans* and YGP was positively correlated with Y. Moreover, the small scale fishermen only use vertical longline up to depth of 150 - 200 m because of the absence of winch in their boats but experimental fishing showed the deeper presence of *Xiphias gladius*, *Thunnus obesus* and *Thunnus allalunga* under the moored FADs (Taquet et al. 1998).

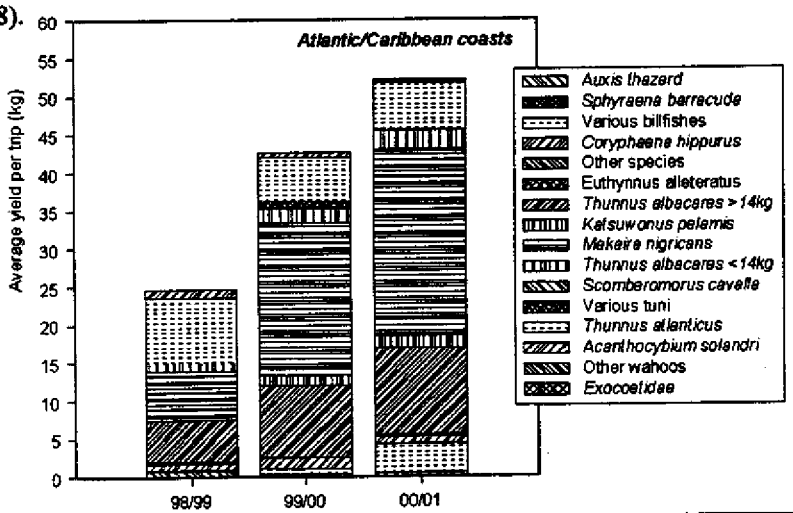


Figure 4. Average catches per FAD fishing trip per species, Martinique

According to the results based on the sample used in this study, the strategic choice of the aggregator (tp) and of the depth layer to prospect (BI) appear to be the fishing power components that explain most of the variability in the catches of the large pelagic fisheries in Martinique. The combination of those two components allows to define the fisheries exploiting the large pelagic fishes in Martinique (Table 7). The use of accurate definitions of fisheries is important to better assess the level of exploitation of the stocks because one fishery correspond to one "exploitation diagram" that is a size frequency distribution within the catches. Hence the age structure of the fishes caught is linked directly to the fishery in which operate the fisherman. For example in our fishing trips sample, the moored FAD trolling mainly target juvenile *Thunnus atlanticus* (Figure 5a) whereas the moored FAD longlining fishery essentially target adult fishes such as *Makaira nigricans* (Figure 5b). Actually, information on the type of aggregator and on the depth layer prospected (fishing gears) appear to be important to be collected to monitor the small scale large pelagic fishery in Martinique.

Table 7. Definition of the large pelagic fisheries in Martinique

Fishery	Fishing area	Target species	Fishing gear	Fish aggregator
Moored FAD longlining	Around the island	*Makaira nigricans* *Thunnus albacares*	Vertical longline	FAD
Moored FAD trolling	Around the island	*Thunnus atlanticus*	Sub-surface trolling lines	FAD
Offshore trolling	Mainly on the Atlantic coast	*Coryphaena hippurus* *Acanthocybium solandri* *Thunnini*	Sub-surface trolling lines	flotsams
Coastal trolling	Mainly on the Atlantic coast	*Thunnus atlanticus* *Scomberomorus sp* *Sphyraena baraccuda*	Sub-surface trolling lines	seamounts

According to the definition of the catchability components given by Gascuel et al. (1995) (Figure 6), the one-off choice of the aggregator is a global fishing efficiency (capacity to find the available fishes) component whereas the choice of the depth layer is a local fishing efficiency. Hence in our fishing trip sample, the variability of the catches seems to depend both on a strategic component at a global level: the choice of the aggregator and therefore on a fishing strategy component at a local level: the use or not of longline.

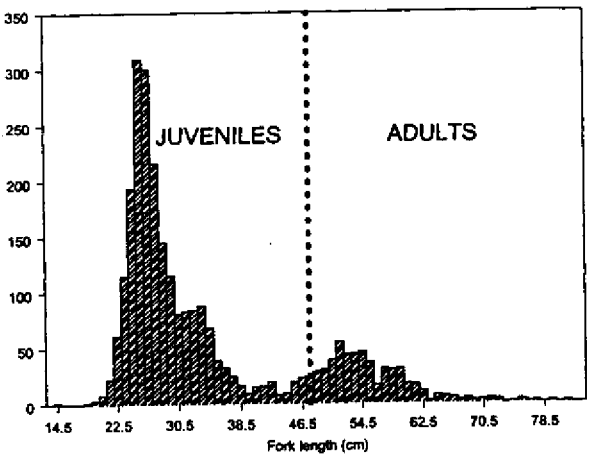


Figure 5a. Size frequency distribution of the *Thunnus atlanticus* caught by the moored FAD trolling fishery. Martinique, 1998 -2001

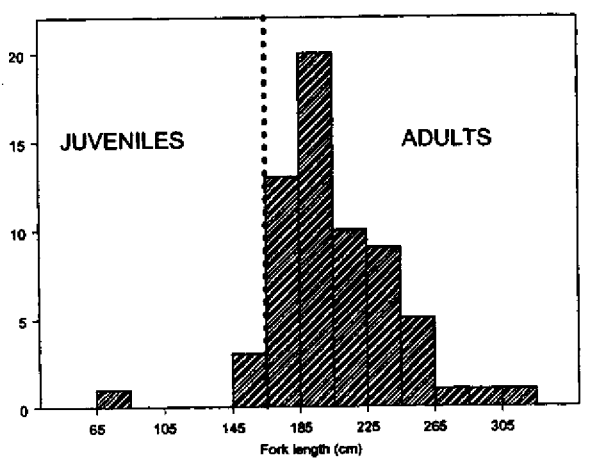


Figure 5b. Size frequency distribution of the *Makaira nigricans* caught by the moored FAD longlining fishery. Martinique, 1998 -2001

Variables Explaining the Variability of the Catches Per Trip in the Moored FAD Fishery

The variable explaining most of the catch per trip variability in the moored FAD fishery in Martinique is the use or not of vertical drifting longline (BI). It is worth to note this variable explicit the difference between the two moored FAD fisheries defined above, difference relying on the fishing gear used. Hence the theorical definitions of the two moored FAD fisheries seem to be correspond to two strata in the catches per trip.

In Gascuel et al.'s (1995) typology (Figure 6), "BI" is a fishing power component, namely of the local catching efficiency (el). The other explanative variable is a seasonal parameter which can be related to the availability "d" of the fishes function of the time period. So if the fishing mortality F is d*Pg*fn, in an attempt to precise the pressure of the FAD fishery on the stocks, one can express F as : F_{FAD}= d * **el** *ε.

The variables: use or not of longline (BI) and fishing season (Ysaison) appear to be particularly important to collect to monitor the moored FAD fishery.

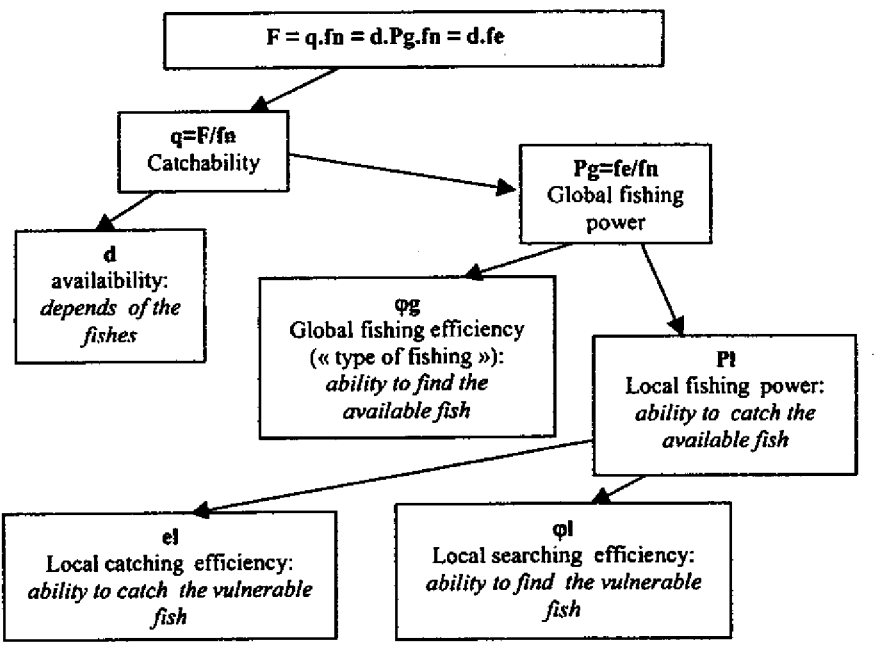


Figure 6. Components of the catchability (redrawn from Gascuel et al., 1995)

Variables Explaining the Variability of the Catches Per Trip in the Offshore Trolling Fishery

The explanative variables are the area where the landing point is located (zone) and the year (anech). The main fishing grounds for offshore trolling are on the Eastern Coast of the island, so the location of the harbour (zone) is very important to access the fishing areas. The offshore trolling is a very random fishery whose catches rely on the ability of the fisherman to find schools of dolphin fishes based on very few information (currents, bird flights...). The fishing effort parameters collected for this study seem to be inefficient to quantify this subjective efficiency because all the fishing trips appear to be identical with our parameters (long, involving high powered boats with the same fishing gears and a high gas consumption). So only geographical and yearly variations are retained in the model which is not of high interest to monitor the fishery.

Moreover, only the successful offshore trolling trips are recorded in our sample because if they catch nothing, the fishermen don't go to the market where the surveys are implemented.

Variables Explaining the Variability of the Catches Per Trip in the Coastal Trolling Fishery

The main explicative variable is the trip length which can be considered as a nominal fishing effort unit, providing also some information on the local searching efficiency (φl): a long fishing trip usually means either the fisherman chose to spend a long time travelling to a seamount located far away from the coast either he struggled to find the fish over the seamount and spent a long time searching. Contrary to the moored FAD fishery, the local catching efficiency does not seem to explain the variability in the catches. In an attempt to precise the pressure of the coastal fishery on the stocks, one can express F as: $F_{COAST} = d * \varphi l * E(tsnum) * \varepsilon$. Hence, the trip length appear to be the more important information to collect to monitor the coastal trolling fishery.

CONCLUSION

To conclude, the use of Generalized Linear Models appear to be an efficient method to process the data issued from small skewed data sets which are very often the only available data in the small insular countries where the cost of the data collection is very high compared to the amount of data collected.

According to the results based on the sample used in this study, the monitoring of the large pelagic fishery in Martinique and obviously in most of the Lesser Antilles countries, should include the new definitions of pelagic fisheries presented in Table 7 to better assess the variability and the age structure of the catches function of the strategic choice of the aggregator and of the depth layer prospected.

The fishing effort of the offshore trolling fishery appears to be very uneasy to evaluate because this is a very random fishery. The moored FAD fishing seems to

substitute effective fishing time (local fishing efficiency) to costly travelling time (local searching efficiency) compared to the coastal trolling.

The next step in the analysis of the fishing effort components of the large pelagic fishery in Martinique will be to try combining the three models obtained for the three types of fishing (moored FAD fishing, offshore trolling, coastal trolling) into a General Additive Model (GAM) so as to better explain the variability of the catches per trip at the scale of the whole fishery.

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A Review of the Fisheries Sector of Haiti with Recommendations for its Strengthening

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ABSTRACT

The Republic of Haiti, located in the Caribbean Region and sharing the Island of Hispaniola with the Dominican Republic, is one of the poorest and most densely populated nations of the Western Hemisphere. With around 30,000 subsistence fishers, its coastal resources are probably the most over-exploited and poorly managed. There is a lack of policy, legal, institutional and administrative framework, and resources to ensure sustainable use, management, and conservation of the fisheries and marine resources. In November 2000, the CARICOM Fisheries Unit initiated a programme to improve management of the fisheries, in collaboration with the government of Haiti. Preliminary reviews and surveys conducted indicated that although there is some information available on the fisheries, it is generally incomplete, contradictory, and difficult to locate. There are no systems in place either for collection and analysis of fisheries data or for monitoring, surveillance, and enforcement of fisheries regulations. The limited capacity of the local fishing fleet has partly prevented the exploitation of Haiti's off-shore fishery resources and concentrated effort in the near shore waters. On the positive side, with 59 fishers associations, Haiti has one of the strongest fisherfolk organizational systems in the CARICOM region. Also, the Haitian Fisheries Service has a team of qualified and motivated staff who are available to undertake the task necessary to improve the sector. In this paper, a preliminary assessment of the situation is provided as well as recommendations for specific activities to be conducted for the strengthening of the sector and improving the sustainable management of the fishery resources.

KEY WORDS: Fisheries of Haiti, Haiti's Fisheries Service, sustainable management

Una Revision de las Actividades Pesqueras de Haiti con Recomendaciones para su Fortalecimiento

RESUMEN

La República de Haití, localizada en la región del Caribe y compartiendo la Isla de la Hispaniola con la República Dominicana, es una de las naciones más pobres y densamente pobladas del Hemisferio Oeste. Con cerca de 30,000 pescadores de subsistencia, sus recursos costeros son probablemente los más explotados y pobremente manejados. No existe una estructura política, legal, institucional o

administrativa, ni tampoco recursos para apoyar el desarrollo sostenible y el manejo de los recursos pesqueros. En Noviembre del 2000, la Unidad de Pesquerías del CARICOM, en colaboración con el gobierno de Haití, inició un programa para mejorar el manejo de las pesquerías. Las revisiones preliminares y los inventarios conducidos indican que, aunque hay cierta información disponible sobre las pesquerías en Haití, dicha información es por lo general incompleta, contradictoria y difícil de localizar. No existe un sistema establecido para la colecta y el análisis de los datos pesqueros o para el monitoreo, vigilancia y refuerzo de las regulaciones pesqueras. La capacidad limitada de la flota pesquera ha impedido en parte la explotación de los recursos de aguas profundas de Haití y ha concentrado el esfuerzo en las aguas someras. En el lado positivo encontramos que, con 59 asociaciones de pescadores, Haití posee uno de los sistemas organizativos de pescadores más sólidos de la región CARICOM. Asímismo, el Servicio de Pesca de Haití posee dentro de su personal un grupo de profesionales calificados y motivados quienes están disponibles para conducir las medidas necesarias para mejorar el sector. En este trabajo se hace una evaluación preliminar de la situación y se dan recomendaciones para el manejo sostenible de los recursos de Haití.

PALABRAS CLAVES: Pesquerías de Haiti; Servicio de Pesca de Haití; manejo sostenible

INTRODUCTION

The Republic of Haiti is located in the Caribbean Region (19^0 N, 72^0 W). With a total area of 27,750 km^2 (Cantave 1996, UMVIM 2000), Haiti occupies a quarter of the Island of Hispanola, which it shares with the Dominican Republic. Haiti's coastline measures approximately 1,770 km and the island shelf has an area of around 5000 km^2.

Haiti is considered one of the most densely populated and poorest countries in the Western Hemisphere. With a total population of approximately 10 millions (FAO 1999b) and an unemployment rate of 60%, about 80% of the population lives in abject poverty (World Bank 2000). The standard of living and the socio-economic condition of the people of Haiti, including the fishers and their families are substantially lower than in the other Caribbean countries. The per capita GDP in Haiti was estimated at approximately US$357.6 in 1998 (CARICOM 2000). The fisheries are essentially artisanal and subsistence activities to provide food for local consumption and generate income for the fishers and their families. Poverty and illiteracy are widespread.

The natural environment and the coastal resources appear to have been severely degraded by a combination of factors including, destructive use, over-exploitation, pollution and poor management practices. The coastal resources, probably the most heavily exploited and poorly managed in the Caribbean, are the main source of livelihood and sustenance for the estimated 30,000 fishers and their families that

operate in Haitian waters. Pollution, over-exploitation, loss of bio-diversity and lack of education are issues that need to be address urgently (UNESCO 1997). Fishing occurs mainly in shallow coastal waters due to the limited capacities of the country's traditional, artisanal fishing fleet.

BACKGROUND

Under the fisheries component of the Integrated Caribbean Regional Agriculture and Fisheries Development Programme (ICRAFD) in November 2000 the CARICOM Fisheries Unit (CFU), in collaboration with the government of Haiti, initiated a program to improve fisheries assessment and management. As part of the initiation process a fisheries country profile was prepared based on the literature available on the web and at the CFU's library in Belize. Trying to find and compile information on the fisheries of Haiti was not an easy task. The data available is incomplete, fragmentary, contradictory and difficult to locate. The information gathered during the review was nevertheless useful in analyzing the fisheries situation and planning further consultations and activities.

In an effort to provide support for the strengthening of the Fisheries Service in Haiti, a team of professionals from the CFU embarked on a fact finding and planning mission to Haiti in February 2000. The team gathered information through literature review of existing documents, discussion sessions with fisheries staff, and meetings and consultations with policy makers and other stakeholders in the fisheries sector. Information was also collected through the administration of a multi-disciplinary survey questionnaire, which was administered to key informants during the mission.

FINDINGS OF SURVEY AND LITERATURE REVIEW

The information gathered during the literature review and multi-disciplinary survey highlighted significant inconsistencies in the reported statistics and knowledge of the status of the fishery resources. The number of fishers and fishing boats in Haiti is difficult to determine with any degree of accuracy. Laserre et al. (1985) (cited in FAO 1999a) reported that there are 11,000 fishers. UNDP/FAO (1989) and Puga et al. (1998) (cited in FAO 1999) reported that there were 12,000 fishers in Haiti. However, more recent reports prepared by Breuil (2000) and the Cuban Technical Assistance Mission in Port-au-Prince (Baseline Survey of the Fisheries Department-questionnaire) estimated the total number of marine fishers at 30,000. Approximately 80%of these are reported to be full-time fishers and 20% are part-time fishers. Most fishers start their career in fishing when they are only seven or eight years old. Approximately 90% of the fishermen are reported to be illiterate, compared to a national average illiteracy rate of 75% (Britannica.com. 1999).

The fishing fleet is composed of 5,000 - 6,000 small, artisanal fishing boats that operate mainly within the coastal waters (FAO 1999a). There are currently five

larger vessels involved in offshore fishing under a Cuban technical assistance project.

Many fishermen operate from small wooden artisanal boats, which are propelled by oars or sails (Brethes and Rioux 1986, FAO 1999). More than 60% (2,152) of the fishing boats operate from beaches on the west and southeastern parts of the country. Haitian fishers use mainly traps (Antillean "Z" type) made almost entirely of bamboo, nets (gillnet, trammel net, cast net, bottom net, "folas" and different kind of fishing lines (surface line, long line, bottom vertical line, trawling, beach seine), free diving, and hookah diving. Many fishers operate directly from the coast without the aid of a boat.

It has been estimated that a fishing unit typically operates from 125 to 150 hours per year (Ehrlich et al. 1985). The average catch per fishing unit fluctuates between 3 to 5 kg per trip (Ehrlich et al. 1985).

Two hundred and seventy two (272) species of coastal marine fishes have been reported for Haiti (WCMC 1999). Marine fish production accounts for 93% of the country's total catch (WCMC 1999), while catches from lakes and rivers account for the remaining 7%. The World Bank reported 48,000 MT as average annual marine catch for Haiti from 1991 to 1993, and 500 MT for freshwater fish catch (USAID 1996). According to FAO estimates, in 1999 the total annual marine catch amounted to 6,000 MT, while inland fishing accounted for 300 MT (Breuil 1999b). The value of the landings has been estimated at US$30 million, accounting for 2.5% of GDP.

Haiti exports approximately 350 MT of fish and fish products and imports approximately 12,600 MT valued at US$18,000,000. The consumption of marine product has been estimated at 3.1 kg/year/person (FAO 1999b).

There are three aquaculture farms that produce freshwater fish for the domestic market. There is also a small ornamental fishery that targets nearly 70 different species of fresh water, brackish water, and marine fishes. The ornamental fishery is considered an "informal" sub-sector of the fishing industry, and like the other sub-sectors within the fisheries is largely unregulated. Ornamental fishing is conducted mainly in Fort Liberté, South Capes, and Dame Marie. There are approximately seven establishments engaged in this fishery which targets the export market. FAO (1999a) reported that around 800,000 specimens were exported from Haiti in 1998. Further studies are needed to determine the full extend and socio-economic importance of this fishery as well as the status of the targeted species.

Legislation, Monitoring, Surveillance and Enforcement

The Fisheries law of November 1977 is the main legal instrument by which fisheries activities are regulated in the Republic of Haiti. There are other general laws, which apply to navigation and also affect some aspects of the fisheries sector in Haiti. The Fisheries Law of 1977 requires the registration of all fishermen operating in Haiti. There are also resource management regulations designed to protect and conserve the fishery resources including, closed seasons for lobster and conch and minimum mesh size for certain types of fishing nets.

The National Fisheries Service, a division within the Ministry of Agriculture of Haiti, is responsible for administration and enforcement of the fisheries law and associated regulations. Monitoring, surveillance, and enforcement of fisheries regulations are among the specific functions of the Fisheries Service. There is generally no monitoring, surveillance, or enforcement of fisheries regulations due to lack of resources and equipment, limited organizational capacity, lack of personnel, poverty, and political instability. Normally, no action is taken when violations of regulations are discovered. Although there is very little evidence of fisheries management or conservation in Haiti, fishers from at least one organization, the National Fisheries Association, are reported to practice some form of self-regulation. The existing laws and regulations governing fisheries are outdated and inadequate to protect fish stocks and essential fish habitats and therefore need to be updated. Substantial strengthening of the administrative and enforcement capability of the Haitian Fisheries Service is also needed before it can effectively monitor and have any real impact regulating the fisheries.

Status of the Fisheries and Fisheries Management.

The available information suggest that the fishery resources and associated coastal habitats have been severely depleted and degraded, particularly in the coastal areas due to overfishing, pollution, habitat destruction, and lack of management. The results of various studies confirm that there has been progressive degradation of the coastal ecosystems and marine biodiversity followed by a decreased in the fish yield (Célestin 1999). The insular shelf around Haiti is relatively small and easily accessible to fishermen (Appeldoorn and Meyers 1993) and as a result, the coastal demersal fish stocks are heavily over-exploited. The fishers target mainly lobster, conch, and shallow-shelf reef species. Ferry and Kohler (1987) reported that as much as 70% of the catches taken by traps are juveniles with total length of less than 10 cm. Puga et al. (1998) reported that in Aquin Bay, more than 90% of the lobsters caught are juveniles.

There is an urgent need for further studies to not only assess the status of the marine resources of Haiti but also to develop solutions to the difficult resource management problems facing the country. Urgent action is needed due to the fact that many marine resources appear to be disappearing even before scientists have the chance to account for their existence.

The lobster fishery is one of the most important in Haiti with average annual export of approximately 134 MT between 1994 and 1999 (FAO 1999a). The fisheries legislation specifies a closed season for lobster from April 1 to September 30 each year. There is an urgent need to undertake studies on the biology of the lobster stocks in order to determine the species being captured, length at first maturity, population parameters and general status of the lobster stocks.

The queen conch (*Strombus gigas*) is being exploited intensively for commercial and local consumption. However, the limited shelf area reduces its potential

(Appeldoorn and Meyers 1993). In 1997 the amount of conch exported from Haiti reached 289 MT, apparently due to the re-export of products imported from Jamaica. Wood (1995) found that the conch populations on the Island of Gonaive and at Les Arcadins were seriously over-exploited (0 conch/ha, based on 15 transects), but in Dame-Marie and Rochelois Bank there were still viable stocks (160 adults/ha). Wood (1995) recommended a number of management measures for the queen conch fishery including minimum size restriction, closed season, creation of no-take area,s and limitation of fishing effort.

The existing fisheries regulations appear to be inadequate to protect the fisheries and the coastal environment. Management regulations are generally neither respected by fishermen nor enforced by the fisheries management authorities for several reasons. A draft fisheries management plan was prepared with the help of FAO in 1999, but it has not yet been introduced due to lack of funds and other resources needed for implementation. The main objectives of the fisheries management plan are:

i) Rehabilitation of degraded habitats,
ii) Training of fishermen in basic literacy and more advance fisheries training in fisheries assessment and management, and
iii) Fish stock assessments.

The plan also focuses on the introduction and use of appropriate fishing gears and equipment. The plan seems to suffer from two main weaknesses. It does not really involved fishers organizations and it does not adequately take into account the socio-economic situation and local culture.

Against the background of over-fishing within the inshore fisheries, organized commercial fishing in the offshore waters seems to offer opportunities for investment (World Bank 1997). Re-direction of fishing effort to the currently under-exploited deep-water demersal and coastal pelagic resources is an option that should be considered. This should be explored with caution, but general steps should be taken in order to decrease pressure on the inshore stocks and to improve yield from the deep water, offshore stocks to sustainable levels. Such expansions should be done gradually within a management framework that will permit improved monitoring and collection of fisheries data and effective regulation of fishing effort.

Due to the limited coral reef available in the marine waters of Haiti, another potential initiative to reduce pressure on the depleted near-shore fishery is the construction of artificial reefs to enhance fish populations. Artificial reefs could also be used within "protected areas" to enhance recovery of depleted fish stocks.

Haiti neither has any well-equipped marine research institution nor adequate numbers of marine scientists to conduct the types of research that is needed to achieve sustainable fisheries development. For these reasons the potential benefits from closer cooperation with regional and international organizations such as CARICOM, FAO, and the World Bank are substantial.

Structure and Functions of the National Fisheries Service

At this time, the Government of Haiti does not have in place either the basic organisational and institutional capability, legislative framework, sufficient knowledge of the resource systems, or a clear policy and plan for sustainable development and conservation of the fisheries resources. The National Fisheries Service is the organization responsible for fisheries and aquaculture development and management in Haiti. The Fisheries Service is a sub-division of the Department of Natural Resources, which is located within the Ministry of Agriculture.

The main functions of the Fisheries Service include:

i) Licensing and registration of fishers,
ii) Data collection and monitoring of the fisheries,
iii) Research,
iv) Fisheries management, planning and policy formulation,
v) Development of cooperatives,
vi) Aquaculture development,
vii) Management of the ornamental fishery,
viii) Provision of extension services to the fisheries sector,
ix) Training of fishers, and
x) Post-harvest technology and quality assurance.

The Fisheries Service has a staff complement of 22 professional staff, including 12 persons who have been trained to the bachelors' degree level and six persons who have been trained to the masters' degree level.

Although the Fisheries Service is responsible for sustainable development, management, and conservation of the fisheries resources, it has neither the organizational structure nor funding needed to undertake the complex tasks associated with these responsibilities. The work of the Service is constrained by a lack of funds and basic office facilities and equipment, including electricity supply, computers, telephone, desk, chairs, papers, water, office space, and motor vehicles. The Fisheries Service is therefore not able to fully carry out its responsibilities, given the numerous fishing beaches, some in remote locations, and large expanse of maritime waters under its jurisdiction. There is a need to review the organizational structure and develop a program to gradually strengthen and upgrade the capability of the Haitian Fisheries Service through staff training and provision of equipment, as well as development of clear policies, legislative framework, and work programs. The main areas identified for improvement in the future are:

i) Habitat protection,
ii) Institutional strengthening and training,
iii) Fisheries data collection and management,
iv) Stock assessment,
v) Surveillance, monitoring, and enforcement
vi) Fisheries technology (processing and quality control), and
vii) Fisheries co-management and community participation.

Conflicts and International Intrusion

Haitian fishermen from Anse d'Hainault, Dame Marie, and Tiburon frequently operate around the Navassa Island from September to November. Navassa Island is claimed by both Haiti and the USA (Haiti Forum 1999). Haitian fishers are also reported to operate illegally in the waters of the Dominican Republic around Jaragua National Park and Montecristi National Park. On the other hand, fishers from Martinique, who introduced FADs in Haiti, have been reported to operate illegally in the area of Anse d'Hainault (Mar and Pesca 2001).

Fisher's Organizations

A recent positive development has been the mushrooming of a number of fisher folk organizations, particularly in the 'Artibonite', West (Ouest), and southern provinces. With approximately 140 fisher's organizations, Haiti has one of the strongest fisherfolk organizational systems in the CARICOM region. Approximately 52% of the fishers are reported to be members of a fisher's organization. Many of these organizations appear to have been formed during the course of the last three years. These fledging organizations need to be sustained and their capacities built, whilst ensuring that the initial motivation and incentives are kept alive. The support of a local NGO, FONHADES of Port-Au-Prince has been pivotal in facilitating the emergence of the fisher's organizations. This NGO has been providing technical support to the departments' organizations in building 'provincial' umbrella organizations (FONADHES 2000). Gwoup Insyativ Pou Yon Mouvman Nasyonal Peche Oganize (GIP) or the Federation of Organizations of Fishers in Haiti founded in 1997, having already brought together, KOOPECH, made up of 11 primary organizations in the West (OUEST) department and KOPDA, made up of 13 primary organizations in the 'Artibonite' Department.

The goals of these organizations seem to be to promote their interests, to play the regulatory role that has not been effectively promoted by the government, to develop viable economic entities with access to credit facilities, to participate in community welfare activities, and to seek to reduce their dependency on government largesse (CFU 2001).

The EU Funded ICRAFD Project (CFU)

The CARICOM Fisheries Unit and the Haitian Fisheries Service have prepared a five-year work plan to be implemented under the Fisheries Component of the Integrated Caribbean Regional Agriculture and Fisheries Development Project (CFU 2001), which is funded by the European Union. The Work Plan will seek to address some of the critical issues affecting the fisheries sector in Haiti by focusing on:

i) Development of clear and adequate planning and policies framework,
ii) Improving the fisheries database, information management systems, and flow of information to stakeholders for planning and management decision making, and

iii) Strengthening human and institutional capacities for administration, fisheries research, resource management, and conservation.

Fishery management decision-making and planning must be informed by quantitative information on the structure of the sector and the status of the resources. To this end, the Project will seek to address those issues associated with providing fisheries data for assessment and management and as an effective tool for monitoring and regulating catch and fishing effort.

Establishing and operating a national data collection system requires a great deal of effort, resources, expertise, and cooperation among all the stakeholders in the fisheries. Haiti does not have in place the basic organisational and institutional capability or sufficient knowledge of the resource for successful establishment and operation of a national data collection system.

The project will therefore take a step-by-step approach to the establishment of a data collection system and the generation of data and information for policy making, management planning and monitoring of the fisheries. As a first step, a national sample-based fishery survey will be undertaken to better understand the scope, status and socio-economic contribution of the fisheries sector to the national economy. This sample survey will focus on the collection of basic data on catch, effort, and biological and socio-economic aspects of the fisheries. The data and information obtained will be used to design a data collection system for on going monitoring of the fisheries.

The information on the status of the fisheries in Haiti is incomplete, fragmentary, contradictory, and difficult to locate. An important component of this work plan will be a search for and compilation of existing documentary material on the fisheries in Haiti., The project will also provide support for the collection of biological and socio-economic data on the commercially important species groups as well as technical assistance for the analysis and interpretation of the data and preparation of management recommendations. Support will also be provided to enable scientists and resource managers from Haiti to participate in regional and sub-regional initiatives such as the fisheries assessment and management workshops.

Technical assistance will be provided to the Fisheries Department to improve the institutional capability of the Department, strengthen the planning and policy framework and improve the system of governance. Specifically, the Project will:

i) Assist with the preparation of a comprehensive national fisheries policy, fisheries management plan, and work plan for the fisheries department,
ii) Assist with preparation and establishment of a mechanism for providing policy advice and enhancement of participatory approaches to decision-making regarding the fisheries sector,
iii) Support a review and preparation of recommendations for strengthening of the legal framework, organisational structure and operational arrangements of the Fisheries Department, and provide resources to assist with the implementation of the recommendations agreed upon,

iv) Provide long and short term training opportunities for staff of the fisheries department,
v) Empower resource users so that they can assume greater responsibility for sustainable use and management of the fisheries,
vi) improving public awareness of the benefits and importance of the fisheries sector and the need for sustainable resource management;
vii) Strengthen aquaculture production by rehabilitating the research, extension, and training facility at the Fisheries compound in Port-au-Prince, and
viii) Explore the potential for development of small-scale pelagic fisheries and the cultivation of sea moss (*Gracilaria* spp.) to improve the livelihood of persons who are dependent of fisheries and aquaculture.

The activities designed to strengthen community involvement and education will directly tackle the major knowledge gaps and human relations problems facing the artisanal fisheries sector. These are the absence of a functional extension unit in the Fisheries Department, the lack of awareness of conservation and management issues among resource users, the absence of effective mechanisms for enforcing management measures, and the weak links between the department and the resource users and other stakeholders.

The strengthening of resource user organizations and the strengthening of operational linkages between resource users and the department of fisheries will be addressed through a deliberate mobilizing and organizing program to be coordinated by staff of the fisheries department, and supported by staff of local NGOs who will benefit from training, which will build their capacity for field work organizing and mobilizing fisher-folks. They will also provide technical support to the fisher folk organizations that will eventually emerge, and provide the Public Relations input that will cement relations between the department and the resource user groups.

The project will promote greater awareness by planning and promoting a public awareness campaign that will utilize group interaction, print and mass media, supplemented by a radio call-in program, in which all stakeholders will be active participants. This will be supported by a National Dialogue Group of representatives of all major stakeholders that will regularly meet to deliberate on burning issues related to the improvement of the industry and the sustenance of the resources. The matters discussed by this forum will feed into the public awareness campaign.

DISCUSSION AND CONCLUSION

The current situation in Haiti is very challenging due to the overall low level of development, widespread poverty, lack of basic services and infra-structure, severe environmental degradation, and large number of persons who are dependent on the fisheries resources for survival. This situation is further compounded by the lack of adequate fisheries legislation, lack of capability for monitoring and enforcement, lack

of financial resources for fisheries programs, and lack of organization and institutional capability for fisheries development and management, including physical office space and facilities. The Haitian Fisheries Service has no budgetary allocation. For these reasons the fisheries in Haiti is largely unmanaged and unregulated.

Despite these constraints, there are some positive factors around which we can work to improve the fisheries situation in Haiti. There is a cadre of trained personnel with general fisheries background employed by the Fisheries Department. There is a staff of 22 persons including 11 university graduates, six of whom have post-graduate training in fisheries and aquaculture. There is a physical facility with substantial aquaculture installations. Both the building and the aquaculture facilities are in a state of disrepair. There are several well organized and active NGOs, fisher's organizations and universities in Haiti involved in the fisheries sector. It will therefore be possible to develop and implement a carefully targeted program of work to gradually improve the national and local capability for sustainable fisheries development and management, and consequently enhance the contribution of fisheries and aquaculture to the economic development of the country.

Interventions in the fisheries sector by themselves will not solve the problems unless they form part of a larger sustainable development program seeking to address the larger issues of improved governance, improved productivity, and improved environmental management and human development. Improvement in the basic socio-economic conditions and living standard are needed to reduce the heavy dependence on the already over-exploited fishery resources for survival.

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Promoting Long-term Sustainable Use and Conservation of Marine Resources in the Eastern Caribbean – A Regional Collaborative Project

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ABSTRACT

The potential for Marine Protected Areas to support fisheries management has been recognised internationally. Within the Caribbean, Marine Protected Areas are increasingly being seen as tools for managing resource use with regard to coral reef fisheries and thus, a number of fairly new Marine Protected Area initiatives are taking place, which are seen as part of the action strategy for the management of the use of a number of fisheries resources. A role for Marine Protected Areas in Biodiversity conservation in the Caribbean region has also been identified. Against the backdrop of limited budgets and staff resources, eastern Caribbean marine resource management agencies and academic research institutions have expressed a strong need for an effort to help them coordinate available information that may be utilized in evaluation of candidate sites for coral reef fisheries reserves and other marine protected areas in the region. These agencies have also requested assistance in improving regional capacity for monitoring and assessing marine habitats, and data management and synthesis to fill priority gaps in the information. Additionally, a need has been expressed for assistance in developing a coordinated geo-spatial references inventory and data management program of available marine fisheries related information. In support of this, a strategic, collaborative, intervention is being initiated in the eastern Caribbean, with the Natural Resources Management Unit of the Organisation of Eastern Caribbean States, US National Oceanographic and Atmospheric Administration' National Marine Fisheries Service, University of the West Indies' School of Graduate Studies and Research, Caribbean Conservation Association, US Agency for International Development, and the US Department of State all having a part to play. This contribution outlines both the context and the content of this initiative.

KEY WORDS: Coral reef fisheries, management of resource use, marine protected areas

MARINE PROTECTED AREAS

The most commonly referred to generic definition of a Marine Protected Area (MPA) is that of the World Conservation Union's (IUCN) Marine Program (Kelleher and Kenchington 1991), which defines a MPA as: "an area of intertidal or subtidal terrain, together with its overlying waters and associated flora, fauna, historical and cultural features which have been reserved by legislation to protect part or all of the enclosed environments". This definition has been expanded (de Fontaubert et al. 1996) to accommodate a wider range of objectives and multiple benefits, viz.:

> "Marine Protected Areas ... are coastal or oceanic management areas designed to conserve ecosystems together with their functions and their resources. MPAs range from small, highly protected reserves that sustain species and maintain natural processes to larger multiple-use areas in which conservation is coupled with various socioeconomic activities and concerns".

In the United States, MPAs have been defined as "any area of the marine environment that has been reserved by Federal, State, territorial, tribal, or local laws or regulations to provide lasting protection for part or all of the natural or cultural resources therein" (US Presidential Executive Order 13158, May, 2000). In general MPAs "... can protect marine biodiversity by protecting endangered species, critical habitats, seed banks, and sources of recruits through the establishment of non-extractive zones or harvest refugia" (Eichbaum et al. 1996). Numerous other benefits, emanating from the setting up of MPAs, have been cited (Sobel 1996, Crosby et al. 2000). These can be placed into five broad categories:

i.) Protect biodiversity and ecosystem structure, function and integrity,
ii.) Improve fishery yields,
iii.) Expand knowledge and understanding of marine ecosystems,
iv.) Provide recreation and tourism opportunities, and
v.) Provide socio-economic benefits for coastal communities.

Eichbaum et al. (1996) contend that large multiple-use protected areas can be thought of as demonstrating the concept of ecosystem-based management, where limits of protection in a geographical sense are based on the extent of movements of organisms and physically linked processes. The underlying ecology thus defines the outer boundaries for the area of protection. In recognizing these linkages, MPA planners can work toward conserving ecosystem integrity, not just individual

resources or ecosystem structure. MPA management strategies should be designed with ecological linkages in mind so that the protected area reflects the specific objectives for which it was created (Eichbaum et al. 1996, Crosby et al. 2000). Two basic approaches can be used to promote the long-term, self-perpetuating existence of living natural resources within MPAs (Crosby et al. 2000). The first is based on the principle of "sustainable use," the second is based on the principle of "no-take". Sustainable use approaches are predicated on the concept that the living resources of an MPA replenish themselves naturally and can be harvested (i.e., commercial, recreational and/or subsistence), within limits, on a continuing basis without eliminating them. "No-take" marine reserves are a relatively new and often very controversial human-access management tool for replenishing exploited fish stocks, particularly in North America. In the eastern Caribbean, the Fisheries Acts of at least seven nations define "marine reserves" in which " any person who, ... fishes or attempts to fish ... is guilty of an offence ..." (c.f. Government of Saint Lucia, 1984). Unlike traditional extractive use management strategies, "no-take" marine reserves provide a spatial refuge for living marine resources by banning all fishing and other extractive activities within the reserve's boundaries (Crosby et al. 2000).

The potential for MPAs to support fisheries management has been recognised internationally (c.f. Caddy and Oliver 1994). Within the Caribbean, MPAs are increasingly being seen as tools for managing resource use with regard to coral reef fisheries (Miller and Richard 1997, Corless et al. 1997, Goodridge et al. 1997, Hatcher et al. in press). At the Caribbean Workshop on Marine Biodiversity held in Montego Bay, Jamaica from the 27-29 October, 1998, the two working groups met to discuss respectively: the relationship between Tourism and Marine Biodiversity, and the relationship between Integrated Fisheries Management and Marine Biodiversity Conservation. Both working groups identified a role for Marine Protected Areas in Biodiversity conservation. In fact, the workshop agreed that there was need to establish and maintain a regional network of marine and terrestrial protected areas. This could be done along the broad terms supported by the Convention on Biological Diversity, and the Protocol on Specially Protected Areas and Wildlife in the Wider Caribbean Region ("the SPAW Protocol") of the Cartegena Convention (c.f. Aiken 1999, Haughton and Jacobs 1999, Murray 1999, Salabarria Fernandez 1999, Vanzella-Khouri 1999). More recently the consensus is "that MPAs were not a panacea for rescuing troubled fish stocks, but they could be considered as one tool in a kit of management techniques" (Anon. 2000).

The International Group of Experts on Marine and Coastal Protected Areas (Crosby et al. 1997) have stated that these areas:

i) Have a critical role in the management for long-term conservation and sustainable use of marine and coastal biological diversity;
ii) Function as focal points for development of governance for coastal and ocean systems; and
iii) Provide for local community education and training in the importance of conserving marine and coastal biodiversity.

The National Center for Ecological Analysis and Synthesis (NCEAS) *Scientific Consensus Statement on Marine Reserves and Marine Protected Areas* (issued a at the AAAS meetings of February 2001) succinctly summarizes the state of scientific knowledge about the benefits of no-take MPAs (which the NCEAS terms marine reserves [MRVs]), and strongly advocates using MRVs to offset impending marine conservation crises in heavily overused parts of the oceans. The benefits afforded by MRVs include *inter alia*: increases in abundance and diversity of organisms inside reserves, decreased mortality and habitat destruction, reductions in extinction probability, increased abundances and sizes of organisms outside reserves due to spillover effects, replenishment of depleted populations of organisms, and buffering against environmental variability (AAAS 2001, Crosby et al. 2000).

THE CURRENT STATUS OF MARINE PROTECTED AREAS IN THE EASTERN CARIBBEAN

Among the island nations of the eastern Caribbean, MPAs have been seen primarily as tools for fisheries management except in very few instances. In seeking to diversify their economies, eastern Caribbean States are paying particular attention to promoting conservation and expanding eco-tourism in the marine environment. Having said that, in most instances the declaration of these marine protected areas has been done under the aegis of the respective fisheries acts. At present, fairly new MPA initiatives are taking place in Anguilla, Antigua and Barbuda, Commonwealth of Dominica, Saint Lucia, and St. Vincent and the Grenadines. The Barbados Fisheries Management Plan, 2001 - 2003 (Government of Barbados 2001) cites the establishment or expansion and enforcement of "agreed upon marine protected areas" as part of the action strategy for the management of the use of shallow-shelf reef, coastal pelagic, turtle, and lobster resources of that country, primarily to deal with issues such as:

i) Overfishing due to high mortality of juvenile and adult reef and/or coastal pelagic fish
ii) Habitat degradation and destruction

In all instances the relevant fisheries authorities are the agencies taking the lead or having responsibility for demarcation, management planning, and/or management itself. Responsibility for day-to-day management has in some cases been envisaged as being passed on to a group of stakeholders. In the case of the Cades Bay Marine Reserve in Antigua, "negotiations" are at present taking place with stakeholders to provide a basis for management of the area. In Dominica, a Local Area Management Authority (LAMA) has been designated for the Soufriere/Scott's Head Marine Reserve (SSMR) and "any permission required under the (Marine Reserve Regulations, No. 7 of 2001) shall be obtained from the Local Area Management Authority" (Commonwealth of Dominica,2001: parentheses mine). In Saint Lucia, the Canaries/Anse La Raye Marine Management Area (CAMMA) is expected to be managed under the Soufriere Marine Management Association (SMMA), while in Saint Vincent and the Grenadines the Tobago Keys Marine Reserve was expected

to be managed by a separate authority set up for that purpose.

The experience, where some attempt at management of the MPAs has begun, has led to a number of observations that can inform future MPA management:

i) The process of developing a management structure involving participation of all stakeholders is long and often tedious.
ii) Participatory approaches to management while time consuming may be more sustainable.
iii) A clear vision of the role the MPAs will play is needed, as well as the management goals and objectives to ensure that the vision is achieved.
iv) Involvement of all stakeholder groups at some time in the planning cycle is important for success of the marine protected area.
v) There is need to acknowledge the very real limitations in capacity which exist since they impact seriously on sustainability and efficacy of the structures set up for the management of MPAs.
vi) MPAs which are perceived as successful may be the target of requests for research activities which may require the creation of well defined frameworks to guide the design and conduct of research and monitoring programmes and activities.
vii) Of major importance to the management of MPAs is the status and health of the habitats found in those areas.
viii) Management plans for MPAs need to be kept under review to ensure that their relevance and appropriateness is maintained.

MARINE PROTECTED AREAS AND ISLAND SYSTEMS MANAGEMENT

Small islands are influenced by their surrounding marine environment and themselves impact the seas around them in a time frame much shorter than for larger landmasses. In fact, accepted definitions suggest that the entire land mass and the marine area it controls constitute the coastal area of small island States. The island itself is seen as a collection of systems all interacting with each other, such that an intervention on any one system will impact on adjacent, or even distant, systems. Our management framework, therefore, must consider the intricate interactions and linkages between social, cultural, physical and biological systems on small islands and must provide the mechanisms for multi-disciplinary and multi-sectoral management (Anonymous, in press). This framework is what we in the Organisation of Eastern Caribbean States (OECS) region call Island Systems Management (ISM). It has been suggested that ISM should be seen as "an adaptive management strategy which addresses issues of resource use conflicts, and which provides the necessary policy orientation to control the impacts of human intervention on the environment" (Chase, 1994; see also Nichols and Chase, in press). It hinges on the linkages between systems and the recognition that in order for management to be more effective, it needs to be fully integrated, boundary-less and flexible. Within the

fisheries management context, ISM is not inconsistent with good fisheries management (Murray and Nichols, 1998) or the management of MPAs.

The experiences in the OECS have shown that the interface between the use of Marine Protected Areas and Island Systems Management is often within the process of decision-making. This reiterates the suggestion that the process for development of MPAs can be seen as consisting of three general phases and eight steps (BC Parks 1997):

Identification Phase

Step 1. *Identification of key marine values and marine protected area system goals and objectives* — The first step is to identify the range of key marine values, attributes and features that would best contribute to a system of MPAs, and to ensure that they are adequately reflected in the system goals, objectives, planning frameworks and criteria that will direct area identification, evaluation and selection.

Step 2. *Identification of areas of interest* — This would take place through (a) systematic application of goals, objectives and criteria through overview studies and (b) identifying and consolidating already known and/or well-supported areas of high value or significance. Opportunities would be provided for stakeholders to nominate areas of interest, and a database of such areas would be undertaken by national agencies working together.

Evaluation Phase

Step 3. *Technical evaluation of areas of interest* — All areas of interest should be evaluated according to a standard set of criteria including, among others, regional, national and international significance; rarity, scarcity or uniqueness; representativeness; naturalness; ecological vulnerability, sensitivity and fragility; scientific importance; recreational value; and immediacy of need for protection.

Step 4. *Identification of socio-economic issues and concerns associated with areas of interest* — Prior to selection of MPAs, there would be need to identify the full range of socio-economic issues and concerns associated with any given area of interest. These should give consideration to the social and economic values of a given area; the level of community support; practicality of protecting the area; and the opportunity for forgoing partnerships for future area management.

Step 5. *Selection of specific areas for special interim management* — If necessary, special interim management arrangements could be developed on a case-by-case basis.

Decision Phase

Step 6. *Making decision to protect areas through planning processes* — This would have to be done through some formal planning process, which would resolve competing issues and values and ensure all interests are considered. During this step, appropriate assessments of environmental, social and economic implications of designating and area would be completed.

Step 7. *Formal designation of new marine protected areas* — This crucial step involves the selection of the most appropriate/compatible legislation to ensure that the area can be legally managed in accordance with the intended/required management regime(s). This process would clarify the management authority, the geographic boundaries for the MPA and acceptable or permissible uses.

Step 8. *Management of marine protected areas* — A management plan, developed with stakeholder involvement, is prepared for each protected area. This plan would identify the terms and conditions around the "where" and "when" of permissible uses.

These eight steps can also be used for setting up MPAs within an ISM framework.

In a concluding section to the Proceedings of the 1st International Workshop on Marine and Coastal Protected Areas, held in Camberra, Australia, in August 1994, participants (Anonymous 1994) set out suggestions on the necessary conditions for successful management of coastal and marine resources; guiding principles for coastal and marine management; and factors related to the principles that are most likely to lead to effective management implementation. These principles (*ibid.*) include, but are not limited to:

i) Achieving a balance between the "top down" legislative agency and the "bottom up" community involvement approaches to planning and management;
ii) Making a strong link to the stakeholders of the area throughout the planning and implementation of management;
iii) Managing human activities in a structured way;
iv) Developing management of marine and coastal resources based on long-term resource protection and sustainable utilisation;
v) Making clear from the earliest stages the management aims and goals; understanding that marine management is a dynamic process;
vi) Having "key movers" integral to the process; a good and well-managed public information programme supporting the entire process through to implementation and periodic revisions;
vii) Having knowledge to support the planning and management process;
viii) Recognizing the scale and linkages in marine and coastal environments in analysis and identification of sites, and the selection process, through to planning, establishment and management;

ix) Having integration between the various sectors such as industry and conservation managers;
x) Having appropriate resources available to support the development and implementation of the management process; and,
xi) Instilling local pride and ownership of the project.

A STRATEGIC INTERVENTION

The St. George's Declaration of Principles for Environmental Sustainability in the OECS (SGD) has enunciated a number of principles (principles 6, 7, 11, 12, 13, 15) that pertain to promoting conservation and (possibly) expanding eco-tourism in the marine environment. Against the backdrop of limited budgets and staff resources, assistance from a suite of international donor institutions would benefit these island nations' efforts to utilize their coral reef marine protected areas in this regard. Numerous recent, current and planned regional and international institutions and programs, as well as individual eastern Caribbean fisheries agencies, have/are/will be gathering both general marine-related and coral reef fisheries specific information. Local eastern Caribbean marine resource management agencies and academic research institutions have expressed a strong need for an effort to help them coordinate available information (coral reef fisheries and benthic habitat assessments, sources and sinks related to ocean currents, *in situ*, and remotely obtaining physico-chemical characteristics) that may be utilized to evaluate candidate sites for coral reef fisheries reserves and other marine protected areas in the region. These same local officials also have requested assistance in improving regional capacity for monitoring and assessing marine habitats, and data management and synthesis to fill priority gaps in the information base (i.e., local and regional circulation patterns). Additionally, a need has been expressed for assistance in developing a coordinated geo-spatial references inventory and data management program of available marine fisheries related information.

A strategic intervention in support of this is being initiated in collaboration with NOAA/NMFS, UWI School of Graduate Studies and Research, CCA, USAID and the US Department of State (DOS). The larger programme as envisaged would include:

i) Development of a regional information database on fisheries harvests and marine protected areas in the Eastern Caribbean,
ii) Development of a comprehensive meta-database on existing information on the life history, relative abundance and distribution, of fishes, and invertebrates by species for selected Eastern Caribbean islands,
iii) Assessment of coral reef community structure at selected existing and candidate fishery reserve sites,
iv) Assessment of ocean current dynamics impacting selected existing and candidate fishery reserve sites,

v) Development of GIS baseline information and maps that show the distribution of major habitat types, coastal zone use, protected areas, and fish distribution across the region,
vi) Convening of a workshop in the Eastern Caribbean on the scientifically quantitative basis for establishment and evaluation of no-take marine reserve management regimes (c.f. Appendix V in Crosby et. al. 1997),
vii) Development of proposals for pilot projects in one or more Eastern Caribbean country to demonstrate the effectiveness of this scientifically quantitative approach for establishing marine fisheries reserves, and
viii) Initiation of the development and preliminary training for establishment of information clearinghouse resources and a web-based GIS through CEPNET or a similar program.

The implementation of the activities listed above would promote partnerships both regionally and internationally, provide training experiences to a "new cadre of marine scientists and data management technicians" as well as promote long-term sustainable use of marine resources in the Eastern Caribbean. As part of this broader initiative, OECS NRMU, NOAA/NMFS, US AID and DOS State have agreed to a partnership which will hopefully initiate the first steps for the development of the more comprehensive programme. The OECS/NOAA/USAID/DOS partnership project will focus specifically on:

i) Identification of priority data needed to populate a regional information database on coral reef fisheries harvests and marine protected areas in the Eastern Caribbean;,
ii) Assessment of coral reef community structure at selected existing and candidate fishery reserve sites, and
iii) Development of proposals for pilot projects in one or more Eastern Caribbean country to demonstrate the effectiveness of this scientifically quantitative approach for establishing coral reef fisheries reserves.

For the Member nations of the Organisation of Eastern Caribbean States, this partnership is consistent with the directive given to the NRMU by the fourth meeting of the Environment Policy Committee (EPC IV), the ministerial committee with oversight on the activities of NRMU, namely: OECS NRMU should develop a joint programme for coastal and marine resources and focus on the environmental aspects of fisheries. Funds are being sought to facilitate other activities of the broader program. The current partners welcome any initiatives in support of this program, as well as any willing new partners.

THE LAST WORD?

As areas managed to maintain as much natural integrity as possible, and where natural processes are allowed to continue, the development of MPAs within an ISM-like framework will form one of the foundations of a sustainable marine environment (c.f. BC Parks 1997, Crosby et al. 2000). This framework will enable MPAs within eastern Caribbean States to be of assistance to fishery managers by helping to ensure

viable populations of all marine species, and thus the continuation of sustainable commercial and sport fisheries. At the same time, through the opportunities they also provide for recreation and tourism, MPAs will contribute to the sustainable economies of the Small Island Developing States of the Eastern Caribbean region.

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Introducing the 1998 Marine Fisheries Census of Jamaica

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ABSTRACT

In 1998 the Government of Jamaica undertook a census of fishing units in the marine fisheries, including vessels and fishers that fish without vessels. A two-stage process was used: a listing survey that encompassed all coastal areas; and a questionnaire census of all listed units. The questionnaire comprised 10 sections seeking information on the following subject areas: Respondent; Fisher or boat owner; Captain and crew; Fishing operations; Fishing practices; Gear used; Details of the catch; Marketing of the catch; and with regard to Pedro Bank, the damage caused by Hurricane Mitch. Information was collected from a total of 5,492 units, of which 4,107 were boats, and 1,385 were fishers without boats, including spear fishers. An unexpectedly high proportion of surveyed vessels were reported as being inactive (18%). The fishing units were distributed among 200 sites ranging in size from 1 – 300 boats/site. The median number of boats per site was 15. The vessels were predominantly canoes fishing small-scale gear: traps, lines, and nets. These data will form the basis of future development and management plans. They can support a variety of analyses many of which cannot easily be foreseen at present. Therefore, rather than attempt a complete analysis that will be published in a report, they are being set up in an accessible format in SPSS with instructions for users who wish to query the data for various purposes. This report includes basic analyses to illustrate the contents of the database.

KEY WORDS: Fisheries statistics, Jamaica

INTRODUCTION

In 1995, the Jamaica Fisheries Division started a data collection programme based on random stratified sampling. Prior to this, the Division relied on landing estimates from sample surveys (1962, 1968, 1973 and 1981). In 1994, the Division computerized its licensing and registration system and undertook an island-wide registration programme, which served as a preliminary sampling for the data collection programme. However, in order for the data collection program to provide accurate results an accurate sampling frame was needed. In 1998, the Division undertook a census to obtain an accurate sampling frame of vessels (artisanal, industrial and recreational) and gear by landing sites and fishery. The census was a collaborative effort between the Fisheries Division (FD), the Statistical Institute of Jamaica (STATIN), the Jamaica Information Service (JIS), and the CARICOM Fisheries Resource Assessment and Management Program (CFRAMP).

METHODOLOGY

Early in the process, the Jamaica Information Services (JIS) was contracted to develop an awareness programme to sensitised fishers and the public about the census. This was done to obtain the fishers' cooperation. This activity involved the development and distribution of posters to all fishing beaches and communities around the island, commercials on radio, television and the printed media. On completion of the awareness programme, the main survey was conducted.

There were two main instruments. The first was the Listing Record which in most cases was completed first and contained informant information on the boats that were known to moor at each section of coast line where boats were found to occur. The purpose of the listing record was to provide a complete list of all boats. The second instrument was the detailed census instrument or Main Questionnaire that recorded the detailed information on each boat on the Listing Record that could be found for interviewing.

Once the vessels at a site were listed, the main questionnaire was administered. The main questionnaire had nine sections:

Section 1 - information on respondent (name, address, role, education, experience);
Section 2 - information on vessel owners and users;
Section 3 - information on vessel (name, name of fishers);
Section 4 - Information on crew;
Section 5 - fishing operations (fishing grounds, operations, vessels involved);
Section 6 - Fishing practices (gas used, fishing duration, purpose, storage);
Section 7 - gear specification (gear types and usage);
Section 8 - catch characteristics (catch composition, seasonality); and
Section 9 - marketing arrangements (catch distribution)

In October 1998, Hurricane Mitch affected the southern areas of the island. There was extensive equipment damage on Pedro Bank and the Pedro Cays. Fishing equipment was also damaged on the south shelf. In order to capture the pre-Mitch situation (main questionnaire) and post-Mitch situation on the Pedro and Morant Bank, a supplemental questionnaire was developed. The supplemental questionnaire (section 10: the impact of hurricane Mitch), focused mainly on the value of damage to fishing equipment, changes in fishing activities and financial support to replace or repair equipment.

An interviewer's instruction manual was developed, which explained all the questions in the main questionnaire. The manual covered; overview of the fisheries sector, explanatory note, the interviewer's task, general survey procedures, guidelines for completing the questionnaire, the questionnaire, notes on boat size, vessel types, fishing areas in Jamaica, storage facility, gear type, and fish types.

A pre-test was conducted in July 1998. This 'early' activity facilitated extensive comments from all the parties concerned locally and abroad, particularly CFRAMP and the consultant. After the pre-test a few changes were made to the questionnaire. The manual and the control forms were finalized. There were also a few last minute changes in the questionnaire to accommodate some additional information that was needed by the Fisheries Division (FD).

To ensure that there was not an undercount, the boats as registered at beaches by parish were given to supervisors on a list supplied by the Fisheries Division. The interviewers systematically canvassed the entire length of coastline assigned to them.

The approach to analysis and access that was adopted with this census was to make the data available in a form that can be readily accessed by potential users, rather than to provide a large number of pre-analysed tables. With this approach users can query the data and obtain specific answers to their questions. Consequently, the data from this census have been made available as files that can be used by the Statistical Package for the Social Sciences (SPSS). This statistical software package provides a readily available means of accessing the data for export to other programs or for analysis within SPSS.

RESULTS

Overview of the Census Data

The purpose of the listing survey was to provide a list of all vessels as a cross check for the census. Therefore, all vessels in the listing survey should have appeared in the census, and few if any new vessels should have been encountered in the census. The listing survey recorded 3,619 vessels of which 549 were not in the census (Table 1). The census recorded 3,558 vessels of which 488 were not in the listing survey. The total number of vessels recorded by both surveys was 4,107.

Table 1. Cross tabulation of active boats by whether from census, listing record or both sources.

In Census not in LR			In LR not in Census			In LR and Census			Total
Not in use	In use	Total	Not in use	In use	Total	Not in use	In use	Total	
118	370	488	40	509	549	567	2503	3070	4107

In order to provide a database that included all the vessels encountered, the census data and the listing survey data were merged into a single file. However, for these vessels the majority of data collected in the census is missing. Few of the vessels that were in the listing survey but not in the census could be categorized as to vessel type.

Vessels were categorised as shown in Table 2. Of the 3,558 vessels in the census only 78 (2%) could not be categorised as to vessel type. Of these 23 were vessels that were not in use. For certain types of analyses that required information on the total numbers of vessels per landing site, the vessels that could not be categorized were allocated proportionally to the vessels categories based on those that could be categorized.

Vessels were found to be operating from a total of 194 fishing beaches (Figure 1). Whereas many of these are well known fishing beaches, several are here recorded for the first time.

Table 2. Numbers of active vessels by category

Vessel category	Not in use	In use	Total	% in use
Wood unmechanised < 10 m.	138	812	950	85
Wood mechansised < 10 m	79	348	427	81
Fiber unmechanised < 10 m	53	158	211	75
Fiber mechanised < 10 m	358	1402	1760	80
All mechanised 10-25 m	30	115	145	79
Other	4	8	12	67
Missing	63	539	602	90
Total	725	3382	4107	82

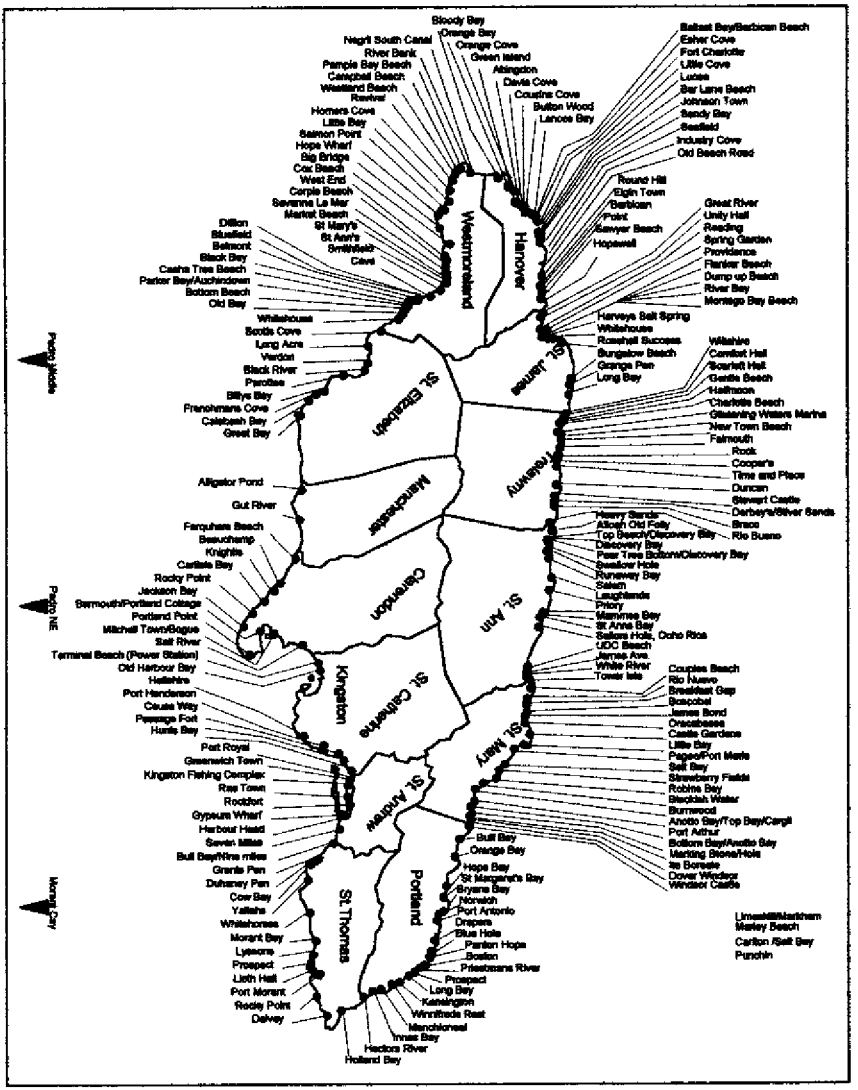


Figure 1. The distribution of mooring sites for fishing vessels in Jamaica

Characteristics of Vessel Owners, Owner/captains and Marketing

The numbers of owners, captains and owner/captains in the survey is shown in Table 3. The proportion of owners that captain their own vessels is lowest for the largest vessels and is lower for mechanised vessels in each of the two smaller vessel types.

The characteristics of the vessel owners are shown by vessel category in Table 4. The proportion of female vessel owners is highest for the mechanised fibreglass vessels < 32ft and the larger vessels. It is almost negligible for other categories.

The proportion of vessels that is rented, leased or lent to other groups of fishers is low; only 4% overall (Table 5). The number of groups to which vessels are rented, leased or lent, is seldom more than two (Table 6). The extent of these practices appears to be higher for owners with more than one vessel.

The disposition of fish caught to various purchaser groups differed considerably according to the type of fish and the parish (Table 7). For example, in St. Elizabeth where the population is relatively low, the proportions sold to vendors is high, whereas in St. James where the tourism industry is predominant, the proportions sold to hotels and restaurants is relatively high. On the Pedro Cayes, virtually all fish is sold to carrier boats.

Table 3. The numbers of captains, owners and owner-captains plus the percentage of owners who captain their vessel

Role	Wood unmech <10 m	Wood mech <10 m	Fiber unmech <10 m	Fiber mech <10 m	All mech 10-22 m	Other	Missing	Total
Captain only	68	41	14	305	27	2	99	556
Owner only	39	24	11	202	35		162	473
Owner-captains	668	251	124	736	41	5	82	1907
Percentage of owner-captains	86%	79 %	83 %	59 %	40 %	71 %	24 %	65 %

Table 4. Characteristics of vessel owners by vessel type and parish and no-boat fishers by parish.

Vessel category	Sex		Education (percent of respondents)						Age in years				Years fishing (mean)
	Males	Females	None	Primary	New/ Junior secondary	Traditional/ Comp. high	College/ University	Other	No. of responses	Mean	Min	Max	
Wood unmech < 32ft.	804	4	2	75	19	5	-	-	777	51	14	90	25
Wood mech <32ft	337	7	0	68	20	11	1	-	337	48	23	83	22
Fiber unmech <32ft	152	4	-	65	28	7	-	1	152	47	18	78	21
Fiber mech <32ft	1263	110	1	58	31	8	1	0	1260	44	18	98	19
All mech 32-75ft	97	15	-	56	27	12	5	-	95	45	17	83	20
Spear fishers	635		0	48	35	16	0	0	626	33	13	98	12
No boat fishers	130	3	1	49	36	14	-	-	127	36	13	79	13

Table 5. The extent to which vessels are rented, leased or lent.

Type of use				Total
Rented	Leased	Lent	None of the above	
44	5	71	2,662	2782

Table 6. The number of groups to which vessels are rented, leased or lent

Number of groups	Type of use				Total
	Rented	Leased	Lent	None of the above	
1	29	5	49	4	87
2	2		11		13
3			4	1	5
4			1		1
Total	31	5	65	5	106

Characteristics of the Fleet

The distribution of vessels by vessel type and parish is summarised in Table 8. A relatively high proportion of recorded vessels were deemed to be inactive (not in use)(Table 8). This table also shows the number of individuals surveyed that were designated as "No boat fishers". These included both spear fishers and land-based fishers. Although the census has gathered a considerable amount of information on this hitherto little known group of fishers, it is not a census for these groups as it was not designed to census them, and they were interviewed opportunistically. T he length frequency distribution of vessels by vessel category is shown in Figure 2. The numbers of boats targeting the various categories of fishery resources is shown in Table 9. The average numbers of crew and other workers to be found on vessels is shown by vessel category and parish in Table 10.

The Fishing Operations, Gear and Practices

The various types of gear found to be in operation are listed in Table 11. The numbers of vessels of each category and overall that use each type of gear is shown by parish in Table 12. The extent to which various combinations of gears are used by vessels is shown in Table 13. When nets are the main gear, pots are the most common second gear, but only slightly more so than lines. When lines are the main gear, pots are the most common second gear.

Table 7. The distribution of fish in each of the species categories to various groups for two contrasting parishes (N = number of respondents.)

Group to which fish is sold or given	Percentage of fish going to each group									
	Coastal pelagic	Offshore pelagic	Reef	Deep slope	Snapper	Conch	Crab	Lobster	Shark	Unknown
St. James										
% Kept by fisher	24	15	21	3	14		3	7		26
% Given to family/friends	1	3	4		1				68	5
% Sold to wholesale vendors		2								
% Sold to vendor	3	7	3		2					
% Sold to hotel/restaurant	7	15	5	20	7	100	30			
% Sold to processing plants										
% Sold to consumer	67	70	73	80	80		50	93	40	69
% To other							50			
N	28	301	410	15	205	1	3	3	4	25
St. Elizabeth										
% Kept by fisher	23	13	8		9			5		2
% Given to family/friends	4	1	3		1					1
% Sold to wholesale vendors	12	28	25	100	19			62		
% Sold to vendor	41	42	50		41			16		64
% Sold to hotel/restaurant		1	1		2			4		0
% Sold to processing plants					1					

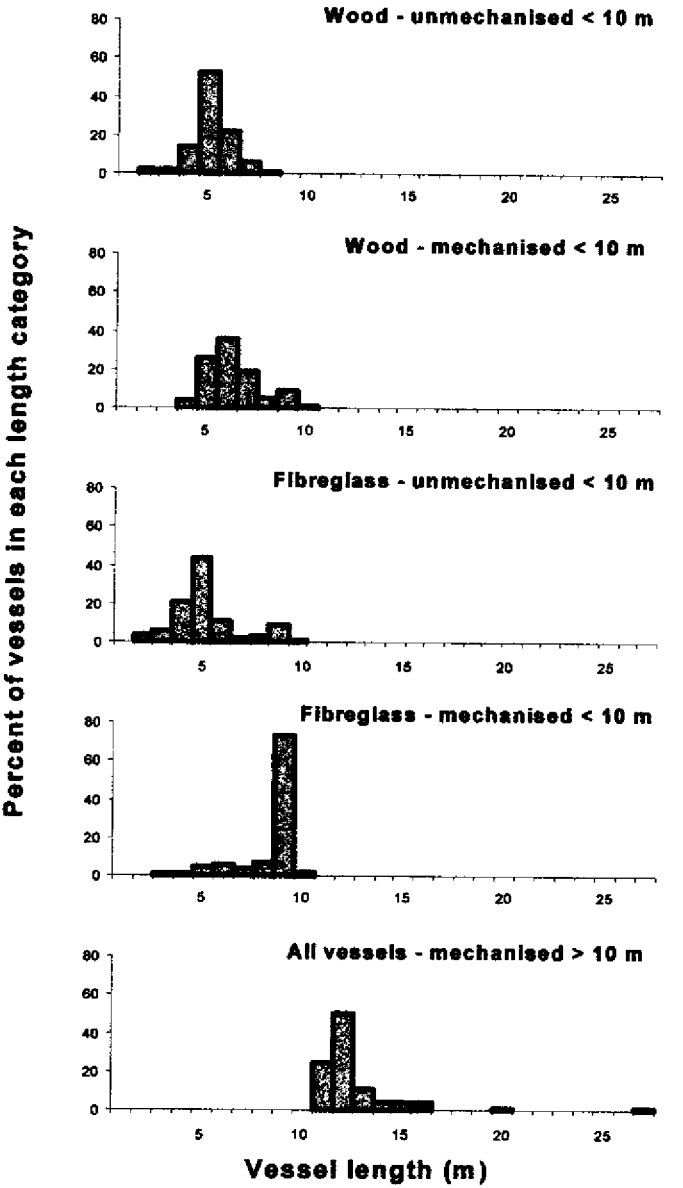


Figure 2. The length distribution of vessels in the five vessel categories

Table 8. Distribution of vessels by parish

Parish	All vessel categories					No boat fishers			
	In Use	% by parish	Not in Use	Both	% in Use	Spear-fishers	Land-based	Total	% by parish
Portland	189	6	45	234	81	77	14	91	7
St. Mary	226	7	51	277	82	122	37	159	11
St. Ann	174	5	18	192	91	88	3	91	7
Trelawny	165	5	21	187	88	157	5	162	12
St. James	196	6	27	223	88	179	34	213	15
Hanover	368	11	51	419	88	261	17	278	20
North Coast	1318	39	213	1531	86	879	110	989	71
Kingston	137	4	53	190	72	16	22	38	3
St. Andrew	85	3	27	112	76	4	36	40	3
St. Thomas	155	5	31	186	83	56	4	60	4
Westmoreland	462	14	102	564	82	33		33	2
St. Elizabeth	142	4	10	152	93	18	24	42	3
Manchester	140	4	40	180	78	18		18	1
Clarendon	362	11	83	445	81	20	7	27	2
St. Catherine	426	13	144	570	75	122	11	133	10
South Coast	1909	56	490	2399	80	292	104	396	29
Pedro Cays	146	4	19	165	88	1		1	0
Morant Cays	9	0	3	12	75			0	0
Total	3382		725	4107	88	1172	214	1386	

The Catch, Estimates of Landings, and Seasonality

The average catch/trip in kg per vessel and gear type is was asked for traps, diving, lines and nets. Note that these values are as reported by the respondents from memory and are therefore only useful as general indicators of catch. The seasonality for low/high catch by type of fishery was reported by the respondents.

The Numbers of Fishers

The numbers of individuals directly engaged in fishing in Jamaica cannot be reliably determined from the data in this survey because it was survey of vessels not fishers. However, the data on numbers of vessels (Table 2) and crew (Table 3) for the various types of vessels can provide some indication of the minimum number of persons engaged in fishing. The estimated number of crew for vessels of all types is 7,691. There are also an estimated 520 workers that go out on fishing vessels. Adding to this the 3,382 vessel captains give an overall estimate of at least 11,593 individuals actively engaged in the harvesting of fish. Many more are involved in other aspects of the industry. This is a minimum estimate because vessel owners and captains may change crew. Thus, although there may be 11,593 captain, crew and worker positions on fishing vessels, if many of these are part time, then the actual total number of individuals who derive some or all of their income from working in the harvesting subsector may be considerably higher.

Table 9. The percentage of boats targeting the main fishery types by parish

Parish	Percent of boats targeting:										Total number of boats
	Coastal pelagic	Offshore pelagic	Reef	Deep slope	Snapper	Shrimp	Conch	Crab	Lobster	Irish moss	
Kingston	14	8	14	1	62	0	0	0	1	0	142
St. Andrew	2	21	11	0	62	5	0	0	2	0	66
St. Thomas	6	16	43	1	34	0	0	0	0	0	155
Portland	3	16	53	4	24	0	0	0	0	0	174
St. Mary	1	39	44	3	14	0	0	0	0	0	233
St. Ann	3	33	48	3	13	0	0	0	0	0	174
Trelawny	4	16	60	1	20	0	0	0	1	0	161
St. James	2	33	31	0	33	0	0	0	0	0	201
Hanover	2	25	51	2	21	0	0	0	0	0	358
Westmoreland	4	27	54	1	13	1	0	0	0	0	464
St. Elizabeth	1	22	54	0	21	0	0	0	1	0	148
Manchester	0	2	65	0	32	0	0	0	1	0	140
Clarendon	2	4	71	0	17	0	0	0	5	0	366
St. Catherine	9	2	38	0	40	9	0	0	2	0	409
Pedro Cays	3	2	91	0	3	0	1	0	1	0	148
Morant Cays	0	0	100	0	0	0	0	0	0	0	9
Percent of total	3.8	17.7	50.5	1.1	24.4	1.3	<0.1	<0.1	1.0	<0.1	

Table 10. Average numbers of crew and workers by vessel category

	Wood unmech <10 m.	Wood mech <10 m	Fiber unmech <10 m	Fiber mech <10 m	All mech 10-25 m	Other	Missing
Crew	1.6	2.3	1.8	2.7	4.2	1.0	2.0
Workers	0.1	0.1	0.1	0.2	0.3	0.0	0.1
N	812	348	158	1402	115	8	539

Table 11. The types of gear found to be in use

Pots	Diving	Lines	Nets	Mullet net
Z-traps	SCUBA	Trolling	Bait net	Shove net
Jack pots	Hooka	Hand line	Beach seine	Shrimp net
Crab traps	Free lung	Palanca	Cast net	Sprat net
Diamond		Drop line	China net	Trammel
Bamboo wood		Rod & reel	Gill net	Trawl
		Long line	Lobster net	

Table 12. Percent of vessels using main gear types

Parish	Nets	Lines	Diving	Pots
Kingston	19	69	1	11
St. Andrew	47	34	0	19
St. Thomas	29	31	8	32
Portland	11	48	5	37
St. Mary	12	63	2	23
St. Ann	15	43	5	37
Trelawny	20	36	3	41
St. James	15	48	5	32
Hanover	10	53	1	36
Westmoreland	18	27	6	49
St. Elizabeth	10	21	2	67
Manchester	24	11	9	56
Clarendon	39	17	16	28
St. Catherine	60	16	8	17
Pedro Cays	1	2	10	88
Morant Cay	0	0	0	100
All parishes	24	33	6	37

Table 13. The combinations of main gear versus second gear

	Main gear	Second gear			
Type	Percent second gear	% nets	% lines	% diving	% pots
Nets	16	5	43	5	47
Lines	10	17	5	6	72
Diving	7	23	39		5
Pots	12	24	67	9	0
Total	12	16	42	7	36

The above estimate of the number of fishers in Jamaica is very close to that which is available for the Licensing and Registration System (LRS), i.e. about 12,000. However, the LRS includes some vendors and some foreign fishers licensed for the industrial conch fishery.

CONCLUSIONS

This report provides only an introductory analysis of the survey data with the aim of making the reader aware of the information that is available. These survey data can be further analysed to provide information on a wide variety of issues that are relevant to fisheries management and development in Jamaica.

There is the need for these survey data to be supported by a good system of recording information on landing sites, and of mapping landing sites. Ideally, this information would be stored in a GIS and updated regularly. However, a paper filing system with an information sheet on each landing site and a wall map would be useful to provide all Fisheries Division members with ready access to the information.

ACKNOWLEDGEMENTS

This census was funded in part by the Canadian International Development Agency through CFRAMP and in part by the Government of Jamaica. Thanks to the many vessel owners, fishers and their relatives who provided the information contained in this report. Thanks are also due to Mr. Peter Espeut for his help with designing the questionnaire.

Status Report on a Jamaican Reef Fishery: Current Value and the Costs of Non-management

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ABSTRACT

The reef fishery on the north coast of Jamaica is one of the most intensely overfished in the Caribbean. Discovery Bay lies in the center of the north coast and the reef fishery there is typical of the rest of the fishery on this coast, with a narrow, accessible fishing ground which provides food and employment to large numbers of people, despite its overexploited state.

Management measures that could rebuild fish stocks were suggested a quarter of a century ago. However, the central government has not been able to introduce the necessary measures. The University of the West Indies has implemented several management measures on a small scale around Discovery Bay but these have not been applied on a wider scale.

This paper provides an updated status report of the reef fishery on a segment of the north coast with a fishing area of about 12 km^2. We estimate current fishing effort to be over 7000 boat trips per year using traps, lines, or nets. In addition, over 5000 spear fishing trips are made per year. The average income is between US$13 and $29 per trip. The total catch in the study area is about 60 tons per year, worth about $300,000. Despite its overexploited state, the productivity of the reef remains high with an estimated yield of 5 tons km^{-2}.

We estimate that the cost to Jamaica over the past 25 years of not managing its fisheries on the north and south coast is around $1.3 billion. Managing small-scale multi-species fisheries is undoubtedly difficult, but the figures here suggest that it is surely worth the effort.

KEY WORDS: Jamaica, small-scale fishery, valuation

Informe sobre el Estado de una Pesquería de Arrecife en Jamaica: Valor Actual y Costa de No-manejo

La pesquería del arrecife en la costa norte de Jamaica es una de la más intensamente explotada del Caribe, un hecho que se ha reconocido durante décadas. Discovery Bay esta ubicado en el centro de la costa norte y la pesquería del arrecife

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aquí es típica para el resto de la pesquería en esta costa. Los arrecifes se encuetran en una plataforma submarina muy estrecho, accesible. El crecimiento alto de la población humana y las intensas presiones económicas han atraído un gran número de personas en la pesquería, representando una fuente importante de alimento y de empleo, a pesar de su estado de sobre-explotación.

Hace un cuarto de siglo, se sugirieron medidas de manejo para reconstruir los stocks de peces. Sin embargo, el gobierno central no ha sido capaz de introducir tales medidas. La Universidad de las Indias Occidentales ha implementado varios medidas de manejo de pequeña escala alrededor de Discovery Bay, como la introdución de una luz de malla más grande en las trampas pesqueras, y una asistencia en el establecimiento de la reserva pesquera Discovery Bay Fishery Reserve. A pesar de éxitos locales, éstas estrategias de manejo no se han aplicado en una escala más grande.

Este artículo presenta un informe del estado actualizado de la pesquería del arrecife en un segmento de la costa de 20 km adyacente a Discovery Bay. Se evaluó el esfuerzo actuál de la pesca, la captura por unidad de esfuerzo, la composición en especies y el valor global de la pesquería. Se examinan cambios en las capturas durante los últimos cinco años. Se efectuaron estimaciones de la costa a Jamaica por no haber manejado la pesquería en los últimos 25 años.

PALABRAS CLAVES: Jamaica, pesquería, valor actual

INTRODUCTION

The reefs on the north coast of Jamaica are often recognized as one of the most intensively overfished shallow coralline reef areas in the Caribbean. This widespread recognition of the problem is largely due to over 30 years of research on the reefs of Discovery Bay and numerous publications reporting the lack of fish (Munro 1983, Aiken and Haughton 1987, Hughes 1994, Picou-Gill et al. 1996). This paper provides an updated status report on the fishery in the Discovery Bay area and compares current fishing effort and catch rates to historical figures.

Discovery Bay lies in the center of the north coast of Jamaica and the reef fishery there is typical of those along the entire coast. The coral reefs lie on a very narrow, accessible submarine shelf. The coral reef fishery here is an important source of food and employment, despite its overexploited state. Its open access nature, coupled with high human population growth and intense economic pressures, has drawn large numbers of people into the fishery.

There are a variety of strategies that have been suggested for the management of the Jamaican reef fisheries (Munro 1983), and there are several reviews of these options (Munro and Williams 1985, Mahon 1989). Some management measures have been implemented locally, with the assistance of the Discovery Bay Marine Laboratory of the University of the West Indies (UWI), on a small scale and in the short-term. These included introducing a larger mesh size for fish traps and the

establishment of a small fishery reserve. However, little has been done at a national level. Fishers all agree that the fishery is declining but economic factors have led them to intensifying fishing effort over the years (Aiken and Haughton 1987), rather than reducing it.

METHODS

Collection of Catch and Effort Data

Catch and effort data in the Jamaican north coast artisanal reef fishery were collected from 19 July 2000 to 18 July 2001 at five landing sites in and adjacent to Discovery Bay (Rio Bueno; Old Folly and Top Beach in Discovery Bay; Swallow Hole in Runaway Bay; and Salem; Figure 1) three or four times a week, on randomized pre-determined days. To encourage cooperation from fishers, inducements were offered in the form of one ticket in a raffle for every 10 kg of detailed catch data provided, or one ticket for 25 kg of aggregated catch data.

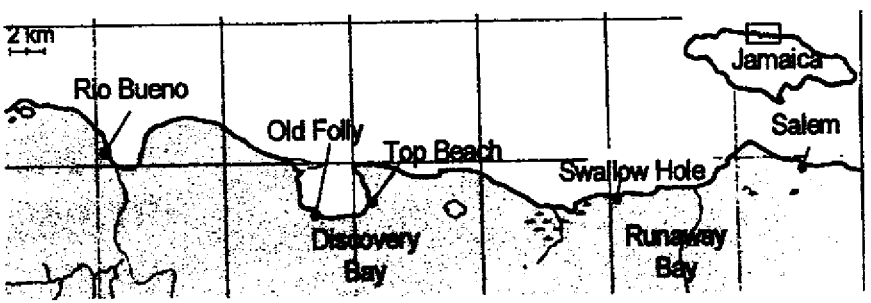


Figure 1. Map of Jamaica, showing study area and the five landing sites.

On each data collection day, the number of active boats (at sea that day), motorized and unmotorized, was enumerated by counting the incoming boats as they were landing on the beach, by counting the empty spaces among the rows of boats and from information from key informants.

From the active boats landing at the site, the number of fish and the total weight of each species (to the nearest 0.01 kg) in the catch were recorded separately for all consenting fishers. If sorting of the catch was not possible, an attempt was made to record the total number of fish and total weight of the catch. Fishing effort information (time spent at sea, number of crew members, the number of fish traps hauled, average soak time of gear, mesh size of each fish trap or net, depth fished) was also collected whenever possible.

The number of boats missed by the data collectors (due to unusual landing time, too many boats landing at once, or uncooperative fishers), was also counted and

recorded; the type of fishing gear most likely used by the missed boats was noted.

A detailed formal survey was also carried out among the active fishers at the five landing sites using a standard questionnaire to obtain information on the age of the fishers, full/part time status, other occupations, number of dependents, primary and secondary gear used, the size of boats and engines used, and the number of fish traps of various mesh sizes and other gears in use in the fishery.

The survey area covered 26 km of shelf edge at a depth of 100 m and a fishing area of approximately 12 km^2. This excluded the central part of Discovery Bay >30 m deep, which is too deep to be fished and is not coralline. Full details of the survey and the data collection and analyses are provided by Sary (2001).

In addition, unpublished catch and effort data, obtained in a similar way to that described above from the same five landing sites, collected by the UWI's Fisheries Improvement Programme (UWI/FIP) from January 1996 to December 1997, was collated and used to examine changes in catch rates in the fishery over the last 5 years. Other sources of data concerning the fishery in the area are the works of Nembhard (1970), Sahney (1983), Munro (1983), Haughton (1988), Picou-Gill et al (1996) and Sary et al (1997).

RESULTS

The Fishers, Fishing Gear and Fishing Effort

Key characteristics of the fishing community, the fishing gear used and the effort expended are summarized in Table 1. There are about 130 active fishers in the area, almost 60% of them relying on fishing as their sole income earning activity. On average, each fisher supports another 4 people. The average age of fishers is 49 years.

There are approximately 85 boats (not including derelict boats or boats under repair/construction) that are based at the five landing sites and ten boats that are based at isolated locations along the coastline but operate in the fishing area, in a similar fashion to boats at the main landing sites. Almost two thirds of fishers own a boat. The average boat size is 6.5 m. The majority of the boats are small, usually unmotorized wooden canoes about 3 m in length, while the remaining third of the boats are the standard Jamaican 8 m reinforced fiberglass open canoes, which are powered by outboard engines (usually 35 to 65 hp).

Almost 70% of the fishers use fish traps as their primary or secondary gear. Three mesh sizes are used in wire mesh traps. The most common has 43 mm maximum aperture (32 mm or 1 ¼" between knots), and about 71% of the traps in the fishery are made of this mesh size. Larger 55 mm mesh (38 mm or 1 ½" between knots) are less often used (26% of traps) and 33 mm (25 mm or 1" between knots) are now uncommon (3%).

On an average day there are about 20 boats fishing on the narrow fringing reef along this 26 km shelf, about 12 of them non-motorized. They have approximately

29 people operating from them (captain, share fishers, and crew). In addition, about 15 spear fishers are also fishing in the area each day. This represents over 7000 boat days per year, and over 5000 spearfishing days per year. Many fishers operate more than one gear on each fishing trip.

Trap fishing boats haul an average of seven traps per fishing trip. Thus, during the estimated 5000 trap fishing trips (or boat days) in the area during the year, over 34,000 trap hauls were made. Nearly 90% of the trap hauls are of 43 mm (1.25") mesh traps and nearly all the rest of the hauls are of 50 mm (1 ½") mesh traps. These figures do not reflect the actual proportion of the various mesh size traps in the fishery simply because the smaller mesh traps are hauled almost twice as often as the larger mesh traps. Trap fishers set their traps 27 m deep on average.

Table 1. Characteristics of the fishers and the fishing fleet at five landing sites (Rio Bueno to Salem) on the north coast of Jamaica, 2000-2001.

		Number	Fishing effort year^{-1}	
Estimated number of active fishers		130		
Average age		49		
Primary gear:	Trap fishers	80	4900	boat days
	Line fishers	19	2400	boat days
	Net fishers	5	340	boat days
	Spear fishers	26	5000	fishing days
Functional boats (sea worthy)		95		
Boats motorized		45		
Average boat length (m)		6.5		
Average motor size (hp)		28		
Traps hauled	1" mesh traps		200	trap hauls
	1.25" mesh traps		30100	trap hauls
	1.5" mesh traps		4000	trap hauls
	TOTAL		34300	trap hauls
Mean soak time	1.25" mesh traps	2.8 days		
	1.5" mesh traps	5.2 days		

About 50% of the fishers use hook and line as their primary or secondary gear. Over 2000 boat trips are spent hook and line fishing, most of them for drop line fishing usually at night (targeting nocturnal reef fish and deep-slope snappers), or in the afternoon (fishing for parrotfish; a small but little known part of the fishery). Very few line fishing trips are for troll fishing. A small number of fishers use gill nets, about 1 boat per day, setting their nets in shallow reef areas. Net and line fishing boats appear to spend nearly twice as much time at sea per trip as trap fishing boats.

About 32 fishers are full- or part-time spear fishers. Their enumeration is difficult because they do not generally operate from boats and will enter and leave the water anywhere along the shore. A limited set of visual surveys along the coast provided the estimates of fishing effort.

Catch Rates

The catch rates in various gears are summarized in Table 2 and incomes from fishing are given in Table 3.

The average catch of a trap fishing boat is 6.1 kg per trip, and the average income is $29 per trip (all figures in US$); this is shared between the boat captain and his crew. The most important fish families in the trap catch are parrotfish and surgeonfish. The more valuable snappers are the third most important family. Other commercially valuable groups, such as groupers, jacks, and grunts are much less common. About 10% of the catch consists of unmarketable trash fish, much of which is nonetheless consumed. The total catch over the entire area by fish traps is about 30 tons per year, with a value of $140,000.

The most lucrative fishing activity appears to be net fishing, with an average income of $34 per boat trip, but the success of this activity may be partly seasonal when jacks are more common in the fishing area. Also, several net fishers are in fact spear fishers using nets and boats. They herd fish into the net and spear any fish too large to be gilled in the net. This activity is very labor intensive. Nonetheless, given the relatively high catch rates per boat, it is not clear why more fishers do not take up net fishing.

Dropline fishing is the least rewarding with fishers making less than $10 per trip, though this type of fishing may still be popular since it is the least gear and labor intensive of all the fishing practices. The estimated catch of all drop line fishers is about 4.7 tons per year, with a value of $25,600. Troll lines yield a total of 1.1 tons valued at $5,600. Net fishing yields 2.2 tons per year, with a value of $11,700. Spear fishers were estimated to land 23 tons, with a value of $122,000.

Costs, Catch Values and Incomes

The total catch by all fishing gears in the study area is about 60 tons per year, worth about $300,000. Shared among the approximately 130 active fishers in the area, it represents a yearly income of about $2,300 per year for the average fisher.

The value of the catch is relatively high because of the high demand for fish in Jamaica. Fish are generally sold on north coast fishing beaches directly to the consumers, or occasionally to vendors, in two categories. The "quality" fish are currently sold for $5.90/kg (J$120/lb) and these include groupers, snappers, goatfish, jacks, large grunts and most pelagic predators (Spanish mackerel and wahoo) and lobsters. Almost any large fish is rated as "quality" and small "quality" fish are downgraded to "common". "Common" fish include most of the other reef species, such as parrotfish, surgeonfish, angelfish, small grunt and crabs, which are sold for $4.90/kg (J$100/lb).

Table 2. Estimated catches of traps, lines, nets, spears, and total catch, by fish family, at five landing sites (Rio Bueno to Salem) on the north coast of Jamaica, July 2000 to July 2001.

	Traps		Drop lines		Troll lines		Nets		Spears		All gears
Catch composition	kg/ boat/ day	kg/ yr	kg/ boat/ day	kg/yr	kg/ boat/ day	kg /yr	kg/ boat/ day	kg/yr	kg/ trip/ day	kg/yr	kg/yr
Scaridae	2.34	11500	-	-	-	-	0.56	190	1.38	7050	18740
Sphyraenidae	-	-	0.16	330	3.04	820	0.15	50	1.4	7140	8340
Acanthuridae	0.97	4750	-	-	-	-	0.16	50	0.23	1170	5970
Lutjanidae	0.53	2600	0.36	760	-	-	0.43	150	0.12	610	4120
Serranidae	0.28	1360	0.44	920	-	-	-	-	0.31	1580	3860
Carangidae	0.17	850	0.67	1400	-	-	1.79	610	0.06	300	3160
Haemulidae	0.29	1430	-	-	-	-	0.88	300	0.18	910	2840
Mullidae	0.24	1180	-	-	-	-	-	-	0.23	1180	2360
Holocentridae	0.35	1710	0.2	420	-	-	-	-	0.063	320	2450
lobsters and crabs	0.16	780	-	-	-	-	-	-	0.16	840	1620
Muraenidae	0.23	1110	0.08	180	-	-	-	-	-	-	1290
Balistidae	0.13	620	-	-	-	-	-	-	-	-	620
Scombridae	-	-	0.1	210	0.67	180	-	-	-	-	390
Belonidae	-	-	0.1	210	0.41	110	0.12	40	-	-	360
others families	0.38	1880	0.15	310	0.01	4	2.25	760	0.50	1900	4850
TOTAL CATCH	6.07	29700	2.26	4740	4.07	1110	6.34	2150	4.50	23000	60770

Unmarketable species include moray eels, scorpion fish, filefish and very small fish. These are generally kept by the fisher for home consumption or given away to indigent persons or to people who help pull the boats up on shore.

Table 3. Estimated value of the catch and income per fishing trip, at 5 landing sites (Rio Bueno to Salem) on the north coast of Jamaica, July 2000 to July 2001.

	traps	lines	nets	spears	All gears
fishing trips year^{-1}	4900	2370	340	5100	
	Catch composition by value (kg)				
quality (US$5.90/kg)	5990	2510	1260	10500	20260
common (US$4.90/kg)	21340	3200	870	12310	37720
trash (no value)	2410	130	30	160	2730
	Value of the catch (US$)				
total value year^{-1}	$140,000	$30,000	$11,700	$122,000	$303,700
income trip^{-1}	$29	$13	$34	$24	

The cost of entering and remaining in the fishery is high, except for spear fishing, primarily due to the capital needed to obtain and maintain a boat. The initial costs may range from $800 to $8,000, depending primarily on whether a new or second hand boat and engine are bought (Polunin et al, 2000). Plywood boats are the least expensive at about $400 to $900, while fiberglass boats cost over $4,000 new. Dugout canoes are now rare due to the scarcity of large accessible cottonwood trees. Large fiberglass boats need large engines (35 to 65 hp) that cost up to $3,600 new. Some of the wooden boats are motorized with small engines (e.g. 4 - 10 hp) that cost up to $1,250.

Other costs of fishing depend on the method involved. For trap fishing, the materials needed include mesh wire, sticks, nails, lacing wire, and rope, and these materials cost about $30 to $50 per trap, depending on the size of the trap and the type of mesh wire used. Most fishers build their own traps, but some hire others to build them. With ongoing repairs, fish traps last about a year before they need to be replaced, although many are lost sooner than that because of storms, careless setting near the reef drop-off, or theft. Trap fishers seem to set their traps very deep and often unmarked, perhaps to avoid theft or poaching by spear fishers. These practices tend to increase the number of lost traps. Motorized boats also need to purchase fuel, which of course varies depending on the size of boat and engine, the condition of the engine, the frequency of fishing trips, the number of traps hauled, and the distance the traps are set away from the beach.

Drop line fishers can expect to spend about $50 - $200 for gear per year (fishing line, hooks). Bait is often caught by the fisher himself, or bought at sea from another fisher. Troll fishers may spend money on artificial bait ($5-$10 each) and

a great deal on fuel. For this reason, trolling is not commonly practiced, except when moving between fishing grounds to operate other fishing gear. Net fishers, who usually use gill nets of 50 mm (2") to 100 mm (4") mesh size, would spend from $100 to $200 (about 12 kg of net) on average per year.

DISCUSSION

Catch per Unit Area

Our 2000/01 survey yielded an estimated total catch of demersal and neritic pelagic species of 60,770 kg by the five fishing beaches. This included 29,700 kg landed in traps, 5,410 kg on lines, 2160 kg in nets and 23,000 kg taken by spearfishers, all taken from a total shelf area of 12 km^2. The harvest is therefore 5 tons/km^2.

These harvests per km^2 are very high by Caribbean standards, but not by those of Pacific coral reef systems (Munro 1984). However, the surveys of 1968, 1996/97 and 2000/01 (Tables 4 and 6), as well as other published surveys in the area (Picou-Gill et al. 1996, Sary et al. 1997) have provided consistent estimates of catches and there appear to be no reasons for challenging their accuracy.

Changes in Catch Rates Over Time

There are several data sets that warrant comparison with the current results. These are the 1968 and 1981 surveys of the Jamaican fishery (Nembhard 1970, Sahney 1983) and data collected by the UWI/FIP in 1996 and 1997.

In the 1968 survey, catches were reported by parish and the catches at selected beaches were raised by the total number of operational boats, motorized or non-motorized, operating in the parish. Fortunately, the beaches selected to represent St. Ann were Salem and Swallow Hole and it is therefore possible to make a direct comparison between the 1968 and the 2000/01 data. Table 4 shows the landings by all gears, with catches aggregated to conform with the 1968 survey. Catches have fallen 13% by weight and at least 17% by value, using 2001 prices. However, as there are very few large fish of any species in the catches, our estimates of value in 2000/01 are inflated. Perhaps half of all the "quality " fish are too small to fetch the premium price and the decline in value is therefore probably around 20%.

If catches over the whole study area have declined by the same amount as at Salem and Swallow Hole (-13%), the fishery yield in 1968 from these reefs would have been about 5.7 tons/km^2.

The catches reported by Nembhard (1970) for the parish of Trelawney are based on the beaches of Rio Bueno and Charlotte and are therefore not comparable with our data. In any event, the catch rates reported for this area have a number of anomalies, such as large quantities of parrotfish reported to have been taken on hook and line and of tuna caught in traps and are therefore not considered further.

In the 1981 survey (Sahney 1983), catches from the eastern, northern and

western parishes were aggregated and no comparison can be made with the current survey.

Table 5 shows that in 1968, only four motorized craft fished from Salem and Swallow Hole; they seemed to be used irregularly and thus landed very little. The numbers of active motorized craft had risen to about 18 on these two beaches by 2000 - 2001, landing over 1,000 kg per year with a value of $5,366. Non-motorized boats fell from 47 to 21 and the catch/boat/year fell from 596 kg to 287 kg. The corresponding value fell from about $3,300 to less than $1,400.

No spear fishers were recorded in St. Ann in 1968. Since then it has become an increasingly important activity. Spear fishing catches remain difficult to estimate because spear fishers move freely along the coast and most do not use established landing sites.

Table 4. Changes in total catch and value of the catch between 1968 (from Nembhard 1970) and 2000-01, at Swallow Hole, Runaway Bay and Salem fishing beaches, on the north coast of Jamaica.

	Catch		Prices	Value of catch	
	1968	2000/01	2000/01	1968	2000/01
	kg	kg	US$/kg	US$	US$
Kingfish, wahoo	34	260	5.90	202	1534
Tuna, bonito	517	0	4.90	2533	0
Snapper	3648	2778	5.90	21522	16390
Goatfish	1482	776	5.90	8745	4578
Jacks	4719	1704	5.90	27842	10054
Mullet	1196	1	5.90	7058	6
Parrotfish	5563	4340	4.90	27260	21266
Goggle eye	222	471	4.90	1087	2308
Herring, sprat	17	0	4.90	84	0
grouper	3350	1111	5.90	19766	6555
lobster	377	317	5.90	2224	1870
shrimp	90	0	5.90	534	0
Other	6804	12506	4.90	33340	61279
TOTAL	28020	24264		152196	125841
% change		-13.4			-17.3

In addition, we have records of catch rates of 43 mm (1 ¼") mesh fish traps for 12 month periods in 1996 and 1997, from the same fishing beaches covered in 2000 - 2001. Changes in the catch rates, by family (in grams/trap/haul and in number of fish/trap/haul), are shown in Table 6. The catches have been relatively stable over this time period, with the average catch of under 1 kg /haul. Nonetheless, it appears that there has been a very slight increase in the catch rates of fish traps in the fishery,

both in weight and number of fish, over the five-year period, but only the increase in the number of fish between 1996 and 2000-01 is likely to be significant. The increase in the catch appears to be due to an increasing number of small fish in the catch, especially small parrotfish. As a result, the average fish size in the catch has actually decreased, especially those of parrotfish, but also other groups such as grunts and groupers.

Table 5. Changes in the catch and the value of the catch of motorized and unmotorized boats between 1968 (from Nembhard 1970) and 2000-2001, at two landing sites (Swallow Hole in Runaway Bay, and Salem), on the north coast of Jamaica.

	1968		2000/01	
	motorized	non-motorized	motorized	non-motorized
Number of boats	4	43	18	21
Catch year^{-1}	kg	kg	kg	kg
traps	1393	24253	16330	2408
lines	-	1393	570	1879
nets	-	985	1503	36
spears	-	-	223	1315
TOTAL CATCH	1393	26627	18626	5638
Catch boat^{-1}	348	619	1035	268
Value year^{-1}	US$	US$	US$	US$
Total value	7870	144327	96590	29250
Earnings boat^{-1}	1968	3356	5366	1393

The value of the catch (in 2001 dollar values) has also increased slightly but it is still only a little more than $4 per trap haul. The total weight of high quality fish has actually decreased since 1996 and there are more lower-valued (common) species in the catch than before. The average fish size in all commercial categories appears to have decreased.

The Costs of Non-Management

Our data show that catches have declined in value since 1968 by 17 - 20% at 2001 prices. However, we have done an evaluation of management strategies since 1975, when Munro (1975) suggested that an increase from the then prevalent 33 mm maximum aperture mesh (25 mm or 1" between knots) to a mesh size of 66 mm maximum aperture (50 mm or 2" between knots) would increase the value of trap catches by about 30%. An increase to 43 mm (1 ¼") mesh would increase harvest

values by 19%. Line catches would also have increased because of the delayed recruitment of all species to the trap fishery. Recruitment rates were also predicted to increase if larger mesh sizes enabled some species to reach maturity before recruitment to the fishery.

Table 6. Changes in trap catches: Comparison of catch rates, catch value, and mean fish size in 1.25" mesh traps, between three 12-month periods (in 1996, 1997, and 200-2001) on the north coast of Jamaica.

	1996	1997	00-01	1996	1997	00-01
catches sampled	(110)	(44)	(278)	-	-	-
traps reported	(672)	(279)	(1832)	-	-	-
Catch composition by family						
	g trap^{-1} haul^{-1}			# of fish trap^{-1} haul^{-1}		
Scaridae	244	349	355	2.0	2.7	3.6
Acanthuridae	153	197	153	1.8	2.4	1.7
Holocentridae	50	73	51	0.6	0.8	0.5
Mullidae	18	26	49	0.1	0.2	0.4
Lutjanidae	80	34	48	0.3	0.1	0.2
Haemulidae	58	40	42	0.4	0.3	0.4
Balistidae	30	3	41	0.1	0.03	0.1
Serranidae	39	35	39	0.2	0.2	0.3
Muraenidae	48	28	36	0.03	0.04	0.1
invertebrate	7	11	16	0.01	0.02	0.03
Carangidae	10	25	14	0.1	0.2	0.1
Pomacentridae	14	5	10	0.2	0.1	0.1
Kyphosidae	6	-	10	0.01	-	0.01
others (18 families)	51	47	39	0.21	0.19	0.20
TOTAL	806	873	903	6.0	7.3	7.6
Catch composition by value						
quality	155	96	140	0.7	0.5	0.7
common	559	691	683	4.8	6.4	6.4
trash	92	86	79	0.5	0.4	0.5
Mean fish size (g)	135	120	119	-	-	-
Catch value	US$ trap^{-1} haul^{-1}					
	$ 3.66	$ 3.96	$4.17	-	-	-

Since 1975, the use of 33 mm mesh has declined on the northern coast of Jamaica and, as a result of efforts of the UWI FIP in the Discovery Bay area in the past decade, a substantial proportion of traps have 55 mm (1 ½") mesh. The latter mesh size was calculated by Munro (1975) to produce a very similar relative harvest to the 66 mm mesh, but without the same benefits of delaying recruitment to larger sizes. However, effective fishing intensity has actually increased since 1975, as a result of the increases in numbers of motorized canoes and spear fishers.

Annual catches have declined in value in the survey area by $30,000, mostly as a result of increasing effort, declining recruitment rates and, perhaps, changes in the ecosystem since 1968. If we assume that the decline was linear, the value would have fallen by $6,000 by 1976 (by which time it might have been possible to have management measures in place) instead of increasing by $52,000. If we compound this loss over the next 25 years at 10%/year we arrive at a figure of somewhat over $6.4 million that was lost from this 12 km^2 area of fishing grounds, fished in 1968 by 124 boats. The narrow shelves of the northern, western, and eastern parishes total 699 km^2 (Haughton 1988) and proportionately the compounded total loss would have been about $375 million. If we extend this argument to cover the southern shelf of Jamaica and the proximal oceanic banks (3,471 km^2), all of which are intensively fished with traps, but only assign them half the productivity of the narrow northern shelves, the compounded loss in direct primary production from this shelf and banks is $930 million. Thus, in total, Jamaica has probably lost $1.3 billion over the past 25 years. This figure does not include losses from the vast Pedro Bank and from Morant Bank to the south of Jamaica, that were lightly exploited 25 years ago but which are now reported to have greatly depleted fish stocks.

The foregoing figures might err by a few hundred million dollars. It is undoubtedly difficult to manage small-scale, multi-species, multi-gear fisheries. However, the figures suggest that it is surely worth the effort, and that management would pay economic, social, and political dividends.

ACKNOWLEDGEMENTS

This study was part of the work of the Caribbean Marine Protected Areas Project, funded by the United Kingdom Department for International Development. Nadine Earle and John Samuels collected the vast majority of the data on the fishing beaches, with assistance from several graduate students of the University of the West Indies. Data for 1996 - 1997 were collected by staff of UWI Fisheries Improvement Programme, funded by the Kaiser Jamaica Bauxite Company. We would like to thank the fishers of the area for their assistance in answering all our questions and allowing us to weigh their catches.

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Global Climate Change: How Might it Affect the Fisheries of the Caribbean's SIDS?

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ABSTRACT

Climate change represents an important additional stress to the many ecological, social, and economic systems already affected by pollution, increasing resource demands, globalization, and non-sustainable management practices in the Small Island Developing States of the eastern Caribbean. Climate change is expected to occur at a rapid rate relative to the speed at which ecosystems can adapt and re-establish themselves. The principle effects on fisheries will be felt at national and local levels, as centers of production are altered and changes to the ecosystems occur. Notwithstanding, the relatively minor impacts on fisheries initially suggested by the global community of climate change scientists, in this contribution we give consideration to some of the direct and indirect impacts on the sector as a whole. We note that to remove the suggested impacts of climate change out of the realm of speculation and into that of probability, there is need for a fully integrated approach to vulnerability assessment. We suggest that it is also important to take into consideration the value of non-marketed goods and services such as subsistence assets, community structure, traditional skills and knowledge which would also be at risk from climate change. Policies and development programmes which seek to use natural resources in general, and fisheries resources in particular, in a sustainable manner, and which can respond effectively to changing conditions such as climate change need to be put in place as soon as possible if eastern Caribbean States are to survive any of the impacts of global climate change.

KEY WORDS: Climate change, eastern Caribbean, vulnerability of fisheries

INTRODUCTION

In 1993 it was generally believed that prosperity and technical progress would make both mitigation and adaptation to global climate change affordable and avert the associated dangers (Ausubel 1993). However, it is now fairly much accepted that human induced climate change represents an important additional stress in Small Island Developing States (SIDS) to the many ecological, social, and economic systems already affected by pollution, increasing resource demands, and non-sustainable management practices. The SIDS of the eastern Caribbean are no exception. Changes in climate have the potential to affect the geographic location

of ecological systems, the mix of species that they contain, and their ability to provide the wide range of benefits on which the societies rely (Watson et al. 2000).

The Intergovernmental Panel on Climate Change (IPCC) has noted that the primary influence of anthropogenic climate change on ecosystems is expected to be through the rate and magnitude of change in climate means and extremes (Watson et al. 2000). Climate change is expected to occur at a rapid rate relative to the speed at which ecosystems can adapt and reestablish themselves and through the direct effects of increased atmospheric carbon dioxide concentrations (*ibid.*). Some coastal ecosystems are particularly at risk, including mangrove ecosystems, coastal wetlands, sandy beaches, and coral reefs (IPCC 1996a). Changes in these ecosystems would have major negative effects on tourism, freshwater supplies, fisheries and biological diversity (*ibid.*). In particular it has been suggested that globally marine fisheries production is expected to remain about the same in response to changes in climate, with high-latitude freshwater and aquaculture production being likely to increase if natural climate variability and the structure and strength of ocean currents remain about the same (Watson et al. 2000). The principle effects on fisheries will be felt at the national and local levels, as centers of production shift. The apparent positive effects of climate change in higher latitudes (longer growing seasons, lower natural winter mortality, faster growth rates) may be offset by negative factors such as changes in established reproductive patterns, migration routes, and ecosystem relationships (*ibid.*)

GENERAL IMPACTS ON SIDS

Habitats and Ecosystems

Climate change will lead to changes in sea level, increasing it on average, and also could lead to altered ocean circulation, vertical mixing, and wave climate. As a result, nutrient availability, biological productivity, the structure and functions of marine ecosystems, and heat and carbon storage capacity may be affected, with important feedbacks to the climate system (IPCC 1996b). Low-lying island States are especially vulnerable to climate change and associated sea-level rise because in many cases much of the land area rarely exceeds three to four metres above present mean sea level. Many islands with greater variation in topography are also vulnerable to climate change effects, particularly in their coastal areas, where the main settlements and vital economic infrastructure almost invariably are concentrated (Watson et al. 2000).

Some small island States will confront greater vulnerability (Figure 1 and Figure 2) because their existing sea and coastal defense systems are not well established (IPCC 1996a). The relatively recent impacts of Hurricane Luis in 1995 and Hurricane Lenny in 1999 on the eastern Caribbean has shown this clearly (Cambers 1996, Bythell, Cambers and Hendry 1996, Lawrence and Magloire 1999, Smith Warner International 1999a,b, James 2000). Hurricane Luis caused widespread and intensive damage throughout the coastal environment of Anguilla (Cambers 1996,

Bythell et al. 1996). Damage was severe in all major coastal and marine ecosystems with sand dunes unlikely to recover except perhaps over a time scale of decades, and even this is doubtful against a background of predicted increased hurricane frequency and sea level rise (*ibid.*).

Given current projected rates of increase, sea-level rise *per se* is not expected to have widespread adverse effects on coral reefs. Some researchers argue that a rising sea level actually may be beneficial because the new conditions would be favourable for inducing vertical growth (Watson et al. 2000). The climate change effect of greatest potential significance to coral reefs is likely to be an increase in seawater temperatures. Some species of corals in the Caribbean live near their limits of temperature tolerance. Elevated seawater temperatures will impair biological functions and lead to increased mortality. Corals will also continue to be subjected to increasing anthropogenic stresses that will, however, limit the innate capacities of the corals to adapt to the effects of climate change (*ibid.*).

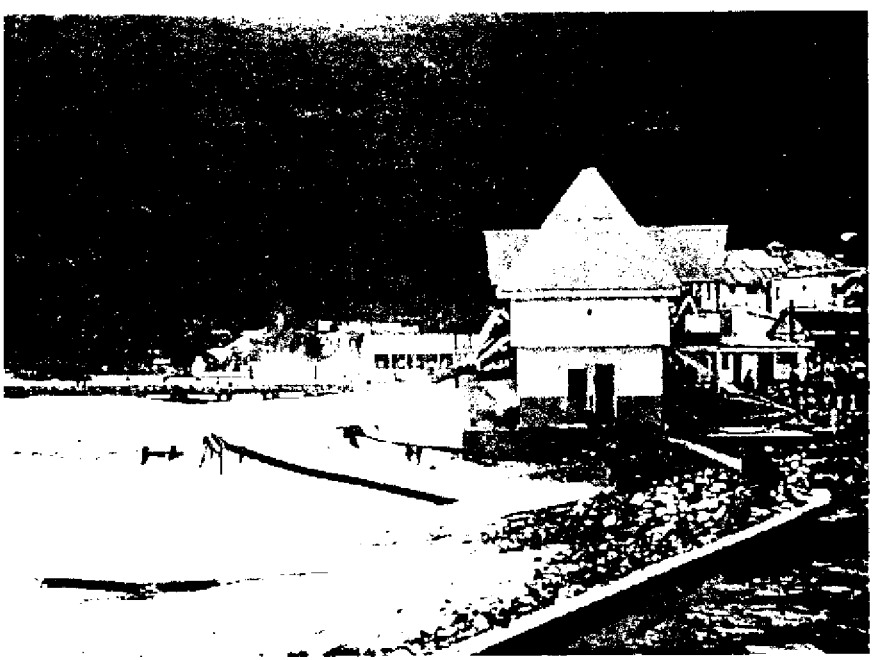


Figure 1. Greater vulnerability shown in Soufriere Saint Lucia because of inadequate sea and coastal defense systems



Figure 2. Settlements like Baron's Drive in Soufriere Saint Lucia are likely to be at risk given their location at or near present sea level

The adaptive capacity of mangroves in all likelihood varies with species, as well as with the presence or absence of sediment-rich, macrotidal environments and the availability of adequate fresh water to maintain the salinity balance (Watson et al. 2000). A decrease in rainfall in the Caribbean would reduce mangroves' productive potential and increase their exposure to full-strength seawater. Additionally, their adaptive capacity is likely to be reduced by coastal land loss further exacerbated by the presence of, and increased concentration of, infrastructure in coastal areas (*ibid.*). Climate change will add to stresses such as pollution and further compromise the long-term viability of these ecosystems.

It has been suggested (Edwards 1995 cited in Watson et al. 2000) that seagrass meadows, which exist in shallow, intertidal coastal environments, are the ecosystems most likely to be negatively affected by climate change effects, particularly sustained elevation of sea-surface temperatures or increases in freshwater runoff from land. However, there is growing consensus that the main threats to seagrasses are likely to come from human induced disturbances such as dredging, overfishing, water pollution, and land reclamation (Watson et al. 2000.).

Higher rates of erosion and coastal land loss are expected as a consequence of the projected rise in sea level. Watson (2000) has noted that sea level is expected to rise about 15 – 95 centimeters by 2100. Elevated sea levels will alter littoral currents, and the higher reach of waves on the shore will alter the pattern of sand distribution, contributing further to the decline of beach profiles. Low-lying islands are also expected to experience increased sea flooding, inundation, and salinizations of soils and freshwater lenses as a direct consequence of sea level rise (Watson et al. 2000).

Tourism and Infrastructure

It is suggested that even if there is no increase in the frequency and intensity of extreme weather events there may be shifts in their geographic location to places less prepared and more vulnerable to such events (*ibid.*). The passage of "left-handed" Hurricane Lenny in late 1999 demonstrated this quite clearly (Lawrence and Magloire 1999, Smith Warner International 1999a and b, James 2000). Gray (1993 cited in Watson et al. 2000) has reported that, based on historical data for the Caribbean Sea, increases in sea-surface temperature of 1.5°C have been associated with an increase in hurricane frequency of some 40%. In a number of islands, vital infrastructure and major concentrations of settlements are likely to be at risk, given their location at or near present sea level (see Figures 1and 2) and their proximity to the coast. Vulnerability assessments also suggest that shore and infrastructure costs could be financially burdensome for some small island States (Watson et al. 2000). Hurricane Lenny caused extensive damage to coastal infrastructure in Antigua and Barbuda, St. Kitts/Nevis, Anguilla, Dominica, St. Lucia, St.Vincent and the Grenadines, and Grenada ranging from damage to fisheries and tourism related coastal infrastructure (Lawrence and Magloire 1999, Smith Warner International 1999a and b) to inland landslides and road damage (James 2000).

Economic Activity

Tourism is the dominant economic sector in some of the Caribbean States, accounting for example for 69% of Gross National Product in Antigua and Barbuda in 1995 (Watson et al. 2000). Climate change and sea-level rise would affect tourism directly and indirectly due to loss of beaches to erosion and inundation, increasing stress on coastal ecosystems, damage to infrastructure from tropical storms, and an overall loss of amenities. An increase in severe floods and droughts as a result of increased frequency and magnitude of the El Nino Southern Oscillation (ENSO) phenomena is projected (Watson 2000). This can jeopardize the viability and threaten the long-term sustainability of the fishing industry (*ibid.*), which is seen as becoming more important to the economies of eastern Caribbean States.

In general, socioeconomic systems such as human settlements, agriculture, forestry, water resources, and fisheries are vulnerable to changes in climate, including the magnitude and rate of climate change, as well as changes in climate variability (Watson 2000). The draft third assessment report of IPCC working group II (IPCC 2001a) has clearly noted with medium confidence that for SIDS "declines in coastal ecosystems would negatively impact reef fish and threaten reef fisheries, those who earn their livelihoods from reef fisheries, and those who rely on the fisheries as a significant food source". This contribution considers some of the types of impacts that may also need to be considered by the fisheries industries of eastern Caribbean islands.

IMPACTS ON THE FISHERIES OF EASTERN CARIBBEAN ISLANDS

Fishing, although largely artisanal or small-scale commercial, is an important activity on most of the small islands of the eastern Caribbean. While marine fisheries only account for approximately 1% of the global economy, many coastal and island States are far more dependent on this sector than this statistic would suggest (IPCC 1996, WG II, Section 16.1.1). For example, the annual yield of lobsters from the shelves and banks of the Caribbean islands (excluding the U.S. Virgin Islands) has a retail value in restaurants of approximately US$40 million (Vicente 1996 cited in Watson et al. 2000). Similarly, marine fish account for 16% of global animal protein consumption, but the contribution to protein intake is much greater in developing countries, where animal protein tends to be relatively expensive (IPCC 1996a).

Habitats, Ecosystems and Biology

While the modest temperature increases projected for regions such as the Eastern Caribbean are not anticipated to have a widespread adverse effect on small island fisheries (Watson et al. 2000), a temperature rise could have a negative effect on productivity in areas such as shallow lagoons like that of Codrington in Barbuda (Van der Meerin 1998). The lagoon serves as an important habitat for lobsters, more particularly juveniles. Severe fluctuations in salinities or temperature would compromise reproductive processes or larval survival, possibly proving to be a severe detriment to the survival to the population (Alm et al. 1993 cited in Watson

et al. 2000). On the other hand, warming-induced changes in current patterns could conceivably increase upwellings at sea, bringing more nutrients to the surface and providing more food for the fish.

Fisheries in the small island States were not expected to be adversely affected by sea-level rise *per se*, but it was recognised that a higher sea level would be a critical factor for fisheries if the rate of rise is higher than the projections at that time suggested (IPCC 1996a). In such circumstances, the natural succession of coastal ecosystems on which some species depend (e.g., mangroves, seagrasses, corals) and which function as nurseries and forage sites for a variety of commercially important species would be disrupted (IPCC 1996a). Fish production thus would suffer if these habitats were endangered or lost (Costa et al. 1994). It is estimated, for example, that Antigua and Barbuda is currently losing its mangrove systems at an average annual rate of about 1.5 - 2.0% with a sea level rise of 3 - 4 mm per year (Government of Antigua and Barbuda 2001). Thus, there would be little or no mangroves in Antigua by 2075, since the coastal slopes of most areas do not allow for landward retreat. However, if the sea level rise were 10 mm per year, this condition would be reached as early as 2030 or 2035 (*ibid.*).

Recent studies in three countries in the Caribbean, conducted through the auspices of the Caribbean Planning for Adaptation to Global Climate Change (CPACC) project's component five – Coral reef monitoring for climate change impact, have indicated that significant amounts of coral bleaching are observable on the coral reef systems of the region (CPACC unpublished reports). This coupled with stresses of an anthropogenic nature can impact on the species composition of Caribbean fisheries as the coral reef ecosystem is degraded. Increased mortality of snapper and grouper species, such as that observed at the end of the warm season in Sénégal in 1987 (Caverivière and Touré 1996), is also possible. Reproductive biology of snapper species may also be impacted by increased sea temperatures, given the "impression" of extended seasons and affect reproductive seasonality (c.f. Grimes, 1987) of snappers. In contrast to the possible negative effects on mortality, it is suggested that higher temperatures may lead to increased growth of somatic tissue in snappers (Hekimoglu, Luo and Ault, in press); additionally, it has been shown (Rakocinski et al. in press) that within-site variability in growth of juvenile white trout is primarily (and positively) driven by water temperature.

The extent to which global climate change may increase the incidence of disease in fish, was highlighted in late 1999 when a number of islands in the southern Caribbean suffered mass mortalities of several species of reef-associated fish. Studies carried out in Barbados showed that the fish died due to the effects of infection by *Streptococcus iniae* (Willoughby et. al. in press). A plume of water originating in the region of the Orinoco River in South America and characterized by high chlorophyll-a concentrations and low nocturnal oxygen levels, in addition to atypically high seawater temperatures, were recorded in south and central Caribbean at the time of the kill. It is suggested that the fish had not been previously exposed to the pathogen and that the atypical environmental conditions, including elevated seawater temperatures, high phytoplankton concentration, and reduced

oxygen levels worked in concert to stress the fish and increase susceptibility to the bacteria (*ibid.*). This occurrence is consistent with the suggestion of the draft third assessment report of the IPCC Working group (IPCC 2001a) which has indicated that sea surface warming would result in increased frequency of marine diseases. Placed within the context of global climate change, this raises an ominous red flag for the fisheries of the region.

The Sub-committee on Environment of ICCAT's Standing Committee on Research and Statistics (SCRS) in 1996 noted that "thermal anomalies have significant effects on the catchability of tunas (and) cause major variations in recruitment (thus, these and other) environmental anomal(ies) could have ... negative effects and be a potential danger to conservation of (tuna) resources" (author's parentheses; ICCAT 1997). The 1999 meeting of the Sub-Committee noted that "strong inter-annual fluctuations in tuna abundance ... are more likely to be linked to the effects of environmental conditions than to changes in stock abundance" (ICCAT 2000). Thus, climate change is also likely to have a significant, and possibly negative, impact on tuna, and we also suggest, other pelagic fisheries in the region.

Infrastructure and Vessels

In most of the eastern Caribbean States more than 50% of the population reside within two kilometres of the coast (Watson et al. 2000). Projected sea level rise, which may conceivably be accompanied by inundation, increased flooding, coastal erosion with consequential losses especially during extreme events (Watson et al. 2000), places most of the (coastal) infrastructure associated with the fisheries sector at risk. In fact, significant damage to fish landing sites, fish markets (Figure 3), fishermen's locker rooms, and other onshore facilities (which have recently been constructed with foreign aid?), could result from any increase in the frequency of intensity of extreme events such as floods, tropical storms and storm surges (Pernetta 1992, Alm et al. 1993, both cited in Watson et al. 2000). About 16% of Antigua and Barbuda's fishing fleet was either destroyed or lost as a result of Huriccane Luis and another 18% was damaged (Government of Antigua and Barbuda 2001). The severe and costly damage caused by Hurricane Lenny (1999) on fisheries infrastructure in the islands of Dominica and St.Lucia is testimony to the above fact. (Lawrence and Magloire 1999, SMMA 1999).

Preparedness for the Impacts of Climate Change

In preparing for the impacts of climate change, the cost of insurance is an important factor that must be taken into consideration (Watson et al. 2000). Insurance costs are highly sensitive to the effects of catastrophic events such as hurricanes and floods. High-risk locations usually face higher insurance premiums, and thus the increased likelihood of extreme events resulting from climate change would thus be likely to raise costs of insuring fisheries infrastructure, a direct increase in costs to the industry.

Fishing vessel owners are at present hard pressed to obtain insurance coverage for their vessels. Since most of the vessels in the region are less than 12m in length, the actual design and construction methods in use evolved from experience rather than from a structured approach to fishing vessel development and safety. The industry led initiatives to develop new vessel designs or to modify old vessels have been implemented without professional advice in naval architecture or marine engineering. This has led to a perception of fishermen's vessels as high insurance risks. This perception will be reinforced within the context of increased frequencies or intensity of extreme weather events. To adapt to this likelihood, fishermen would be constrained to ensure that their vessels are more resistant to the vagaries of the weather. This would perforce be associated with the adoption of building codes and other design and construction standards (whether for infrastructure or for vessels). This may mean a consequential increase in vessel and other construction costs, again increasing the overall costs to the fisheries sector.

Adaptation and Mitigation

It is hard to predict the quantum of damage or the cost of adaptation. That would vary depending on the kind of mitigation needed, the area to be protected, the design specifications to be adopted, and the availability of the necessary construction materials. What is fairly well accepted, however, is that the overall cost of infrastructure protection or damage mitigation is likely to be beyond the financial means of the island States of the eastern Caribbean islands.

A study that estimated loss potential of hurricane events associated with 50-year return periods and done as part of the Caribbean Disaster Mitigation Project illustrates this. The average estimated loss to wharves for the three countries studied (50% upper prediction limit maximum likelihood estimate) was on the order of EC$ 5.7 million (Vermeiren and Pollner 1999). Since in the eastern Caribbean islands, wharves and piers are invariably not distinguished between those used for fishing vessels as opposed to other vessels, if one were to equally prorate this estimate based on the numbers of different types of vessels (say trading, fishing, transportation, tourism, recreation) utilizing these onshore facilities, the rough estimate of the value/loss to the fishing industry would be on the order of EC $ 1.1 million (the replacement costs estimated similarly would be on the order of EC$ 124.1 million; *ibid.*). While this median (too low half the time and too high the other half the time) estimated costs might not be excessive in the context of large economies, they represent considerable financial resources that the eastern Caribbean islands may have to reallocate (Watson et al. 2000). In addition to the coast of replacement and repair to fishing vessel and gear caused by a hurricane, there is a loss of revenue due to the disruption of the fishing industry. After hurricane Luis in Antigua and Barbuda, many individuals who became unemployed as a result of the closure of hotels and businesses sought short-term employment in fishing (Government of Antigua and Barbuda 2001). Most of this short-term effort was probably directed at already over-exploited near-shore resources (*ibid.*), thus the immediate response to increased intensity and frequency of hurricanes may be a

concomitant increase in the level of overexploitation of near-shore resources. In Dominica after Hurricane Lenny, much of the employment generated by the fishing industry was temporarily compromised in light of the losses to infrastructure, equipment, coastal habitats, and the (forced) decommissioning of one west coast fishing fleet (Lawrence and Magloire 1999).

The implications of severe changes in the fisheries sector, is not to be underestimated or overlooked. Of major concern should be the question of how would fishers adapt to possible changes in fish populations, and consequently the potential for exploitation. If marginal fishers are not able to adapt to the change, then the question of their re-deployment in other already stressed sectors may pose a daunting challenge for administrators and governments. If as already indicated that change is likely to take place faster than the ability to adapt, then the question of retooling the adaptable fishery can be an expensive one, given that the appropriate fishery can be readily identified, and that the appropriate training provided in a timely manner.

Traditional fishing methods such as seine fishing rely on a certain type of physical near-shore environment that may be changed as a consequence of sea level rise. This can conceivably mean that this type of fishing may no longer be possible. In a number of OECS Member States, the beach seine fishery contributes a significant part of the landings and fishing effort (as much as 40% in Dominica). In a number of communities where often it is the share of the catch from this fishery, given to persons who assist in hauling the seine, that provides their daily protein. Included in the social cost may be the need to retrain or provide alternative employment for beach seine fishermen, as well as alternative sources of animal protein for those who depend on this fishery for subsistence.

As seen the world over, recreational fisheries also exist where persons cast hand held lines directly from shore. While little economic gain accrues from this, the social benefits of recreation cannot be discounted. The cost to the economy of mitigating the impacts of reduced opportunity for recreation may not yet be quantifiable, but as for sport it is fairly well established that the absence of this social safety valve can have a (negative) ripple effect on the society.

Changes in the biology of fish populations can be detected through identifiable indicators in the short term, but the extent to which these changes occur is not easily determined. This would make it difficult for the resource manager to employ measures aimed at the sustainable exploitation of fish populations simply because the resources to do so are not readily available to assist in these determinations. Management of the use of fishery resources then takes on a new and complex dimension, further taxing the already limited capabilities or capacities of fisheries departments. However, issues of fisheries management take on a totally different complexity if potential impacts are to be elevated to new dimensions. Consider not only changes in biology but in the behavior of schools as a consequence of alterations in oceanographic conditions. Changes in thermoclines, for example, as a result of influences of increased ocean temperatures are likely to influence the vertical migratory patterns of schools to the extent that accessibility to fishers is

compromised. The extent to which behavioral changes are influenced will be dependent on the magnitude of changes in the thermal envelope, changes in oceanographic conditions as a result of alterations to the temperature regime, and the persistency of such changes. The temporal persistence of such changes may result in permanent alterations in the behavior and physiology of populations.

It is suggested that the seasonal changes now evident in the fisheries of the region are the result of changes in physical oceanographic conditions. An analysis of climatic variables in the western tropical Atlantic from 1978 - 1985 (Muller-Karger 1990) point to the possibility of temperature playing a significant role in migratory patterns in fish, recognizing that "temperature changes are associated with the seasonal movement of different water masses into the region and erosion of the seasonal thermocline by winds." The link between changes in circulation patterns and the appearance/disappearance of fish populations around the Lesser Antilles (Muller-Karger 1990, Mahon 1990), support the argument that changes in ocean temperatures will affect fish movements either directly or indirectly through other temperature dependent variables. It is further surmised that as a result of the influence of elevated sea temperatures, changes in the patterns of global mass movements of water masses such as the El Nino-Southern Oscillation and the North Atlantic Oscillation will play a significant role in enhancing localized impacts of climate change.

The consideration of all these factors possibly paints a grim picture of fisheries management and development in a region not known for its ready adaptability to change. A comprehensive analysis of possible changes in the behaviour of fish stocks as a consequence of climate change is beyond the scope of this paper as space and time will not permit discussion on all factors that are likely to have an effect on fisheries. The major question remains - how does one develop a management strategy when changes in the characteristics of fisheries take place at a rate greater than the ability to adapt to change?

Fisheries management and development agencies must take this question into consideration for long-term planning strategies for fisheries development — to determine priorities for action, to steer development away from the areas likely to exhibit the greatest rate of change, and to provide a greater concentration on the more resilient fisheries. However any shift towards resiliency will be costly both in terms of retooling the industry and in the manpower requirements for securing that change, a hard fact that must be absorbed into the planning for change.

CONCLUSIONS

To remove the suggested impacts of climate change out of the realm of speculation and into that of probability underscores the need for a fully integrated approach to vulnerability assessment. The interaction of various biophysical attributes such as size, elevation and relative isolation, with the islands' socio-economic and socio-cultural character ultimately determines vulnerability. Further, since some eastern Caribbean islands are prone to periodic non-climate-related

hazards such as earthquakes and volcanic eruptions, the overall vulnerability cannot be accurately evaluated in isolation of these threats (Watson et al. 1997).

It is also important to take into consideration the value of non-marketed goods and services such as subsistence assets, community structure, traditional skills, and knowledge provided by the fisheries sector, and which would also be at risk from climate change. In the eastern Caribbean islands these assets are just as important as marketed goods and services. Determining the cost of change to the society in general as some values are eroded in the face of altered traditional practices, a consequence of altered ecosystems on which livelihoods are dependent, will be difficult, but may have far reaching implications.

Policymakers in the eastern Caribbean islands will, as in the rest of the world community, have to decide to what extent they want to take precautionary measures by enhancing the resilience of their more vulnerable systems by means of adaptation. The uncertainty in the magnitude of climate change impacts does not mean that SIDS cannot better position themselves to cope with the broad range of possible climate changes or to protect against possible future outcomes (IPCC 1996b). Delaying such measures may leave a nation poorly prepared to deal with adverse changes and may increase the possibility of irreversible or very costly consequences. A proactive approach to securing change in the industry will obviously be less costly than attempting to address change after it has taken place. Economic and social consequences must inform developments on the refocusing of the sector if the sustainability of livelihoods of fishers is to be guaranteed.

The challenge of addressing climate change raises an important issue of equity, namely the extent to which the impacts of climate change or mitigation policies create or exacerbate inequities both within and across nations and regions" (IPCC, 2001b). As a guiding principle, policies and development programmes which seek to use resources in a sustainable manner, and which can respond effectively to changing conditions such as climate change, would be beneficial to the eastern Caribbean islands even if climate change did not occur. As part of the "urgent requirement" (McConney 2000) of an integrated ocean policy, sectoral policies and programmes need to be implemented for the fisheries sector without hesitation if it is to survive the onslaught of global climate change.

ACKNOWLEDGEMENTS

Thanks are extended to Ms. Valerie Isaac-St. Hill and Ms. P. Imara Murray for their comments on an earlier draft of this contribution.

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Planning for Disaster Management and Vulnerability Reduction in the Fisheries Sector of Caribbean Island States

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ABSTRACT

Within the insular Caribbean, planning for disaster management has traditionally been divorced from the normal planning process for the major economic sectors. In the fishing industry, planning for disaster management has often been limited to removal of fishing vessels to "safe" areas before a hurricane event and making arrangements for compensation to fishermen for damage to fishing gear and vessels. With the increase in the number and intensity of hurricanes being experienced in the region and the recognition that other natural and man-induced disasters that pose a potential threat to the fisheries sector, this level of planning is no longer sufficient. Instead, a more proactive approach is necessary. Planning for disaster mitigation in the fisheries sector needs to be integrated into national planning for disaster mitigation. Fisheries Management Plans should reflect the understanding of the need to reduce the vulnerability of the Fisheries Sector to disasters. More thought needs to be given to ensuring that there is accurate information on which to base post-disaster assessments, that artisanal fishermen are encouraged to adopt a small business management approach to their occupation, that a high priority is given to personal safety at sea, and that fisheries infrastructure is designed in a manner that minimizes the probability of damage occurring during a disaster. This paper reviews the current status of planning for disaster mitigation in the fisheries sector in the British Virgin Islands and discusses some of the approaches that should be taken to reduce the vulnerability of the fisheries sector to natural disasters.

KEY WORDS: British Virgin Islands, disaster management, vulnerability

INTRODUCTION

Disaster management is a part of the natural cycle of life within the Caribbean region. At the most basic level, persons living in the Caribbean are aware that the Caribbean lies within the Hurricane belt. They know that during the months of June to November (the Hurricane Season) there is a high probability that at least one of

the countries will experience the effect of tropical waves, depressions, storms, and the more cataclysmic hurricanes. They understand that there is a need to prepare before hand for the possibility of these events by engaging in such activities as securing of property, purchasing additional food supplies, and engaging in minor improvement of homes.

Fishermen are directly affected by the Hurricane Season. During this period, fishers are reminded:

i) To pay special attention to the weather forecasts,
ii) To exercise extreme caution when venturing offshore,
iii) To reduce the amount of fishing gear that they may have at sea, and
iv) To make arrangements to have their fishing vessel safely secured if/when warning is given of a storm event.

This level of preparation is necessary and useful, however is it enough? The answer to this question is a resounding no. A look at the experience of the island of Dominica, for instance, will demonstrate that the dislocation within the Fisheries Sector caused by hurricanes and other natural disasters is high, and that it is advisable to spend more time, money, and effort in planning for disaster reduction.

Case Study – Dominica

Dominica is located in the Eastern Caribbean at 15°N and 61°W. It is the largest and most mountainous of the Windward Islands with a total land area of 289 square miles. During the last thirty (30) years, natural disasters have had a dramatic impact on agriculture, forestry fisheries, and the overall natural environment in Dominica (Michael, unpublished). Dominica has experienced the pervasive and destructive impacts of hurricanes and landslides. During the last three decades, Dominica has been directly impacted by at least ten (10) tropical storms and hurricanes, the most significant of which were: David, Frederick, Allen, Hugo, Iris, Luis, Marilyn, and Lenny. All of these events impacted on the coastal and marine resources of Dominica, several of them resulted in extensive direct loss to the Fisheries Sector. Table 1 summarises the Fisheries related impacts of hurricanes and other disasters experienced in Dominica during the period 1979 to 1999.

A brief review of Table 1 will indicate that the impacts of natural disasters such as hurricanes and landslides are varied. The include the following:

i) Loss of income to fishers,
ii) Destruction of/damage to Fisheries habitat,
iii) Destruction of/damage to fisheries infrastructure such as landing sites and fishing complexes,
iv) Reduction in/disruption of food supply,
v) Damage to/loss of fishing vessels and gear, and
vi) Economic losses to the country

While the above paragraphs focus on hurricanes and weather related disturbances, it must be noted that the Caribbean may be affected by several other natural disasters. These include earthquakes, floods, storm surges, and volcanic activity. Apart from the natural disasters, the potential for a range of man induced

disasters also exists. Among these man induced disasters are those resulting from marine pollution, industrial activity, and development (construction).

Table 1. Fisheries related impacts of selected natural disasters occurring in Dominica -1979 to 1999. (Summarised from Michaels, unpublished).

Event	Date	Fisheries Related Impacts
Hurricane David	August 29, 1979	472 or 75% of fishing boats destroyed A further 157 or the remaining 25% lost engines Excessive landslides Extensive coastal erosion
Hurricane Hugo	September 17,1989	Damage to the Agriculture Forestry and Fisheries Sector estimated at EC$49,000,000
Hurricane Luis	September 18, 1989	Ten (10) fishing Boats destroyed Completion of Roseau Fishing Complex set back by six months at an additional cost of EC$2,000,000
Hurricanes Iris, Marilyn and Luis	August 27, Sept 5and Sept 18, 199	Fishery landing sites, boat houses, boats and engines lost to an estimated value of EC$ 3,500,000
Hurricane Lenny	November 18-19,	Significant lost of coastal infrastructure and unquantifiable damage to damage to coastal and marine environments Coastal Flooding Fisheries Complex ground floor and ancillary equipment severely damaged – EC$3,500,000 estimated damage Twenty five (25) boats lost and one hundred and twenty-six (126) boat sheds destroyed Overall damage to the Fisheries sector – EC$1 600,000
Tropical Storm Debbie	September 9 and 10 1994	Losses in Fisheries and non-banana agriculture amounted to EC$ 5,000,000
Layou Valley Landslide	November 1997	Pot fishery destroyed Dramatic fall in fish sales Fishermen dislocated and forced to use other landing sites Reefs located two miles offshore covered with mud Aquatic life in Layou river obliterated

Note that Iris was a Tropical Storm and did not reach Hurricane intensity, however, its effects were similar to that of a hurricane.

Given the experiences of the Caribbean with disasters in the past (hurricanes and more recently increased volcanic activity), and the potential for similar disasters in the future, there is a need for improved planning for disasters within the region. There is now widespread acceptance of the importance of "Comprehensive Disaster Management" as the fundamental strategic base of Disaster Management Planning. This has arisen largely because it is realized that responding to disasters as they

occur does not mitigate the effects of the disaster nor reduce vulnerability to future hazard impacts. In summary, Comprehensive Disaster Management means the capability to manage all types of emergencies by coordinating wide- ranging actions in all four phases of the Disaster Cycle – Mitigation, Preparedness, Response and Recovery. It embraces all risks, natural and man-made and action extends from the district and community to national policy levels.

Within the Fisheries Sector, it must be realized that preparing for the immediate threat of a disaster is not enough. More long-range planning is necessary. Disaster management must become an integral part of the Fisheries planning process as well as a part of the national planning process. More attention must be given to risk assessment and vulnerability reduction within the sector. National fisheries management organisations must form strategic linkages with national and regional disaster management agencies, as well as partnerships with fishermen and other stakeholders, to facilitate better planning for disaster management within the sector.

While several examples can be drawn from the experiences of other Caribbean countries in terms of the analysis of need and the associated recommendations, it has been decided that the emphasis will be placed on the British Virgin Islands (BVI) for two related reasons:

i) It is the location from which two of the authors of this paper have functioned during the last year, and
ii) The BVI has an international reputation for being in the forefront of disaster management thinking in Small Island Developing States.

This paper therefore:

i) Describes the conceptual framework as it relates to the linkage between disaster management and fisheries management within the region,
ii) Discusses the status of the British Virgin Islands as it relates to planning for disaster management within the fisheries sector, and
iii) Makes recommendations for policies, strategies, programs and projects that would reduce the vulnerability of Caribbean Countries to disasters.

PLANNING FOR DISASTER MANAGEMENT IN THE FISHERIES SECTOR OF THE BVI

In the British Virgin Islands considerable emphasis has been placed on the protection of life and to some extent safeguarding fishing gear and equipment, however, the focus has been almost exclusively on hurricane hazards. As development has proceeded, man induced hazards have become increasingly significant and threaten the viability of the sector. For example, the discharge of toxic and hazardous waste into the marine environment, or the illegal dumping of industrial waste, all have the potential to produce disastrous consequences.

We can say that some attempt has been made to offer a higher level of protection to marine vessels in general, through the construction of two marine shelters and several breakwaters. A Marine Pollution Action Group exists, and there

is ongoing dialogue among officials of the United States mainland Government, the UK Government, and the Governments of Puerto Rico, the United States Virgin Islands, and the British Virgin Islands to arrive at a Memorandum of Agreement with regard to joint action in the face of major marine pollution incidents in general and oil pollution in particular.

There also have been attempts to educate fishermen in safety at sea techniques, thus reducing their vulnerability to risk. There has also been an attempt to tie the requirement for safety gear on vessels to the licensing and registration process for fishing vessels.

Recently, a mitigation and development planning framework has been developed by the Office of Disaster Preparedness as the basis for long term mitigation. This National Mitigation Strategy recognises the vulnerability of the environment in general and proposes corrective action in a range of areas. These are summarised below:

i) Policy Measures
ii) Administrative Measures
    Legislation
    Institutional Capacity Enhancement
    National Mitigation Sub-Committee
    Private Sector, Non Governmental Organisation and Community Based Organisation Partnership
iii) Preventative Measures
    Land Management and Development Control
iv) Property Protection Measures
    Building Regulations and Land Infrastructure Development Guidelines
v) Natural Resource Protection Measures
    Conservation and Enforcement
vi) Structural Mitigation Measures
    Protective Barriers and Stabilization Structures
vii) Public Information Mitigation Measures
    Hazard Identification and Risk Assessment
    Outreach Programs
    Education and Training
viii) Emergency Services Measures
    Preparedness and Response mechanisms

REDUCING THE VULNERABILITY OF THE FISHERIES OF THE BVI

In addition to what is broadly proposed, we wish to highlight a number of areas in which we think concerted long-term interagency action should be undertaken. For convenience these may be divided in structural and non-structural mitigation activities. Mitigation represents a method or way of reducing vulnerability to disasters. Structural mitigation activities relate to the design, construction, and maintenance of infrastructure whereas non-structural activities relate to human

activities that can reduce risk.

Structural Mitigation Activities

Design of Fisheries Infrastructure — Historically, shore side fisheries infrastructure has been designed to provide maximum convenience to fishers and management personnel. This has resulted in designs that emphasize operational convenience for fisheries and administrative efficiency for officials. This often results in facilities located within a storm surge zone, with very costly and sensitive equipment located on the ground floor. The effect of Hurricane Lenny on the Fisheries Complex in Dominica clearly demonstrates that in future buildings should be designed to combine resistance to natural hazards with convenience to the human population.

Construction Materials and Techniques — The quality of construction materials and the nature of the workmanship have a major impact on the structural integrity of buildings. Most of the Caribbean faces two major natural hazards – hurricanes and earthquakes. Building materials and construction styles should reflect that reality. Expert advice should be sought on these matters and the necessary supervision provided at all stages in the construction of fisheries infrastructure.

Physical Planning and Development Control — The location of buildings of all types, allied to the two areas identified above, can either increase or decrease vulnerability. Buildings which are poorly sited or where the natural environmental protection, such as dunes and mangrove swamps, are eliminated are vulnerable to hazards. It is important though that development control issues are not seen as an isolated concern of the fisheries sector. Indeed, the needs of the sector should be completely integrated into national development control policies and practices, which are sensitive and responsive to the needs of the sector.

Foreshore Protection — The coast is a complex environment in which a host of dynamic forces impact each other. In many Caribbean islands, coastal roads are main arteries, and hotels on the coast are a major part of the economic infrastructure. Action is often taken on the coast to protect infrastructure and land based facilities. If these are not carefully designed and constructed, they can predispose the fisheries sector to hazards such as hurricanes earthquakes and industrial pollution.

Non-structural Mitigation Measures

The National Integrated Development Strategy (NIDS) of the British Virgin Islands identifies vulnerability reduction as one of the strategic planks of national development to promote sustainability. While it may be true that the fisheries sector contributes less than 5% of GDP (NRMU 1998) its significance may be under-reported because of the difficulties associated with quantifying the spin off benefits of the sector, since so much takes place at a cottage level. In terms of direct

employment, approximately three hundred (300) fishermen directly employed represent a substantial proportion of the indigenous labour force. Further, the use of more modern technology suggests that the economic potential of the sector is considerable, especially if the techniques advanced in the Fisheries Management Plan are employed. The non-structural mitigation activities that may be followed are considerable, and in the interest of brevity, we will merely highlight a few of these:

i) *Risk and Vulnerability Assessment* — There is a clear need to professionally assess the vulnerability of the fisheries sector, its infrastructure and the people involved to the effects of hazards of all kinds. Such a study would produce the greatest benefit. There is for example, anecdotal evidence that hurricanes have been the most disastrous of the hazards. However, information recently coming to light suggests that it is the destruction of habitat and nursery areas through industrial and domestic waste, along with developmental activities that is causing the more significant impact.

ii) *General Environmental Protection* — The Ministry of Natural Resources and Labour has publicly lamented the inadequacies of current environmental legislation. Expeditious action to improve such legislation could become a major contributor to mitigating the effects of hazards and indeed eliminating some hazards altogether. It would of course be necessary to have the appropriate enforcement mechanisms following closely on the heels of any such legislation.

iii) *Improved Information Gathering* — At present there is no systematic process of collecting and updating information of the fisheries sector that could be used to assist with disaster planning and management. There is need for accurate up to date information on the fisheries sector that could be used to assist with planning for vulnerability reduction. Information of the length, make, model and age of fishing vessels, as well as estimates of their value and their insurance status should be collected and updated regularly. It may be advantageous to store this information in a centralised government system.

iv) *Operational Plan for Vulnerability Reduction* — The Fisheries Management Plan presents a comprehensive framework for the management of the sector; however, it does not embrace vulnerability reduction or mitigation specifically. It would be necessary to develop operational guidelines, which focus on issues such as:

Retrofitting of existing facilities
Improving shelter arrangements for fishing vessels
Guidelines for marine safety

The re-introduction of a twenty-four hour ship to shore radio system.

In that regard, strong emphasis should be placed on training fishers in marine safety and the use of safety equipment such as flares, life jackets and radio communication equipment. Fishers should also be trained in navigation and basic seamanship skills. The local H. L. Stoutt Community

College offers such training. Arrangements should be made to facilitate fishers in fully utilizing this resource.

v) *Capacity Building* — There is a need to continue the ongoing process of capacity building within the Fisheries Unit of the Conservation and Fisheries Department. This should include greater emphasis on vulnerability reduction and disaster management as an integral part of the strategy for sustainability. Advantage should be taken of ongoing training in disaster management at the local community college, as well as safety at sea modules provided by the Office of Disaster Preparedness and volunteer rescue organizations such as the Virgin Islands Search and Rescue (VISAR) and the local Red Cross.

vi) *Empowering Fishers* — The Virgin Islands Fisheries Act 1997 makes provision for a Fisheries Advisory Committee, it identifies a role for Fisher organizations in the management of the Fishing Industry. The Fisheries Advisory Committee should be implemented. This committee, in addition to "empowering" the fishers, could then play a strong role in disaster planning for the sector. The development of strong fisher organizations should be encouraged and facilitated. By working closely together in a cooperative relationship, fishermen may find it easier to access resources such as marine insurance and training opportunities. They would also be in a position to spread the risk normally associated with investment in the Fisheries Sector. They would also be able to offer mutual assistance to each other in several other aspects of disaster management.

vii) *Interagency Actions* — There is no single agency that can unilaterally execute all the tasks necessary to promote mitigation. The Fisheries Unit of the Conservation and Fisheries Department should take advantage of existing administrative structures such as the Marine Pollution Action Group and the National Mitigation Task Force to ensure that the vulnerability concerns of the sector are placed on the front burner.

CONCLUSION

In conclusion, there is a great opportunity in the British Virgin Islands to elevate vulnerability reduction in the fisheries sector to a new plane of significance. This has much to do with the overall environment that exists for disaster management in the Territory and the development of a number of strategic initiatives that are designed to reduce the Territories overall vulnerability to hazards of all kinds in all sectors. It is clear however, that in the final analysis, it is the expertise, energy, and commitment that fisheries officials can bring to bear on the process through advocacy and interagency collaboration that will largely determine the extent to which fisheries becomes a hazard resistant and truly sustainable sector.

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Size Matters: Fisheries Management and Social Capital on the Turks and Caicos Islands

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ABSTRACT

Recent research[1] on the management of conflict in tropical fisheries indicates that flexible local institutions supported and recognised by government form an integral part of fisheries management and are crucial to the successful management and resolution of conflicts. But what happens when such institutions do not exist or are not fully matured? Evidence from the Turks and Caicos Islands shows that in some circumstances factors other than institutional formation are equally important.

Based on data collected in the Turks and Caicos Islands between 1999 - 2000, this paper describes the constraints to fisheries management on small islands and then analyses how conflicts are managed and resolved. The paper finds that, although a number of institutional structures are found on the islands, social capital is also a very important component in the process of conflict management. The analysis of social capital is now popular in the social sciences, but has rarely been applied to fisheries management issues.

KEYWORDS: Conflict, fisheries, social capital

INTRODUCTION

Although there are a number of exceptions, it is arguable that fisheries need management so that they can provide a continuous stream of nutritional and income benefits to fishing communities over time. Without management the 'tragedy of the commons' often results (Hardin 1968): economic rent is reduced, stocks may be overfished and all meaningful control of the benefit stream from the resource is lost (Cunningham et al. 1985). Management is thus needed to protect the biological health of the stock and concomitantly the well-being of the community dependent upon fishing. Recent research (Hatcher et al. 1976) has shown that co-operation and compliance between stakeholders is key to successful fisheries management. Management, however, inevitably results in trade-offs between the multiple stakeholder groups involved: fishermen, processors, conservationists, tourists and

[1] Research was conducted as part of the research project The Management of Conflict in Tropical Fisheries (R7334) funded by the UK Department for International Development (DFID) through the Fisheries Management Science Programme. The views expressed in this paper are not necessarily those of DFID.

so on; and the three paradigms that shape management systems: conservation, rationalisation and social/community (Charles 1992). Without careful management of such trade-offs, conflicts often emerge as each group tries to consolidate its position and a middle ground between the needs of the community, the market and the fishery is reached. Fisheries worldwide are under pressure from increased competition and decreasing resources and, although violent conflict is rare, low-level chronic conflict is an ever-present feature of many fisheries. Tropical fisheries, particularly those in countries where there is a heavy economic reliance on fishing, are all too aware of the potential for increased conflicts over the allocation and usage of natural resources. In spite of the rise in the overall level of conflict in fisheries, specific institutions for managing conflicts are rare and, in developing countries in particular, methods for managing conflict are only just beginning to gain credence at the policy level.

There are, generally, two channels for managing or resolving conflicts. At the formal level, Fisheries Departments and Fishermen's organisations can mediate between conflicting stakeholder groups, providing a platform for concerns and a means of communicating government policy to user groups. At the informal level, the traditional structure of fishing communities can help alleviate conflicts through long-established dialogue processes and recognised methods of resolving conflicts. But what happens when such institutions do not exist or are not mature enough to tackle conflicts? In some cases, conflict management and resolution is non-existent because economic or political problems have led to institutional failure and the usual channels of mediation and consensus have been eroded (see Bennett et al. 2001 for example). In other cases, institutions have failed to emerge altogether due to insufficient state support or, particularly in the case of small-islands, due to size and context constraints. In these cases there is clearly some other mechanism that is being used to manage and mediate in conflicts because evidence of violent, uncontrollable conflict is rare.

Research on the Turks and Caicos Islands has demonstrated that social capital has a very important role to play in how fisheries are managed and, importantly, how conflicts are dealt with. The following paper examines the nature of social capital and its role in the management of fisheries conflicts and asks whether the development and recognition of social capital at the policy planning stage might be a viable way forward for other small island fisheries in the region. This paper is organised as follows. First we explore the literature on institutions and social capital. Then we outline the management and administration of the conch and lobster fisheries on the islands and then go on to describe the conflicts reported in the Turks and Caicos coastal zone. Based on this information we offer an analysis of how social capital aids conflict management in the islands and what the policy implications might be for other small islands in the region.

SOCIAL CAPITAL

Although it is not possible to date the first use of the term 'social capital', it has rapidly gained in currency in the last 20 years or so. In broad terms, social capital is the glue that holds society together. From the perspective of the individual it is a product of social relationships that individuals can use to increase their well-being (Rudd 2001); the extent and nature of those relationships is a function of the individuals location in the social structure (Adler and Kwon 2001). From the perspective of society, social capital "encompass[es] the norms and networks facilitating collective action for mutual benefit' (Woolcock 1998).

Social capital is a public good that only exists when it is shared, it is not held by an individual, but by others that the individual relates to (Dhesai 2000, Narayan 1997). Some argue that social capital can be constructed through local interactions (Falk and Kilpatrick 2000); others maintain, however, that it cannot be 'created' but is the by-product of other social activities (Molinas 1998), whilst others suggest that creation of social capital at the local level is possible but requires state support. (Pretty and Ward 2001). The amount of social capital that society can make use of is a function of the amount of social capital each individual has acquired: societies with good and extensive links between individuals are more cohesive than those societies where only a minority can access social capital.

Social capital is often referred to as beneficial to society, but this is not necessarily the case. Social capital can build barriers as dense networks create definitions between those in the network and those outside (the caste system for example), these dense networks can also negative externalities because they can lead to and support cronyism, nepotism and corruption (Narayan 1999).

A useful model for studying social capital is put forward by Pretty and Ward (2001). They examine in turn the four elements crucial to social capital: trust; reciprocity; common rules and networks (Pretty and Ward 2001). Trust is an essential ingredient in social capital because it enables community members to 'predict' each other's future moves, thus reducing information costs. The ability to trust the behaviour of others also helps reduce deviant behaviour. For this reason, trust is a key to compliance with, and the monitoring and enforcement of, regulations. Trust is a fundamental building block of reciprocity. The informal exchange of favours only works were trust has been built and reciprocity in turn helps generate and foster trust and strengthen networks. Pretty and Ward (2000) identify norms as the 'mutually agreed or handed-down [modes] of behaviour that place group interests above those of individuals'. These norms have in turn been established as a result of repeat actions which, as explained earlier, rely upon trust and help facilitate collective action. Networks are crucial to society and rarely exist in isolation. Multiple distinct networks are often linked, thus broadening the base upon which relationships are formed and mediated. Networks rely upon trust – that which exists between people who know each other, but also between people associated with a known network such as a church, political party, or sports club. Despite the obvious role of social capital in the successful management of natural resources, this is still a relatively new field of study.

Social capital has been shown to have a positive effect on the sustainable use of the environment. It arises from shared relationships (collective action) which leads to increased economic efficiency at the community level and is able to internalise economic externalities such as erosion (Swinton, 2000: 5). Social capital also has an important role to play in fisheries management because it can have positive effects on co-operation and compliance. Molinas (2000:414) argues that co-operation is more likely to result if there is a high probability that interactions will be repeated; in other words, repetition occurs when levels of trust are sufficiently high to ensure that the cost of gaining information on future moves is low. Co-operation between individuals and groups is also more likely to happen when the gains from such actions are high and defectors can be identified and punished and the costs and ability to monitor behaviour are lower. This is a characteristic of small islands where there is higher visibility, more 'gossip' and less chance of what Molinas refers to as 'errors in interpretation' in behaviour. Cooperation is also boosted by shared beliefs that engender trust and bind groups together. The smaller the population, the more discussions can take place on important issues and the higher the degree of mutual dependencies (reciprocities) between members.

The role of social capital in facilitating the management of a resource, and in particular managing conflicts over that resource, comes to the fore when there are few other institutions to fulfil such a role. Large-scale fisheries often benefit from extensive formal and informal institutional frameworks. Large state institutions can provide finance and support for a wide range of initiatives such as Fishermen's Union and Co-operatives to improve fisheries management, policy implementation and conflict management. Informal institutions, such as the traditional chief structure found in many West African states, also help to focus fisheries management initiatives and to act as a mediator in conflicts and disputes. Such institutional arrangements, however, often rely upon large populations and 'mature' institutional frameworks, a factor often missing on small islands that may have neither the financial capacity, skills-base nor historical background to develop such frameworks.

Although from a Caribbean perspective, the Turks and Caicos Islands are comparatively well developed and not suffering from many of the economic and political problems witnessed by other small islands in the region, they do provide an excellent case study on the role of social capital in managing fisheries conflicts.

MANAGEMENT OF THE TURKS AND CAICOS ISLANDS FISHERY

The Turks and Caicos islands lie in the Western Atlantic. They are approximately 145 km north of the island of Hispaniola and lie at the southern end of the Bahamas archipelago. They consist of eight main islands of which six are inhabited. Although fish has been an important source of protein to the islands since pre-Columbian times, formal evidence of commercial fishing dates from 1887 (Sadler 1997, Bene and Tewfik 2001), but increased significantly in the early 1950s with the introduction of freezing technology (Brownell and Stevely 1981). Fishing on the islands relies on three principle commercial stocks: queen conch (*Strombus*

gigas), spiny lobster (*Panulirus argus*) and finfish (mainly grouper and snapper). Of these, the conch and lobster fishery is the most important socially and economically and are the principal stocks exported. Although all inhabited islands are engaged in fishing these species, only South Caicos and Providenciales have processing plants licensed to export product.

Stock and Effort Management

The Turks and Caicos Island fishery is open access and held as state property. The number of entrants to the fishery is currently not limited (except by nationality, see below), but all fishermen require a licence. Both major export stocks are managed. Queen conch (*Strombus gigas*) is protected under CITES[2], and as such is managed by quota, minimum size restrictions, a closed season (July 15th - October 15th) and a Closed area (East Harbour Conch and Lobster Reserve). The quota is set at 1.6 million pounds per year (this amounts to approximately 600,000 lbs of processed conch meat) and is set by the Quota Management Committee which allocates it on a quarterly basis. At the time of the study the quota was split 50:50 between South Caicos and Providenciales with the plants on each island then competing for the quota. During the last season, each plant has been given its' individual share of the quota, (over 100,000 lbs). Conch is caught exclusively by free-diving (breathing apparatus is illegal). Lobster (*Panulirus argus)* is managed by a combination of closed season (which runs from April through August), and minimum landing size. The lobster fishery opens in August with what is known as the 'Big Grab': a one or two week period when about 30% of the annual catch is taken. The lobster fishery is mainly a dive-based fishery, although there are three boats on South Caicos using traps (pots).

Processing-Sector Management

As the only legal means of exporting product, the processing plants have an important role to play in the fishery. The plants are largely price-takers (from the market in the USA), although each year there are reported to be meetings and petitions initiated by the fishermen to persuade the plant operators to increase the price paid for product. By and large, processors are free to use the quota and manipulate prices as they see fit (although recent government moves now apportion the conch quota across quarters) which in some cases can lead to the hoarding of frozen product until the next season or the refusal to buy product until the price in Miami has improved.

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[2] As a result of the low level of stocks in Florida, queen conch entered Appendix 2 of CITES at the 11th hour during a meeting in 1995, although there was no suggestion that stocks were threatened in other places in the Caribbean (DECR, pers.comm 2000)

Conflicts Reported on the Islands

As part of a three-country study into the management of conflict in tropical fisheries, field interviews on the islands were conducted in 1999 and 2000 with a wide range of stakeholders. The aim of the study was to ascertain what conflicts were actually present in the fishery, why those conflicts had arisen and how they were managed. In total, 19 respondents from South Caicos, 13 from Grand Turk, and 20 from Providenciales were interviewed (Table 1).

Table 1. Distribution of respondents by island and stakeholder group

Island	Stakeholder
South Caicos	Fishermen (13)
	Processors (1)
	Sport Fishermen (2)
	School for Field Studies (2)
	Government officials (1)
Grand Turk	Fishermen (6)
	Fisheries Advisory Committee (1)
	Diving Operations (1)
	Tourism (1)
	Government (4)
Provo	Fishermen (12)
	Processors (1)
	Fisheries Advisory Committee (1)
	Sport Fishermen (2)
	Conservation bodies (1)
	Government (2)
	Conch farm (1)

METHODS AND RESULTS

A semi-structured questionnaire was used for each of the principal stakeholder groups in the fishery: fishermen, processors and the conservation/tourist sector. The questionnaire consisted of two sections. First, a contextual and situational section, which asked questions on access rights, fishing patterns, the nature of the business (for non-fishing respondents), and who the principle decision-makers are in that sector. This was then followed by a second section specifically on conflict management which was designed to elicit information on the principle conflicts, probable causes, how such conflicts were resolved, and which were the hardest to resolve and why.

Conflicts Reported

Illegal fishing in various forms was reported by both fishermen and fisheries officers. Discussions on illegal fishing covered the use of bleach to catch lobster and 'illegal' entrants to the fishery. Bleaching, most common to South Caicos, is used to extract lobster from their burrows. It is highly destructive to the reef and only

used by a small percentage of fishermen. Detection is difficult despite widespread knowledge in the community about who is using bleach. Illegal entrants to the fishery include poaching by Dominican Republic vessels, but the most frequently mentioned problem was that of "Non-belongers' in the fishery. According to the Fisheries Protection Ordinance (Chapter 104, para 6 (g (a) and i), neither a commercial fishing licence nor a commercial fishing vessel licence "may be issued to persons other than "Belongers". Although the scale of the problem is not entirely clear, there are reported to be a considerable number of "Non-belongers" (almost exclusively Haitians and Dominicans) working in the commercial fishery. The law also states that 'the holder of a Commercial Fishing Vessel Licence [....] shall not [...] allow the particular vessel to be used for commercial fishing [...] unless there is a "Belonger" aboard the vessel at all times. Both fishermen and fisheries officers confirmed, however, that many vessels went to sea without the required "Belonger" on board. "Belonger" fishermen can apply to have assistance on the boat, and given the arduous nature of free-diving, it is not uncommon for relatively young "Belonger" fishermen to find that they are physically no longer able to dive and being able to hire in other labour is therefore useful. But fishermen and Fisheries Officers report that this situation is widely abused with "Belonger" fishermen staying at home or working on-shore whilst "Non-belongers" work the boat.

Lobster-pot removal or theft was the most reported conflict between the fishing and tourist industries. Few fishermen use lobster pots yet fishermen mentioned this issue on Grand Turk and fisheries officers on Providenciales. The root of this conflict is competition for space within the marine environment, which is leading recreational divers to leave the Marine Parks and search for new dive sites elsewhere – often close to grounds traditionally used by fishermen. This has led to confrontations between fishermen and divers, each cutting or damaging the others' equipment.

All stakeholder groups also frequently reported lack of enforcement as a conflict. Firstly, there is a perceived lack of enforcement of foreign poaching vessels that fish illegally in Turks and Caicos waters and also within the Marine Park boundaries. Occasionally they are caught, the vessel impounded, and the crew arrested. The DECR, however, admit that there are probably a number of vessels that escape detection due to the lack of capacity for effective enforcement. Secondly, the lack of enforcement on illegal fishing activity, such as bleaching and the use of non-belongers, was mentioned.

The size and distribution of the conch quota was cited as a conflict on both South Caicos and Providenciales. Conch is managed by quota allocated to the processing plants, not the fishermen. Fishermen on South Caicos (where 95% of the population is dependent upon fishing) expressed an interest in the quota being assigned according to the number of fishermen and need – the result being that South Caicos would receive more quota as it has more fishermen and a less diversified economy than Providenciales. Not surprisingly, the fishermen all state that the quota should be larger – or abolished altogether. The processors too would

like more quota (whether this means more quota from other plants or an overall increase was not clear).

The presence of part-time fishermen in the fishery was a conflict raised by Fisheries Officers and, to a lesser extent, some full-time fishermen. There are currently no restrictions on who can apply and be issued with a commercial fishing licence (except nationality, as mentioned above). As a result, it is estimated that up to 60% of the 160 licences issued on Providenciales by late 2000 were to part-time fishermen. The large number of part-time fishermen in the fishery results in increased effort particularly during the opening of the lobster season (with the added consequence of lower earnings for full-time fishermen). Full-time fishermen also reported that part-time fishermen are generally less-skilled and thus may be causing more damage to the reefs.

Overall, conflict was not seen as a significant or insurmountable problem on the islands, and conflicts reported were almost exclusively confined to the different stakeholder groups – there were few inter-sectoral conflicts (between the large fishing and tourism sectors, for example).

CONFLICT MANAGEMENT ON THE ISLANDS AND BEYOND: THE ROLE OF SOCIAL CAPITAL

The failure of formal and informal institutions is often the cause of inadequate or non-existent conflict management in a fishery (Bennett et al. 2001). However, this was found not to be the case in the Turks & Caicos Island. Here, the formal institutions, such as the Ministry of Natural Resources, the Department for Environmental and Coastal Resources (DECR), and the Fisheries Advisory Committee (FAC) all function within a democratic, open, and stable situation. Whilst no formal platform for conflict management exists, they each have a role to play in mediating between conflicting stakeholders and intervening in day-to-day problems. However, it was also clear from the data collected that there were informal institutions on the islands that played a very significant role in managing and resolving conflicts. These institutions can be explained by the theory of Social Capital. Using the framework set out by Pretty and Ward (2000), the following examines how trust, reciprocity, norms and networks act as a conflict management mechanism on the islands.

The Role of Trust, Reciprocity, Norms, and Networks in Conflict Management on TCI

Trust is the fundamental building block of social capital is the key element that helps reduce transaction costs between community members. Building trust amongst a community is, it could be argued, easier the smaller the population – and this is certainly the case in TCI. The ability of the community to know the behaviour of all other members and the high visibility of broken trust helps ensure that the level of illegal fishing methods (predominantly bleaching of lobsters) is contained, even if it is not prevented. Because the long-term consequences of bleaching are well

known, damaged social standing within the community (which is based on the amount of trust an individual can generate) plays a large part in managing this conflict largely because it is cheaper in the long run to comply than risk losing the trust of the community. (see Hatcher et al. (2000) for an econometric analysis of compliance and trust in fishing communities).

Conversely, the level of mis-trust between the "Belonger" and "Non-belonger" community is a major impediment to managing conflicts related to poaching by foreigners and the use of "Non-belongers" on fishing vessels. The complicit behaviour of the "Belongers" who hire the "Non-belongers", and the law which (albeit unwittingly) allows it to happen also contribute to eroded trust in this area. By establishing clear and enforced guidelines on this issue, all fishermen would be able to predict the moves of others and the level of trust would increase.

Reciprocity is an important feature of islands with small populations where, once again, the ability to trust other community members is crucial to survival, and broken trust is very visible. On TCI there is a strong reciprocal relationship between the plant-owners and the fishermen who operate in a highly symbiotic relationship. The plant owners rely on the fishermen for product; almost all the fishermen need the plants to buy their catch and occasionally rely upon the plant owners to loan them money for news boats and engines. The inter-dependence that has arisen on a commercial basis is reinforced by that which has been created due to familial and island links between plant owners and fishermen.

The acceptance or rejection of norms (accepted modes of behaviour) are requisites to manage conflicts within small fishing communities. In much the same way that trust and social standing can enforce certain behaviours, the establishment of certain norms that uphold the wishes of the majority can also establish 'right' and 'wrong', which ultimately help mediate in conflicts. The environmental consequences of bleaching are understood, and there is strong community pressure to enforce the law. The norms of fishing behaviour that dictate that bleaching is 'bad' help mediate in the conflict (by taking legitimacy out of the hands of those that use bleach). Whether community interests are able to finally eradicate bleaching, though, remains to be seen. Although hooking is less environmentally destructive than bleaching, it too causes conflicts between those that abide by the law and those that did not. By the time this study was conducted the practice of hooking lobster had been 'legitimised', if not formally legalised. So widespread had been the use of the hook that the level of acceptance of its use had grown so that community interest was able to over-ride individual interests.

The most contentious conflict within the fishing community relates to the use of "Non-belongers" on boats. Those that (illegally) use "Non-belongers" defend their actions sometimes on the basis that this is the only way for them to make a living, sometimes on the basis that 'everyone else is doing it'. It is difficult to ascertain how widespread this practice is, but there is also significant lobby that disagrees strongly with this law being broken. While commonly held norms (that the law should be respected) can and do hold society together, the case of "Non-belongers' on fishing boats demonstrates how such norms are subject to

considerable pressures (economic and financial in this case) and are constantly changing to reflect group interests (societies view of the practice). Whether community interest (that fishing is reserved for "Belongers") is able to over-ride individual interest (that fishing needs "Non-belonger" labour) in this case remains to be seen.

Finally, networks which define different groups within society have an important function to play in conflict management because they provide the routes of communication and dialogue needed to resolve issues. Networks on the islands are, *inter alia*, based around churches, political allegiance, language groups, island of birth, sports teams and familial connections. Due to the small population there are highly complex links between networks and many points of overlap. With many islanders able to identify with a wide range of networks, problems, concerns, and the early seeds of conflict can be discussed with a wide variety of actors in the hope of finding mediation and solutions. The networks which define islanders' identity also help foster support for conservation measures such as the existence of the Marine Parks. Networks, however, can have negative impacts. As noted earlier, Fisheries Officers reported that enforcement is made much more difficult when the offender is a member of the extended family or engaged in the same networks as the officer (a common occurrence). The powerful identification with networks also means that there are clear lines drawn between different communities or groups ("Belonger/Non-belonger" for example) which can foster mistrust which in turn hampers efforts at encouraging dialogue to resolve conflicts.

CONCLUSIONS

Institutions are important to the management of fisheries, and to the management of conflict in those fisheries. Some fisheries do, however, succeed in managing conflicts without the benefit of extensive institutional structures – either because such structures have never emerged, or they have failed. In these cases, there are clearly other factors that enable conflicts to be contained and resolved, and social capital is an important element to understanding why this happens. Whilst the proximity of family members and loyalty to particular islands both can cause difficulty in the formulation of policy, the enactment of management plans and enforcement of legislation on small islands, size can also be a positive factor in preventing conflict escalating out of control. Where establishing specific conflict management institutions is not feasible due to economic or political constraints, or where the size of the population makes such an exercise extremely difficult, the development and enhancement of social capital may be the answer. Capacity building of local (informal) institutions that enforce norms that benefit the community would be a low-cost means improving natural resource management. Social capital as a mechanism for regulating communities and resolving conflicts has always existed, but it is only now that its real significance is being recognised. Fisheries on the Turks and Caicos amply demonstrate that intra-familiar and island networks are important factors in the enforcement of fisheries regulations and in

maintaining the peace. Further research needs to be conducted on how networks are organised on the islands and how policy makers might harness them. Understanding how communities co-operate and what types of social capital mediate their behaviour may provide invaluable tools in improving fisheries policy and avoiding conflicts in the future.

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A Perspective on the Implications of USA Fisheries Policies on the Belize Fishing Industry

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ABSTRACT

The fishing industry in Belize contributes significantly to the country's national economy. In the year 2000, the fishing industry ranked as the fourth highest foreign exchange earner in Belize and contributed approximately 6% to the Gross Domestic Product. Total earnings amounted to 71.8 million Bze dollars of which the capture fisheries sector valued 24.3 million Bze dollars and the shrimp mariculture sector 47.5 million Bze dollars. This industry is considered to be successful and lucrative mainly because it has been able to maintain very high quality products and access to foreign markets through well-organized fishing cooperatives. Fisheries and other related policies of the United States of America over the years have influenced and thus impacted the fishing industries in Belize and the Caribbean, particularly in the aspects of trade and the development of traditional fisheries. As a result, several of Belize's fisheries policies and enabling legislations have been structured to make the most of US and other available markets. Compliance with policies formulated or supported by the US, have also highlighted Belize's political will to support the global efforts in the sustainable management of fisheries stocks and the conservation of endangered species. This in return has increased Belize's eligibility for foreign aid to facilitate its own national efforts in fisheries management. While acknowledging the aforementioned benefits, the challenges that confront Belize in adopting U.S policies should not be overlooked. The implementation of these policies has had some negative impacts on the fishing industry due mainly to financial and human resource constraints of the fishing cooperatives and Government of Belize for institutional strengthening and capacity building. It must also be noted that compliance with these policies have led to negative cultural consequences such as the restriction and in some instances the prohibition of traditional fishing for certain species.

KEY WORDS: Fishing industry, fisheries policies, fishing cooperatives

Una Perspectiva Sobre las Implicaciónes de las Políticas de Pesquería Estadounidense Sobre la Industria Pesquera de Belíce

En el año 2000, la industria pesquera de Belíce se calificó en cuarto lugar con respecto a otros sectores en cuanto a la ganancia de divisas y contribuyo aproximadamente 6% al producto nacional bruto. En total se generó 71.8 millones de dólares Beliceña del cual 24.3 millones de dólares se atribuye a la pesca de captura y 47.5 millones de dólares al maricultura de camarón. La pesquería tiene éxito y se considera lucrativa principalmente porque mantiene alta calidad de productos y a la vez mantiene acceso a los mercados extranjeros a través de las cooperativas pesqueras. La política Estadounidense sobre pesquerías ha influenciado é impactado las industrias pesqueras de Belíce y el Caribe particularmente en los aspectos de comercio y el desarrollo de pesquerías tradicional. Como consecuencia de esto, algunas políticas y legislaciónes sobre pesquerías en Belíce han sido estructurada para tomar ventaja de los mercados en los Estados Unidos como en otros países. El hecho de que Belíce cumple con las políticas establecidas o apoyadas por los estados unidos manifiesta su voluntad política para apoyar los esfuerzos globales en el manejo sustentable de las pesquerías y en la conservación de las especies en peligro de extinción. A su vez, esto ha aumentado la elegibilidad de Belíce para ayuda exterior para facilitar su propio esfuerzos nacionales en el manejo de la pesca. Mientras que se reconoce los beneficios mencionados anteriormente, es muy importante reconocer los retos con los cuales Belíce es enfrentado por adoptar las políticas Estadounidense. La implementación de estas políticas ha demostrado impactos negativos en la industria pesquera debido a los constreñimientos económicos y de recursos humanos de las cooperativas pesqueras y el gobierno de Belíce para fortalecimiento institucional y de capacidades. Además, al cumplir con las políticas ha dado raíz a consecuencias culturales negativas tales como la restricción y en algunos casos la prohibición de pesca tradicional para algunos especies.

PLABRAS CLAVES: Pesqueria de Belice, coopertivas

INTRODUCTION

Belize is located in the Western Caribbean just below the Yucatan Peninsula of Mexico and is bordered on the west and south by Guatemala (Figure 1). Belize has been blessed with numerous coastal resources, which have provided sustenance and an economic foundation for its human population. The most striking feature is the longest barrier reef in the Western hemisphere that supports a thriving fishing industry.

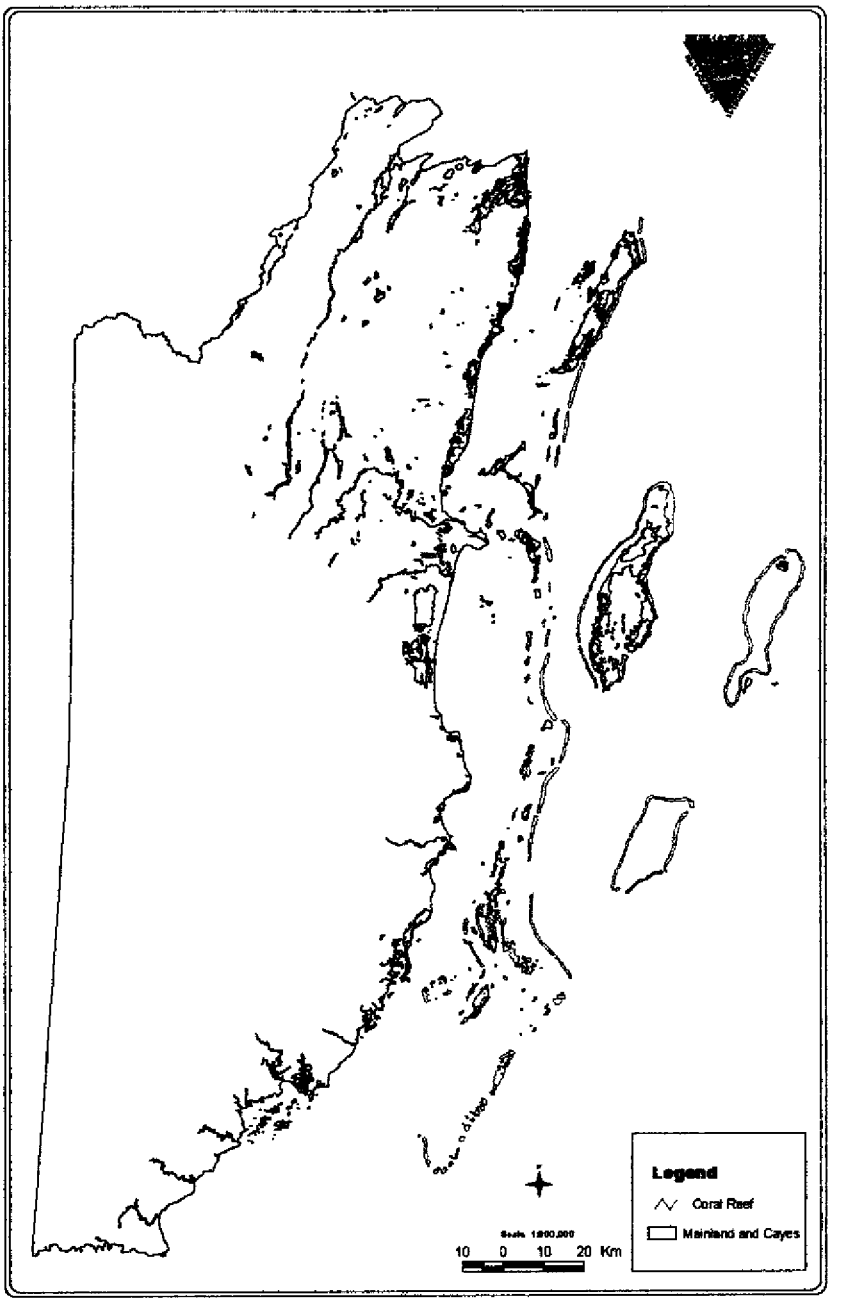


Figure 1. Belize barrier reef system

The Fishing Industry contributes significantly to the economy of Belize mostly from exports of lobster, conch, and shrimp. The Fisheries Sub-sector contributed 6% to Belize's Gross Domestic Product (GDP) in 2000. Export statistics for the year 2000, reflected earnings valued at Bze $71.8 million with lobster contributing Bze $18.8 million, conch Bze $4.86 million and marine farmed shrimp Bze $47.5 million (Appendix 1).

The sector is characterized as a commercially artisanal industry except for the industrial trawl fishery for shrimp. The artisanal fishing fleet is composed of open boats, sail sloops, and canoes. The industry is considered to be lucrative and successful mainly because of the good prices obtained on the foreign market and because most fishermen belong to one of the four main cooperatives. They play a dominant role in the industry and are entirely owned by local investors and fishermen that are the main shareholders.

The Belize Fishing Industry has been successful because of its ability to adapt to both local and global changes thus allowing it to capitalize on the benefits of certain policies and maintain the level of operations and activities in the sector necessary for its continued growth. It is envisaged, however, that the proliferation of more robust policies geared directly or indirectly towards the sector could have profound implications on the integrity and continued success of the fishing industry.

Legislative and Management Framework

The laws governing the fisheries sector in Belize dates back to September 24, 1948. Through subsequent amendments, the Fisheries Ordinance, Chapter 133 of the laws of Belize, 1948 was consolidated into the Fisheries Ordinance, Chapter 174 of the laws of Belize, 1980. Since then further amendments have led to the current Fisheries Ordinance, Chapter 210 of the laws of Belize, Revised Edition 2000. Complimentary to the Fisheries Ordinance is the Fisheries Regulations, 1977 that has undergone several amendments with the most recent being the Fisheries Regulations of 1999.

The Belize Fisheries Department, Ministry of Agriculture, Fisheries, and Cooperatives was established in 1965. The department is responsible for administration and management of the fisheries resources in Belize. This mandate is guided by the principal objective to develop clear research policies and adequate, relevant, and systematic research and monitoring programs to generate information for policy formulation and decision-making. The Fisheries Advisory Board (FAB) comprised of fishermen and representatives of government and non-governmental organizations serve as an advisory body to the Minister of Agriculture, Fisheries, and Cooperatives. This body is very important and strong since it establishes the much needed check and balance between the bureaucratic Government of Belize (GOB) and the major stakeholders of the industry. Their presence and participation on the board gives direction to the fishing industry and sector.

The Belize Fishing Cooperatives

The Belize Fishing Cooperatives could be regarded as one of the few true grassroots businesses in Belize. They are owned and managed by the fishermen who make up their membership. The primary objective of the Fishing Cooperatives is "to promote the economic and cultural welfare of its members by providing procedures and means for the efficient production, distribution, processing and sale of marine products through the united efforts and funds of its individual members" (Cooperatives of Belize By-Laws 1968).

Approximately 75 % of all full-time fishermen in Belize are members of one of the four Fishermen's Cooperatives, Northern, National, Placencia, and Caribeña or the recently formed Toledo Fishermen Cooperative. These cooperatives purchase, process, and export fisheries products on behalf of the fishermen making them direct beneficiaries of the benefits from sales.

The Fishing Cooperatives are considered the backbone of the fishing industry since they themselves have invested much of their earnings back into their operations, upgrading their facilities, and providing services to members and the communities. Furthermore, the fishing cooperatives are the businesses that provided the initial capital investments into the productive sectors of the communities of San Pedro, Ambergris Caye, Caye Caulker, and Placencia that are presently the most popular tourist destinations in the country.

Since their inception in the 1960s, the fishing cooperatives have advanced significantly the Belize Fishing Industry (Gordon 1986) and have thus become very important in the Belizean economy. Prior to the establishment of the cooperatives there were approximately 600 full-time fishermen. The number of fishermen escalated to 800 by the mid 1970s and subsequently to 3,000 in the year 2000. Concomitantly, in 1955 the total catch was 260,924 kg valued at Bze $191,635, and in 1979 the total catch was 534,061 kg valued at Bze $7,938,390 (Gordon 1986). In the year 2000, the Belize Fishing Cooperatives exported Bze $24,300,000.00 worth of seafood products.

Impact of Fisheries Policies on the Belize Fishing Cooperatives

The major success of the Belizean Fishing Cooperatives can be attributed directly to their ability to negotiate better markets and thus attain better economic yields for their marine products. In December 1995, the Hazard Analysis Critical Control Point (HACCP) became mandatory in Belize. This is an American food safety system that has been endorsed worldwide by many of the major importing countries, such as the European Union, Canada, Australia, Japan, Mexico, and most of the Caribbean and Central American countries. The Codex Alimentarius of the Food and Agriculture Organization has also given its endorsement to this food safety system.

Compliance with HACCP have allowed Belizean cooperatives to continue to compete and obtain access to lucrative markets while at the same time maintain its reputation of being the source of very high quality seafood products. However, HACCP has placed a significant strain on the cooperatives, considered as the corner

stones of the Belize Fishing Industry. In addition to significant capital costs to gain HACCP certification, processors continue to experience significant financial outlays for renovations to their processing facilities in order to meet the required standards and maintain access to the markets they are dependent on. HACCP also gives more responsibility to the producers as it requires substantial investments in capacity building for personnel directly involved in processing. This also includes an additional increase in human resources by the Government of Belize for the training of such personnel in order to deliver essential services to the fishing cooperatives and to ensure proper monitoring and compliance with HACCP.

The queen conch, *Strombus gigas*, is the second most important marine species fished in Belize and is the second largest capture fishery. It is exported and distributed to the local market primarily by the Fishing Cooperatives. The queen conch is currently listed on Annex II of the Convention on the International Trade of Endangered Species of Wild Fauna and Flora (CITES). Paragraph 2 (a) of this convention states that:

> "All species which although not necessarily now threatened with extinction may become so unless trade in specimens of such species is subjected to strict regulation in order to avoid utilization incompatible with their survival".

Regulation of trade of the queen conch requires exporting countries to implement management measures such as quotas that have direct bearing on the future development of this traditional fishery in Belize. This in turn places an added challenge to the fishing cooperatives and the fishing industry in adapting to a possible reduction in the level of exploitation allowable for this species, which has been one of their main export commodities and is important to their economic stability.

Belize has also been able to reap the benefits of access to markets in the United States as a result of its compliance with other policies directly related to its fishing industry. On an annual basis, the Government of the United States certifies Belize to export captured shrimp to major importers. However, this certification is based on the condition that the trawlers operating in Belize (by the cooperatives) utilize a Turtle Exclusion Devise (TED). As a result, the Belize Fisheries Department, Ministry of Agriculture, Fisheries, and Cooperatives have made it a policy that TEDS are a requirement for the granting of a license to trawl in the waters of Belize. This policy is also currently in a draft statutory instrument awaiting approval and signature by the Minister of Agriculture, Fisheries, and Cooperative.

Implications of International Agreements and Policies

Belize's local policies towards the conservation of biodiversity through the sustainable management of its natural resource and the protection of unique and critical ecosystems and species has resulted in it being perceived as one of the leaders in the conservation of the worlds environments. Belize is also party to

several international agreements and commissions including the 1982 United Nations Convention on the Law of the Sea (ratified on 13th August 1983), the Convention on International Trade in Endangered Species of Wild Flora and Fauna (ratified on 19th August 1976) and the Western Central Fisheries Commission (member since 1985) directly relevant to the environment and the Belize Fishing Industry.

As a result of this image, Belize has become eligible for substantial funding and resources to aid and facilitate its local efforts in the continued and successful conservation and management of its fisheries and other marine resources. Government and the Non-Governmental Organizations (NGOs) have received tremendous support with both financial and human resources for programs geared towards the conservation and management of these resources. Approximately 90 - 100% of most environmental NGOs' programs and supporting budgets are funded by international funds. Belize's recognition and acceptance by the international community also plays an important role when negotiating matters corresponding to other sectors. However, the adoption, implementation and compliance with these international agreements, commissions and policies have posed several challenges to Belize for instance:

i) *The Restriction and Prohibition of Traditional Fishing* — In 1996, Belize became party to the World Heritage Site Convention that resulted in the declaration of seven marine sites as world heritage sites (Appendix II). These seven sites include areas that were considered as important traditional fishing areas that fishermen are now either prohibited from fishing today or restricted with regards to the traditional fishing activities they once engaged in these areas. As a result the management of these areas have been met with great opposition and challenges. Fishermen in some areas such as the Blue Hole Natural Monument and the Half Moon Caye Natural Monument have been restricted from exploiting productive conch areas that have been fished traditionally by their last four generations. This prohibition or restriction has also led to the reduced access to certain species and thus traditional fisheries exploited by fishermen. Considering that fishing by different communities is usually area specific, some fishers restricted from fishing certain species from one area of the country will seldom move to another area to gain access to those species. Quite often, this is not an economically feasible option and is dependent on the type and scale of fishing activity traditionally engaged in by fishermen. In addition to this, fishermen have lost economic benefits from the sale of unique products derived from restricted species. Examples of these include but are not limited to jewelry and ornaments crafted from corals and the hawksbill turtle shell.

ii) *Cultural Implications* — In subscribing to agreements such as the Inter American Convention for the Protection and Conservation of Marine Sea Turtles and CITES, the commercial and subsistence fishing of marine sea turtles in Belize have been subjected to restrictive measures and, for the hawksbill turtle, totally prohibited. The hawksbill turtle and the other

marine sea turtle have been a resource traditionally fished by several of our local Belizean ethnic groups, such as the Garífuna (culture of whom was proclaimed a Heritage to Humanity by UNESCO 2001), the Mestizos and the Creoles. The meat of these turtles has traditionally been a part of these ethnic groups' diets, but now they must adjust to this change. In the case of the Garífuna people in Belize, marine sea turtle has played a role in traditional rituals and as a result has great cultural importance for this particular group.

iii) *Impact on Available Resources* — Resources required to enforce these policies and agreements have been tremendous, especially on the institutions and organizations that have the legal mandate over the environment and the marine resources in Belize. In order to continue the trade of economically important species, such as the queen conch, *Strombus gigas,* Belize is expected to update status assessments of its stocks and prove to CITES that the exploitation of this species is being done in a sustainable manner. However, for most third world countries like Belize that lack both the financial and technical capacity, assessments of this nature are usually difficult to realize. Government's budgetary allocations for the management of its natural resources that include vital components such as monitoring, enforcement, and research are decreasing on an annual basis. For developing countries like Belize, it is becoming more and more difficult for Government to support these activities when they are faced with more pressing environmental, social, and economic issues.

CONCLUSIONS

Thus far, the Belize Fishing Industry and associated cooperatives have been extremely flexible in adapting to past and present policies directly and indirectly related to the fisheries sector. However, with the effects of globalization there is concern regarding the industry's ability to further absorb and adapt to the direct, indirect, and potential impacts of this process. Increasing the vulnerability of the industry would compromise sustained economic growth of the sector. This could have serious repercussions on the social and economic status of the country of Belize. Such challenges to the fishing industry could also trigger the breakdown of infrastructure and institutional mechanisms already in place to facilitate the implementation of current and past policies and the management of marine resources. This in turn could tarnish Belize's reputation as an environmentally friendly nation in the international community and thus have negative implications on the sustainability of local efforts and programs.

The aforementioned need to be taken into consideration by developed countries when formulating policies and agreements that require substantial investments for their adoption and successful implementation by developing countries.

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Appendix I. Fisheries Production and Export Statistics (2000).

Commodity	Production	Production exported (lbs)	Export Value (BZE dollars)
Fin Fish	109,575.0	86,630.0	160,751.72
Fish Fillet	28,204.5		
Lobster Head Meat	50,837.0	26,670.0	201,125.0
Lobster Tail	555,254.0	646,120.0	18,563,505.0
Conch	513,469.0	526,450.0	4,858,240.0
Stone Crab Claws	8,671.0	3,995.0	63,920.0
Pink Sea Shrimp	99,285.0	33,900.0	372,900.0
White Farmed Shrimp	8,002,118.0	5,027,351.5	47,458,177.59
Squid	555.0	6,127.0	57,975.98
Others		10,226.0	93,487.73
Total	**9,367,768.5**	**6,351,116.5**	**$71,830,083.02**

Source: Belize Fisheries Department

Morphometrics and Management of the Caribbean Spiny Lobster, *Panulirus argus*

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ABSTRACT

The Caribbean spiny lobster, *Panulirus argus*, supports important fisheries throughout much of its range. As a result, spiny lobster stocks in most countries are almost or are already fully exploited. Spiny lobsters are one of the most studied animals in the Caribbean and fishery statistics are available from many countries, but there is no Caribbean-wide stock assessment. Effective management of this species requires that local scientific studies, national fishery statistics, and national fishery regulations be integrated into a regional fishery management policy. To that end, a comprehensive group of morphometric equations have been developed that will allow scientists, fishery managers, and law enforcement personnel from different countries to convert the various length and weight measurements. These equations are gender specific and allow conversions to be made between carapace length, tail length, total length, tail width, fresh and frozen tail weight, and fresh and frozen whole weight. The relationships between morphometric equations presented in other studies is also reviewed.

KEY WORDS: *Panulirus argus*, spiny lobster, morphometrics, minimum size limits

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INTRODUCTION

The Caribbean spiny lobster (*Panulirus argus* Latreille, 1804) is distributed throughout the Caribbean from Brazil to the United States and Bermuda. Spiny lobsters are fully exploited or over-exploited in much of this range (Cochrane and Chakalall 2001). The potential dependence of local populations on pan-Caribbean egg production requires that all countries exploiting this species develop management strategies that are consistent and promote sustainable yield (Lyons et al. 1981, Ehrhardt 1994). The purpose of this study was to develop a comprehensive group of morphometric equations to help scientists, fishery managers, and law-enforcement personnel from different countries interpret catch statistics and integrate international research in efforts to improve the management of the pan-Caribbean spiny lobster fishery.

Many countries with *P. argus* fisheries have compiled landings records and research results concerning their fishery. These databases contain valuable

information about *P. argus* in different areas and years, but the parameters measured in these databases often differ from those currently in use or are inconsistent from country to country. The morphometric equations developed in this study were designed to facilitate comparisons between historical databases and their modern equivalents. Our equations should also assist modern researchers with the exchange of size-related information, regardless of the exact parameters recorded.

These morphometric equations can be used to facilitate the enforcement of different size and measurement parameters from different government agencies or nations. At present, carapace length is the preferred standard measure to assess lobster size because of its ease of measuring and inflexibility. (Smith 1958, Simmons 1975, Soares and Cavalcantes 1984, Florida Administrative Code 2001). Carapace length is also unaffected by cooking the lobster (Ibbott et al. 2001). However, use of carapace length as an enforcement parameter requires that lobsters be maintained whole. If landing or shipping lobsters in a whole condition is impractical, direct measurement of the tail must be as accurate as possible to sustain the intent of management strategies. Tail length measurements are inherently more variable than carapace measurements because of the flexible joints between the abdominal somites and the variable curve of the tail.

In this study, we used morphometric equations and confidence limits in two ways. First, we used the equations to reexamine historical databases and explore the differences between the morphometric equations developed in several regional spiny lobster fisheries in the Caribbean. Second, we evaluated which tail dimension most accurately predicts carapace length. Using these equations, researchers and enforcement personnel should be able to more reliably interpret research findings and be able to determine if a harvested lobster conforms to a specific carapace size limit from an examination of the tail.

METHODS

We collected fifty intermolt lobsters of each sex for each 5-mm carapace-length (CL) size class between 50 and 100 mm. The majority of the lobsters were collected in the middle Florida Keys between June 1985 and July 1986. An additional 215 lobsters from the same location were collected and measured during December 1989 to complete the data set. Measurements were taken of carapace length, total length, tail length, and tail width. Weights were obtained for whole lobsters, tails only, and frozen tails. Weights were not determined for individuals with numerous missing appendages. All measurements were made to the nearest mm with Vernier calipers, and all weights were measured to the nearest 0.1 g using a triple beam balance.

The carapace (head, body, or front section) was measured from the anteriormost edge (front) of the groove between the supraorbital spines (horns) directly above the eyes, then along the middorsal line (middle of the back) to the rear edge of the dorsal part of the carapace, excluding any translucent membrane. The tail (segmented portion) was detached from the carapace, placed dorsal-side up, and measured lengthwise along the middorsal line (middle of the back) from the

anteriormost portion of the exoskeleton of the first abdominal somite to the farthest extension of the tail fan (telson or uropod, whichever was greater). These measurement criteria are consistent with Florida Administrative Code, Chapter 68B-24, Spiny Lobster (Crawfish) and Slipper Lobster. Total length was measured from the anterior edge of the carapace between the supraorbital spines to the farthest extension of the tail fan. This measurement was made by placing the lobster dorsal-side down on a measuring board, with the anterior margin of the carapace between the supraorbital spines held against a nail that delineated zero on the measuring board. Tail width was measured across the second abdominal somite immediately posterior to the spines on the abdominal segment. Measurements were made in a straight-line and did not incorporate the curve of the carapace or tail. After total weight and tail weight were determined, tails were individually bagged, frozen, and reweighed (with the bag removed) so that frozen weight could be determined.

The relationships between pairs of morphometric variables were determined by using type II least-squares regressions (SAS® 1988). Transition points in the morphometric relationships were determined by optimizing residuals (Lovett and Felder 1989). Significant differences in regression analyses were determined by analysis of covariance ($P < 0.05$) (Snedecor and Cochran 1989). To better support law enforcement applications and allow compatibility with historic databases, equations incorporating both sexes are reported regardless of any differences revealed by the analysis of covariance. Analysis of covariance was also used to compare equations developed for lobsters from different locations in the Florida Keys.

Total weight:carapace length and total length:carapace length regression lines were plotted to compare regression equations from different areas and to identify discrepancies in morphometric equations between different studies. Limited access to the raw data from many historic studies precludes more formal statistical analysis.

RESULTS AND DISCUSSION

Significant differences ($P < 0.05$) exist between sexes for most of the morphometric equations examined. The tail weight:tail length and tail weight:tail width relationships and their reciprocals, tail length:tail weight and tail width:tail weight relationships, are the only equations that did not have differences related to gender. Dimorphic growth for *P. argus* has been identified in all studies that had adequate sample sizes (for review, see Lyons et al. 1981). The gender-specific morphometric equations and the combined-sex equations (both genders included) for length:length comparisons are presented in Table 1. The length:weight equations and their reciprocals, the weight:length equations, for total and tail weight are given in Tables 2 and 3, and the length:frozen weight and frozen weight:length equations are given in Table 4. Tail weight:total weight equations and their reciprocals are given in Table 5. These tables were designed to present a large number of morphometric equations concisely and for all equations, except the male carapace

length-to-tail length equations for dimorphic growth, R^2 values are greater than 0.9334 and are not reported further.

Table 1. Length and width regression equations for *Panulirus argus* from Florida.

Variables[1]	Sex[2]	Regression Equation[3]
Carapace Length : Total Length	B	TTL=2.67*CL+13.30
	M	TTL=2.51*CL+22.19
	F	TTL=2.80*CL+6.32
Total Length : Carapace Length	B	CL=0.37*TTL-4.99
	M	CL=0.40*TTL-8.85
	F	CL=0.36*TTL-2.26
Tail Length : Total Length	B	TTL=1.56*TL-5.72
	M	TTL=1.57*TL-5.26
	F	TTL=1.57*TL-7.89
Total Length : Tail Length	B	TL=0.64*TTL+3.67
	M	TL=0.64*TTL+3.36
	F	TL=0.64*TTL+5.04
Tail Length : Carapace Length	B	CL=0.58*TL-7.13
	M	CL=0.62*TL-10.95
	F	CL=0.56*TL-5.07
	M<73mm	CL=0.58*TL-5.66
	M>73mm	CL=0.62*TL-9.48
Carapace Length : Tail Length	B	TL=1.71*CL+12.19
	M	TL=1.60*CL+17.52
	F	TL=1.79*CL+9.08
	M<73mm	TL=1.73*CL+9.79
	M>73mm	TL=1.62*CL+15.38
Carapace Length : Tail Width	B	TW=0.59*CL+2.66
	M	TW=0.54*CL+4.80
	F	TW=0.61*CL+1.66
Tail Width : Carapace Length	B	CL=1.71*TW-4.54
	M	CL=1.84*TW-8.85
	F	CL=1.63*TW-2.70

[1] All equations for male and females were significantly different ($P< 0.05$).
[2] B = both sexes included, M = male, F = female
[3] TTL= total length, CL= carapace length, TL = tail length, TW = tail width.

Table 2. Total-weight regression equations for *Panulirus argus* from Florida.

Variables[1]	Sex[2]	Regression Equation[3]
Carapace Length : Total Weight	B	$TTWT=0.001989*CL^{2.80327}$
	M	$TTWT=0.002229*CL^{2.77012}$
	F	$TTWT=0.001839*CL^{2.82810}$
Total Length : Total Weight B	T	$TWT=0.00003671*TTL^{3.00056}$
	M	$TTWT=0.00002080*TTL^{3.10922}$
	F	$TTWT=0.00005812*TTL^{2.91274}$
Tail Length : Total Weight	B	$TTWT=0.00008379*TL^{3.06710}$
	M	$TTWT=0.00005494*TL^{3.17957}$
	F	$TTWT=0.00001059*TL^{3.03328}$
Tail Width : Total Weight	B	$TTWT=0.003820*TTL^{2.97976}$
	M	$TTWT=0.002580*TTL^{3.09175}$
	F	$TTWT=0.004410*TTL^{2.93167}$
Total Weight : Carapace Length	B	$CL=9.1975*TTWT^{0.35673}$
	M	$CL=9.0640*TTWT^{0.36100}$
	F	$CL=9.2734*TTWT^{0.35358}$
Total Weight : Total Length	B	$TL=30.0684*TTWT^{0.33327}$
	M	$TL=32.0479*TTWT^{0.32162}$
	F	$TL=28.4571*TTWT^{0.34332}$
Total Weight : Tail Length	B	$TL=20.9218*TTWT^{0.32393}$
	M	$TL=21.8696*TTWT^{0.31451}$
	F	$TL=20.4409*TTWT^{0.32668}$
Total Weight : Tail Width	B	$TW=6.47799*TTWT^{0.33680}$
	M	$TW=6.85046*TTWT^{0.32344}$
	F	$TW=6.36063*TTWT^{0.34110}$

[1] All equations for male and females were significantly different ($P< 0.05$).
[2] B = both sexes included, M = male, F = female
[3] TTWT = total weight, TTL= total length, CL= carapace length, TL = tail length, TW = tail width.

Table 3. Tail-weight regression equations for *Panulirus argus* from Florida.

Variables[1]	Sex[2]	Regression Equation[3]
Carapace Length : Tail Weight	B	$TWT=0.0007762*CL^{2.76273}$
	M	$TWT=0.0011139*CL^{2.69606}$
	F	$TWT=0.0006205*CL^{2.82755}$
Total Length : Tail Weight	B	$TWT=0.00001518*TTL^{2.95717}$
	M	$TWT=0.00001239*TTL^{2.99242}$
	F	$TWT=0.00001962*TTL^{2.91217}$
Tail Length : Tail Weight^{ns}	B	$TWT=0.00003424*TL^{3.04245}$
	M	$TWT=0.00003154*TL^{3.05013}$
	F	$TWT=0.00003575*TL^{3.03269}$
Tail Width : Tail Weight^{ns}	B	$TWT=0.001434*TTL^{2.94439}$
	M	$TWT=0.001298*TTL^{2.97468}$
	F	$TWT=0.001438*TTL^{2.93983}$
Tail Weight : Carapace Length	B	$CL=13.3570*TWT^{0.36196}$
	M	$CL=12.8153*TWT^{0.37509}$
	F	$CL=13.6238*TWT^{0.35366}$
Tail Weight : Total Length	B	$TL=42.6089*TWT^{0.33818}$
	M	$TL=43.6335*TWT^{0.33418}$
	F	$TL=41.3428*TWT^{0.34339}$
Tail Weight : Tail Length^{ns}	B	$TL=29.3589*TWT^{0.32868}$
	M	$TL=29.5720*TWT^{0.32678}$
	F	$TL=29.2590*TWT^{0.32974}$
Tail Weight : Tail Width^{ns}	B	$TW=9.2404*TWT^{0.33983}$
	M	$TW=9.3409*TWT^{0.33817}$
	F	$TW=9.2642*TWT^{0.34016}$

[1] All equations for male and females were significantly different ($P< 0.05$) unless indicated by ^{ns}.
[2] B = both sexes included, M = male, F = female
[3] TWT = tail weight, TTL= total length, CL= carapace length, TL = tail length, TW = tail width.

Table 4. Frozen-tail-weight regression equations for *Panulirus argus* from Florida.

Variables[1]	Sex[2]	Regression Equation[3]
Carapace Length : Frozen Tail Weight	B	$FWT=0.001948*CL^{2.5474}$
	M	$FWT=0.001780*CL^{2.5555}$
	F	$FWT=0.001095*CL^{2.6037}$
Total Length : Frozen Tail Weight	B	$FWT=0.0000430*TTL^{2.7622}$
	M	$FWT=0.0000330*TTL^{2.8091}$
	F	$FWT=0.0000520*TTL^{2.7270}$
Tail Length : Frozen Tail Weight^{ns}	B	$FWT=0.0000670*TL^{2.9052}$
	M	$FWT=0.0000625*TL^{2.9199}$
	F	$FWT=0.0000690*TL^{2.8877}$
Tail Width : Frozen Tail Weight^{ns}	B	$FWT=0.002268*TTL^{2.8258}$
	M	$FWT=0.002307*TTL^{2.8259}$
	F	$FWT=0.002208*TTL^{2.8285}$
Frozen Tail Weight : Carapace Length	B	$CL=12.9574*FWT^{0.36951}$
	M	$CL=12.7389*FWT^{0.37765}$
	F	$CL=13.7272*FWT^{0.35283}$
Frozen Tail Weight : Total Length	B	$TL=42.6751*FWT^{0.33662}$
	M	$TL=42.7389*FWT^{0.33917}$
	F	$TL=42.9267*FWT^{0.33653}$
Frozen Tail Weight : Tail Length^{ns}	B	$TL=30.4160*FWT^{0.32456}$
	M	$TL=29.9693*FWT^{0.32505}$
	F	$TL=30.1141*FWT^{0.32407}$
Frozen Tail Weight : Tail Width^{ns}	B	$TW=8.62522*FWT^{0.35388}$
	M	$TW=8.57275*FWT^{0.35383}$
	F	$TW=8.68980*FWT^{0.35355}$

[1]All equations for male and females were significantly different ($P< 0.05$) unless indicated by ^{ns}.
[2]B = both sexes included, M = male, F = female
[3]FWT = frozen tail weight, TTL= total length, CL = carapace length, TL = tail length, TW = tail width.

Table 5. Weight:weight regression equations for *Panulirus argus* from Florida.

Variables[1]	Sex[2]	Regression Equation[3]
Tail Weight : Total Weight	B	TTWT=3.07*TWT-1.13
	M	TTWT=3.31*TWT-17.37
	F	TTWT=2.90*TWT-2.71
Total Weight : Tail Weight	B	TWT=0.32*TTWT+3.86
	M	TWT=0.29*TTWT+7.61
	F	TWT=0.33*TTWT+1.76

[1]All equations for male and females were significantly different ($P < 0.05$) unless indicated by ^{ns}.
[2]B = both sexes included, M = male, F = female
[3]TW = tail weight, TTWT= total weight.

Sexual dimorphism is a common phenomenon among crustacea (Gray 1929, for review, see Hartnoll 1982). For *P. argus*, the greater length and girth of the male carapace are the primarily responsible for the differences in the male and female morphometric equations. The male carapace increases in length disproportionately with increasing total size. A distinct transition point is apparent in the carapace length:tail length equation. Males greater than 73 mm CL have a disproportionately larger carapace than do smaller males and all females (Figure 1).

Allometric growth is often associated with sexual maturity in crustaceans (Teissier 1960, Wenner et al. 1974, Hartnoll 1982). Some authors have suggested suggest that female *P. argus* have positive allometric tail growth (Khandker 1963, Munro 1983), presumably to facilitate egg bearing. Results from our study indicate that female tail length does not increase in disproportion to increased carapace length (Figure 1). Increased carapace growth for male lobsters larger than 73-mm CL may be indicative of the onset of sexual maturation. This transition point in males does not indicate that females also mature at this size nor does it imply that males can successfully mate at this size. The 73 mm CL maturation estimate for male lobsters in this study is one of the smallest reported for this species. Additional research that uses direct observations of gonadal development and addresses the potential growth inhibition from both Florida's more temperate climate than other Caribbean locations and the periodic confinement of 15% of sublegal-sized lobsters in traps should be conducted to better determine male reproductive maturity.

Male mating success may depend on behavioral and size constraints that do not develop until after reproductive maturity. The evidence for behavioral or size constraints delaying reproductive activity was supported by Hunt and Lyons' (1986) observation that molt increments do not decrease in male lobsters until after 85 mm CL. The decreased growth rate might indicate a shift in energy use corresponding to the onset of reproductive activity. There is also no difference in male allometric

growth between Florida Bay and the Atlantic Ocean lobsters (P>0.05), but Florida Bay has a very low occurrence of female lobsters with spermatophores or eggs and is not considered to be an area used for lobster reproduction. This lack of reproductive activity among lobsters with secondary sexual characteristics in Florida Bay indicates that other factors influence reproductive success in male lobsters.

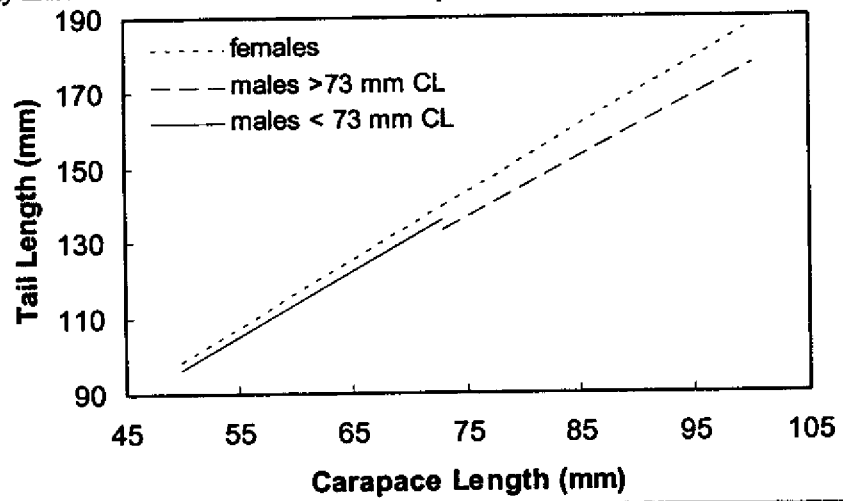


Figure 1. Regression of tail length on carapace length for male and female *Panulirus argus* from Florida. Location of transition point for males (73 mm CL) was selected to maximize randomness of combined residuals. No transition point was apparent for females.

Haughton and Shaul (1989) reported that in Jamaica, there are allometric growth differences in male *P. argus* carapace length:telson length equations at 69 mm CL. The presence of this transition point in Jamaica adult lobster population suggests that similar growth and maturation pressures exist in both Jamaica and the Florida Keys. The 4 mm difference between the two transition-point estimates may be due to Haughton and Shaul's (1989) use of telson length and our use of tail length.

Detailed analysis of morphological differences between the sexes can lead to a better understanding of the ecology and behavior of many animals. For a commercially important species like *P. argus*, morphometric differences have a more practical use. The variation in size between males and females may cause a disproportionate number of one sex to be harvested in fisheries where size limits are the principal management tool (Cobo de Barany et al. 1972, Simpso 1976). Disproportionately high numbers of males are captured in most *P. argus* fisheries, and the male-to-female sex-ratio in the landings may be as high as 1.5 to 1 (Creaser 1952, Buesa Mas 1965, Simpson 1976, Lyons et al. 1981, Munro 1983). The impact of harvesting up to 50% more males than females could affect egg production by limiting the sperm availability (MacDiarmid and Butler 1999).

POPULATION COMPARISONS

Comparison of weight:length morphometric equations from throughout the Caribbean do not indicate population level differences among spiny lobsters from different areas in the Caribbean. Visual comparisons of the weight:length morphometric equations from different areas (Table 6) revealed no weight-to-length differences throughout the range of this species with the exception of Olsen and Koblic's (1975) weight:length equation from St. John. However, Olsen and Koblic's (1975) equation (Table 6) does closely resemble the equation representing female lobster in Columbia (Squires and Riveros 1978). No satisfactory explanation is apparent to explain the discrepancy in Olsen and Koblic's (1975) findings, but their reported lack of any difference between weight:length morphometric equations for male and female may have been caused by unequal number of male and female lobsters and larger male lobsters in their sample. Olsen and Koblic (1975) indicate that in some locations males comprised 75% of the population and males averaged 20 mm CL larger than females. The flatter slope of the lines generated from equations that combined both sexes was caused by the disproportionate number of large males in those samples. Farrugio's (1975) data from Martinique included 1.5 times more males than females (22 and 14 respectively) greater than 100 mm CL. While Correa (1987) did not combine his male and female equations, he did have 2.3 times more males than females (496 and 214 respectively) greater than 115-mm CL. Correa's (1987) range of samples of large female lobsters greatly exceeded the range observed in Florida and may have contributed to the relative flatter slope for the equation he reported. The abundance of large males in these data sets used to create combined sex equations introduced a bias into the equations that was avoided in the Florida equations by sampling equal numbers of male and female lobsters in each size class.

Comparison of length:length morphometric equations from throughout the Caribbean also do not indicate population level differences among spiny lobsters from different areas. A visual comparison (Figures 2 and 3) of the carapace length:total length equations (Table 7) reveals two things of note:

i) Total lengths for lobsters from Cuba are larger than those of lobsters with similar carapace lengths from other locations and,

ii) The regression line for female lobsters from Cuba has a higher slope. The differences in both Cruz et al.'s (1981) equations seems to originate from the same source.

Cruz et al. (1980) defined total length to include the portion of the carapace that extends forward of the eyes to the base of the antennuals. The carapace length discrepancy between Cuban measurements and measurements from other locations is more pronounced in larger lobsters and results in a greater slope in the Cuban carapace length:total length regression equation for female lobsters (Figure 3). Among male lobsters, the measurement difference between the Cuban and Florida regression equations decreases with increased male size. (Figure 2). The dimorphic growth of the male carapace apparently obscures the relative size of the carapace length measurement discrepancy apparent in equations for male lobsters.

Table 6. Survey of length:weight relationships for *Panulirus argus*. All units were reported in mm or g. Relationships not expressed in equation format were either graphs or examples for specific size classes.

Location	Sex[1]	Relationship[2]	Reference
Jamaica	B	$TTWT=0.00271*CL^{2.738}$	Munro 1983
Florida	B	$TTWT=0.00422*CL^{2.64091}$	Lyons *et al.* 1981
	M	$TTWT=0.00315*CL^{2.69934}$	
	F	$TTWT=0.00361*CL^{2.68379}$	
Jamaica	M	$TTWT=0.00316*CL^{2.71}$	Haughton and King unpbl.
	F	$TTWT=0.00499*CL^{2.62}$	
St. John	B	$TTWT=0.0021*CL^{2.778}$	Olsen and Koblic 1975 Martinique
	M	$TTWT=0.0023*CL^{2.77}$	Clairouin 1980
	F	$TTWT=0.0021*CL^{2.80}$	
Venezuela	M	$TTWT=1.45143*CL^{2.694114}$	Cobo de Barany *et al.* 1972
	F	$TTWT=1.5749*CL^{2.66933}$	
Colombia	M	$TTWT=0.00516*CL^{2.578}$	Squires and Riveros 1978
	F	$TTWT=0.00221*CL^{2.7921}$	
Belize	B	$TWT=0.0012*CL^{2.689}$	Wade *et al.* 1999
Brazil	M	$TTWT=0.0000514*TTL^{2.966}$	de Amorim Borges 1964
	F	$TTWT=0.0000865*TTL^{2.859}$	
Martinique	B	$TTWT=0.000203*TTL^{2.707}$	Farrugio 1975
	M	$TTWT=0.0002339*TTL^{2.687}$	
	F	$TTWT=0.000168*TTL^{2.733}$	
St. Kitts	M	$TTWT=0.0000347*TTL^{3.04}$	Reid 1989
	F	$TTWT=0.0000275*TTL^{2.65}$	
Venezuela	M/F	TTWT:CL	Khandker 1963
Panama	B	TTWT:CL and TTWT:TTL	Butler and Pease 1965
Florida and Bahamas	B	TTWT:CL and TTWT:TTL	Smith 1948
Florida	M/F	TTWT:CL	Smith 1958
Bermuda	M/F	TTL:TTWT	Creaser 1952
Florida	B	TTL:TTWT	Dawson and Idyll 1951
Puerto Rico	B	TTWT:CL	Feliciano 1958
Bahamas	M/F	TTWT:CL	Simpson 1976
San Andrés	M/F	TTL:TTWT	Sanchez-Aponte and Sanchez 1985
Florida	M/F	TTWT:TTL	Schroeder 1924
Belize	M/F	TWT:TTL and TWT:CL	Weber 1968

[1]B=both sexes included, M=males, F=females
[2]CL=carapace length, TWT= tail weight, TL = tail length, TTL = total length, TTWT = total weight

Table 7. Survey of length:length relationships for *Panulirus argus*. All units were reported in mm. Citations are presented for references presenting morphometric data that lacked specific equations.

Location	Sex[1]	Relationship[2]	Reference
Martinique	M	$TTL=4.00*CL^{0.97}$	Clairouin 1980
	F	$TTL=3.25*CL^{0.97}$	
Colombia	M	TTL=2.34*CL+47.9	Squires and Riveros 1978
	F	TTL=2.40*CL+39.4	
Cuba	B	TTL=2.5402*CL+36.35	Cruz et al. 1981
	M	TTL=2.5197*CL+32.84	
	F	TTL=2.9290*CL+9.87	
San Andrés	M	TTL=2.19*CL+2.23	Sanchez-Aponte and
	F	TTL=2.49*CL-0.20	Sanchez 1985
St. Kitts	M	TTL=2.28*CL+38.3	Reid 1989
	F	TTL=2.19*CL+4.40	
Providencia	M	TTL=2.520*CL+23.39	Correa 1987
	F	TTL=2.208*CL+39.35	
Antigua	M	TTL=2.61*CL	Peacock 1974
	F	TTL=2.91*CL	
Brazil	M	ln(TTL)=0.86*ln(CL)+1.61	Soares and
	F	ln(TTL)=0.94*ln(CL)+1.29	Cavalcantes 1984
Brazil	M	CL=0.423*TTL-9.32	de Amorim Borges 1964
	F	CL=0.366*TTL-1.255	
Martinique	B	CL=0.415*TTL-9.977	Farrugio 1975
	M	CL=0.405*TTL-10.989	
	F	CL=0.413*TTL-11.000	
Jamaica	M	CL=2.44*TSL-23.27	Haughton and Shaul 1989
	F	CL=1.62*TSL+4.01	
Venezuela	M	TTL=2.708*CL+3.8	Cobo de Barany et al. 1972
	F	TTL=2.969*CL+3.6	
Venezuela	M	CL=0.32(TTL-22.2)+7.7	Khandker 1963
	F	CL=0.29(TTL-21.4)+7.1	
Bermuda	M/F	CL:TL and TTL:CL	Creaser 1952
Florida	B	TL:TTL	Dawson and Idyll 1951
Puerto Rico	B	TTL:CL	Feliciano 1958
Pan Carib.	M/F	TTL:CL	Smith 1958
Belize	B/M/F	TL:CL (multiple equations)	Wade et al. 1999

[1]B=both sexes included, M=males, F=females
[2]CL=carapace length, TL = tail length, TTL = total length, TSL = telson length

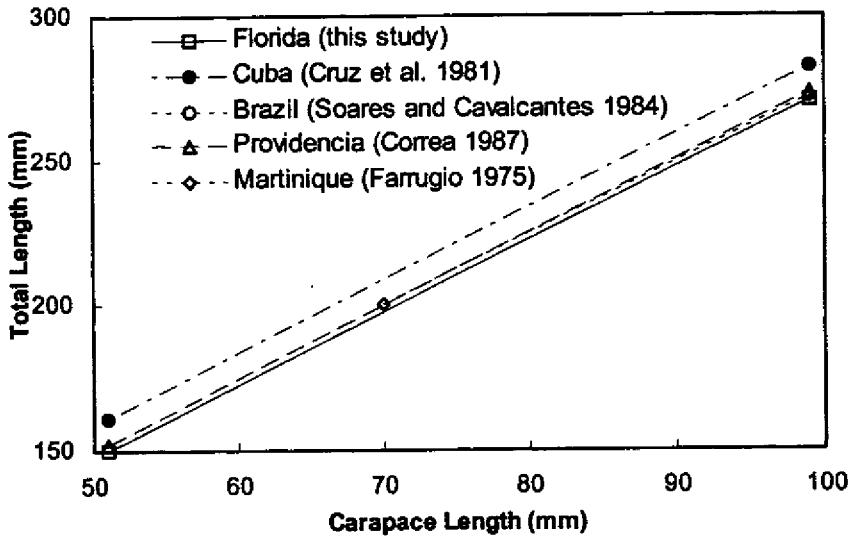


Figure 2. Comparison of regressions of total length on carapace length for male *Panulirus argus* in select locations. Regressions for Florida, Brazil, Providencia, and Martinique are indistinguishable between 70 and 100-mm CL, emphasizing the consistency of many of the morphometric equations from different locations.

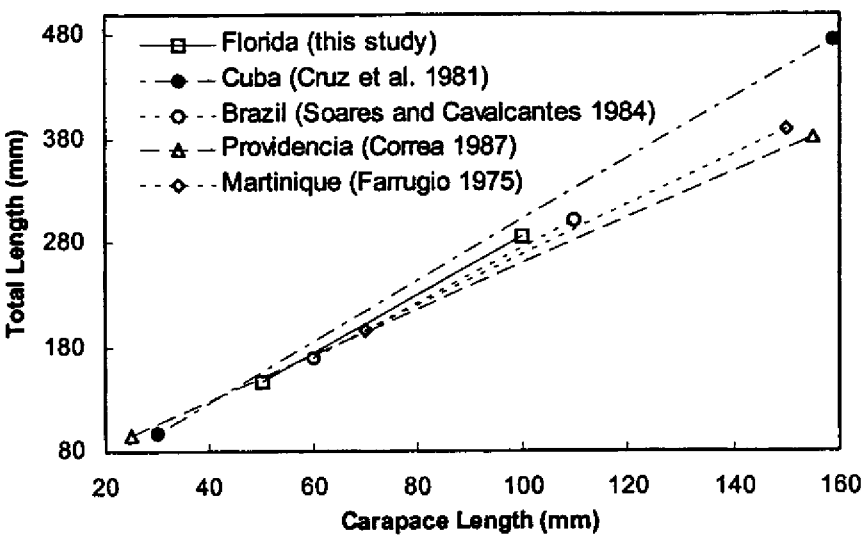


Figure 3. Comparison of regressions of total length on carapace length for female *Panulirus argus* in selected locations.

Several equations reported in Table 7 are not included in the visual comparison (Figures 2 and 3) because of small sample sizes or incomplete methodological explanations in the original paper. Of these, the total length:carapace length regression line for female lobsters in Venezuela has a slope similar to the regression line for Cuban females (Cobo de Barany et al. 1972), and Sanchez-Aponte and Sanchez (1985) reported a line with a slope similar to but with an intercept 20 mm lower than other estimates. The methods used by Cobo de Barany et al. (1972) and Sanchez-Aponte and Sanchez (1985) to measure length is not clearly defined, but may more closely follow the methods described by Cruz (1981) and account for the reported differences in the morphometric equations developed in from those studies (Cruz pers. comm.).

Recent mitochondrial DNA evidence supports a hypothesized pan-Caribbean population, with the possible exception of a Brazilian subspecies (Silberman et al. 1994, Sarver et al, 1998). The similarity of total weight:carapace length equations throughout the range of *P. argus* could also be considered circumstantial evidence for a single Caribbean-wide population. At least, similar morphometric relationships suggest that similar environmental forces are acting on *P. argus* throughout its range. The deviation of Cruz's (1980) total length:carapace length regressions from regressions from other areas (Figures 2 and 3) appears to be related to the method he used to measure total length, but the possibility that a semi-isolated population of lobsters in Gulf of Batabano requires more direct examination (Cruz pers. comm.). The slope differences in the female total length:carapace length regressions (Figure 3) may be artifacts of specific studies and do not have a consistent trend correlated with latitudinal or physical oceanographic features. Unfortunately, without the original measurements used to create the equations that produced the regression lines, it is impossible to determine whether these slopes are significantly different.

ENFORCEMENT CRITERIA

The state of Florida requires that harvested lobsters have a carapace length greater than 3 inches (76.2 mm) or that the tail length be greater than 5.5 inches (139.7 mm) once separated from the carapace (Florida Administrative Code 2001). Florida Fish and Wildlife Conservation Commission officers currently use a gauge to determine the length of the carapace and tail. The gauge is used to obtain a straight-line measure that does not account for the curvature of the exoskeleton. This measuring technique is consistent with the methods used in this study. Results from our study indicate that a 76 mm CL lobster will have a 142 mm (5.59 inches) tail length using the general CL to tail length equation that does not consider the gender of the lobster. Using this equation, fewer than 5% of lobsters with a CL of 76 mm would have a tail length less than 139 mm (5.47 inches), which conforms to the tail length size limit as currently enacted.

Problems commonly occur with the enforcement of different size limits for *P. argus* because size limits may vary from country to country. Enforcement personnel

are often required to determine whether a lobster tail, which is removed from the carapace, conforms to a specific legal standard. A conservative way to resolve this problem is to use 95% confidence limits to define the smallest CL that would represent more than 95% of the tails of a specified length. Determination of the lower bound of the 95% confidence interval for the CL from a specified tail length is calculated using the equation :

carapace length = (0.566 * tail length) - 6.52

Because the carapace of the lobster is often discarded during processing, there is considerable interest in determining the most appropriate and reliable method to measure lobster size using only the tail. Tail length measurements are not as precise as carapace measurements because the tail is jointed and flexible. In the *Panulirus marginatus* fishery in Hawaii, tail width was a better indicator of CL than tail length (Uchida et al. 1980). In our study, tail length is slightly more accurate as an estimator of carapace length than is tail width, despite the relative inflexibility of the tail somite. Seventy-six-mm CL lobsters are expected to have a tail width of 48 mm. Ninety-five percent confidence limits suggest that a tail width of 46 mm is expected to occur in 5% of tails removed from 76-mm CL lobsters. A 46 mm tail width corresponds to a 72 mm CL lobster and a 139 mm tail length corresponds with a 73 mm CL lobster. However, tail width may be less susceptible to measurement error because of possible confusion when using a straight-line or curve-of-the-tail measurement method. Adoption of tail width as a measurement standard is also an attractive alternative to the tail-length standard because to accurately determine tail length, the lobster must be sacrificed and the tail removed from the carapace. Tail width, on the other hand, can be measured while the lobster is alive, allowing the release of undersized individuals. Tail width as the criteria for a minimum size regulation offers the advantage of being a single measurement that is applicable when the lobster is in both whole condition and once the tail has been separated from the carapace. A single measurement criteria, like tail width, would eliminate the somewhat complicated application of regression equations and 95% confidence limits required to ascertain if a lobster tail once removed from the carapace conforms to a minimum legal carapace size. Regrettably, measuring tail width is more difficult than measuring carapace length; particularly on live lobsters, because of the rapid and forceful contractions of the tail during handling. Ultimately, the determination of which measurement criteria is better for a specific area may depend on the experience of the lobster fishermen and the proportion of the fishery that land tails separated from the carapace.

ACKNOWLEDGMENTS

We wish to thank D. Eaken, W. Teehan, J. Quinn, and J. Leiby for their editorial comments. The need to review the impact that morphometric equations have on the interpretation of biological criteria and on the management of *P. argus* was initially described in Lyons et al. (1981), and we gratefully acknowledge Bill's contributions in this field.

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Management of Tunas and Tuna-Like Species in CARICOM Countries: Recent Trends Urge a New Perspective and Approach

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ABSTRACT

Fisheries for large pelagic resources are important to Caribbean Community (CARICOM) countries. Many countries have been expanding these fisheries, and others have expressed the intention to do so. The management of tunas and tuna-like species in the Atlantic Ocean is the mandate of the International Commission for the Conservation of Atlantic Tunas (ICCAT). Several of these resources are fully or overexploited, with most of the catch being taken by large fishing nations of the Atlantic and distant water fleets.

There is an urgent need for CARICOM countries to ensure that they will get a fair long-term share of the sustainable yield of large pelagic resources in the Atlantic Ocean. ICCAT has recently re-examined the criteria and is attempting to improve the process for allocating these resources among countries that fish in the Atlantic. CARICOM countries, many of them small island developing States (SIDS), have reached a common position that differs in several important respects from the position of the larger industrialized fishing nations. The principles underlying these positions depend on interpretations of clauses in the relevant UN Agreements that pertain to the treatment of new participants in these fisheries, the provisions for developing states, and the capacity for responsible management, as well as other factors.

Also at issue is the management of stocks of small tuna and tuna-like species such as wahoo, *Scomberomorus* species and blackfin tuna, which are less widely distributed than the large tuna and billfish species. ICCAT monitors catch trends for most of these small tuna species, but their management is best handled by the appropriate regional or sub-regional arrangement. CARICOM countries are in the initial stages of exploring options for managing those pelagic species within their jurisdiction.

KEY WORDS: Tuna fisheries, ICCAT, CARICOM

INTRODUCTION

Most CARICOM countries are categorized as small island developing States (SIDS), and have a close association with and dependence upon the sea. In most states, especially within the Eastern Caribbean, large pelagic fishes have historically supported important small-scale and artisanal fisheries. Significant recreational and sport fisheries are an important component of tourism-based economies.

With extended jurisdiction, and as a part of ongoing economic development, many CARICOM countries have begun to expand their offshore fishing capacity for large pelagic fishes, or have expressed the intention of doing so. These species are distributed across several EEZs (shared stocks) and in most cases extend into the High Seas (straddling stocks). Several species occur throughout the Atlantic and are fished by fleets from many nations, including distant water fleets.

Over the period of record, 1950 to the present, there has been steady growth in the fishing effort and catches of these species from the stocks that are shared by CARICOM countries. The vast majority of the landings are taken by fishing fleets from the larger, developed countries. As a result of poor management, many of the major stocks are now either fully exploited or overexploited.

Adherence to the relevant articles of the United Nations Convention on the Law of the Sea (UNCLOS) (United Nations 1983) and related international agreements[1] require countries to fish responsibly, and so avoid excess fishing capacity and overexploitation of the stocks concerned (Ruckes 1996, Doulman 1997). To acquire their fair share of the sustainable yield while ensuring that they do not contravene the agreements, CARICOM countries need to put in place the management measures obligated by these agreements and to take part in negotiations with other fishing nations to determine how the resources can be allocated.

In this paper we provide a view of the current situation regarding large pelagic fisheries in CARICOM countries, as well as recent developments and trends in regional and international management approaches applied to Atlantic tuna and tuna-like fisheries, including issues concerning the application of catch allocation criteria. Given these recent developments, we outline an approach for fulfilling the needs of developing large pelagic fisheries in CARICOM countries, including obtaining a fair share of these resources and ensuring compliance with the pertinent international fisheries agreements.

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[1] Such as the UN Agreement on Highly Migratory Stocks and Straddling Stocks (hereafter referred to as the UN Fish Stocks Agreement) (United Nations, 1995), the FAO Code of Conduct on Responsible Fishing (FAO, 1995), and the Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas (FAO, 1997).

CARICOM FISHERIES FOR LARGE PELAGICS

The species of large pelagic fishes caught by CARICOM countries are generally considered in two categories (SEFSC 1994): oceanic and coastal (see Mahon 1996 for a list of the species in these groupings). The oceanic species tend to be distributed offshore, and have wider geographical distributions. The coastal species tend to occur on or near continental/island shelves. While the oceanic species may hold the greatest potential for expansion of fisheries, it is the coastal species that provide most of the present yield, in particular dolphinfish (Mahon 1996, Mahon 1999).

Fisheries for large pelagic species have been integral components of small-scale fisheries in most CARICOM countries for as long as records have been kept (Mahon 1996). Despite limited access to resources and technology, Eastern Caribbean CARICOM countries have been gradually upgrading their small-scale fishing fleets for over two decades. This has included the adaptation of local vessels for longlining, and the addition of small purpose built longliners ranging from 10 to 20 metres in length (Mahon and Singh-Renton 1993, Mahon 1996). Other CARICOM countries have begun to consider the feasibility of expanding their fisheries for large pelagics (e.g. Mahon 1995). Although there has been slow but steady growth in fishing capacity in several CARICOM countries, few have expressed their development plans in quantitative terms.

MANAGEMENT OF ATLANTIC TUNA AND TUNA-LIKE SPECIES

Oceanic Species

Given the highly migratory habits and ocean-wide distributions of many of the large pelagic species, realistic assessment and management of the stocks concerned can be achieved effectively only through internationally coordinated efforts, as specified by the UN Fish Stocks Agreement (United Nations 1995). For about 30 species of tuna and tuna-like fishes occurring in the Atlantic Ocean and adjacent seas, including the Caribbean Sea, the required international coordination is effected through the activities of the International Commission for the Conservation of Atlantic Tunas (ICCAT).

ICCAT coordinates the collection of fisheries statistics among the harvesting countries and maintains a centralized database for use in stock assessments, which are updated periodically. ICCAT also coordinates relevant biological, ecological, and environmental research. Through consultations of its committees, sub-committees, and working groups, ICCAT proposes, adopts and coordinates the implementation of stock management measures, as required and appropriate.

Coastal Species

The stocks of coastal species are probably less widely distributed. These coastal species also come under the auspices of ICCAT, but have received little attention so

far, owing to the present emphasis on oceanic species and also to the lack of adequate data for quantitative assessments. For those coastal stocks shared primarily among the countries of the wider Caribbean, greater coordination of their assessment and management may be possible under certain regional arrangements.

The CARICOM Fisheries Resource Assessment and Management Program (CFRAMP), involving 12 Caribbean countries, commenced in 1991. CFRAMP conducted, as well as supported, several activities including institutional strengthening, human resource development, and research, all aimed at improving statistics, assessment and management of fisheries throughout the CARICOM region.

A focal activity of CFRAMP has been the establishment of the Caribbean Regional Fisheries Mechanism (CRFM), which will have legal status. The purpose of the CRFM is to sustain and build on CFRAMP. Membership of the CRFM will be open to CARICOM, as well as non-CARICOM countries in the region. In this way, the CRFM can provide a forum for promoting regional coordination and collaboration in the management of shared marine resources, both at the technical/scientific and political levels.

The Western Central Atlantic Commission (WECAFC), in existence since 1976, addresses fisheries development and management within Latin America and the Caribbean. In recent years, WECAFC has established *ad hoc* working groups that provide opportunities for collaboration on the assessment and management of certain shared resources, e.g. shrimp, groundfish, and flyingfish. This role may expand to other species.

CARICOM Participation In ICCAT

CARICOM has participated in selected ICCAT activities as an observer since 1991. During the 1990s, there have been significant changes in large pelagic fishing operations within the Atlantic Ocean that have led to marked increases in catches. In particular, the large-scale use of artificial floating objects by tropical purse seine vessels since 1991, as well as the introduction of bird radar, sonar, and satellite imagery, have increased fishing efficiency in the relevant tropical tuna fisheries. New fishing strategies have also developed. The extensive use of artificial floating objects has increased the numbers of young fish caught, with the largest impact felt by the bigeye tuna stock, and to a lesser extent, yellowfin tuna. Recent ICCAT stock assessments show clear evidence of over-exploitation of several major Atlantic tuna stocks.

Over-capitalization, as well as ineffective and inadequate ICCAT management measures, has been more important in causing the over-exploitation of important Atlantic tuna stocks such as bluefin tuna, and swordfish. For those stocks thought to be at levels below that of Maximum Sustainable Yield (MSY), annual total allowable catch limits (TACs) are applied. The Total Allowable Catch (TAC) is usually allocated among the interested ICCAT Contracting Parties. Within the Atlantic Ocean, TACs are already in place for bluefin tuna, swordfish (except

Mediterranean swordfish), northern albacore, and southern albacore. An overall general catch limitation recommendation is also currently in effect for bigeye tuna.

ICCAT is expected to apply TACs more often in the future to achieve better co-ordinated management, and to rely increasingly on species statistical document programs (e.g. ICCAT 2001a) to compare reported catches with trade statistics. In view of many of these developments at ICCAT, coupled with the need to defend their fisheries interests, two CARICOM Member States, Trinidad and Tobago and Barbados, recently became full members of ICCAT.

Allocating Shared Resources

Allocation of shared resources among users has been an issue for many decades. Even before UNCLOS, international commissions such as ICNAF (later NAFO) grappled with this problem. In light of UNCLOS, Gulland (1981) and Caddy (1982) outlined the process of negotiating allocations of fishery resources, including the variety of criteria that could be applied.

ICCAT practice has been to allocate catch quotas based solely on historical catches. Certain ICCAT member countries have sought to review current catch allocation criteria, in order to recognize the needs of developing fisheries, developing states, and the sovereign rights of coastal states. In 1998, ICCAT established an Ad Hoc Working Group on Allocation Criteria, to analyse and recommend catch allocation criteria. During 1999, three ICCAT members, the European Union (EU), the USA, and Brazil proposed sets of criteria, with other countries subsequently contributing additions and modifications. Together, CARICOM countries reviewed the catch allocation criteria proposed by the three ICCAT Members and a position paper that was submitted by Trinidad and Tobago to the ICCAT Working Group in May 2001 (ICCAT 2001b). The ICCAT Working Group concluded its discussions during a fourth meeting held in November 2001.

The identification of Parties, eligible to participate in catch allocation negotiations, should rely on simple qualifying criteria, which take into account access rights. For any particular sea area, therefore, coastal states rights should naturally be given at least equal status to those of high seas distant water fleets, as prescribed by the relevant international agreements (United Nations 1983).

In its recently completed review of qualifying criteria (ICCAT 2001c), ICCAT has agreed to include cooperating non-member countries of ICCAT, in addition to ICCAT member countries, as qualifying participants in its catch allocation negotiations. ICCAT has also included another qualifying criterion that deals with the ability to conduct responsible fishing and scientific research.

Catch Allocation Criteria

Gulland (1981) and Caddy (1982) presented criteria that could be used in quota allocations of shared resources, e.g., historical catches, occurrence of spawning and nursery areas, occurrence of migration routes that may make certain areas more suitable for fishing than others, and socio-economic criteria such as investment in the

fishery and the influence on employment. These and other more recent criteria can be broadly grouped as 'biological/conservation criteria', and 'socio-economic criteria'. With the increased awareness of the impact of fishing on fishery resources, and the development of the international agreements for conservation and management, a third category, 'responsibility criteria' has emerged.

ICCAT's recent review of catch allocation criteria (ICCAT 2001c) has grouped them into the following categories:

i.) Status of the stocks and the fisheries concerned;

ii.) Past/present fishing activity of qualifying participants;

iii.) Status of the qualifying participants; and

iv.) Contribution to compliance, data submission, and scientific research.

Category (i.) includes the biological and conservation criteria, categories (ii) and (iii) address social and economic concerns, and category (iv) covers responsibility criteria.

Biological/conservation Criteria

Several criteria can be considered in this category, including the status of the stock concerned, occurrence of critical habitats such as spawning and nursery areas, the distribution of stock biomass in a country's EEZ (Caddy 1982, 1987), and availability of suitable fishing areas. ICCAT intends to address biological and conservation issues using the following two criteria.

Status of the Stock and Existing Level of Fishing Effort — This criterion is taken from the UN Fish Stocks Agreement, and addresses access to the fishery by new participants. The same Agreement also provides for forms of cooperation with developing states, to facilitate their access to, and participation in high seas fisheries. Certain nations argue that additional access to the fishery cannot be allowed when stocks are overexploited or are being rebuilt. In these instances, accommodation of new entrants, particularly those of developing states, would have to be facilitated by a redistribution of existing TACs.

Distribution and Biological Characteristics of the Stock Including the Occurrence of the Stock in Areas under National Jurisdiction and on the High Seas — This criterion should include the consideration of critical habitats, as well as the availability of suitable fishing areas. Coastal and island states should be able to exercise their right to sustainably exploit resources within their claimed EEZs. The proportion of the biomass of a stock that occurs in the EEZ of a country can be the basis for a claim for an allocation. This can be a complex issue if migratory routes and time spent in an EEZ during migration are taken into consideration. Caddy (1982, 1987) has developed models for various types of sharing based on migration. A quantitative index could incorporate the size of the EEZ and the average known catch rate in it.

Socio-economic Criteria (Or Criteria Relating to Past/present Fishing Activity and the Status of Qualifying Participants)

These criteria attempt to reflect the value that a country places on the resource (Gulland 1981). Interestingly, the recent review by ICCAT splits socio-economic criteria into two categories: criteria relating to past/present fishing activity, and criteria relating to the status of qualifying participants. We now examine further those socio-economic criteria, which can help or hinder the interests of developing CARICOM large pelagic fisheries.

Historical Catches — This criterion has featured prominently in negotiations for allocations in several fora, notably NAFO and ICCAT. It has no rational basis (Gulland 1981). There is no reason why any country should accept an inequitable distribution of the benefits of a resource purely because it has been so in the past. Moreover, this criterion is clearly linked to other more pragmatic criteria such as 'existing level of fishing effort' and 'economic and/or social importance of fishery to habitual participants'.

Notwithstanding, the larger developed ICCAT nations are clinging to this criterion, and have placed it in a separate category to retain the emphasis on 'past' fishing activities. The other criterion, in the same category with 'historical catches', deals with 'present' fishing activity in a weak, qualitative manner by referring to a country's 'fishing interests, patterns and practices'.

Interests of Artisanal, Subsistence, and Small-scale Coastal Fisheries — The UN Fish Stocks Agreement and the FAO Code of Conduct for Responsible Fisheries both recognise the need to avoid adverse impacts on, and ensure access to fisheries by persons involved in artisanal, subsistence and small-scale fishing. In developing states such as CARICOM states, these fisheries usually involve significant portions of the populations and promote food security and food quality.

Owing to their complex and diverse nature, adequate statistical coverage of artisanal and small-scale coastal fisheries is often not possible. Thus, TAC levels should be set to accommodate possible under-reporting of catches by these fisheries. Given the coastal nature of these fisheries, much of the catch may be young fish. The harvest of young fish by large-scale fisheries should therefore be limited as much as possible, to accommodate for the special needs of artisanal, subsistence, and small-scale coastal fisheries.

Needs of Coastal Fishing Communities — Coastal communities may be defined as local communities in coastal areas, which have traditional or cultural practices that make them highly dependent on fishing and fish resources. Like the artisanal, subsistence, and small-scale coastal fisheries, coastal community fisheries are usually limited in their capacity and options for change. The FAO Code of Conduct and the UN Fish Stocks Agreement make clear provisions for the needs of these communities.

Needs of Coastal States — UNCLOS, clearly recognises the sovereign rights of coastal states for the purpose of exploring and exploiting all the natural resources found in their EEZs, and also notes that the right to fish on the High Seas is subject to, *inter alia*, the rights, duties and interests of coastal states. The UN Fish Stocks Agreement also addresses coastal states rights and needs, particularly the issues of co-operation and shared access.

Sovereign Rights of States Under UNCLOS and the UN Fish Stocks Agreement — This is a general right of all states to a share of highly migratory and High Seas resources wherever they may occur.

Needs of Developing States — Access to fish resources usually contributes significantly to poverty alleviation, basic food security and hence social and economic stability. In the case of SIDS and coastal developing states, access to fish resources is a natural and essential part of their culture and development. The UN Fish Stocks Agreement makes specific provisions for addressing the special needs of developing states, including the need to accommodate socio-economic expansion and economic diversification, and so ensure comparable initial development opportunities.

Economic and Social Importance of the Fishery to Habitual Participants — Like the 'historical catches' criterion, this criterion supports the historical fisheries. It is therefore a duplication of the 'historical catches' criterion, simply rephrased. Despite this, certain ICCAT nations have argued strongly for its retention in this second format. Since many stocks are already over-fished, a criterion that seeks to protect excessive capacity and overcapitalisation appears invalid. In view of this, its reiteration in the form of a second criterion is clearly illogical.

Contribution of the Fishery to National Food Security/ Needs, Consumption, Export Revenue, and Employment — This criterion, although accepted by ICCAT, appears to have elements already addressed by other criteria such as 'economic and social importance of the fishery', 'historical catches', and the food security and needs of developing states. Depending on the nature of the fishery, the same catch may be taken with different levels of employment. Arguments that favour the distribution of social benefits among a larger number of persons, particularly in countries with low per capita income, would be a component of the case of special needs for developing countries.

Responsibility Criteria

These criteria, addressing adherence to conservation measures and participation in the management process, are important in providing direct benefit to countries that fish responsibly. ICCAT intends to apply three responsibility criteria:

i.) *Contribution to Conservation and Management, Accurate Statistics, and Research* — appropriately rewards countries which comply with agreed conservation and management measures and which contribute accurate statistics and research. In measuring the respective contribution and cooperation of states, it would be necessary to take into account differences in available management resources between developed and developing states.

ii.) *Exercise of Responsibilities Concerning Vessels* — is clear in its reference to flag state responsibilities that are prescribed by the relevant international agreements.

iii.) *Record of Compliance* — appears to capture the same ideas as criteria (i) and (ii), except that it is specific in addressing compliance with ICCAT conservation and management measures. Depending on its interpretation and application, however, this criterion may extend the emphasis in favour of historical fisheries, leaving new entrants to the fisheries comparatively empty-handed.

A NEW PERSPECTIVE AND APPROACH FOR CARICOM COUNTRIES

The UN Fish Stocks Agreement is clear regarding the mechanisms for cooperation for straddling and highly migratory fish stocks, and the responsibilities of countries sharing the resources. Countries are expected to participate in or become members of a relevant management organization, and should have the capacity to take part in the process.

ICCAT is the established forum for management of tuna and tuna-like species for the Atlantic Ocean and adjacent seas. Recent ICCAT assessments of several large tuna and billfish stocks show them to be either fully or overexploited, mainly as a result of prolonged overcapitalisation and ineffective management measures. New entrants to the fisheries are faced with stringent catch limits imposed by ICCAT to arrest stock declines or for stock rebuilding, allowing no room for additional access.

Many CARICOM countries rely on their living marine resources for food security, employment opportunities and economic development. CARICOM countries therefore need to ensure that their needs as developing states, and as SIDS, are properly recognised by ICCAT and other organisations responsible for the management of shared stocks that CARICOM countries exploit. On the other hand, if the responsibilities for management are not adequately addressed, arguments for countries' rights to allocations will be considerably weakened (Chakalall et al. 1998).

ICCAT does not have adequate data on small, coastal tunas and tuna-like species to facilitate quantitative assessment and management of the fisheries targeting these species. Consequently, it may be several years before ICCAT begins

to address these species in a manner that will meet the needs of CARICOM countries. Given that the small tunas and tuna-like species are less widely distributed, the relevant CARICOM fisheries could probably be monitored and managed more efficiently by an appropriate regional arrangement (Mahon 1996, FAO 1998).

To meet these challenges at the regional and international levels, CARICOM countries will need to:

i.) fulfil their national responsibilities to comply with the relevant international fishing agreements,

ii.) continue and expand coordinated CARICOM participation in ICCAT, and

iii.) determine, establish, and activate an appropriate regional forum for management of the small, coastal tunas and tuna-like species of importance to them.

Countries should also seek assistance from the United Nations, particularly through the FAO programme of assistance for SIDS, to achieve these aims in a realistic time frame, as provided for by the UN Fish Stocks Agreement.

Address National Responsibilities

Countries will need to ensure that national fisheries information systems are properly maintained, and include the data required for quantifying criteria used for shared resource allocation negotiations. It is therefore important for countries to quantify their fisheries development plans, including projected growth in fleets and catches, as this will promote more focussed and successful negotiations for catch allocation.

Additionally, new or updated national legislation may be required to support the implementation of national monitoring, compliance and surveillance programs prescribed by the relevant international fisheries agreements and specifically demanded by ICCAT and other management bodies. Countries should also have fishery advisory mechanisms that can provide a national forum for coordinating action by, and support from, the governmental and non-governmental stakeholders.

Continue and Expand Coordinated CARICOM Participation in ICCAT

CFRAMP observer participation in ICCAT has enabled CARICOM countries to monitor closely the status and management of several major Atlantic tuna and billfish stocks from 1991 onwards. Recent developments at ICCAT have highlighted the importance and need for CARICOM countries to expand their participation in ICCAT, either individually as members, or through further development of regional representation. To date, two CARICOM countries have become full members of ICCAT. Regardless of membership in ICCAT, all CARICOM countries are obliged to report accurately on their tuna and tuna-like fisheries, and to comply with ICCAT management and conservation measures. In many if not all instances, countries are still in the process of establishing the measures to fulfil their responsibilities to ICCAT.

For countries that cannot afford membership in ICCAT but have large pelagic fisheries interests, coordinated regional representation at ICCAT will continue to play a vital role. The CRFM, which replaces CFRAMP, is best placed to serve this role, and this is discussed further in the following section.

Establish and Participate in Regional Arrangements or Organisations

CFRAMP activities in CARICOM countries, particularly the development of data information systems, have prepared these countries for more active contribution to, and participation in regional fisheries management activities. WECAFC recently established and assumed the leadership role for coordinating working groups on flyingfish, and shrimp and groundfish. The CRFM is expected to take over the coordination of the large pelagic working group (LPWG) started by CFRAMP. Additionally, the Caribbean Fishery Management Council (CFMC) has played a leading role in developing regional management of lobster and conch resources. The establishment in the near future of other WECAFC and CRFM fisheries management working groups are planned. In summary, the institutional model that is emerging for the management of transboundary living marine resources in the Caribbean region appears to be one of flexibility, networking and adaptation of existing institutions.

CRFM — As noted earlier, CARICOM countries recently approved the establishment of the CRFM. Following CFRAMP, the CRFM is expected to provide a regional forum for coordinating the further development of statistics, research and management of living marine resources within the Caribbean area.

In 2000, CFRAMP established a Large Pelagic Working Group (LPWG) to address the management of CARICOM's large pelagic resources, and to coordinate and develop unified strategies among its member countries for participation in ICCAT. The LPWG was active in developing the regionally supported Trinidad and Tobago position on catch allocation criteria (ICCAT, 2001b).

Adoption by the CRFM will broaden the current membership of the LPWG and its potential to contribute significantly to the management of all coastal large pelagic fish stocks within the wider Caribbean region. In achieving closer coordination at the regional level, the LPWG also has the potential to improve statistics and current knowledge of the distribution and abundance of tuna and tuna-like species within the central western Atlantic region as input to ICCAT.

WECAFC — WECAFC is currently conducting a project to acquire and synthesise information on large pelagic fisheries in CARICOM countries and their relation to other Caribbean countries. The project aims to highlight the importance and value of the fisheries, and to contribute to the technical basis for determining catch allocations by quantifying the distribution of stock biomass within CARICOM country EEZs. The project could also compile a database of indicators useful for

quantifying the catch quota needs of SIDS. Given the imminent establishment of the CRFM, the WECAFC project outputs could serve to guide and reinforce this agreed regional fisheries management arrangement during the early formative and developmental stages.

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Compliance and Enforcement of Fisheries Regulations in the Caribbean

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ABSTRACT

One of the most challenging aspects of the global, regional, and national initiatives to protect and manage fisheries resources is that of compliance and enforcement. Illegal activity and non-compliance with laws and regulations is a fact of life in fisheries. Despite the provision of substantial legislative and regulatory measures to protect and manage fisheries, the level of non-compliance with these regulations is unacceptably high. Throughout the region, the available resources and institutional capacity for monitoring, control, surveillance, and enforcement is inadequate to ensure compliance with existing legislations and regulations. At the same time, the level of awareness of both the environmental problems occurring in the fisheries and the laws and regulations designed to protect the sector is low among resource users. Lack of compliance with fisheries regulations is therefore a major constraint that needs to be addressed to effectively protect and manage the fisheries resources of the region. This paper discusses the regulatory framework for fisheries management in the Caribbean region, the state of compliance with existing regulations, and possible steps that can be taken to improve the level of compliance.

KEY WORDS: Compliance, enforcement, fisheries management, Caribbean

INTRODUCTION

The countries of the Caribbean are surrounded by seas and oceans from which are derived countless benefits in the form of food, employment, foreign currency, transportation, information, culture, recreation, and tourism. Today, the fishing industry in the region is a vibrant, dynamic, and growing sector which contributes significantly to the social, economic and cultural life of the region.

Over the past two decades the industry has been innovating and diversifying by developing new products and markets, modernizing the fishing fleet and processing plants, and expanding production in response to growing global demand and national macro economic policies. Caribbean governments, in collaboration with each other and with other stakeholders, have been: strengthening the capability of their national fisheries administrations, upgrading their legislative and regulatory framework, improving the information available for planning, policy formulation, and regulating the industry; and promoting responsible and sustainable fishing operations while taking into account the need to protect and conserve the resource base.

THE IMPORTANCE OF FISHERIES

Living aquatic resources play a very important role in nutrition and food security within the Caribbean region. Fish is a vital source of animal protein and minerals in the diet of Caribbean people, particularly the poor and vulnerable members of society. Per capita consumption of fish is very high in most Caribbean states, ranging from 62 kg in Guyana, 19 kg in the Lesser Antilles and 9.3 kg in the Greater Antilles between 1997 - 1999. The world average per capita consumption was 16.3 kg during the same period (FAO 2001).

Although accurate figures are not available, based on the available FAO statistics, annual nominal production of fish in the region has been growing steadily since the 1950s reaching just above 2 million tonnes in 1997 (FAO 2001)

Exports of fish from the Caribbean and Central American region have been growing steadily and in 1997 were valued at approximately US$204 million, up from US$10 million in 1982 (FAO 2001). The US market is the major destination of most exports from the Caribbean. High-value commodities such as shrimp, spiny lobster, tunas, queen conch, deep-water red snappers, and groupers, which command premium prices on the international market, dominate exports. Generally, marine products with high economic value are exported, whereas products with high nutritive value and lower prices are imported to satisfy nutritional needs.

Perhaps one of the most important roles of fisheries is the employment opportunity that the sector provides for thousands of people in a region where the high levels of unemployment and under-employment continue to be a major concern (International Development Bank 1997). The fisheries sector provides stable full-time direct employment for more than 120,000 fishers in the Caribbean ACP States (Hamilton and Associates 2001) and indirect employment opportunities for thousands of others in the processing, marketing, boat building, net making, and other support industries. The persons engaged in fishing often have low-levels of formal education, limited access to capital and limited occupational and geographic mobility. For these reasons they are highly dependent on the fisheries for their livelihood.

Within the Caribbean region fisheries are important not only as a source of food and employment for commercial and subsistence fishers but also for a growing population of recreational fishers and diving enthusiasts (Haughton and Jacobs 1998). Recreational fishing is defined as fishing conducted for the purpose of pleasure and relaxation rather than for commercial gain or subsistence by the fisherman (Hinman 1997). Popular sport fishing magazines, such as Marlin, Salt Water Sportsman, and Sport Fishing, consistently rate the Caribbean as a prime destination for international anglers for billfishes, such as marlins and sailfish, and for several other species of gamefishes (Anon 1997a and b, Anon 1998). Dozens of international, regional and national fishing tournaments are held each year throughout the region. The Bahamas, Belize, Antigua and Barbuda, Barbados, Grenada, Jamaica, St. Lucia, Trinidad and Tobago, and the Turks and Caicos Islands are among the popular sports fishing destinations in the region.

The Caribbean is regarded as a top dive destination. Each year tens of

thousands of tourists visit the region to dive or snorkel and observe the spectacular coral reef formations and diverse fish, and other biological organism inhabiting the reef ecosystems. Snorkeling, diving and watching coral reef fishes and other marine life are important leisure activities of thousands of local residents in the Caribbean. Over the past two decades, several countries have established marine parks and aquaria to facilitate usage of the fish and marine resources in a non-consumptive manner, to promote education and conservation of these aquatic resources systems while at the same time generate employment and income.

On the basis of the above, it is clear that a viable fisheries sector is important for food security, social and economic stability, peace, and prosperity within the Caribbean region.

STATUS OF THE FISHERIES

In the not too distant past, fish stocks were exploited mainly as common-property resources by small-scale fishermen using primitive fishing technology. The state of the marine habitat and the abundance, distribution, and health of the fish stocks were determined mainly by biological and environmental factors rather than by the impact of human activity. Fishing activities were essentially managed and regulated by cultural mores, with community members acting as "enforcement officers" (Ruddle 1994).

The rapid population growth and demand for fish and marine products, coupled with technological advancement in fish harvesting capability, have dramatically changed this scenario, and today many fish stocks and associated ecosystems are threatened with depletion and degradation. This has given rise to the need for legislative approaches supported by scientific, management, legal, and enforcement capability to protect and manage the fisheries resource systems and maintain their contribution to society.

The available literature identifies a vast array of challenges facing fisheries in the Caribbean, including, for example:

i) Global warming and sea level rise;
ii) Rapid population growth and development in the coastal zone;
iii) Marine pollution and degradation of critical coastal marine habitat;
iv) Growing demand for fish and the impact of globalization;
v) Unregulated and illegal fishing within the EEZ by local fishers;
vi) Unauthorized incursions by foreign fleet in waters under national jurisdiction;
vii) Reflagging of fishing vessels;
viii) Overcapitalization, excessive fleet capacity and overfishing.

These challenges are forcing Caribbean States to think about the fisheries resource systems much more seriously and to develop strategies to conserve, protect and better utilize these resources for sustainable development.

Within the region many species of fish are under stress from over-exploitation and/or habitat degradation and are therefore not making optimum contribution to

our socio-economic development. All the major commercially important species and species groups are reported to by either fully developed or over-exploited (Hoggarth in prep). These include, conch, which has been placed on the CITES list of threatened species; lobsters, shrimp and groundfish, shallow shelf reef-fishes, deep-slope fishes, and some of the large pelagic species which are managed by the International Commission for the Conservation of Atlantic Tunas (ICCAT). (CFMC and CFRAMP 2000, FAO 1998, FAO 1999, FAO 2000).

Frequent illegal incursions and unregulated fishing by foreign vessels in the waters under the national jurisdiction of several CARICOM Member and Associate Member States is a major problem. Among the countries so affected are Antigua and Barbuda, Belize, The Bahamas, Guyana, Jamaica, St. Lucia, St. Vincent and the Grenadines, Suriname, Trinidad and Tobago, and the Turks and Caicos Islands.

In addition to the above, illegal, unregulated, and unreported fishing by local fishers within the territorial seas and EEZ have also been identified as major problems affecting fisheries. Local fishers frequently disregard regulations regarding licensing and registration of fishers and fishing boats, gear limitations, closed seasons, closed areas, and minimum harvest size of fishes among other measures designed to protect and conserve the fisheries resources.

Piracy and other forms of lawlessness among fishermen at sea is also a growing problem across the Caribbean region. The stealing of either the fish traps and other similar gear types that are left unattended at sea for days or the fish that is caught by the gear is a major problem. The incidents of fishermen being held up at sea and relieved of their catch and gear, including their outboard engines, is not uncommon in the region.

Marine ecosystems and their associated fisheries need to be developed and managed on a sustainable basis if their contribution to the nutritional, economic and social well-being of the people of the region is to be sustained. Loss of aquatic biodiversity, excessive fishing capacity, pollution, degradation of essential habitats, and dwindling fish stocks, underline the need to put in place strategies and plans to protect, conserve, and utilize the fisheries resource systems in a sustainable manner in the Caribbean (Haughton and Jacobs 1998).

Globally there have been several positive developments in support of sustainable use of fisheries and other living marine resources. These include both legally binding conventions and agreements and non-binding instruments designed to provide states and other stakeholders with adequate frameworks for utilization, protection, and conservation of natural resources. Among the significant developments are:

i) The 1982 United Nations Law of the Sea Convention
ii) The outcome of UNCED, in particular its Agenda 21;
iii) The Biodiversity Convention;
iv) CITES
v) The Cartegena Convention;
vi) SIDs Plan of action;
vii) The UN Agreement on the Management of Straddling and Highly Migratory Fish Stocks;

viii) The UN Compliance Agreement on High Seas Fishing;
ix) The FAO Code of Conduct for Responsible Fisheries.

THE LEGAL REGIME FOR MANAGEMENT AND PROTECTION OF FISHERIES

The 1982 United Nations Convention on the Law of the Sea is the principal international legal instrument governing fisheries development, management and conservation (United Nations 1982). The rights and obligations of states with respect to the fisheries and marine resources are found in this Convention. Agenda 21 of UNCED, the 1993 UN Agreement to Promote Compliance with Conservation and Management Measures by Fishing Vessels on the High Seas, the 1995 UN Agreement on the Management of Highly Migratory Fish Stocks and Straddling Fish Stocks and the 1995 FAO Code of Conduct on Responsible Fisheries have clarified and elaborated on these responsibilities in relation to the resources of the high seas and within the EEZ. At the heart of these legal instruments is a commitment to the conservation, protection and sustainable use of fisheries and living marine resources for the benefit of mankind. The following specific objectives have been identified:

i) To develop and increase the potential of marine living resources to meet human nutritional needs, as well as social, economic and development goals;
ii) To maintain or restore populations of marine species at levels that can produce maximum sustainable yield as qualified by relevant environmental and economic factors, taking into consideration relationships among species.

According to Article 56 of UNCLOS, the coastal state has sovereign rights for the purpose of exploring and exploiting, conserving and managing the living and non-living resources within the EEZ. Articles 61 and 62 further set out the basic rules for management and protection of fisheries resources in the EEZ, including:

i) The prevention of over-exploitation;
ii) Determination of allowable catch;
iii) Promotion of optimum utilization;
iv) Production of maximum sustainable yields.

Articles 63 to 67 of UNCLOS deal with access to and management of resources such as: fish stocks occurring within two or more EEZs or other areas (straddling fish stocks); highly migratory species; and marine mammals. The management of high seas fisheries is dealt with under Article 116.

The arrangements for management and conservation of straddling fish stocks and highly migratory fish stocks have been further developed and elaborated in The 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks. This is a legally binding instrument on the states that are party to the Agreement. Likewise arrangements for management and protection of fisheries on

the High Seas have been detailed in the 1993 Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas.

In 1995 the FAO Code of Conduct on Responsible Fisheries was adopted by the FAO Conference. SThe Code is a comprehensive, non-binding instrument that establishes principles and standards for the conservation, management, protection and sustainable development of all fisheries (FAO 1995). It is consistent with the abovementioned Convention and Agreements. A number of Technical Guidelines have been prepared to support the implementation of the Code.

A fundamental objective of UNCLOS which is explicitly recognized in the management systems described in the convention, is an obligation on all states to take measures necessary to protect, conserve, maintain or restore fish populations at levels which can produce the maximum sustainable yields as qualified by relevant socio-economic and environmental considerations.

At the regional level there is the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region (the Cartagena Convention). This is a legally binding environmental treaty whose objective is to help the countries of the region to protect, develop, and manage their common waters individually or jointly.

The Protocol Concerning Specially Protected Areas and Wildlife (the SPAW Protocol) was adopted in 1990 by Caribbean governments within the framework of the Cartegena Convention. The general objective of the Protocol is to protect rare and fragile ecosystems and habitats, thereby protecting the endangered and threatened species residing therein. The Caribbean Regional Co-ordinating Unit of UNEP pursues this objective by assisting with the establishment and proper management of protected areas, by promoting sustainable use and management of species to prevent their endangerment, and by providing assistance to the governments of the region in conserving their coastal ecosystems.

The international and regional legal regime and voluntary instruments designed to promote responsible practices to ensure protection, conservation, and sustainable development of fisheries and marine resources provide a framework for states to act. These international and regional treaties and conventions usually do not have any legal force within English Speaking Caribbean States even after they have been signed unless there are specific accompanying national legislation to give effect to them. Carnegie and Anderson (1998) summarized the issue as follows,

> *"The law of the West Indies for the most part knows nothing of self-executing treaties: the operating assumption is that legislation is required to give the force of law to treaty obligations"*. Carnegie and Anderson (1998) argued further as follows, *"Given that treaty law generally has no force in our law without implementing legislation, it might have been expected that, when a West Indian state takes the solemn decision to become a party to a treaty, the implementing legislation would*

> *follow as a matter of course. This logic was not reflected in British practice, which is replete with treaties, which have not been followed by enacting legislation in the direct sense. The situation in the West Indies, until the departure from tradition by Antigua and Barbuda, universally reflected the illogicality of the British tradition which the states inherited."*

The important issue is that regardless of what may exist at the international and regional levels, the legal rights and obligations of those responsible for managing fisheries and the specific management measures to be applied in any given situation must be prescribed by national legislation and regulations in almost all CARICOM Member and Associate Member Countries.

There are several cases where regional governments have signed international agreements and convention designed to protect natural resources but then fail to enact the necessary national legislation and establish administrative arrangements to give effect to these instruments within the state. The example of Jamaica and CITES will be discussed below.

Since the Advent of UNCLOS, most if not all Caribbean states have promulgated laws and regulations designed to give effect to the Convention in their state, and, to protect, conserve and promote sustainable use of the fishery resources under their jurisdiction. For example, in 1983/84 the Member States of the Organization of Eastern Caribbean States (OECS) began to develop harmonized fisheries laws, which effectively provided the legal and administrative framework for fisheries development and management and the undertaking of monitoring, control, surveillance, and enforcement activities. These states further went on to develop an "Agreement Establishing a Common Fisheries Surveillance Zone" which provides the basis for authorized fisheries enforcement officers from any OECS State, to enforce the fisheries laws of the other member states whose waters comprise the Zone (OECS/NRMU 1999). Barbados subsequently updated and harmonized its fisheries legislation with those of the OECS countries. Other Caribbean states including but not limited to Guyana, Trinidad and Tobago, Jamaica, Dominican Republic, Haiti, and Belize have either recently upgraded or are in the process of upgrading their fisheries legislation.

In many cases throughout the region the existing laws and regulations are considered inadequate to protect and manage the fisheries resources in a sustainable manner. This is due partly to the complex nature of the fisheries resource systems and a general inadequacy in scientific knowledge of the nature, characteristic, and status of the fisheries and marine ecosystems. The laws and regulations tend to reflect this uncertainty, and the provisions to protect and manage the resource are often defined in broad and vague terms with huge loopholes, and therefore, do not provide adequate framework for protection and sustainable utilization of these resources.

COMPLIANCE AND ENFORCEMENT

Illegal activity and non-compliance with norms and regulations is a fact of life of modern society and fisheries and marine resources are no exception. Compliance is critically important to success in protecting, conserving, managing and maintaining contribution of fisheries at optimum levels.

In surveys conducted among the CARICOM and Caribbean ACP States, lack of enforcement and compliance with fisheries regulations have been identified as a major constraint that needs to be addressed to effectively protect and manage fisheries (Mahon and Boyce 1992, CFRAMP 1995, Brown 2002a, b). Compliance and enforcement vary significantly across the region from almost no enforcement in Haiti, very little enforcement in the Dominican Republic and Jamaica, to a reasonable level of enforcement in Belize. Although all the CARICOM countries do enforce some fisheries regulation, there is a general lack of resources for monitoring, control, surveillance, and enforcement. Throughout the region, the capability for monitoring, control, surveillance, and enforcement is inadequate to ensure compliance with existing legislations and regulations. The level of non-compliance with fisheries regulations is therefore high throughout the region. Several factors account for this.

Despite the provision of legislative and regulatory measures to protect and manage fisheries, there appears to be a general lack of political will to control domestic fishing effort or to levy fines and penalties against violators, particularly within the artisanal fisheries. This may be partly because the fishery sector is often considered the employer of "last resort" in poor developing countries with limited alternative employment opportunities. Political will and desire to enforce regulations against illegal foreign fishing is perceived to be quite high.

Most countries rely on the coast guard, marine police, and the fisheries department staff for fisheries monitoring, surveillance, and enforcement. There are some countries where it is not clear which agency is responsible for fisheries enforcement, for example the Fisheries Departments report that the Coast Guards are responsible whereas the Coast Guards report that the Fisheries Departments are responsible.

The enforcement of regulations involves an understanding of the law, which prescribes the regulations and the circumstances to which they are applied. In some cases, the enforcement personnel (particularly coast guard and police) are poorly briefed on fisheries regulations and the underlying circumstances of the fisheries, which limits their effectiveness. Patrol vessels are sometimes restricted in their operation by unavailability of operating funds and resources such as fuel. Furthermore, enforcement of fisheries regulations is normally only a small part of the overall responsibility of the coast guard and police who are required to pay much more attention to matters of national security including drug interdiction.

An important purpose of any fishery regulation is to define as clearly and precisely as possible the rules and standards governing operations so that both the enforcement officials and resource users know what is expected and the consequences of non-compliance. Due to the complex nature of the fisheries

resource systems, there are situations in which scientific knowledge of the nature, characteristic, and status of the fisheries and marine ecosystems are either unknown or poorly known, and consequently, plans and strategies for their protection and management can only be defined in broad and uncertain terms (Fisher 1997). In such situations the legal and regulatory framework tend to reflect the same uncertainty and ambiguity and are unlikely to provide adequate protection for the fisheries resources. This will naturally pose difficulties for both the enforcement authorities and the resource users who are seeking to apply and operate according to the regulations. The Government of Jamaica encountered difficulties along these lines in 1999. The Government attempted to impose certain controls on the harvesting and export of queen conch, but the Courts ruled that the Government did not have the legal authority to impose such restrictions on resource users. This occurred despite the fact that:

i) The Jamaican Fishing Industry Act empowered the Minister responsible for fisheries to make and implement regulations deemed necessary to regulate and manage the fisheries; and

ii) Jamaica is a party to the CITES Convention which governs the trade in threatened and endangered species. The queen conch (*Strombus gigas*) is listed on Appendix II of CITES and requires the state to implement measures designed to protect and maintain conch populations at sustainable levels.

Since then the Government has been upgrading the legislation and regulations to more clearly, accurately, and precisely define the rules and arrangements for operating in the fishing industry.

In some countries fisheries laws and regulations have been developed without full involvement of fishers, other resource users, and the general public. The general practice is that once enacted, legislation and regulations are brought to the attention of fishers and other stakeholders via the public media and community meetings with extension staff of the Fisheries Departments. In many cases, fishers and other industry operators are poorly informed about the laws and regulations as well as the underlying status and circumstances of the fisheries resources and marine environment which give rise to the regulatory systems. If fishers and other resource users do not know, support and accept the regulations designed to protect the resource then the chance of success in achieving their objectives is very small. Better integration and involvement of resource users in the planning, formulation, and implementation of plans and regulations to protect and management fisheries will increase chances of success.

The available information leads to the conclusion that in most cases, the "monitoring, control, surveillance and enforcement" function of fisheries management is not adequately integrated in the overall strategy and plan for protection and management of fisheries and marine resources. Enforcement personnel are often not involved in the planning and formulation of fisheries management plans and regulations. They are usually brought in at the end of the exercise to implement what has already been agreed upon. Better integration and

involvement of enforcement personnel in the planning and formulation of the plans and regulations they are expected to monitor and enforce could help to increase their chances of success.

Measures designed to manage and protect fisheries are too often implemented late in the development of a fisheries and as a consequence must result in painful dislocation and displacement of hard working and honest citizen, oftentimes with limited occupational and geographic mobility. This usually creates deep resentment and anger towards the management authorities. Every effort should be made to avoid this type of crisis management in fisheries when draconian measures are unavoidable.

The FAO Code of Conduct on Responsible Fisheries promotes the application of "precautionary approach to conservation, management and exploitation of living aquatic resources in order to protect them and preserve the aquatic environment." In this regard, states are urged to " adopt as soon as possible, cautious conservation and management measures". Furthermore, the Code states that "the absence of adequate scientific information should not be used as a reason for postponing or failing to take conservation and management measures," but rather decisions should be based on "the best scientific evidence available".

Several Caribbean and Central American countries including Belize, Honduras, Panama, St. Vincent and the Grenadines, and more recently Jamaica operate "open registers" and allow the reflagging of vessels. While there are several reasons why vessels choose to operate under a "flag of convenience", FAO (2000) reports that the reflagging of fishing vessels has often been associated with the avoidance of management regulations designed to protect fisheries. Since most Caribbean states do not have resources to adequately monitor and control the operation of these reflagged fishing vessels, which may operate thousands of miles from the state, they pose a special challenge for the state.

CONCLUSION AND RECOMMENDATIONS

Caribbean countries will remain dependent on the fisheries and marine resources in their maritime space not only for social and economic development, but also for peace, prosperity, and food security. Long-term sustainable benefits from the fisheries will be possible only if there is improved protection and management based on improved knowledge and understanding of the resource systems and the socio-economic characteristics of the fisheries. This will require closer cooperation among the countries of the region as well as among stakeholders within the countries. Policy makers, resource managers, researchers, resource users, and enforcement personnel need to work together to ensure the development of adequate policy, legal, regulatory and administrative framework and ultimately to ensure higher level of compliance with fisheries regulations.

Failure to protect the fisheries will not only lead to further depletion of fish stocks, loss of biodiversity, and degradation of the marine environment, but more importantly, will result in increase in conflicts, social and economic dislocation, and

destabilization of coastal communities across the region. The social and economic fallout will not be confined within the borders of the affected states but is likely to have direct and indirect negative consequences in neighboring states. For example if the incidence of illegal incursions by foreign vessels could increase, displaced fishers and other fishing community workers might turn to the high risk, economically attractive drug trade. Alternatively they may decide to migrate, by legal or illegal means, to states where economic opportunities are perceived to be better.

For the reasons noted above, Caribbean governments will in the near future need to give much more attention to upgrading and strengthening the legal and regulatory framework for fisheries protection and management and ensuring greater compliance and enforcement of regulations.

At the international level there has been significant development in the legal and regulatory framework for protection, conservation, and management of fisheries. However, at the national level there are major weaknesses that need to be addressed. One of the first issues that must be dealt with is the fact that in many Caribbean states the existing national fisheries laws and regulations are not adequate to protect, conserve, and manage the fisheries in a sustainable manner. Secondly, the existing human and institutional capacity of States to administer and enforce the existing laws and regulations pertaining to fisheries are also inadequate. Furthermore, the financial and logistical resources available for monitoring and enforcement are woefully inadequate.

In the coming years, States will have to pay more attention to upgrading and strengthening their laws and regulations to protect and manage fisheries and the marine environment based on, and consistent with, international and regional environmental management instruments and their national policies. Likewise, they must invest in strengthening the human and institutional capacity to improve compliance by improving awareness of the regulations and strengthening the systems for monitoring, control, surveillance and enforcement.

The enforcement of fisheries regulations involves an understanding of the law which prescribes the regulations and the circumstances to which they are applied. In a complex area such as fisheries, the enforcement personnel are unlikely to have detailed knowledge of the scientific and technical aspects of fisheries management. In a similar manner, the fisheries scientist and extension workers are unlikely to have a sufficiently detailed knowledge of the procedures and consequences of enforcing the regulations. Closer cooperation and collaboration between the resource managers, extension officers and scientists on the one hand and the legal and enforcement personnel on the other hand is not only necessary at the operational level, but perhaps more importantly, during the formulation of plans and strategies and the development of regulations for fisheries protection and management (Hemming and Pierce 1997).

The scarcity of resources to devote to monitoring, control, surveillance (MCS), and enforcement activities underscores the need to enhance involvement of fishers and their community in development and implementation on measures designed to

protect and manage fisheries. Enforcement personnel should work more closely with resource users and their communities to ensure that they share greater responsibility for resource protection and management. Community policing techniques should be encouraged and promoted throughout the region.

Closer cooperation among the countries of the Caribbean is needed to combat illegal, unreported, and unregulated fishing in the region. Such cooperation should not be limited to MCS and enforcement but must include scientific research and other aspects of resource management. The model being used by the OECS States to facilitate closer cooperation and sharing of limited resources for MCS among countries should be supported and considered for application on a wider scale. Models of cooperation among states in the region developed for counter-narcotics operations might also have application for the protection of fisheries and marine resources and should therefore be explored. The United States Lacey Act provides new opportunities for cooperation in protecting marine species which are traded with the US. The Lacey Act is a federal statute prohibiting the transport, import, or sale in foreign commerce of fish or wildlife taken in violation of foreign law. In November 2000, four persons were sentenced to prison for their roles in conspiring to import into the United States shipments of Caribbean spiny lobster tails harvested in Honduras in violation of Honduran laws intended to preserve a sustainable lobster fishery.

Finally there is a need for further scientific research to better understand the ecology and status of fish stocks in the region as well as the social, economic, and cultural factors to facilitate formulation and implementation of more appropriate and specific regulations and the evolution of social relations to improve the chance of success in protecting fisheries and the marine environment in the Caribbean.

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Reproductive Patterns of *Strombus gigas* from Alacranes Reef *Versus* Chinchorro Bank of Mexico

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ABSTRACT

The reproductive cycle of the herbivore gastropod *Strombus gigas* (Linnaeus, 1758) is analyzed from two different coral reefs, Chinchorro bank on the Caribbean sea and Alacranes reef from the Gulf of Mexico, to determine the variability and similarities of their reproductive cycle under diverse environmental conditions, mainly to understand the behavior of gonads during the spawning season of both sites by a direct method. Twenty organisms were sampled monthly and processed for histological section, from March to November at Alacranes reef and from June to September at Chinchorro. For *S. gigas* of Alacranes, gametogenesis was the dominant stage from March to November, with presence of mature organisms only from June to October. While at Chinchorros, during the reproductive season gametogenesis involved no more than 40 %, with mature organisms involving from 40 to 50 %. There was an increase of mature organisms during September at both localities, but at least at Alacranes, there was no evidence of an accumulation of mature organisms through the winter or of a later spawn. Spawn was detected from June to August with a peak in July but just in 10% of the samples from Alacranes and 40% from Chinchorros. Although 40% post spawners during July at Alacranes, suggest an important spawn from May to July.

This study showed two gametogenic strategies as a response to the environment:

i) Populations of fast gametogenesis during a short lapse of time (*S. gigas* from Chinchorro), and
ii) Population with a continuous gametogenesis throughout most of the year (*S. gigas* from Alacranes).

The variations on the reproductive cycle of a species among different localities can be associated to environmental levels of instability. Predation and competition induce massive spawning and reduction of the spawning periods.

The knowledge of their reproductive cycle of *S. gigas* is mandatory for proper management of their populations. The scope of this paper to present and compare the reproductive cycle of *S. gigas* populations from mainly fishing sites from

Mexico, their variations and similarities in relation to prevailing environmental characteristics of their habitats.

KEY WORDS: Queen conch, *Strombus gigas*, reproductive cycle

INTRODUCTION

Strombus gigas is an important fisheries resource in Mexico and Caribbean sea, and the knowledge of their reproductive cycle is mandatory for proper management of their populations. *S. gigas* has a wide distribution area and its reproductive cycle is under diverse environmental conditions. Mackie (1984), showed that reproductive cycles are a response to life strategies and habitat where populations live. Species are classified in two groups, given the duration of their reproductive cycle: taquitictic, with short reproductive periods and (2) braditictic, with extended reproductive periods. Species with a wide geographical distribution show an ample variation of reproductive strategies in both duration and intensity (Bricej and Malouf 1980, Kennedy and Kratz 1982, Knaub and Eversole 1988). This has been associated to latitude, but with more precision to temperature and food availability (Bayne 1978, Sastry 1979, Webber 1977, Fretter 1984, Mackie 1985), which conditioning in the laboratory of organisms of one specie from different populations has experimentally proven (Loosanoff and Davis 1963, Bayne 1978, Ino 1970, Lubet and Choquet 1971, Hines 1979, Castagna and Kraeuter 1981).

The scope of this paper is to present and compare the reproductive cycle during the spawning of *S. gigas* from two different reef systems in Mexico, by a direct method (histological method) in relation to prevailing environmental characteristics of their habitats.

MATERIAL AND METHODS

S. gigas (Linnaeus, 1758) was studied from two different coral reefs: Alacranes reef from the Gulf of Mexico and Banco Chinchorro on the Caribbean Sea.

Twenty individuals from each site were collected monthly, trying to cover the spawning season of both sites, from March to November at Alacranes reef and from June to September at Chinchorro. Collection was done by SCUBA diving. The shell length and width were measured for all animals, and the whole organism and soft parts were weighted after extraction in the laboratory. To extract the whole body whorl, the shell was broken with a hammer. A section of the visceral mass and gonad was fixed with Bouin solution for *S. gigas* from both localities. Samples fixed with Bouin were rinsed after 24 hours.

Sections of 1 cm^3 were dehydrated with alcohol, cleared with Xylen and included in 53° - 56° melting point paraffin. Sections were cut 7 µm and 12 µm for males and females, respectively with a rotation microtome. All species were stained with Hematoxiline–eosine (Luna 1968) and Masson tri-chromic (Gabe 1968).

Practical classification of Lucas (1965) was used to define the reproductive cycle, which considers five stages:

i) *Rest* — the sex may not be identified from the microscopic section.
ii) Gametogenesis — active cell division, mature gametes may or may not be present.
iii) *Mature* —dominance of mature gametes, although some gametogenesis may be present.
iv) Spawn — partially emptied follicles.
v) *Post spawn* —follicles are partially or totally emptied and broken, eggs and sperms are being reabsorbed, presence of phagocytes.

Sampling Sites

Banco Chinchorro — is a coral reef, it is a false atoll located 16 miles offshore from southern Quintana Roo, on the Caribbean coast of Yucatan peninsula, between 18°22'- 18°48' N and 87°16'- 87°32' W. (Figure 1). It forms an irregular oval of 46 km long, 19 km in the widest part, has an area of 561 km^2. With bordering emerging islands of sand, coral and mangrove that limit an inner lagoon that has a mean depth of 7 m with sandy bottom and patches of *Thallassia*. Depth inside the lagoon reef decreases from 12 m in the south region to 7 to 3 m in the central part to 2 m in the north Chinchorro has four keys, two small keys known as Cayo Norte, the largest Cayo Centro and Cayo Lobos, the smallest located on the southern end. The weather is hot, humid with summer and winter rains, with 10.2 % during winter, average temperature is 26.1° C; average rainfall is 1,249 mm (Garcia 1981).

Alacranes reef — is an oval-shaped bank reef formation, covering an area of 293 km^2 with a maximum length and width of 26.5 km and 14.8 km, respectively (Figure 2). It is located on the north coast of Yucatan, 80 miles off the coast, between 22° 21' and 22° 35' N and between 89° 38' and 89° 49' W (Kornicher and Boyd 1962). The windward zone of the reef system arises at sea level, while the leeward zone is between 1 and 10 m below the surface. These two extremes enclose a lagoon. Near the western and southern reef edges are five small islands: Pajaros, Chica, Perez, Desterrada, and Desterrada (Hilderbrand et al. 1964). The weather is hot, humid with summer and winter rains, with 10.2 % during winter; average temperature is 25.5° C; average rainfall is 444 mm (Garcia, 1981). *S. gigas* were sampled at western of Isla Perez.

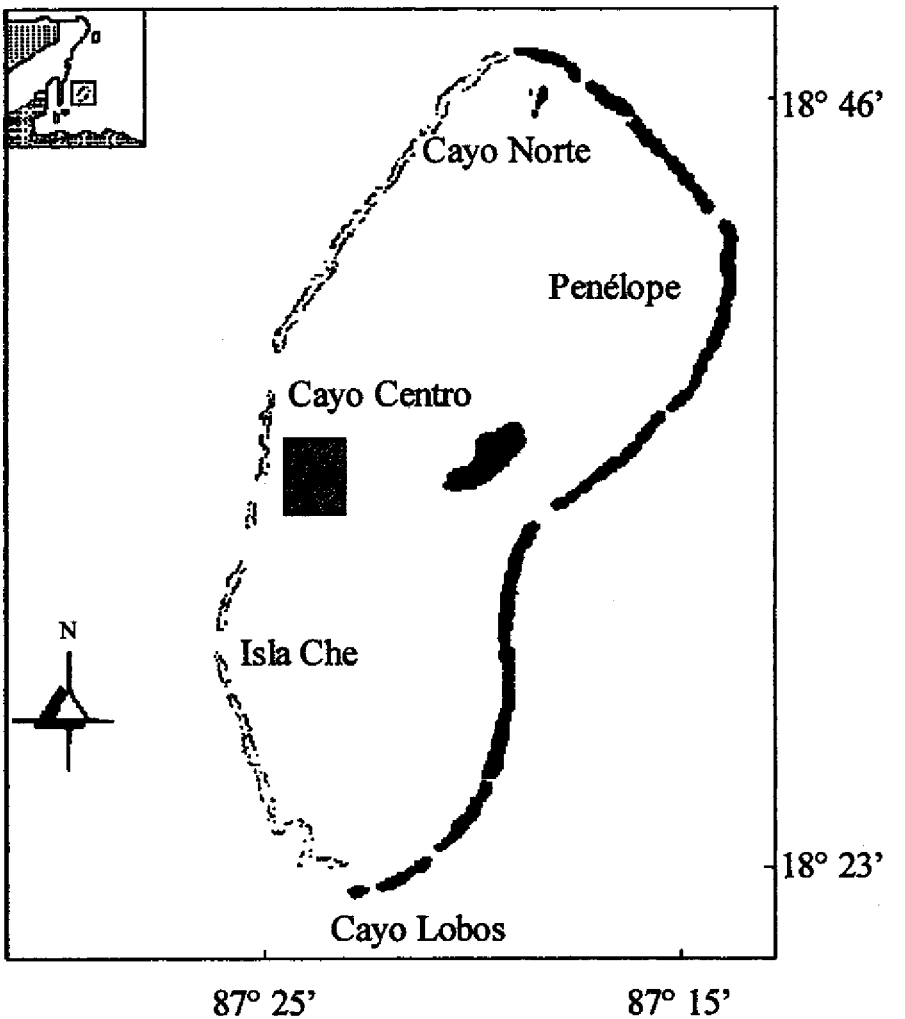


Figure 1. Location of *Strombus gigas* sampling site at Chinchorro reef, Quintana Roo, Mexico

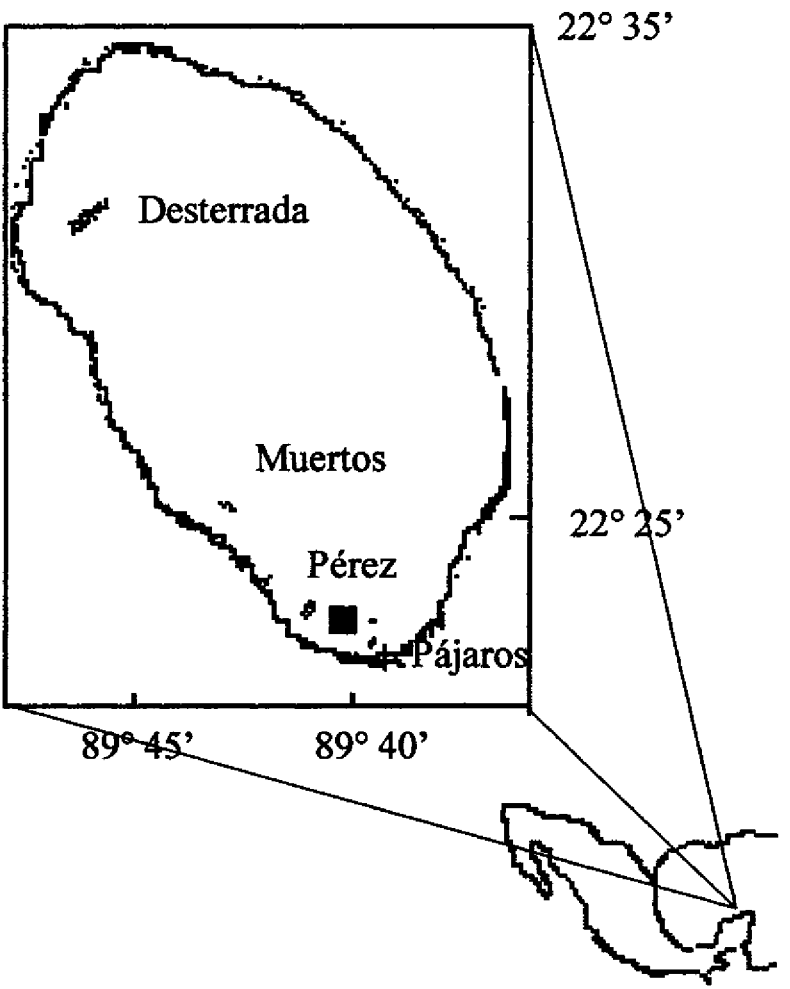


Figure 2. Location of *Strombus gigas* sampling site at Alacranes reef, Yucatan, Mexico

RESULTS

Gonad development

At microscopic levels, both the ovary and testis have a similar structure. From the exterior in, they are covered by a cylindrical and cubic epithelium, underlined by a thin layer of compact connective tissue with few muscular fibers. Under this cover of protective tissue is a layer of reticular connective tissue, in which is embedded the germinal tissue.

The germinal tissue can be identified by its acidophilus staining cells that stand out from the connective tissue as compact packets of cells. As maturation proceeds a follicle is formed, which gradually fuses with other follicles to form an oviduct or seminal duct.

Reproductive Stages

Rest — For both sexes, no signs of sexuality are evident in the connective tissue that forms the gonad. It is hardly differentiated from the digestive gland. The reticular connective tissue occupies 90 % of the gonad. Few follicles can be detected with a diameter of 39.50 ± 12.53 mm. The diameter of germinal cells is 6.05 ± 0.65 mm (Figure 3)

Gametogenesis — In females the gonad becomes thicker and occupies 30 % of the section. The follicles are well defined with diameters of 68.00 ± 18.73 mm. Ovogonias form groups of four to five cells. The nucleus is spherical, with a clear nucleolus. When vitellogenesis starts, cell diameter increases and is distinguished by basophilic cytoplasmic inclusions. Maturing oocytes are 14.25 ± 4.03 mm in diameter. As maturation proceeds the connective tissue is displaced by the follicles increasing in diameter to 153.00 ± 34.19 mm. At this stage, oocytes are 73.00 ± 38.94 mm. The nucleolus is clearly visible within the nucleus, with vacuolated cytoplasm (Figure 4).

For males the connective tissue forming over 80 % of the gonad. Follicles are very abundant with a diameter of 48.50 ± 1.29 mm. Spermatogonia have a diameter of 15.80 mm, as they grow, they separate from the wall of the follicle, occupying the lumen. First order spermatocytes have a diameter of 7mm, and second order spermatocytes of 3.60 mm. The connective tissue retracts to the inner and outer walls of the gonad as spermatogenesis advances, allowing for follicles to anastomose. Spermatids have a diameter of 5.50 mm. At this stage the follicles are 160.00 ± 1.29 mm in diameter and show maturing cells in all stages. Some spermatocytes become apyrene and oligopyrene spermatozoa, forming elongated nutritious cell of 9.35 mm long, with lateral projections that take an acidophilus stain (Figure 5).

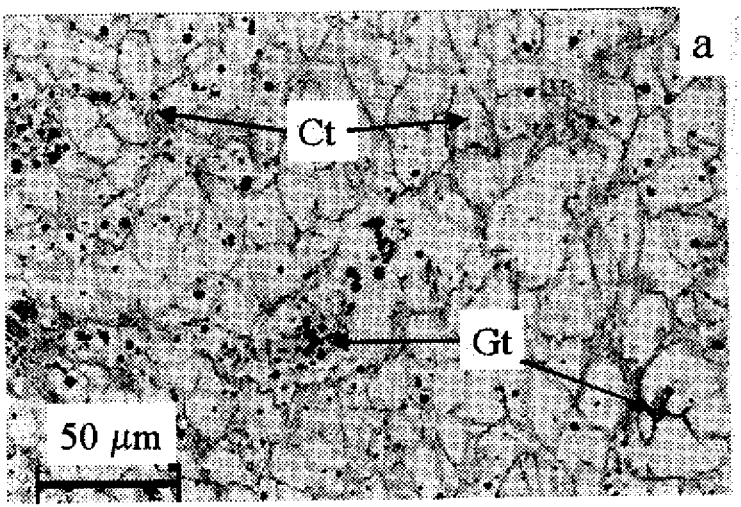


Figure 3. Microphotography of *Strombus gigas* gonad from Chinchorro, Mexico. Rest stage stained with Masson tri-chromic. No signs of sexuality are evident in the connective tissue that forms the gonad. Ct: connective tissue, Gt: Germinal tissue

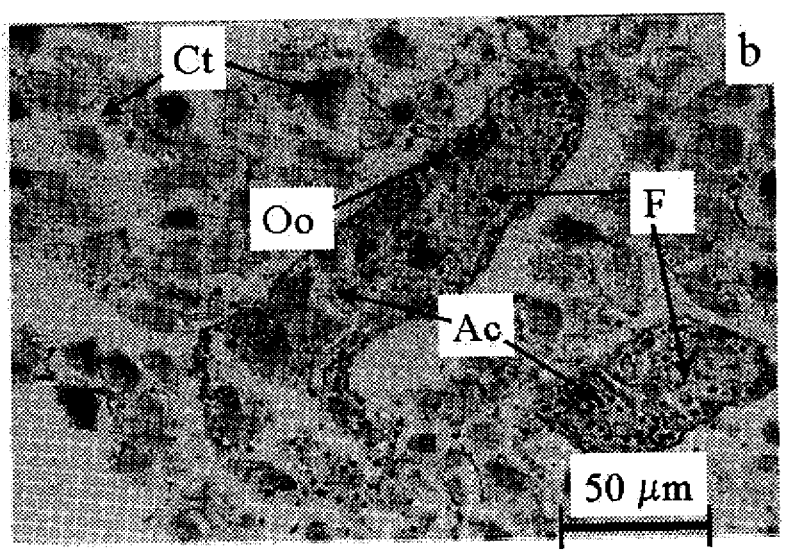


Figure 4. Microphotography of *Strombus gigas* gonad from Chinchorro, Mexico Gametogenesis stage in females stained with Masson tri-chromic. Ac: Accessory cells, Ct: connective tissue, F: Follicle.

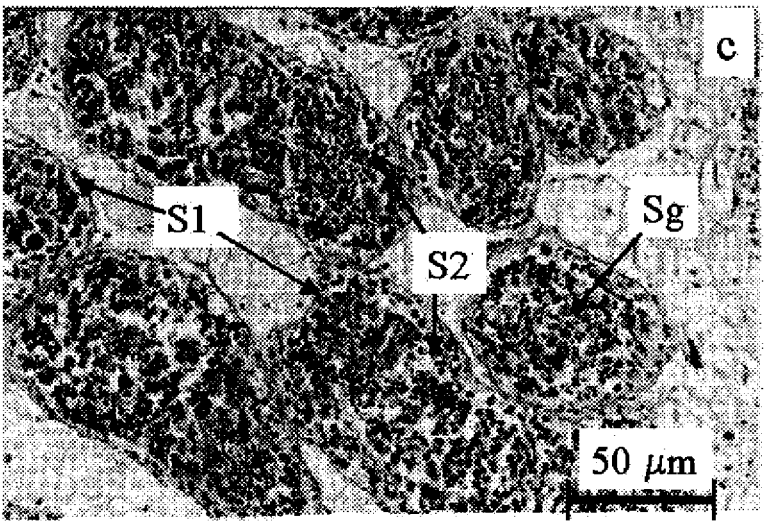


Figure 5. Microphotography of *Strombus gigas* gonad from Chinchorro, Mexico Gametogenesis stage in males stained with Masson tri-chromic. S1: first order spermatocytes, S2: second order spermatocytes, Sg Spermatogonias.

Mature — In females, the follicles are 266.50 ± 77.15 mm, they have anastomose, their walls are very thin and germinal cells are absent. Eggs are 168.50 ± 20.37 mm in diameter, they fill the follicles, with abundance of vitelline granules (Figure 6)

Follicles in males are anastomose and occupy the whole gonadic tissue; their diameter is 114.00 ± 24.51 mm with connective tissue around follicle walls and inner and outer walls of the gonad. Germinal tissue is present and active, but sperms are the dominant stage, forming a large mass in the center of the follicles of eupyrene, oligopyrene and apyrene sperms. The vases deferent are clearly formed and filled with sperm. In areas filled with sperm the walls have columnar epithelium, while in empty sections it is destroyed (Figure 7)

Spawn — In females, the follicles are emptied and their walls start to collapse. Connective tissue starts to form from the outer wall of the gonad and between the gonad and digestive gland. Sparse ovocytes can be detected with disperse vitellum, and residual oocytes in re-absorption (Figure 8)

In males the follicles continue to anastomose, with diameter of up to 334.00 ± 83.33 mm. Sperms are moved to the testis duct, leaving empty spaces in the follicles, but gametogenic activity continues keeping the production of the three types of sperms (Figure 9)

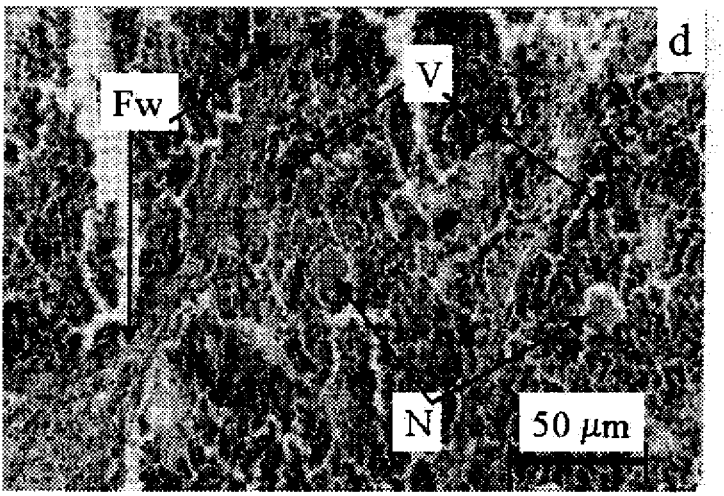


Figure 6. Microphotography of *Strombus gigas* gonad from Chinchorro, Mexico Mature stage in females stained with Masson tri-chromic. Fw: Follicle wall, N: Nucleus, V, vitellum

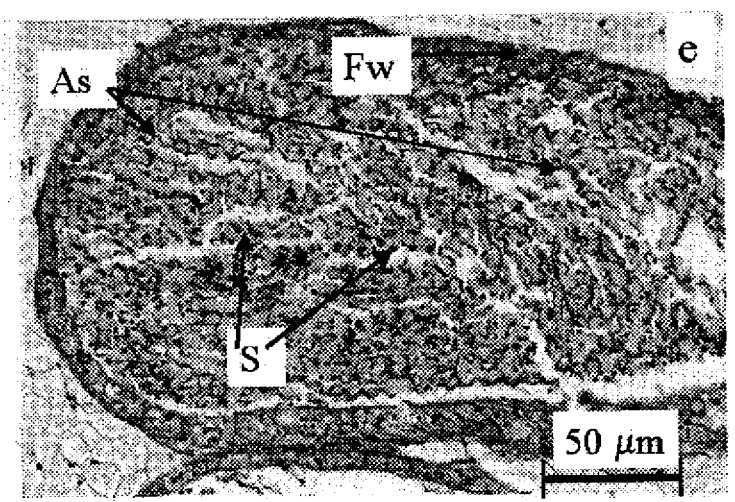


Figure 7. Microphotography of *Strombus gigas* gonad from Chinchorro, Mexico. Mature stage in males stained with Masson tri-chromic. Sperms are the dominant stage, forming a large mass in the center of the follicles of eupyrene, oligopyrene and apyrene sperms. As: Abnormal spermatocytes, Fw: Follicle wall, S: spermatozoids

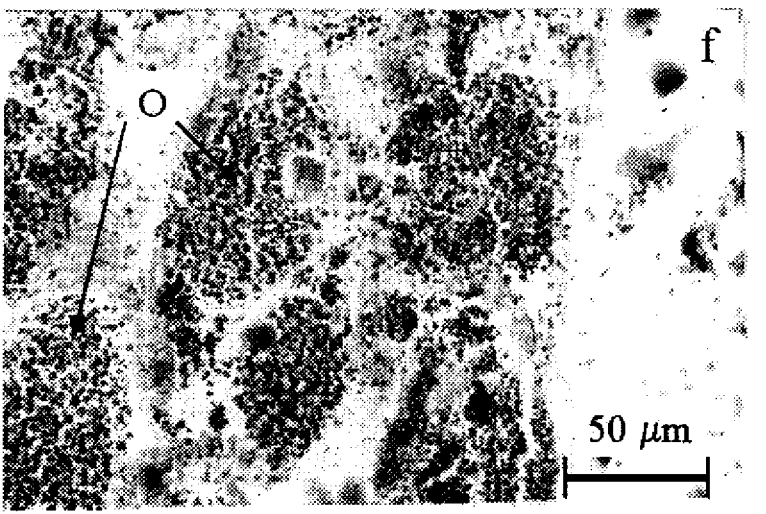


Figure 8. Microphotography of *Strombus gigas* gonad from Chinchorro, Mexico. Spawn stage in females stained with Masson tri-chromic. O: Ovums.

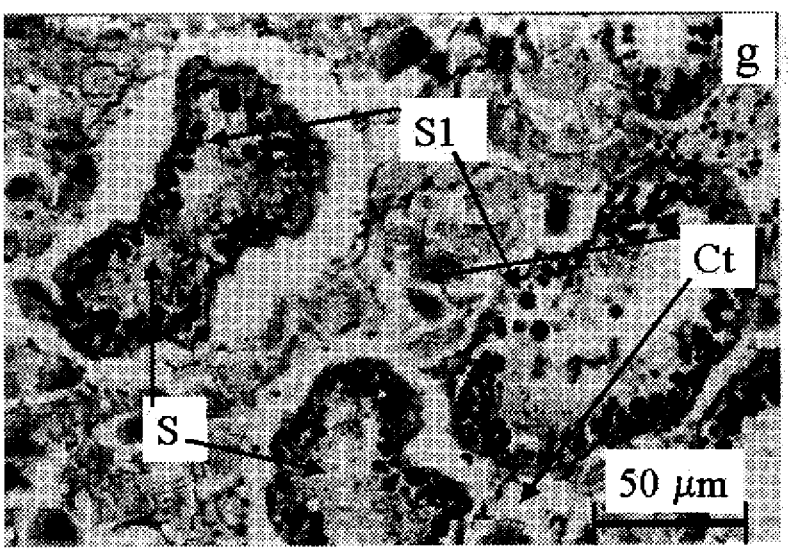


Figure 9. Microphotography of *Strombus gigas* gonad from Chinchorro, Mexico Spawn stage in males stained with Masson tri-chromic. Sperms leaving empty spaces in the follicles, that causes their collapse, but gametogenic activity continues keeping the production of the three types of sperms. Ct: Connective tissue, S: spermatozoids, S1: first order spermatocytes.

Post spawn — In both sexes the gonadic tissue is occupied by reticular connective tissue. Follicles are broken and some reproductive cells can be seen in different stages of development. Numerous phagocytes are among the rest of the follicles and gametes. Any remaining oocytes are broken or present wrinkles on their cell wall. The connective tissue close to the outer wall of the gonad has a packed appearance (Figure 10) shows post spawned male.

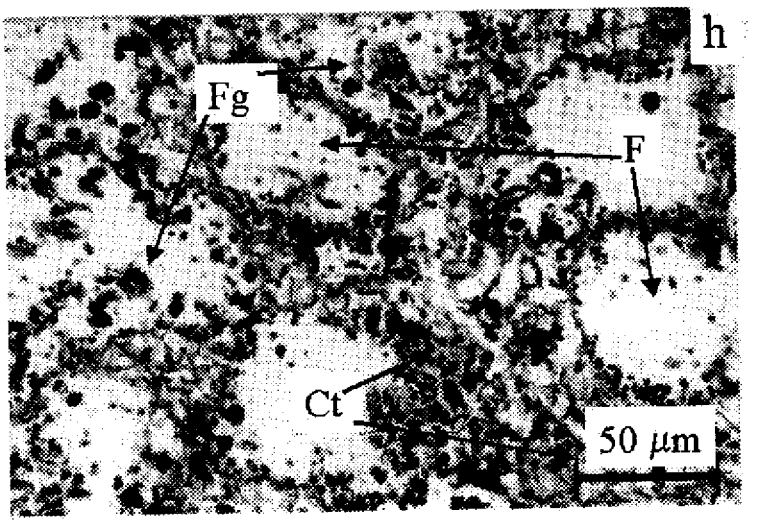


Figure 10. Microphotography of *Strombus gigas* gonad from Chinchorro, Mexico. Post spawn stage in males stained with Masson tri-chromic. Fg: Phagocytes, Ct: Connective tissue, F: Folicles

Reproductive Cycle

Reproductive cycle of S. gigas on Chinchorro reef — was established with organisms for this sample were collected from the central lagoon, from coral and sandy bottoms. The sampling period covers from June to September, as it was designed to cover season spawning period, mainly of higher presence of egg masses in the field.

i) *Females* — The rest stage was present during May (13 %) and September (33 %). Gametogenesis was present through the sampling period in average of 39 % of the female population, with slightly higher frequency during June (50 %). A similar behavior was detected for the mature stage with a mean of 36 % through the sampling period and a maximum of 40 % during May and July. The spawning period is limited to the months of July and August in 20 and 33 % of the population respectively (Figure 11)

ii) *Males* — A rest period in 30 % of the population was registered during September. Gametogenesis was present in two peaks, May (69 %) and

August (67 %), with a minimum of 14 % during September. Followed by a clear mature stage with peaks in June (50 %) and September (57 %), with a minimum during July (20 %). Giving place to a short spawning period during June and July, with a maximum of 60 % in July. Only minimum post spawn was detected during May in 8 % of the male population (Figure 12)

iii) *Both sexes* — For the whole population were detected two low frequency periods of rest during May and September in 13 and 33 % of the population respectively. Gametogenesis was present through the sampling period, with two peaks during May (54 %) and August (44 %). Maturity was constant during the sampling period with a mean of 37 % of the whole population, reaching a maximum (50 %) during September. Spawn was from June to August with a maximum during July (40 %). P ost spawn was only registered during May and June (Figure 13)

Through the five sampling months gametogenesis and mature organisms were present. Spawn was detected from June to August with a peak in July. The presence of a high percentage of mature organisms during September suggest that there might be a spawn later in the year or the accumulation of mature gametes for an early spawn during spring. Action that is supported by the presence of post spawners and organisms at rest during May and June.

Reproductive cycle of Strombus gigas, for Alacranes reef — was determined from organisms sampled along the west of Perez Island, on sandy bottom and *Thallasia*. The samples for this population were also designed to cover the spawning period, based on the presence of egg masses in the field during previous studies.

i) *Females* — The rest stage was present during March (30 %) until November (30 %), May and September do not show this stage. Gametogenesis was present through the sampling period in average of 35 % of the female population, with slightly higher frequency during May (75 %). Mature stage does not observed. The spawning and post spawning periods were limited of June and July with 10 and 20% of the population respectively (Figure 14).

ii) *Males* — A rest period in 20 % mean of the population was registered during March to November. Gametogenesis was present in two peaks, April (60 %) and September (50 %), with a minimum of 10 % during June and July. Followed by a not clear mature and spawn stages. Giving place to a minimum post spawning period during July to October, with 20 and 10% respectively (Figure 15).

iii) *Both sexes* — A discontinuous rest stage was detected in up to 30 % of the population, with only one peak correlated to the spawning period. Gametogenesis is constant through the sampling period, with a minimum of 30 % during July and a maximum in May, previous to the accumulation of mature gametes that is present from June to September. Period that cover the spawning season, although, only a very low percentage of the

population was caught during spawn, the very large percentage of post spawners, clearly defines the spawning period from June to October (Figure 16).

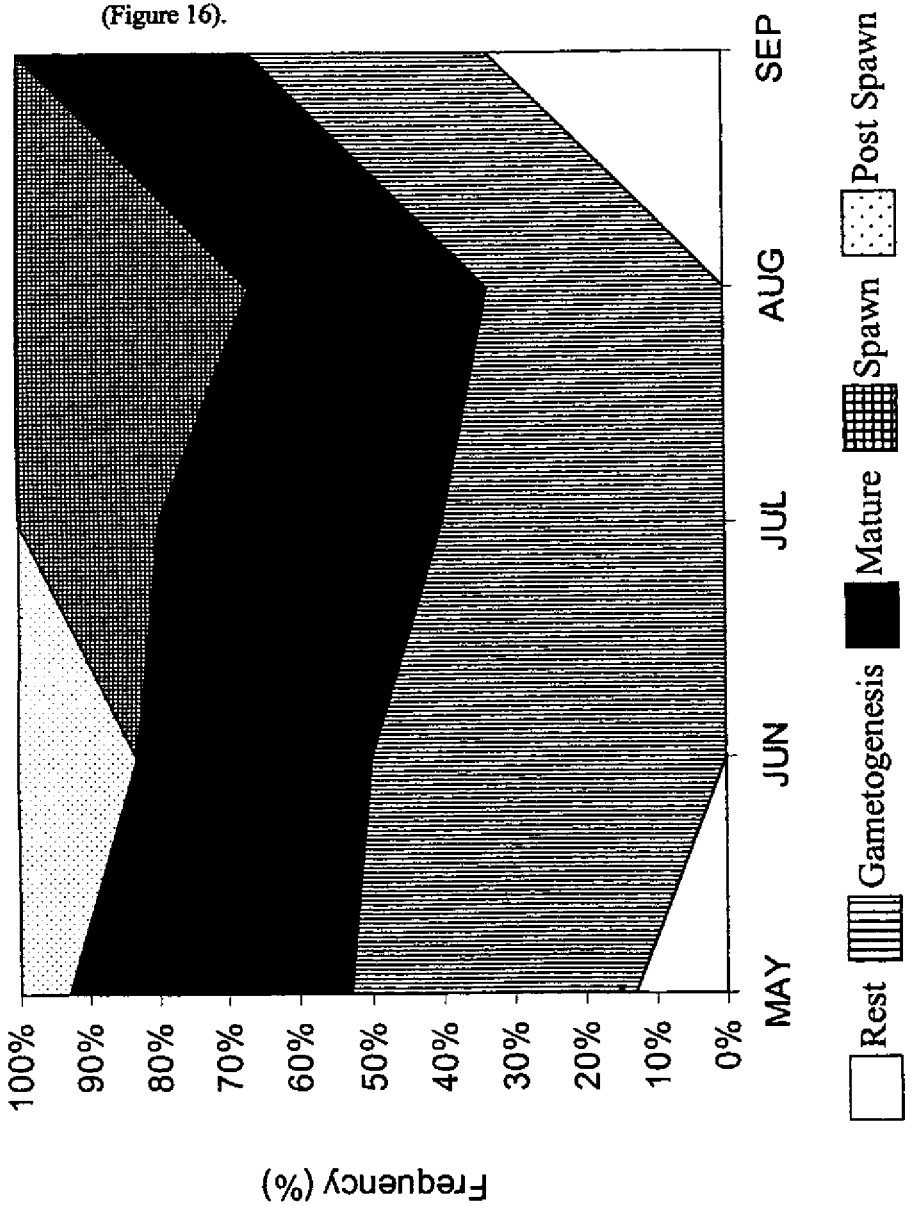


Figure 11. *Strombus gigas.* Percentage of females organism in the different reproductive stages from Chinchorro, Mexico in the Caribbean sea.

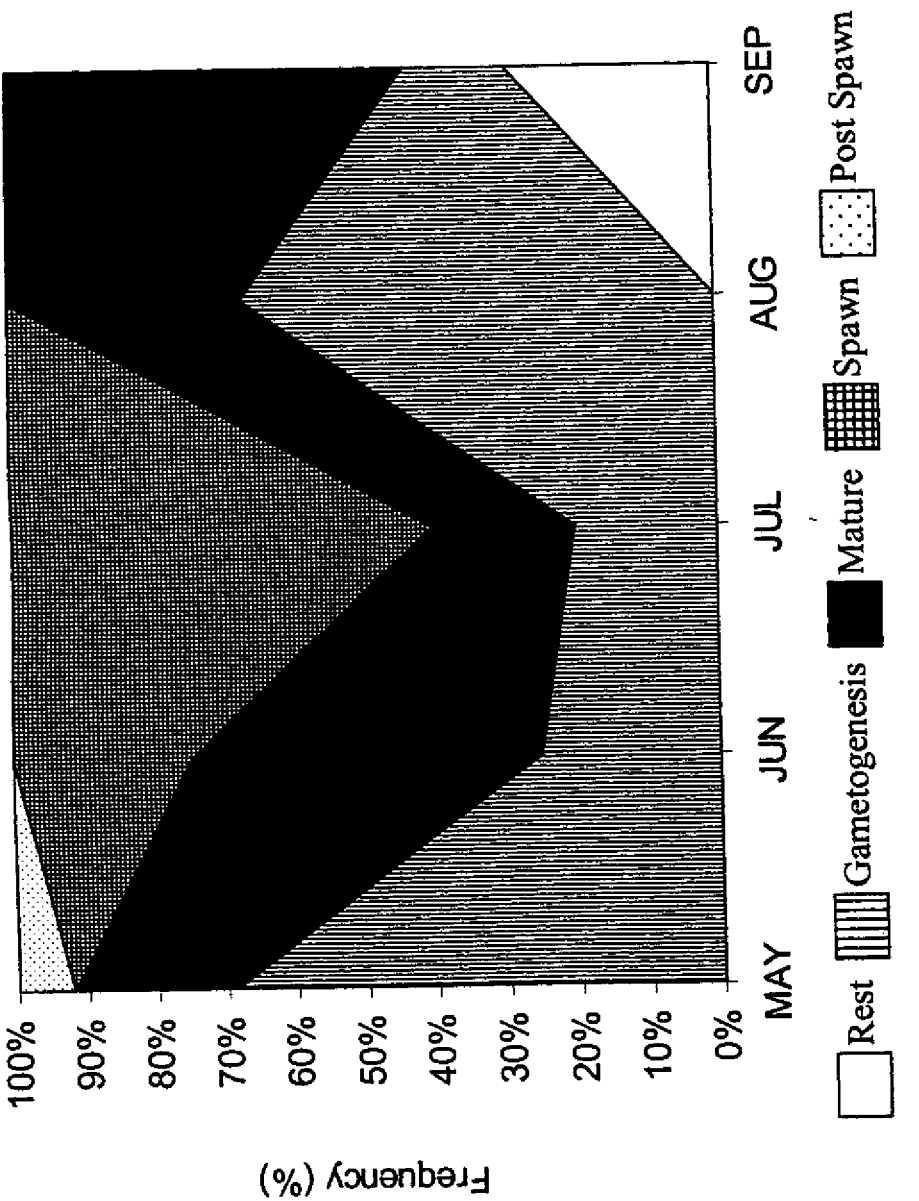


Figure 12. *Strombus gigas*. Percentage of males organisms in the different reproductive stages from Chinchorro, Mexico in the Caribbean sea.

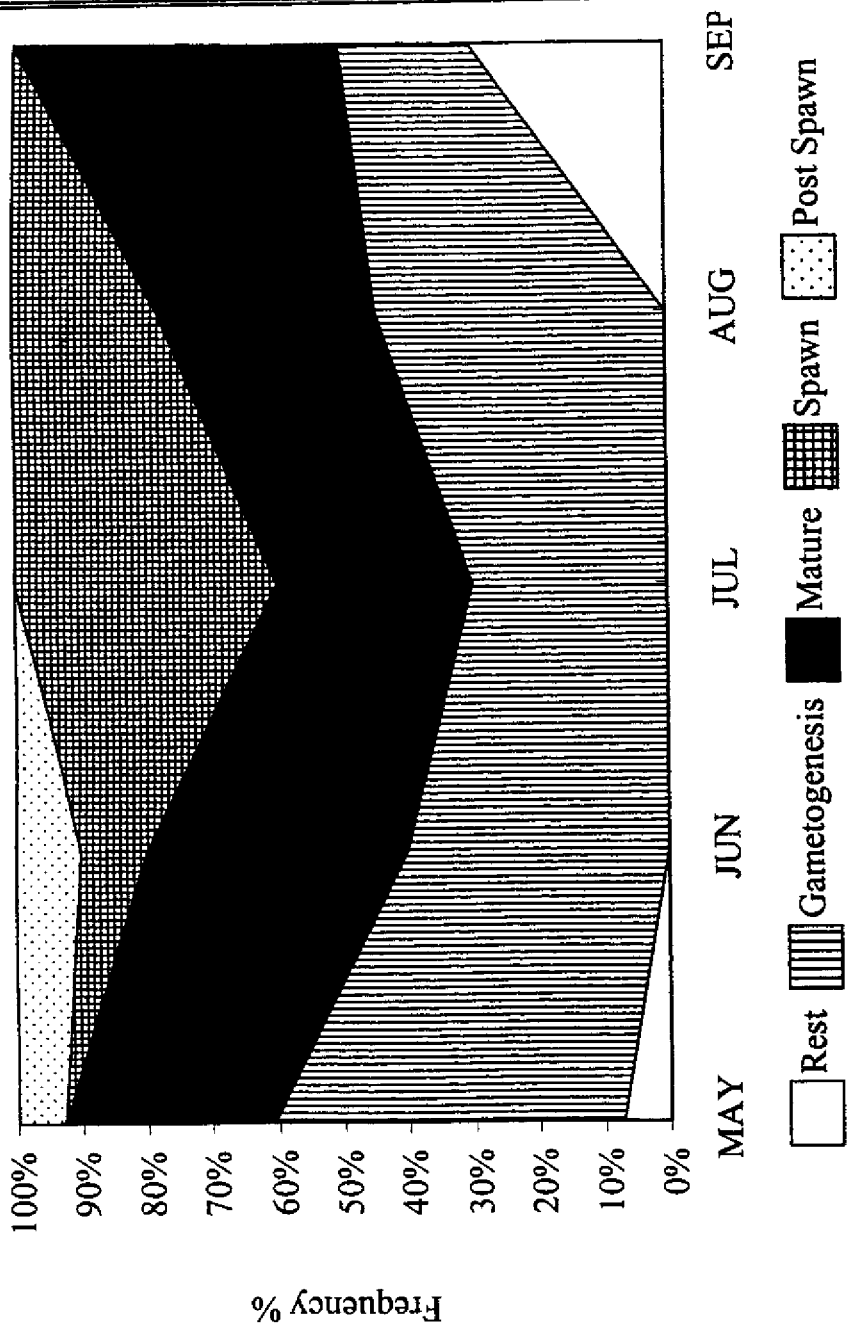


Figure 13. *Strombus gigas*. Percentage of males and female organisms in the different reproductive stages from Chinchorro, Mexico in the Caribbean sea.

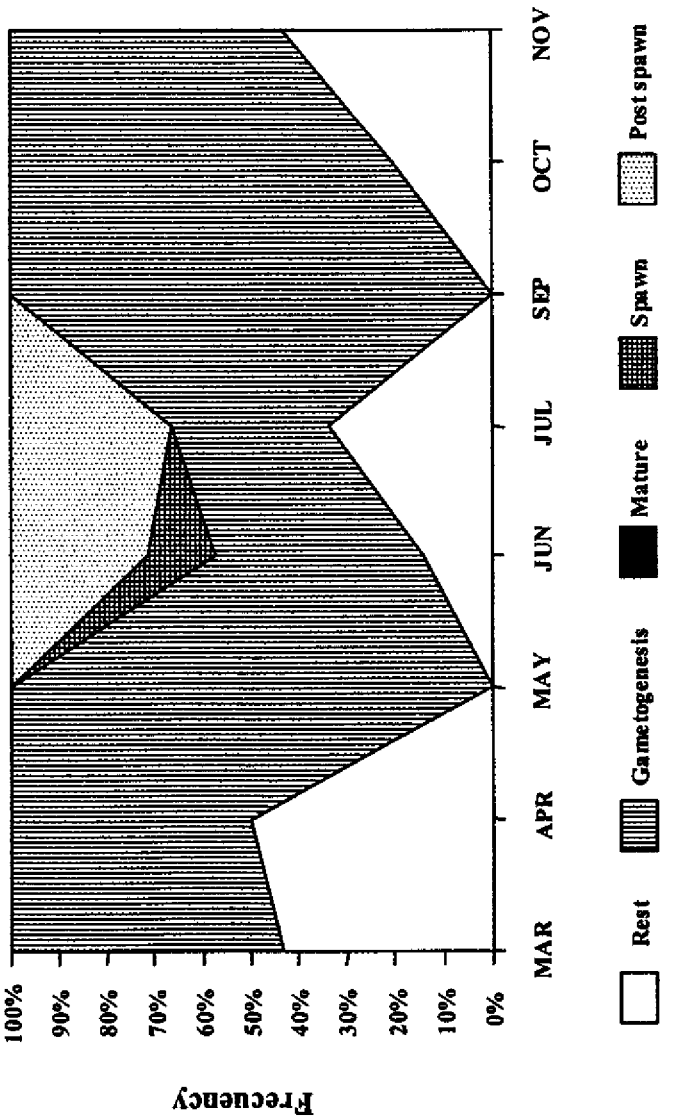


Figure 14. *Strombus gigas.* Percentage of females organism in the different reproductive stages from Alacranes reef, Mexico in the Gulf of Mexico.

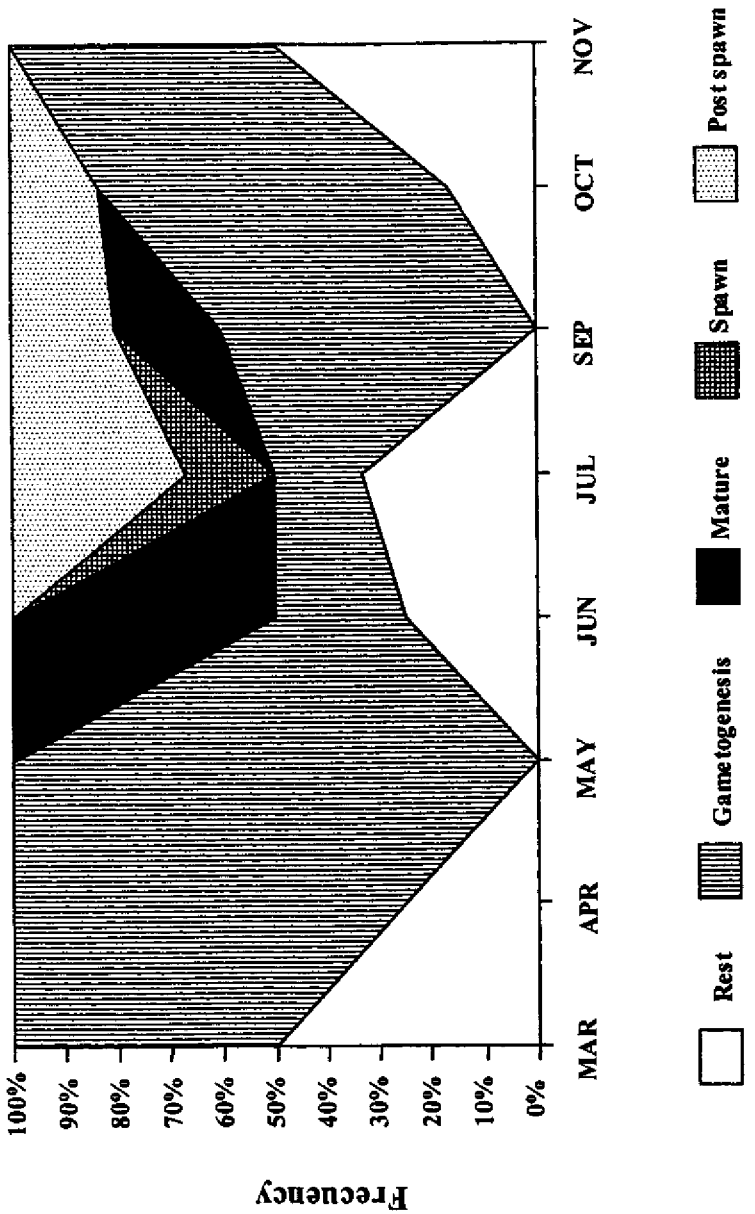


Figure 15. *Strombus gigas*. Percentage of male organisms in the different reproductive stages from Alacranes reef, Mexico in the Gulf of Mexico.

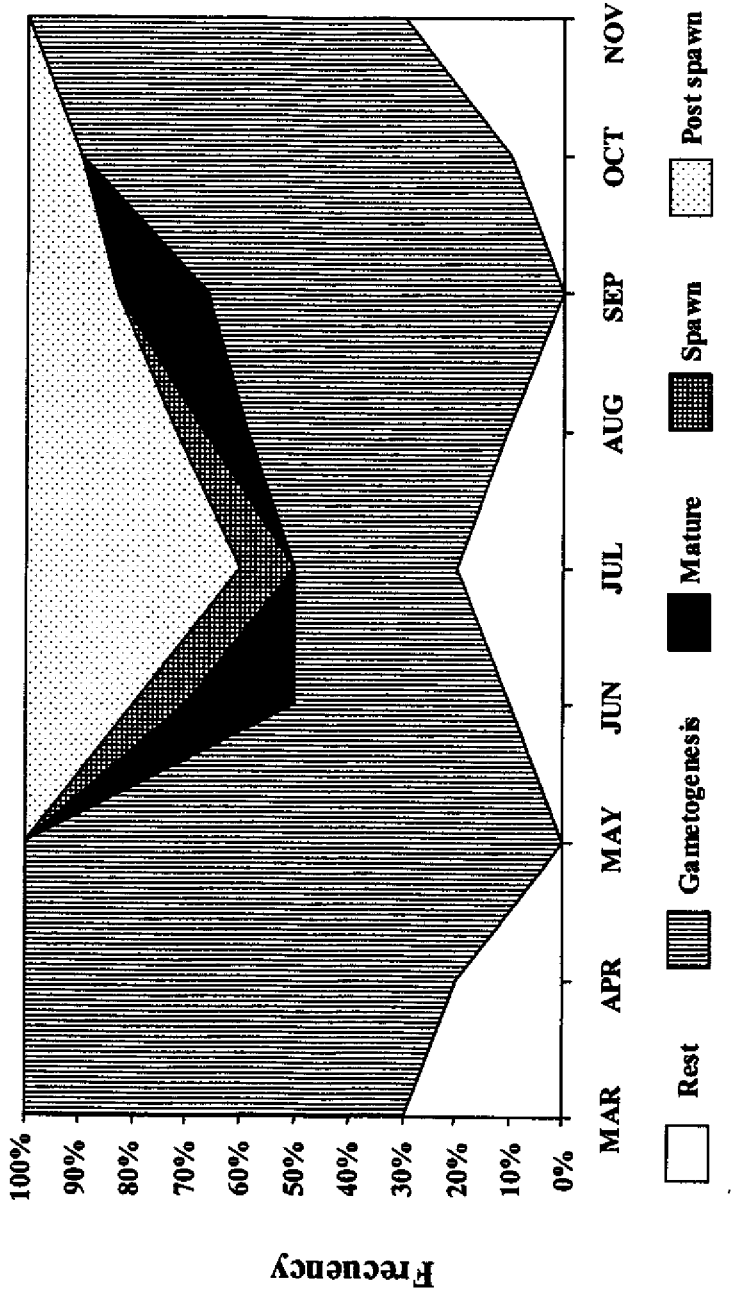


Figure 16. *Strombus gigas.* Percentage of male and female organisms in the different reproductive stages from Alacranes reef, Mexico in the Gulf of Mexico

DISCUSSION

For the two populations of *S. gigas* analyzed spawning occurs during the same months, July to August, although significant variations are evident. The population from Chinchorro reef showed a constant presence of organisms with mature gametes, with up to 40 % at the beginning of the spawning period, increasing up to 50 % at the end of the spawning season, and a maximum percentage of spawners of 40 %, and with no evident post spawning, except for 10 % of the population at the beginning of the season. Whilst the population from Alacranes reef presented a preparation for spawn in just 20 % of the population with the total participation of mature organisms at the peak of the spawning season, when up to 40 % of the population had spawned and 10 % were spawning. A similar increase in the percentage of mature organisms was detected at Alacranes at the end of the spawning season, but it had totally disappeared in October. This population presented a clear post spawn and fast gonad recovery, represented by the high percentage of organisms in gametogenesis during September. Apparently, in both populations a period of re-absorption started in autumn, exhibited by the increasing percentage of the rest stage after September.

Chinchorro Bank, being a more stable environment, more organisms exhibited a readiness for spawn but with fewer spawning. Reproductive seasons reported for *S. gigas* in the Caribbean region does not include histological results. The reproductive season of *S. gigas* has been obtained by observations of copulating or egg-laying periods. Stoner et al. (1992) compiled information on the reproductive seasons for queen conch based on behavior, taking data from different authors. At Bermuda (most northern locality), the reproductive season for *S. gigas* begins in May and ends in September. In the Florida Keys, the reproductive season is between middle January to middle September. At Venezuela (the most southern locality) the reproduction is from mid-March to mid-November. Corral and Ogawa (Stoner et al. 1992) showed that *S. gigas* at Chinchorro bank, Quintana Roo, Mexico produced eggmasses year-round. Pérez Pérez and Aldana Aranda (2000) reported a reproductive period for *S. gigas* from May to September in Alacranes reef. Stoner et al. (1992) said there was no apparent trend related to latitude for the beginning, end, or duration of the reproductive season for queen conch from Bermuda to Venezuela. Geographic comparisons of seasonality in reproduction must be interpreted cautiously due to different methods, frequency, number of observations, and different habitat types. In this study the gametogenic cycle for *S. gigas* presented differeces, even though the gonads samples were taken during the same period for Alacranes reef and Chinchorro bank. Therefore, it can be ascertained that the reproductive activity was controlled by environmental conditions.

Several authors have shown that duration and intensity of the gonadal stages are a function of temperature and food availability (Bayne 1978, Sastry 1979, Webber 1977, Fretter 1984, Mackie 1984), as well as other environmental factors (Bricelj y Malouf 1980, Syed-Shafe 1980, Jones 1981, Kennedy y Krantz 1982, Shephton

1987, Brevber 1980, Jaramillo et al. 1993).

In the reproductive cycle, the factors that induce gametogenesis and define the length and intensity of recovery periods are temperature and food availability (Lubet and Choquet 1971, Bayne 1978). While spawn may be induced by several factors as temperature (Galtsoff 1954, Holand and Chew 1973, Hines 1979), salinity fluctuations (Cain 1974, Stephner 1981), currents (Davis and Chanley 1955, Ino 1970), and the presence of some microalge (Brese and Robinson 1981) among others.

A higher frequency of mature and gametogenic organisms after the spawning peak of July is evidence of rapid gonadal recovery during the summer, which is not the case during fall and winter – spring. Slow gonad recovery is evidenced by increasing frequency of organisms at rest during September, and reminiscent of post spawners and rest organisms observed during May and June. *S. gigas* at Chinchorro has a reproductive strategy of fast gametogenesis. From the results presented herein, the need for a full cycle including several years is recommended, emphasizing environmental factors, such as temperature, food availability, and currents to better understand which might influence the gonad development and spawning periods.

For *S. gigas* at Chinchorro, one or several of these factors may be necessary to induce a massive spawn, as only a fraction of the mature population spawned, with an increasing number of mature organisms towards fall. Spawning may be induced by several factors as temperature (Hines 1979, Stoner et al 1992). Spawning has been reported from March to October at different localities on the Caribbean being more intense during May to August (Hesse 1972, Berg 1981, Orr and Berg 1987). The increasing number of mature organisms in September suggest there might be spawning in late fall or early winter, or that mature gametes are stored through the winter to spawn in early spring, as evidenced by the presence of post spawners and organisms at rest in May.

CONCLUSIONS

The gonadic cycle of any one species may vary in its seasonality, duration, and intensity of the rest and post spawn, as well as the duration and intensity of the gametogenic, maturation, and spawning periods.

Two gametogenic strategies were identified as a response to the environment:

i) Populations with a short gametognic stage or a small percentage of gametogenic organisms, which represents fast gametogenesis (*S. gigas* from Chinchorro), and

ii) Populations with a continuous gametogenesis in a very large number of organisms (*S. gigas* from Alacranes) with a very low percentage of mature organisms previous to a massive spawn in a very short time, with a very fast gonadal recovery, resuming gametogenesis.

With regards to spawning intensity and duration, one variant was identified: (1) Populations with one short defined pulse (*Strombus gigas* from both localities).

The capacity of gonad regeneration is another factor that expresses it self in the duration and intensity of the post spawning and rest periods, and on the gametogenic and maturity periods. For this, two variants were identified:

i) Populations without or with a very short and of low intensity post spawning and rest periods (*S. gigas* from Chinchorro reef), and
ii) Populations with limited or no mature stage that can support a constant or intense spawn. The characteristics presented are summarized in Table 1.

Table 1. Reproductive patterns presented by Strombus gigas at two different sites: Chinchorro bank, Quintano Roo Mexico in the Caribbean sea and Alacranes reef, Yucatan Mexico, in the Gulf of Mexico.

Patterns of S. gigas reproductive cycle	Locality	Locality
	Chinchorro bank in the Caribbean sea	Alacranes reef in the Gulf of Mexico
Gametogenesis		
Intense gametogenesis	+	-
Low intensity gametogenesis	-	+
Spawning		
One short spawning pulses	+	+
Gonad recovery		
Minimum or no post spawn and rest stages	+	-
Limited or no mature stages	-	0

From the results presented herein, knowledge of the reproductive cycle, over several years and different localities, with an emphasis on environmental factors such as temperature, food availability, and currents, as they influence gonadal development and spawning periodicity, are necessary to manage *S. gigas* populations based on reproduction activity.

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The Impact of Heat Stress on Queen Conch Larval Metamorphosis

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ABSTRACT

Physical factors including salinity and temperature are known to influence both invertebrate larval development and metamorphosis. A series of experiments with the queen conch, *Strombus gigas*, have shown that heat stress alone can induce larval metamorphosis. Low levels of metamorphosis are induced by exposure to temperatures 6-7°C above culture temperatures, with maximal induction occurring at increases of 10°C. Normal inhibitors of metamorphosis including the tyrosine kinase inhibitor genistein and the protein kinase C inhibitor phloretin do not block the heat stress response. The role of heat shock proteins in this process will be discussed.

KEY WORDS: Heat shock, larval metamorphosis, *Strombus gigas*

Impacto del Estrés por Calor en la Metamorfosis de la Larva de la Reina Concha

Se sabe que factores físicos tales como la salinidad y la temperatura, influyen tanto en el desarrollo como en la metamorfosis de larvas de invertebrados. Una serie de experimentos llevados a cabo con la reina concha, *Strombus gigas*, han demostrado que el estrés por calor, por sí solo, puede provocar metamorfosis larval. Bajos niveles de metamorfosis son inducidos mediante la exposición a temperaturas de 5-6 grados C por encima de las temperaturas de cultivo, con máxima inducción cuando los incrementos son de 10°C. Tanto las larvas precompetentes morfológicamente, como aquéllas que parecen competentes a la metamorfosis son inducidas por el estrés por calor. Inhibidores normales de la metamorfosis, incluyendo la genisteína inhibidora de la tirosina quinasa, y la floretina inhibidora de la proteina quinasa C no bloquean la respuesta al estrés por calor. Se discutirá el papel de proteinas de shock por calor en este proceso.

PALABRAS CLAVE: Estrés por calor, metamorfosis de larvas, *Strombus gigas*

INTRODUCTION

Environmental factors such as salinity and temperature are known to influence marine invertebrate larval development and survival (see Pechenik 1987 for review, Davis 2000). Recent work indicates that these factors can also directly affect larval metamorphosis (see Pechenik et al. 1998 for review). Heat stress has been shown to induce metamorphosis in several temperate marine invertebrates (Kroiher et al. 1992, Pennington et al. 1999). In these systems, an increase in temperature alone induces metamorphosis without the addition of any other natural or artificial cue. In some cases, as with the brachiopod *Laqueus californianus*, abnormal metamorphosis can be induced by heat stress (Pennington et al. 1999). However, in other cases the induction is similar to that seen with both artificial and natural chemical inducers (Kroiher et al. 1992). In the current study, the effect of heat stress on metamorphosis of the tropical marine gastropod *Strombus gigas* was examined. Exposure temperature and timing of exposure were considered, as was the onset of competency to metamorphosis. Responses to heat stress were compared to those seen with a known inducer of conch metamorphosis, an extract of the red macroalga *Laurencia poitei* (Davis 1994a, Davis and Stoner 1994, Boettcher and Targett 1996, 1998). In order to better understand the cellular mechanisms underlying heat stress induced metamorphosis the expression of heat shock proteins (HSPs) in conch larvae and recently metamorphosed juveniles were also examined.

RESULTS AND DISCUSSION

The queen conch, *Strombus gigas*, was induced to metamorphosis at low frequencies with exposure to temperatures of 6 - 7°C above culture temperatures with maximal levels of induction seen with an increase of 10°C. Elevations in temperatures greater than 10°C led to high mortality in both larvae and recently metamorphosed juveniles. These results parallel those seen with the hydroid *Hydractinia echinata* and the tunicate *Ciona intestinalis*. For both of these species, exposure to temperatures of 10°C above culture temperatures led to normal metamorphosis with higher temperatures leading to death (Kroiher et al. 1992). The levels of queen conch metamorphosis induced by heat stress and the exposure time necessary for induction were similar to those seen in conch treated with extracts of *Laurencia poitei* (Davis 1994a, Boettcher and Targett 1998). However, heat stress appears to disrupt the normal signaling pathway involved in conch metamorphosis as shown by the results of normal inhibitors of conch metamorphosis (Boettcher, unpublished data).

Heat stress induced metamorphosis in queen conch larvae was coupled to changes in the expression of heat shock proteins. Conch larvae exposed to heat stress consistently showed an increase in HSP 90 expression over time. A distinct increase in expression was seen at four hours of exposure with another increase at 24 hours post exposure. This pattern appears to be comparable to that seen for both HSP 70 and HSP 60, although the expression of these proteins has not been as well

studied. Kroiher et al. (1992) also saw increases in expression of proteins corresponding to known heat shock proteins in larval *H. echinata* exposed to heat stress. Further studies examining expression levels of HSPs in heat stress induced larvae, and in those induced to metamorphose by natural and chemical inducers of metamorphosis, will contribute to our understanding of mechanisms controlling normal metamorphosis and the impact of environmental stresses on this process (Feder 1999, Hofmann 1999, Lewis et al. 1999).

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NOTE: This is an expanded abstract and is not meant for citation purposes.

Preliminary Observations on Habitat Use of Juvenile Caribbean Spiny Lobster (*Panulirus argus*) in South Caicos, Turks & Caicos Islands

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ABSTRACT

Habitat requirements of adult Caribbean Spiny Lobsters (*Panulirus argus*) have been described in many studies, but post-settlement and juvenile habitat requirements are still poorly understood. The purpose of the present study was to determine and describe habitats inhabited by juvenile lobster around South Caicos, TCI. Potential lobster habitats were described by estimating benthic coverage using 1m^2 quadrats. Other potential lobster habitats were detected using spectral quality of satellite images. Visual surveys were carried out to estimate densities of juvenile lobster.

Juvenile lobsters were found in habitats with a relatively high abundance of the Rhodophyte, *Neogoniolithon* spp. and not in *Laurencia* spp. dominated habitats as observed in previous studies. Two areas were found to be important habitat for juvenile lobster: Gingerbread and East Bay. Gingerbread was found to be an extensive area with *Neogoniolithon* coverage of up to 50%. East Bay had densely covered areas with up to 80% of *Thalassia testudinum* and 10 to 20% of *Neogoniolithon* spp. Areas with a combined coverage of these two species contained high numbers of lobsters. Gingerbread was found to have a density of 138 lobster/ha, whereas East Bay was found to have a density of 1,199 lobster/ha. Lobster caught at East Bay were significantly smaller than lobster caught at Gingerbread.

KEY WORDS: *Neogoniolithon*, Rhodophyta, spiny lobster, West Indies

Valoracion del Habitat de la Langosta (*Panulirus argus*) Erizo Joven en South Caicos

Los diferentes habitats del la Langosta Erizo del Caribe (*Panulirus argus*) han sido descritos en numerosos estudios, pero los requisitos de post-asentameinto y de la langosta menor tienen un pobre entendimiento. El proposito de este estudio es determeinar y desctibir habitats habitdos por langostas jovenes al rededor de South Caicos. Habitats potenciales como lechos de hierba y algas fueron descritos en detalle. El porcentage de cobertura fue estimado usando 1m cuadrado cada 5 m a lo largo transectos de 30 m de largada. Otros habitats potenciales fueron detectados usando fotografias de satellite. Busquedas oculars fueron llevadas a cabo para

detectar y enumerar las langostas jovenes. Las langostas fueron capturadas con redes de mano para medirlas, pesarlas y sexarlas.

Las langostas jovenes mostraron preferencia por habitats con una relativa abundancia de alga roja especialmente *Neogoniolithon* spp. Se descubrieron dos areas principales donde se hallaron una relativamente densa poblacion de langostas: East Bay y Gingerbread. En East Bay se hallaron pequenyos parches de densidad de *Neogoniolithon* spp. rodeados por una densa zona de *Thalassia testudium*. Gingerbread consistia en uns extensa zona de menor densiada de *Neogoniolithon* spp. En East Bay se hallo la mayor densidad con 1200 langostas por hectarea, en contraste con la densidad de 138 langostas por hectarea de Gingerbread. El tamanyo de las langostas capturadas era mayor en East Bread era menor que el de las capturadas en Gingerbread.

La altura de la *Neogoniolithon* spp. quiza pueda ser la explicacion a la diferencia de densidad en la poblacion de las diferentes areas. El promedio de altura de la *Neogoniolithon* spp. era 13.4 y 7.3 cm. En East Bay y Gingerbread respectivamente. Las langostas se hallaron generalmente bajo los parches de mayor altura de *Neogoniolithon*, ya que estos proporcon mayor cobijo. La profundidad del agua fue otro factor de consideracion en lo que concierne a la densidad de poblacion de la langosta ya que los depredadores no alcanzan facilmente las zones menos profundas de East Bay.

PALABRAS CLAVE: *Neogoniolithon*, Rhodophyta, langosta erizo

INTRODUCTION

The spiny lobster, *Panulirus argus*, is one of the largest fisheries in the Caribbean and many stocks are seriously threatened by over-fishing and habitat destruction (Medley and Ninnes 1997, Eggleston et al. 1998). Along with queen conch, the spiny lobster is the most valuable marine resource in the Turks & Caicos Islands (TCI). To avoid over-fishing in the TCI, it is important that lobster stocks are sustained through careful management, research and monitoring.

Research and management have been focused on adult spiny lobster for decades. However, recruitment of juveniles is critical to the long-term sustainability of spiny lobster populations. Therefore, information on larval availability, larval settlement, and movement to stage specific habitats can help to understand the recruitment processes of the spiny lobster (Herrnkind and Butler 1986). However, juvenile lobsters are difficult to study, and hence little is known about the early juvenile stages (Herrnkind and Butler 1986, Lyons 1986, Butler et al. 1997).

After a relatively long larval period, lobsters migrate to shore where they settle in complexly structured habitats (Butler et al. 1997). *Laurencia* spp. have been described as favorable settlement substrate (Butler and Herrnkind 1992). Specimen of this genus provide shelter and habitat for gastropods, isopods and amphipods preyed upon by the juvenile lobster (Marx and Herrnkind 1985) as well as forming complex structures within which the lobsters can hide (Butler and Herrnkind 1992).

The preference for *Laurencia*-dominated habitats exists when the carapace length (CL) of the lobster is less than 18 mm. When the CL increases, lobsters search for shelter in crevices and caves (Butler and Herrnkind 1992). Accompanying this change in preferred habitat, lobsters discontinue solitary living and begin to aggregate (Butler et al. 1997, Eggleston et al. 1998).

The goal of this study was to describe juvenile lobster habitat and to examine lobster density and juvenile size ranges at multiple sites surrounding South Caicos.

MATERIALS AND METHODS

Habitat Description

Habitats were surveyed at eleven sites around South Caicos (Figure 1). South Caicos is the most southeastern island of the Caicos Bank, being part of the Turks & Caicos Islands. Sites with abundant *Laurencia* spp. were surveyed from October to December 2000. Additionally, local fishermen were interviewed to locate juvenile lobster habitat. Spectral quality of a satellite image was used to detect other areas of interest. As a result, two additional areas were surveyed: Gingerbread and East Bay (Figure 1). Gingerbread was located north of Middleton Cay and west of Moxie Bush on the Caicos Bank just outside the East Harbour Lobster and Conch Reserve (EHLCR). East Bay was located at the southeastern coast of South Caicos within the Admiral Cockburn Land and Sea National Park (ACLSNP). The habitat surveys of these two areas were carried out in March and April 2001.

Habitat was estimated by describing the percent cover of the benthic species present. A $1m^2$ quadrat was placed every 5 m along a 30 m transect line. The quadrat was divided by twine into 100 squares ($10 cm^2$ each) to ease the estimation. Multiple transects were run at each site. Most benthic organisms were determined to genus level. However, seagrasses were determined to species level, whereas all *Porifera* were grouped. For each analysis, tide, water depth and UTM coordinates were recorded.

Lobster Measurements and Density Estimates

Every surveyed quadrat of the benthic community was thoroughly searched for juvenile lobster. Four 50 m^2 plots were examined to estimate density of lobster at Gingerbread. Teams of divers swept the area in sections counting the total number of lobster. At East Bay, lobster counts were conducted by visually estimating the number of lobster in and around the patches of *Neogoniolithon*. The patches were then measured with a transect tape to calculate lobster density.

Lobsters were caught with small nets, measured, and immediately returned to substrate. Carapace length (CL) was measured with calipers (mm), weight was determined with a hand-held spring scale (5g increments), and each specimen was sexed. Observation of potential lobster predators was recorded.

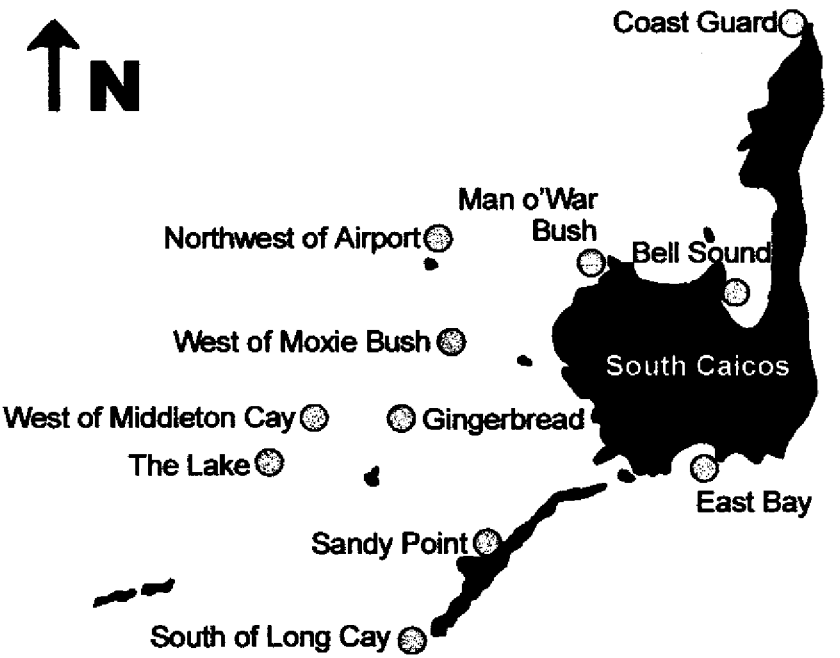


Figure 1. South Caicos and the 11 sites surveyed from October 2000 to April 2001

RESULTS

Benthic Cover

In total, 20 sessile benthic organisms were found at 11 sites (Table 1). Gingerbread and East Bay were the most diverse, however these sites were studied more intensively; the number of observations was 322 and 168, respectively. At other sites the number of observations ranged from 28 to 84 (Table 1).

Total benthic cover ranged from 9 to 53% in the *Laurencia*-dominated habitats (Figure 2). Man o'War Bush and West of Moxie Bush had the highest percentage of *Laurencia* of over 30%. However, no juvenile lobster were observed in these *Laurencia*-dominated habitats. The average water depth of these habitats ranged from 0.1 to 4.2 m. Local fishermen had suggested searching the area South of Long Cay. This area was found to be dominated by another Rhodophyte, *Neogoniolithon* spp., with a mean benthic cover of 18.9% (Figure 2). Again, no juvenile lobster were observed. A similar habitat was found off Sandy Point at Long Cay. *Neogoniolithon* dominated this habitat with a mean benthic cover of 39.6% (Figure

2). One lobster was observed at Sandy Point although *Laurencia* only covered 0.5% of the benthic community (Table 1).

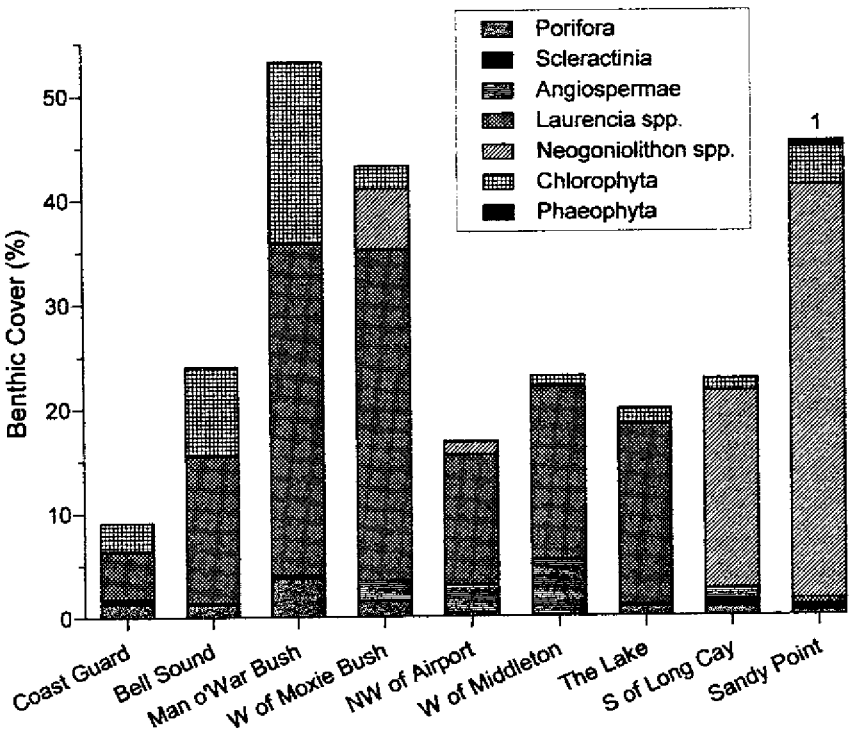


Figure 2. Percent coverage of benthic species for 9 sites surrounding South Caicos surveyed from October to December 2000 and in March 2001. Number of observed lobster is indicated on top of respective bar

As a result of the above patterns, we decided to survey other habitats than those dominated by *Laurencia*. Two areas were found that contained juvenile lobsters: East Bay and Gingerbread (Table 1). These areas were so extensive that an increased number of observations was made to get an accurate description of these habitats.

Gingerbread consisted of an area with dense benthic cover (50 - 70%) and a larger, less dense area with 30 to 40% benthic cover (Figure 3). All surveyed sites at Gingerbread showed a dominance of *Neogoniolithon* (20 - 60%). *Porifera* were present at all sites, mainly represented by the chicken liver sponge (*Chondrilla nucula*) with a benthic coverage up to 12% at some of the sites. Furthermore, low benthic coverage of seagrasses and Chlorophyta were found at all sites (Table 1).

Table 1. Average percent benthic coverage per Phylum (Porifera), genus or species for 11 studied sites off South Caicos. Percentage of sand, coral rubble and number of quadrats (n) are additionally shown.

Study area	Coast Guard	Bell Sound	Man o'War Bush	Northwest of Airport	West of Moxie Bush	West of Middleton	The Lake	South of Long Cay	Sandy Point	Gingerbread	East Bay
n	63	56	35	84	28	42	77	42	28	322	168
Chlorophyta					2.14						0.24
Acetabularia spp.		0.10								0.00	0.00
Batophora spp.	1.83	0.52		1.07	0.02	0.20	0.47		1.13	1.20	0.08
Caulerpa spp.	0.10	7.07	17.4	0.04	0.05				0.06	0.00	0.05
Halimeda spp.	0.13	0.19	0.00	0.08		0.15	0.25	0.94	2.28	0.02	0.16
Penicillis spp.	0.16	0.50	0.02	0.29	0.04	0.67	0.55	0.27	0.19	0.84	0.24
Rhipocephalus spp.	0.09	0.02					0.08			0.00	0.00
Udotea spp.	0.36	0.06				0.01	0.15	0.01			
Phaeophyta											
Dictyota spp.				0.10					0.61	0.29	0.05
Padina spp.							0.03				
Rhodophyta											
Laurencia spp.	4.54	14.1	35.4	12.5	31.7	16.5	17.2	0.01	0.54	0.60	0.46
Neogoniolithon spp.	0.02			1.19	5.79		0.03	18.9	39.6	43.2	10.8
Angiospermae											
Syringodium filiforme					1.98	0.18	0.03			0.00	2.01
Thalassia testudinum				2.68		5.27	0.03	1.03	0.21	1.75	43.2
Porifera	1.31	1.20	3.70	0.32	1.54	0.01	0.84	0.75	0.38	6.68	0.57
Scleractinia											
Favia fragum				0.01							
Isophyllia sinuosa										0.00	
Manicina areolata										0.00	
Porites porites	0.54	0.12	0.06			0.11		0.81	0.44	0.12	0.00
Siderastrea radians		0.08	0.20								
Siderastrea siderea			0.06							0.00	0.00
Sand	89.3	75.9	43.9	81.8	56.7	76.9	80.0	76.7	54.6	46.7	44.2
Coral Rubble	1.57	1.01					0.19	0.58			0.00

The water depth ranged between 0.7 and 1.7m depending on the tide. In total, three lobsters were found within the quadrats (Figure 3), and more were observed in the surrounding area. Sharks, rays, and other lobster predators were regularly observed in this area.

East Bay was dominated by *Thallassia testudinum* and showed the highest benthic coverage of all surveyed sites of up to 82% (Figure 4). A total number of 30 lobsters was found during four observations which all had a total benthic coverage of 10 to 20% of *Neogoniolithon*. No lobsters were found at the sites that

had a lower portion of *Neogoniolithon* (Figure 4). The sites at East Bay had a water depth ranging from 0.2 to 1m. A small lemon shark was observed once at high tide.

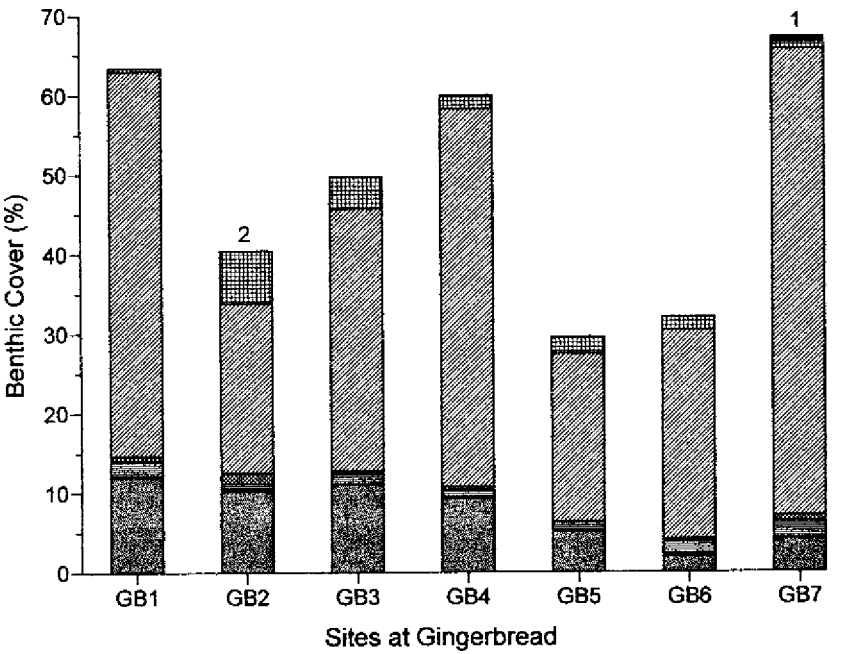


Figure 3. Percent coverage of benthic species for seven locations at Gingerbread off South Caicos surveyed from March to April 2001. Legend can be found in Figure 2. Number of observed lobster is indicated on top of respective bar.

Juvenile Lobster Densities

The average densities found at East Bay and at Gingerbread in dense benthic coverage were relatively high with 1,199 and 138 lobster/ha, respectively. The area surrounding Gingerbread with less dense benthic coverage and at Sandy Point relatively low densities of 4.0 and 6.2 lobster/ha were found.

The carapace length of lobster found at East Bay ranged from 14 to 56 mm with an average of 37.2 mm (n = 30). The carapace length of lobster measured at Gingerbread ranged from 28 to 76 mm with an average of 53.4 mm (n = 30). Lobsters were significantly smaller (t-test, $P < 0.01$) at East Bay than at Gingerbread. The one lobster found at Sandy Point had a CL of 58 mm.

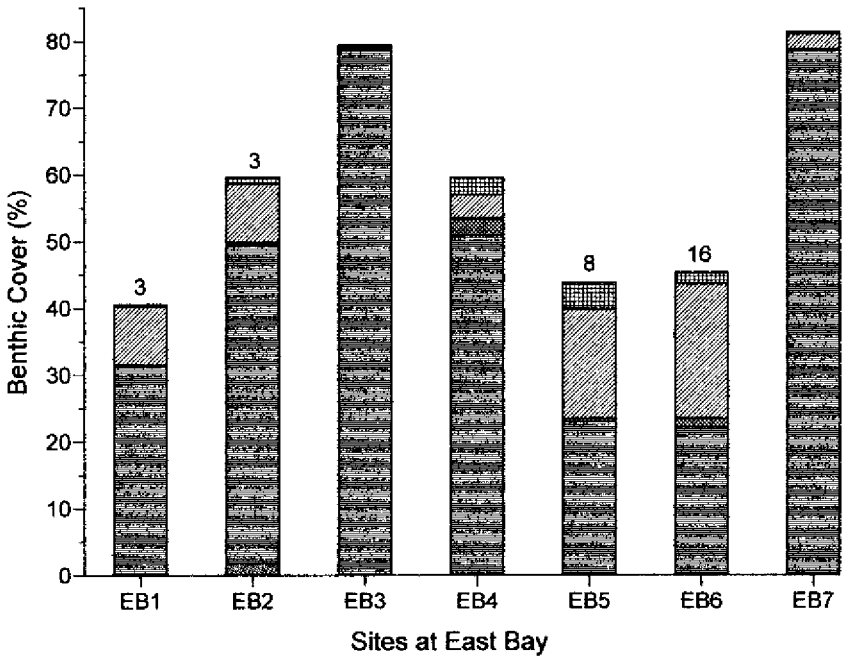


Figure 4. Percent coverage of benthic species for 7 locations at East Bay off South Caicos surveyed from March to April 2001. Legend can be found in Figure 2. Number of observed lobster is indicated on top of respective bar.

DISCUSSION

Laurencia versus *Neogoniolithon*

Previous studies indicated that juvenile lobster prefer to settle in complexly structured habitats of selected Rhodophytes (Butler et al. 1997). The genus *Laurencia* has been described as favorable settlement substrate for spiny lobster (Butler and Herrnkind 1992). The complex structure provides lobster space in which to hide. At the same time, prey species of juvenile lobster like gastropods, isopods and amphipods hide in these structures (Marx and Herrnkind 1985).

The *Laurencia*-dominated habitats surveyed during the present study (Figure 2) should have been ideal habitat for young juvenile lobster according to these previous studies. However, juvenile lobster were not observed in the *Laurencia*-dominated habitats (Figure 2). Even at the sites with highest benthic cover of *Laurencia* (35.4% at Man o'War Bush; Table 1) no lobsters were observed.

Ecological knowledge obtained from local fishermen indicated that juvenile lobster could be found in patches of another Rhodophyte of the genus *Neogoniolithon*. Curiously, previous studies have never linked lobster populations with this red alga. *Neogoniolithon* is the genus of a variety of calcareous red algae that thrive in shallow clear waters. These benthic algae either form a thin layer across the bottom, or grow upwards forming complex reef structures with crevices, caves and holes (Steneck et al. 1997). *Neogoniolithon* spp. support a unique set of algae, fish and invertebrates, possibly providing the lobster with sufficient prey.

The first habitats surveyed with an abundance of *Neogoniolithon* spp. were South of Long Cay and Sandy Point (Figure 2). At Sandy Point the first lobster was found to be hiding in a crevice underneath a patch of *Neogoniolithon*. Although this was only an indication that lobster inhabited this habitat, satellite images were used to detect similar habitat types. Gingerbread and East Bay were found to have a relatively high benthic coverage of *Neogoniolithon*. Gingerbread was dominated by *Neogoniolithon* with a coverage of up to 60% (Figure 3). In East Bay, *Neogoniolithon* was the second dominant species with a coverage of up to 20% (Figure 4). The importance of this observation may be that the lower density of *Neogoniolithon* supported the highest density of juvenile lobster. Juvenile lobster were found to densely populated *Neogoniolithon* patches in East Bay, where the habitat was dominated by *Thalassia testudinum*. Juvenile lobster have been shown to prefer dens with *T. testudinum* growing close by (Herrnkind et al. 1994). The seagrass provides food and shelter for the lobster when they leave their dens. In this study, the combination of *T. testudinum* and *Neogoniolithon* was found to be a relatively good habitat for juvenile lobster supporting high lobster densities.

Lobster Size

Significantly smaller lobsters were found in East Bay than in Gingerbread, which could have been due to a variety of factors. The close proximity of a coral reef and open ocean to East Bay may enable lobster to migrate to adult habitat at a smaller size than at Gingerbread. Migration to the reef from the relatively isolated Gingerbread may be a dangerous undertaking for lobster.

Another reason for the difference in size of lobster between East Bay and Gingerbread may have been the presence of predatory fish and sharks. Juvenile lobster prefer shallow waters (Lipcius and Cobb 1994) and the protected nature and shallowness of East Bay (0.2 – 1.0 m) allows large predators to enter only during high tides. Since lobster become less vulnerable to predation as they grow larger (Smith and Herrnkind 1992), the smaller specimen at Gingerbread may have been caught by predators. Small juvenile lobster may have a decreased mortality rate in the shallows of East Bay.

The smaller size lobster at East Bay may also have been related to fishing activities. The larger specimens at East Bay may have been taken by humans, which would have decreased the average size of lobster in the bay. Close proximity to shore and the town of Cockburn Harbour makes poaching in East Bay a realistic threat.

The size of lobster observed in the present study ranged from 14 to 76 mm carapace length. However, averages of carapace length of 37.2 mm in East Bay and 53.4 mm in Gingerbread indicated that the majority of the lobster were over 30 mm CL. When lobsters reach a CL of 15 to 18 mm, they leave their settlement habitat and move to den structures (Butler and Herrnkind 1992). As observed in this study, *Neogoniolithon* spp. provided these den structures, whereas no lobsters were observed in the *Laurencia* habitat (Figures 2 - 4). Continued surveys in South Caicos are planned to describe the habitat where pueruli settle and post-settlement lobsters hide. The enclosed character of East Bay may help out in these future surveys. East Bay is enclosed by land and reef and has only a small seagrass connection to the bank in the western corner of the bay. Since juvenile lobsters of all size ranges have been observed here, it is expected that all life stages are present and that settlement takes place in East Bay.

The purpose of the present study was to gain a better understanding of the processes affecting the distribution of the juvenile spiny lobster in South Caicos. Investigating larval settlement, determining habitats preferred by juvenile spiny lobsters and analyzing the structure of these habitats need to be continued to increase the knowledge of juvenile lobster behavior and life history processes. Managers may use this information to conserve and perpetuate the critical habitat for long-term sustainability of the Caribbean spiny lobster.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the key financial and logistical support provided by The School for Field Studies, Center for Marine Resource Studies (Publication number SFS/CMRS053). We thank Megan Baldwin, Leigh Berkowitz, Katy Doctor, Pat Gaughan, Cindy Lai, Kara Shuster, Ryan Tabereaux and Lizzy Taylor from the fall 2000 semester and Matt Ewing, Ben Havard, Jeff Iwashita and Elias Kassis from the spring 2001 semester, who all helped to collect the data presented in this paper. We also thank Ilsa Kuffner for her comments on a previous version of this manuscript.

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Size-Dependent Habitat Use of Juvenile Queen Conch (*Strombus gigas*) in East Harbour Lobster and Conch Reserve, Turks and Caicos Islands, BWI

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ABSTRACT

To better understand the habitat requirements of juvenile queen conch, we conducted visual surveys in a variety of habitats within East Harbour Lobster and Conch Reserve (EHLCR) from July 2000 to August 2001. Visual surveys were carried out using integrated line and belt transects at randomly selected sites within the reserve every three to four months. All juvenile conch encountered were enumerated and categorized as small (< 150 mm), medium (150 – 200 mm), or large (> 200 mm), and the habitat type recorded to determine whether ontogenetic shifts in habitat use were evident. The siphonal length of small juveniles was also measured to determine whether habitat use was size-dependent within this category. In addition, because small juveniles often remain in the substrate during the day, we conducted paired diurnal-nocturnal visual surveys in different habitats within the reserve to monitor their emergence. Our results indicate that small, medium, and large juveniles were most abundant in a unique, densely vegetated coral rubble habitat. Algal plain habitat also contained a relatively high number of small juveniles, with the highest densities occurring within a small area (< 5 ha) believed to be a nursery ground. The majority of smaller juveniles (55-90 mm) observed during our surveys were found in this area, primarily at night. From these results we conclude that juvenile queen conch occupy a variety of habitats in EHLCR and that use of these different habitats is size-dependent. Our results also suggest that algal plain habitat may be important for small, post-settlement juveniles, although the generality of this finding remains to be tested.

KEY WORDS: Habitat use, juvenile queen conch, Turks and Caicos Islands

INTRODUCTION

The queen conch (*Strombus gigas*) is an important marine resource that has a long history of supporting subsistence and commercial fisheries throughout its' range (Mulliken 1996). Recently though, queen conch stocks have been overexploited in many areas (reviewed by Appeldoorn 1994), and a variety of measures have been taken to reduce fishing pressure and conserve stocks. One such measure is the establishment of no-take fishing reserves designed to protect critical habitats and

enhance queen conch stocks (e.g., Posada et al. 2000, Tewfik and Béné 2000). However, for these reserves to be effective and their benefits sustained, they need to include the critical habitats of all life stages of queen conch, from post-settlement juveniles to spawning adults (Stoner 1997).

Although the habitat use of adult queen conch is well studied, less in known about the habitat requirements of juveniles, particularly small (< 150 mm) individuals. Because queen conch are primarily infaunal during their first year emerging from the substrate only at night to feed (Iverson et al. 1986, 1989), areas inhabited by small juveniles are often overlooked. Even so, it is reasonable to hypothesize that the survival of small, post-settlement juveniles (age 0 to age 1) is higher in areas where food is abundant and the substrate is conducive to burial. It is also likely that as juveniles grow their habitat requirements change, since, for example, their need to bury to avoid predators decreases with size and shell strength (Appeldoorn 1984).

To better understand the habitat requirements of juvenile queen conch, we conducted visual surveys within East Harbour Lobster and Conch Reserve (EHLCR), a no-take fishing reserve off of South Caicos, Turks and Caicos Islands (TCI). During these surveys we examined the distribution and abundance of juvenile queen conch to assess whether habitat use is size-dependent, and to investigate the presence of a suspected nursery ground within EHLCR.

MATERIALS AND METHODS

The TCI are located at the southern end of the Bahamian archipelago, about 180 km north of Hispaniola. South Caicos is situated on the eastern side of the Caicos Bank with EHLCR abutting the island and covering an area of shallow bank approximately 13 km^2 in size (Figure 1).

Manta-tow surveys conducted in April 2000 revealed that most of the queen conch within EHLCR inhabit the eastern quarter of the reserve. As such, our sampling sites were randomly selected from this area using a remote sensing image (the Landsat 7 Thematic Mapper image, September, 1999) and Idrisi 32 (Clark Labs, Worcester, MA, USA). To ensure that the trend we observed during the manta-tow surveys was consistent throughout the year, sites were also periodically surveyed throughout the entire reserve. Surveys were conducted approximately every three to four months, with more than 170 sites surveyed between July 2000 and August 2001.

Three integrated line intercept and belt transects were run at each site. Line intercept transects were 30 m long and were used to determine habitat type. Habitats intercepted by the transect line were assigned to one of six categories based on substrate composition (Table 1). If a transect line intercepted more than one habitat, the distance at which the transition occurred was measured, and the proportion of each habitat type determined accordingly.

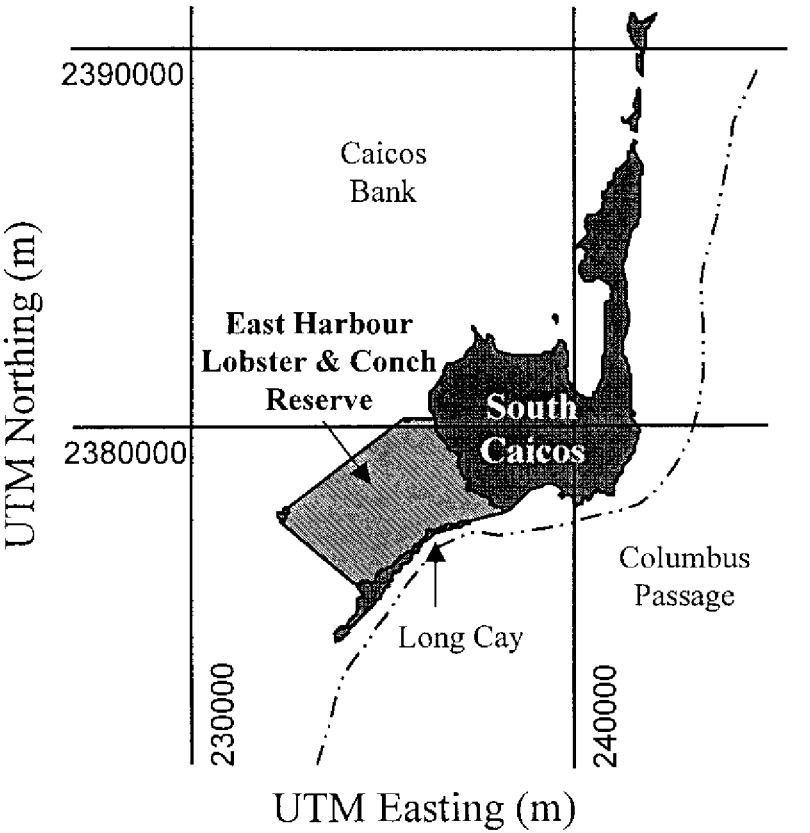


Figure 1. East Harbour Lobster and Conch Reserve, South Caicos, BWI. Coordinates are for the Universal Transverse Mercator (UTM) metric grid system in Zone 19N.

Each intercept transect was bounded by a 3-m wide belt, for a total survey area of 90 m^2 per transect and 270 m^2 per site (3 x 90 m^2). Queen conch found within the belt transect were enumerated and categorized by size/age based on siphonal length (SL), and the development of the shell lip (Table 2). All queen conch categorized as small juveniles (< 150 mm SL) were measured to the nearest mm with vernier calipers.

The abundance of juveniles within the small (< 150 mm), medium (150 - 200 mm), and large (< 200 mm) categories was determined for each transect, and the mean abundance of each size category calculated for all sites. To examine whether habitat use is size-dependent within the reserve, mean abundances were converted to densities (#/ ha) for each site and then compared among habitat types.

Table 1. Habitat categories used during visual surveys of juvenile queen conch in EHLCR (modified from Tewfik and Béné 2000).

Category	Code	Description
Algal plain	AP	Coarse or fine sand with benthic macroalgae (*Laurencia spp., Penicillus spp., Dictyota spp., Batophora spp.)*
Seagrass	SG	Coarse sand bottom dominated by *Thalassia sp.* and/or *Syringodium sp.*
Sand plain	SP	Coarse sand or fine coral rubble with little or no algae or seagrass
Coral rubble	CR	Coarse coral rubble with benthic algae and/or seagrass cover
Gorgonian/sponge	GS	Hard bottom dominated by gorgonians (*Gorgonia spp., Plexaura spp., Pterogorgia spp., Pseudoterogorgia spp.*) and sponges
Coral heads	CH	Small coral heads surrounded by other habitat types; living coral

Table 2. Size/age categories of juvenile queen conch used during visual surveys in EHLCR (from Tewfik and Béné 2000).

Category	Code	Description
Small Juvenile	SM	<150 mm siphonal length, no shell lip
Medium Juvenile	ME	150-200 mm siphonal length, no shell lip
Large Juvenile	LG	>200 mm siphonal length, no lip

To test for differences in the size of small juveniles among habitat types, the mean SL of small juveniles was calculated for each transect and a mean generated for each site surveyed. One site in each of four different habitats where small juveniles were found during the day, was also selected for paired diurnal-nocturnal surveys during each sampling period. The data from all sampling periods were then pooled and day-night length-frequency distributions generated to determine whether small juveniles were more abundant at night within certain habitats.

Data were tested for normality and homogeneity of variance with Shapiro-Wilk and Bartlett tests, respectively (Sokal and Rohlf 1995). When necessary, the data were transformed ($\log_{10}$ or $\log x+1$) to meet the assumptions of parametric statistics (t-test, ANOVA and Tukey's LSD test), and when these assumptions could not be satisfied, non-parametric statistics (Kruskal-Wallis, Mann-Whitney U) were employed. Length-frequency distributions were compared using Kolmogorov-Smirnov two sample tests (Sokal and Rohlf 1995). For all statistical tests, differences among variables were considered marginally significant if $0.1 \geq P > 0.05$ and significant if $P \leq 0.05$. All statistical analyses were performed using Statistica '99 for the PC (StatSoft Inc., Tulsa, Oklahoma USA).

RESULTS

Over the course of our study we encountered more than 5400 juvenile queen conch in six different habitat types, and surveyed over 46,000 m^2 (4.6 ha) of EHLCR. Within the reserve, the density of small (log x+1), medium, and large juveniles was significantly different among habitat types (small, ANOVA $P < 0.01$; medium and large, Kruskal-Wallis, $P < 0.01$), with the densities of all three size categories higher in coral rubble (CR) than in any other habitat type (small, Tukey's LSD, $P < 0.05$; medium and large, Mann-Whitney U, $P < 0.01$; Figure 2). The density of small juveniles was also higher in algal plain (AP) than in seagrass (SG), gorgonian/sponge (GS) or sand plain (SP) (Tukey's LSD, $P < 0.05$), whereas the density of medium juveniles was not significantly different in AP and SG ($P > 0.1$), but was higher in these two habitats than in GS and SP (Tukey's LSD, $P < 0.05$). The density of large juveniles was also higher in SG than in SP (Mann-Whitney U, $P < 0.05$), but not significantly different than in AP, CH, or GS ($P > 0.1$).

Differences in the siphonal length of small juveniles among habitat types were marginally significant (Kruskal-Wallis, $P < 0.1$), with a trend towards larger individuals in CR and coral head (CH) habitats (Figure 3). Day-night comparisons in AP, SG, CR, and SP revealed that more, smaller individuals were present at night in AP, SG, and SP (Figure 4), yet these differences were only statistically significant in AP (Kolmogorov-Smirnov, $P < 0.05$).

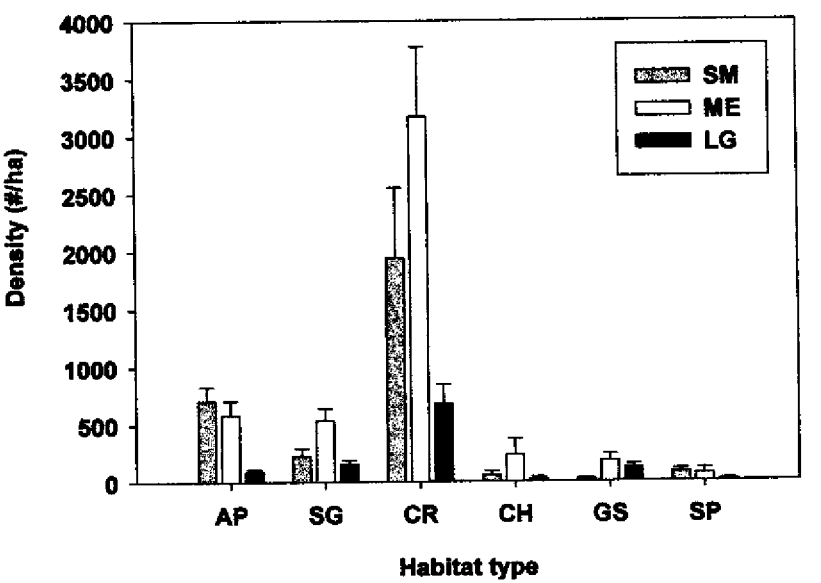


Figure 2. Mean density (± 1 SE) of small (SM), medium (ME), and large (LG) juvenile queen conch observed in different habitats in EHLCR from July 2000 to August 2001. Note: AP = algal plain, SG = seagrass, CR = coral rubble, CH = coral heads, GS = gorgonian/sponge, and SP = sand plain.

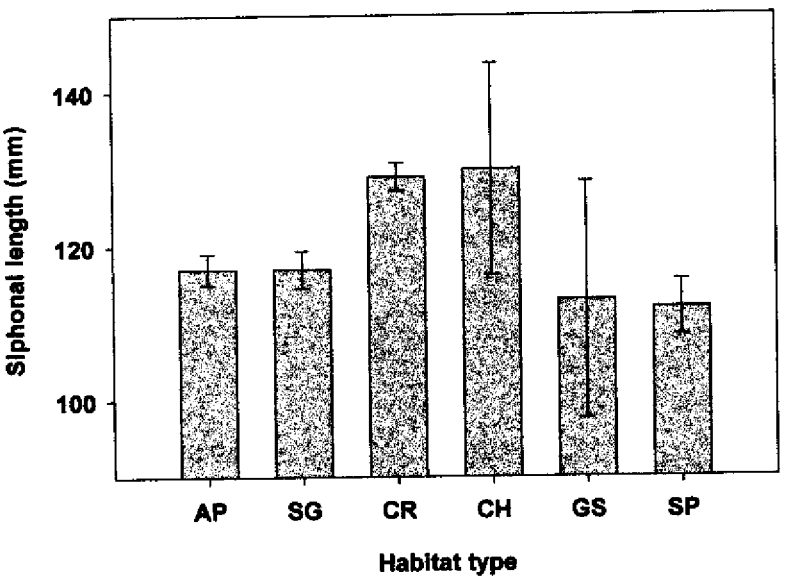


Figure 3. Mean siphonal length (± 1 SE) of small juvenile queen conch found in different habitats in EHLCR from July 2000 to August 2001. Note: AP = algal plain, SG = seagrass, CR = coral rubble, CH = coral heads, GS = gorgonian/sponge, and SP = sand plain.

DISCUSSION

Our results indicate that within EHLCR juvenile queen conch are most abundant in a unique CR habitat overgrown with macroalgae and interspersed with seagrass. Although many small juveniles (< 150 mm) were found within this habitat, the highest number of juveniles between 55 and 90 mm were found within AP, primarily at night. This suggests that within EHLCR larval settlement and juvenile survival may be highest in AP, possibly because the macroalgae within this habitat induce settlement (Boettcher and Target 1996, Davis and Stoner 1994) and provide a suitable food source (Stoner and Waite 1990), while the sandy substrate allows juveniles to bury to avoid predation. On the other hand, no juveniles smaller than 95 mm were found in CR suggesting that the survival of post-settlement juveniles (age 0 to age 1) is low, possibly because the very coarse substrate is not conducive to burial. This notion is supported by our diurnal-nocturnal survey data, which show significant differences in the day-night length frequency distribution in AP but not in CR.

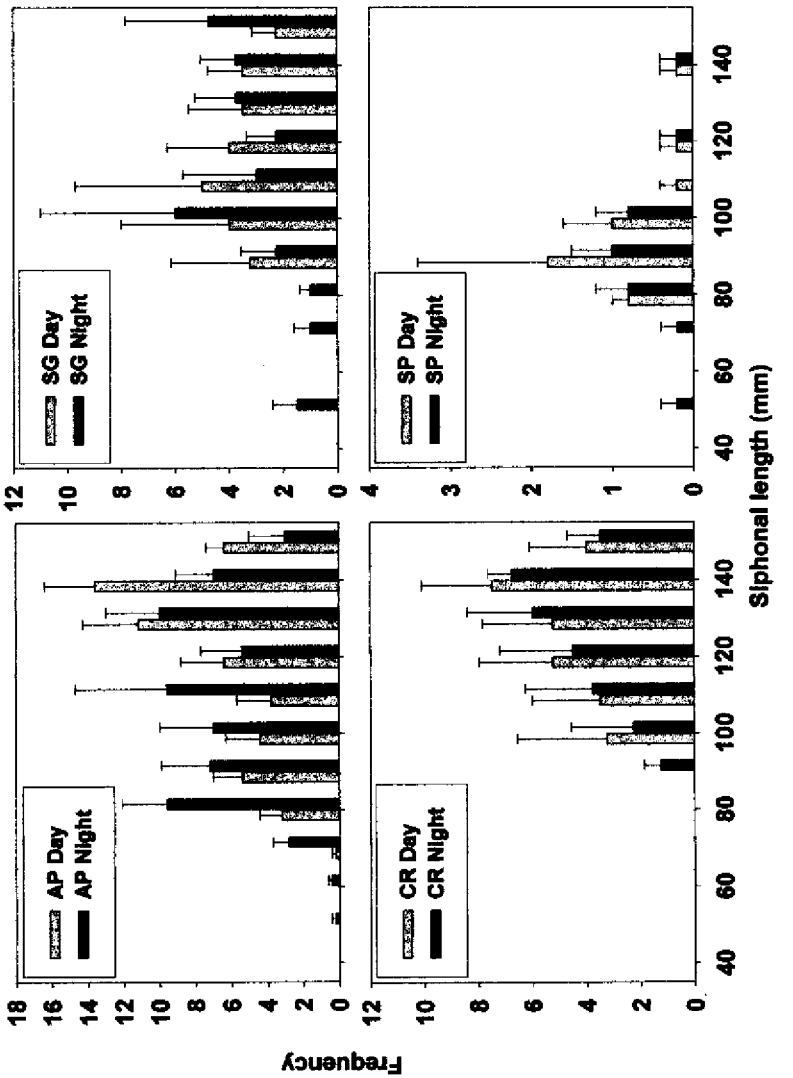


Figure 4. Mean length-frequency distribution (± 1 SE) of small juvenile queen conch observed during paired diurnal-nocturnal surveys in four habitats in EHLCR from July 2000 to August 2001. Note: AP = algal plain, SG = seagrass, CR = coral rubble, and SP = sand plain.

While several studies have identified seagrass as favorable habitat for juvenile queen conch (e.g., Stoner and Waite 1990, Stoner and Sandt. 1991), it is now widely recognized that site-specific factors such as hydrography and predator abundance, likely play a significant role in the establishment and maintenance of nursery grounds rather than habitat type alone (reviewed by Stoner 1997). Although small, post-settlement juveniles did make use of SG and to a lesser extent SP within EHLCR, densities were highest in AP, particularly within a relatively small area (< 5 ha) in the southeast end of the reserve that we believe to be a nursery ground. Additional studies are needed to determine whether the importance of AP habitat in EHLCR is dependent on site-specific factors, or if they are important nursery areas throughout the region.

Preliminary spatial analysis and tagging studies in EHLCR suggest that post-settlement juveniles are moving from the suspected nursery area into adjacent CR habitat (Danylchuk and Rudd, unpublished data). Small juveniles may be moving from the nursery ground where they initially settle into CR when they are larger and no longer need to bury to avoid predation, or are better able to negotiate the coarse CR terrain. Moreover, as they grow juveniles require more food (Ray and Stoner 1995), which might explain why they are moving into the densely vegetated CR habitat and why we found high densities of medium and large juveniles in CR. Regardless of why small juveniles are moving from AP into CR, it is clear that the recruitment of these individuals into suitable areas as they grow is enhanced by the contiguity of critical juvenile habitats. Fortunately in the case of EHLCR, these critical habitats are within the reserve boundaries and therefore protected, however, our study underscores the importance of understanding the habitat use of all life stages of queen conch in designing no-take reserves.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the key financial and logistical support of The School for Field Studies Center for Marine Resource Studies. Thank you to the many students who helped us collect data, and to the Center's staff, especially Kazuki Kageyama, Shannon Gore, Sascha Clark, Shona Paterson, and Jason Stoots. We would also like to thank the Department of Environment and Coastal Resources and Wesley Clerveaux for their continued support. This is contribution SFS/CMRS 052.

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Visual Assessment of Queen Conch (*Strombus gigas*) Stocks in the Turks and Caicos Islands: Cross-Checking Yield Estimates

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ABSTRACT

Once abundant throughout its' range, queen conch is currently threatened in many regions. In response to concerns that its' status is the result of overfishing, fisheries legislation has been enacted in many countries to help regulate harvest rates. To further ensure the sustainability of this important resource, queen conch was placed on Appendix II of the Convention on the International Trade of Endangered Species (CITES) in 1992. To satisfy CITES requirements, a modified version of the Schaefer model was used in the Turks and Caicos Islands during the 1993/1994 licensing year to model historical catch and effort data, estimate catch per unit effort (CPUE), and provide the basis for an annual Total Allowable Catch (TAC). However, since 1994 the model has consistently underestimated CPUE. To cross-check yield estimates derived from the modified Schaefer model, we conducted a visual assessment of queen conch stocks across the Caicos Bank. Surveys were carried out in traditionally fished areas using replicate belt transects at randomly selected sites. All queen conch encountered were enumerated and placed into size/age categories based on siphonal length and lip thickness. In total, 170 sites were surveyed between October 2000 and August 2001, and nearly 4000 queen conch enumerated. Our results indicate that the yield estimate derived using the modified Schaefer model is very close (i.e., within <1%) to those generated using the biomass estimate from our visual surveys, and within 10% of those estimated using the standard Schaefer and Fox surplus production models. As such, we conclude that the modified Schaefer model is producing reasonable yield estimates, but the catch and effort data need to be examined closely to determine why the model is underestimating CPUE.

KEY WORDS: Queen conch, visual assessment, maximum sustainable yield, Turks and Caicos Islands

Evaluación Visual de la Población del caracol (*Strombus gigas*) en las Islas Turcos y Caicos

RESUMEN

El caracol rosa, *Strombus gigas*, quien existiera en abundancia en todo su rango de distribución, se encuentra actualmente en peligro de extinción en muchas regiones. Como reacción a la preocupación de que este estado es a causa de la sobrepesca, se han desarrollado legislaciones pesqueras en muchos países para ayudar a regular la producción de caracol. Para poder asegurar la sostenibilidad de este importante recurso, la especie ha sido ubicada en el Apéndice II de la Convención Internacional para el Comercio de especies en peligro de extinción de la Flora y la Fauna Silvestre (CITES). Para satisfacer los requerimientos de esta Convención, se aplicó una versión modificada del Modelo de Schaefer en Turcos y Caicos en 1995 para modelar los datos históricos de captura y esfuerzo, estimar la captura por unidad de esfuerzo (c.p.u.e.) para el período 1996-2001, y aportar la base para determinar la Captura Total Permisible (TAC). Durante estos años, el modelo subestimó consistentemente la c.p.u.e., debido probablemente a que no tuvo en cuenta las capturas sin registrar destinadas al consumo doméstico. Con el objetivo de ofrecer un medio alterno para estimar la TAC, llevamos a cabo un censo de los stock de caracol en todo el Banco Caicos. Los ejemplares fueron evaluados visualmente en las áreas de pesca tradicionales usando transeptos rectos con réplica, en sitios seleccionados al azar. Los caracoles fueron contabilizados y colocados en categorías talla/edad, basándose en la longitud del sifón y grosor del labio. También fue caracterizado el habitat en cada transepto de acuerdo a la composición del sustrato. Se revisaron más de 200 localidades desde octubre del 2000 y se contabilizaron aproximadamente 3000 ejemplares. Se utilizarán estos resultados para validad los estimados del modelo y mejorar las técnicas actuales de evaluación del stock.

PALABRAS CLAVES: Caracol reina, *Strombus gigas*, Turks & Caicos

INTRODUCTION

Traditionally, queen conch (*Strombus gigas*) has supported local subsistence fisheries because they are relatively easy to catch and highly nutritious (Brownell and Stevely 1981, Nardi 1982). In the Turks and Caicos Islands (TCI), queen conch has been a dietary staple and the basis of a local commercial fishery for more than a century (Doran 1958, Sadler 1997). However, by the mid 1950s, rising economic value and increasing international demand encouraged an extensive commercial fishery to develop in the TCI.

Following a peak in the commercial harvest of queen conch in 1980 (ca. 1,150 MT), catch rates in the TCI began to decline, and it was hypothesized that this trend

was the result of overfishing (Ninnes 1994). In an attempt to sustain local conch stocks, the TCI implemented a number of regulations including size restrictions (7" siphonal length or 8 oz meat weight), gear restrictions (e.g., SCUBA prohibited), a closed season for the commercial harvest (July 15 – October 15), and closed areas (e.g., East Harbour Lobster and Conch Reserve). In 1992, queen conch was also listed under Appendix II of the Convention on the International Trade of Endangered Species (CITES), in response to stock collapses and fishery closures in several areas throughout its' range (Mulliken 1996). Under the CITES agreement, signatory nations and countries that export queen conch to signatory nations, must report all international exports of queen conch and establish a management plan, such as annual export limits to avoid overharvesting. As such, an annual Total Allowable Catch (TAC) was instated in the TCI during the 1993/1994 licensing year to satisfy CITES requirements and help ensure the sustainability of local conch stocks.

To determine a TAC, the status of queen conch stocks was assessed in 1993 using a catch per unit effort (CPUE) time series going back to 1966. A modified version of the Schaefer (1954) model was filled to the time series data to estimate standing stock biomass and determine a TAC based on Maximum Sustainable Yield (MSY) (Medley and Ninnes 1999). However, since the TCI implemented the TAC in 1993/1994, the model has consistently underestimated CPUE (Caribbean Fisheries Management Council 1999), suggesting that it may not be accurately estimating the standing stock biomass. The objective of this study was therefore to conduct a visual assessment of queen conch stocks on the Caicos Bank to cross-check yield estimates derived from the modified Schaefer model with those generated using the standing stock biomass estimate from the visual surveys.

MATERIALS AND METHODS

Visual Stock Assessment

Historical landing records and surveys of TCI fishers indicated that most of the queen conch landed in the TCI are harvested from a fished area approximately 120,000 ha in size or about 1/6 of the Caicos Bank (Figure 1). Thus, we employed a stratified random sampling design that included only traditionally fished areas to conduct our visual assessment of the Bank.

Visual surveys were carried out from October 2000 to August 2001. Sites were randomly selected within fished areas using a remote sensing image (a Landsat 7 Thematic Mapper image) and Idrisi 32 (Clark Labs, Worcester, Massachusetts USA). At each site, we ran three 3-m wide belt transects, for a total survey area of 90 m^2 per transect and 270 m^2 per site. Queen conch within the belt transects were enumerated and categorized by size/age based on siphonal length (SL), development of the shell lip, and the physical properties of the shell (Table 1). The abundance of queen conch in each size/age category was determined for each transect, and the

mean abundance of each category calculated for each site. Mean abundances were then converted to densities (#/ ha) for each site.

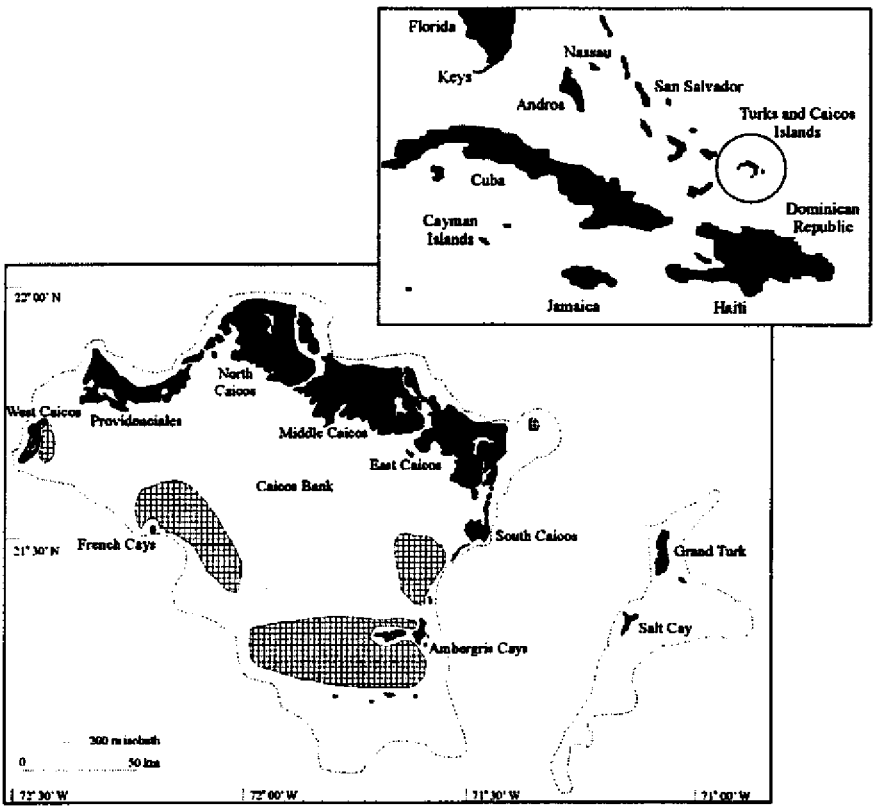


Figure 1. Location of the study area in the Turks and Caicos Islands. Hatched polygons are traditionally fished areas surveyed from October 2000 to August 2001.

Table 1. Size/age categories used during visual queen conch surveys on the Caicos Bank (from Tewfik and Béné 2000).

Category	Code	Description
Small Juvenile	SM	< 150 mm siphonal length, no shell lip
Medium Juvenile	ME	150 - 200 mm siphonal length, no shell lip
Large Juvenile	LG	> 200 mm siphonal length, no lip
Sub-adult	SA	Shell lip thickness < 4 mm
Young adult	YA	Shell lip thickness > 4 mm, broad flaring shell lip, prominent spines, limited effects of bioerosion
Old adult	OA	Shell lip thickness >4 mm, worn, thick shell lip, worn spines, moderate to heavy effects of bioerosion

Yield Estimates from Standing Stock Biomass

To estimate the standing stock biomass available for harvest, we determined the average landed meat weight of a total of 200 young (YA) and old adult (OA) conch collected from our surveys. The average meat weight was multiplied by the combined density estimate of young (YA) and old adult (OA) conch from our surveys to obtain a biomass per ha, which was then multiplied by the total fished area (120,000 ha) to obtain a standing stock biomass estimate.

Because we enumerated large juveniles (LG) and sub-adults (SA) as part of our visual surveys, we were also able to estimate the conch biomass available for exploitation the following year (i.e., recruitment yield). To do so, we determined the combined density of LG and SA in the fished area and employed this value in the following decay model:

$$N_2 = N_1 exp(-M(t_1-t_2))$$

where N_2 is the density at time t_2, N_1 is the density at time t_1, and M is natural mortality.

To determine yield estimate the standing stock biomass estimate obtained from the visual surveys was incorporated into the models presented by Garcia et al. (1989) as follows:

$$MSY_S = (BM)^2 / 2MB - Y_{avg}$$

$$MSY_F = MBexp((Y_{avg}/MB)-1)$$

where MSY_S and MSY_F are the maximum sustainable yields for the Schaefer and Fox versions of the model, respectively, B is the estimate of standing stock biomass, and M is the natural mortality rate. Since the TCI fishery is characterized by fluctuating landings, which may bias the yield estimate we replaced the current yield (Y_c) in both models with the mean landings for the past five years (Y_{avg}).

Yield Estimates from Surplus Production Models

Yield estimates were derived by fitting the standard Schaefer and Fox surplus production models to the CPUE time series using the linear catch-effort relationship as follows:

$$MSY_s = -a^2 / (4b) \quad and \quad f_{msy} = -a / (2b)$$

$$MSY_f = -(1/d)exp(c-1) \quad and \quad f_{msy} = -1/d$$

where a and c are the slopes, and b and d are the intercepts of the regression lines (Garcia et al. 1989). We also determined a yield estimate by fitting the modified Schaefer model to the CPUE time series following the methodology of Medley and Ninnes (1999). In the modified Schaefer model, a variable recruitment index is used

instead of a constant, intrinsic rate of increase (see Medley and Ninnes 1999 for additional details).

RESULTS

Standing Stock Biomass and Recruitment Yield

A total of 170 sites and about 4.6 ha of the Caicos Bank was surveyed during our visual assessment. The combined mean density of YA and OA from our surveys was 203 conch/ha, which using an average meat weight of 152 g per individual, produced a standing stock biomass of 3,703 MT available for harvest in traditionally fished areas on the Bank. In addition, based on a combined density of 87.5 conch/ha for LG and SA and a value of −0.80 for $-M(t_1-t_2)$ within the region (A. Tewfik, pers. comm.), we estimated that 714 MT of conch would be recruited to the fishery next year.

Comparison of Yield Estimates

The yield estimates generated using the standing stock biomass estimate from the visual surveys and the models presented by Garcia et al. (1989) were 747 MT for the Schaefer formula and 743 MT for the Fox formula. The values for M used in the models were ($M = 0.25$) for the Schaefer model and ($M = 0.23$) for the Fox model. These values were chosen by determining which values produced yield estimates that equaled the yield estimate derived using the modified Schaefer model, since the Garcia et al. (1989) models we used assume that natural mortality is equal to fishing mortality.

From the CPUE data, the standard Schaefer and Fox surplus production models generated yield estimates of 822 MT and 802 MT, respectively. As in previous years, the modified Schaefer model fit the time series data reasonably well (Figure 2), however, the expected CPUE for 2000 was still below the observed CPUE (Figure 3). Nevertheless, the model produced a standing stock biomass estimate of 3941 MT with a yield estimate of 748 MT (Table 2).

CONCLUSIONS

The yield estimate derived using the modified Schaefer model is very close (i.e., within <1%) to those generated using the biomass estimate from our visual surveys, and within 10% of those estimated using the standard Schaefer and Fox surplus production models. In addition, the yield estimate from the modified Schaefer model was within 5% of the recruitment yield estimate using a decay model, while the standing stock biomass derived from the model was quite close (within 6%) to that estimated from our visual assessment. Taken together, these results suggest that the modified Schaefer model is doing a reasonable job estimating standing stock biomass and in turn, yield estimates that are the basis of the TAC in the TCI. Our results also suggest that differences between predicted and observed CPUE are more likely

related to the way catch or effort are measured, rather than a problem with the modified Schaefer model. For instance, catches destined for local consumption are not accounted for which could result in the under- or overestimation of CPUE depending on trends in local consumption. Moreover, effort measured in boat days does not account for changes in the type of boat used or the number of fishers harvesting conch in each boat. As such, a more precise estimate of catch and effort could further improve the predictive power of the modified Schaefer model, and contribute to the continued sustainable harvest of queen conch in the TCI.

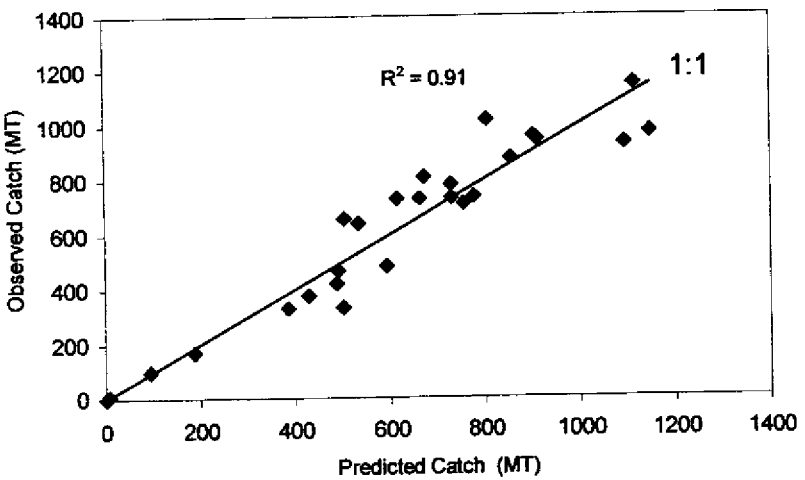


Figure 2. Relationship between observed catch and that predicted by the modified Schaefer model (R^2 = 0.91) from 1974 - 2000.

Table 2. Parameter estimates and 95% confidence intervals for the modified (variable-r) Schaefer model (see Medley and Ninnes 1999). Note: K = carrying capacity, r = fitted parameter multiplied by the average recruitment index, q = catchability, MSY = maximum sustainable yield, f_{msy} = effort at MSY, and F_{msy} = fishing mortality at MSY.

Estimate	Parameters	95 % Confidence Interval	
K (MT)	7187.19	6517.79	8062.16
r (year^{-1})	0.42	0.35	0.49
q (boat day^{-1})	4.31 X 10^{-06}	4.04 X 10^{-06}	4.48 X 10^{-05}
MSY (MT)	747.57	714.43	805.33
f_{msy} (boat days)	4828	4144	5787
F_{msy} (year^{-1})	0.23	0.18	0.30

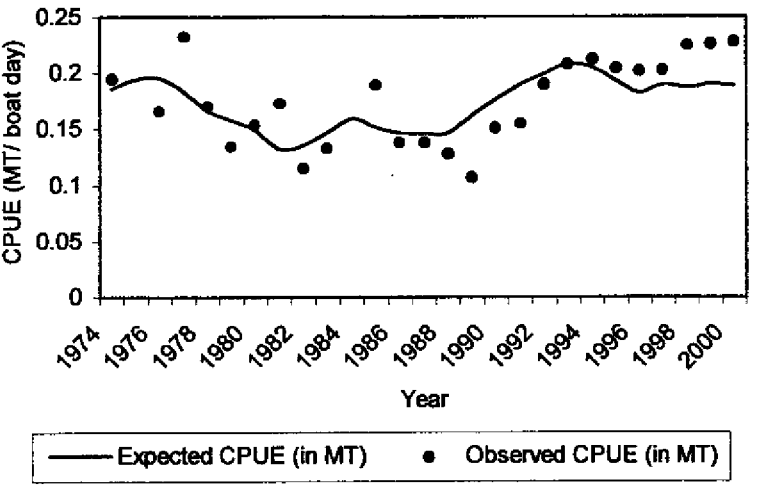


Figure 3. Observed CPUE (closed circles) versus that predicted by the modified Schaefer model (solid line) for 1974 - 2000.

ACKNOWLEDGEMENTS

We gratefully acknowledge the key financial and logistical support of the Department of Environment and Coastal Resources and The School for Field Studies Center for Marine Resource Studies. Many thanks to Dwaine Cox, Walter Hanchell, Ingelise Giles, and Kimberly Baldwin for their assistance in the field, and Murray Rudd for helping with site selection.

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Developing a Spatially Explicit Agent-based Model of Queen Conch Distribution in a Marine Protected Area in the Turks and Caicos Islands

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ABSTRACT

Queen conch, *Strombus gigas*, is an important commercial resource in the Turks and Caicos Islands (TCI). The TCI government is funding the development of an agent-based model (ABM) to help better understand queen conch distribution and manage the artisanal fishery. ABMs are built from the 'bottom up' and simulate each individual agent – conch, fishers and the fishery manager – within the pertinent system. Agents follow relatively simple rules of behavior at the individual level but can engage in behavior that leads to complicated aggregate patterns of interaction. ABMs permit modelers to perform a variety of resource management experiments in a computer-generated artificial fisheries management laboratory, potentially increasing our ability to implement the principle of adaptive management while reducing the risk and/or time lags of real-world experiments. The purpose of this paper is to outline the development of the spatial components of a pilot model in which simple foragers (conch) live, grow, and disperse. The model of the South Caicos East Harbor Lobster and Conch Reserve (EHLCR) uses habitat data derived from Landsat 7 satellite imagery as an environmental base and is implemented using the *Swarm* modeling platform. In the model, conch survival is dependent on (1) food intake and (2) mortality risk within each habitat type. The challenges of expanding the model from this pilot phase to incorporate more sophisticated fisher and fishery management agents in an expanded commercial fishery model are outlined.

KEY WORDS: Queen conch, Marine Protected Areas, Agent-based models, swarm

INTRODUCTION

An important commercial fishery for queen conch (*Strombus gigas*) exists in the Turks & Caicos Islands. As an Appendix 2 species under CITES, the government of the TCI is mandated to manage the fishery sustainably in order for TCI exporters to maintain access to international markets for conch. Sustainable management of the conch fishery requires an understanding of the distribution and population dynamics of queen conch on the Caicos Bank. In addition, it requires that fishery managers understand how fishers react to alternative policies that might be used to manage the conch fishery. Without such insights, the TCI conch fishery may well be over-fished and follow the decline of other fisheries in the Caribbean region (see Appeldorn 1994).

Traditional fisheries science models can be used to set aggregate total allowable catch (TAC) for the conch fishery in the TCI (Medley and Ninnes 1999), but provide little insight about the effects of alternative policy approaches for fishery management when species distribution is patchy and/or fishers are heterogeneous in skills or preferences. Increasing computer power and the recent development of powerful object-oriented programming languages and geographic information systems (GIS) have opened up opportunities for alternative approaches to fishery modeling. Agent-based models (ABMs) (or individual-based models, as they are known by ecologists) are one such new modeling tool (e.g., Railsback et al. 1999, Janssen et al. 2000, Kohler and Gumerman 2000).

ABMs, as the name suggests, incorporate individual agents into a model that is spatially and temporally explicit. The environment itself can display heterogeneity in resource endowment (e.g., food, energy, space, habitat quality), distribution, and rate of renewal. Populations of agents are represented by real numbers rather than population densities. Autonomous agents are situated in the environment, can sense it, and can both act on, and be affected by, the environment while pursuing individual or collective goals. Agents interact locally with other agents in a spatially-explicit model and, therefore, interact with an effectively low population (Uchmanski and Grimm 1996).

In order to improve understanding of conch distribution and the effects of various policy options on ecological and economic outcomes, a pilot agent-based model of the South Caicos East Harbor Lobster & Conch Reserve (EHLCR) region is being developed. The model will simulate key processes driving abundance, location, and production of conch. We use Landsat satellite imagery to develop an environmental base for use within the Swarm modeling platform. Modeling experiments will comparatively assess fishery policies, including design of this important conch MPA. The purpose of this paper is to outline the development of the spatial components of a pilot model of a fishery in which simple foragers (conch) live, grow, and disperse.

METHODOLOGY AND RESULTS

Image Preparation and Processing

A radiometrically-calibrated Enhanced Thematic Mapper plus (ETM+) image acquired by Landsat 7 on 20 Sep 1999 was purchased from the US Geological Survey by the School for Field Studies, Center for Marine Resource Studies (CMRS). The procedures for various image preparation and analyses throughout this project are largely based on protocol developed at the Center for the Study of Institutions, Population and Environmental Change (CIPEC), Indiana University (Green 1999).

The ETM+ sensor records data for three bands of visible (Bands 1, 2, 3 – wavelengths of 0.450 – 0.515, 0.525 – 0.605, 0.630 – 0.690 microns, respectively) and three bands of near infrared (NIR) (Band 4 – 0.75-0.90 microns) and infrared (IR) (Bands 5 and 7 – 1.55-1.75 and 2.09-2.35 microns, respectively) electromagnetic radiation at a resolution of 30 meters. It also records a thermal band (Band 6, 60-m resolution), and a high-resolution (15 - m) visible band (Band 8), which were not used in this project. Each band at 30 - m resolution consists of 7,801 columns and 6,941 rows of data. Thus, there are almost 325 million data points for the six relevant visible and infrared bands. Figure 1 shows the footprint of the Landsat 7 image.

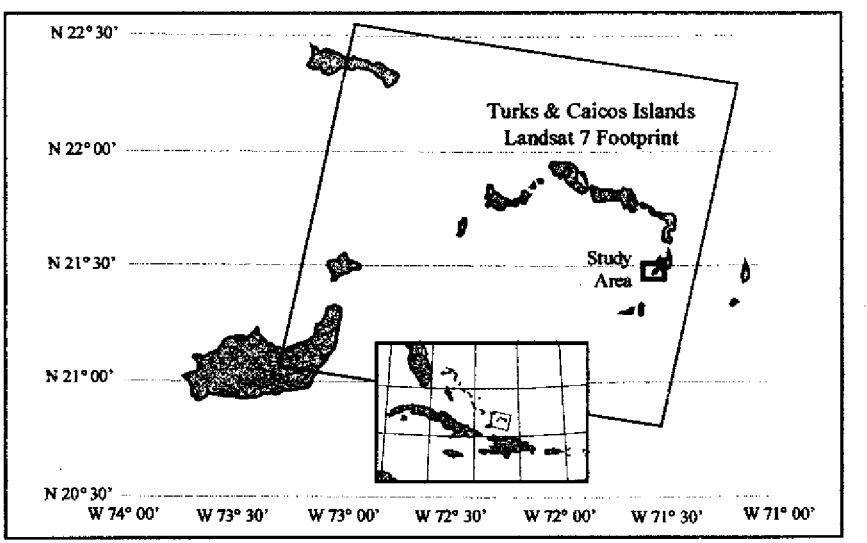


Figure 1. Landsat 7 Footprint in relation to the Turks and Caicos Islands study site

A sub-scene of the eastern Caicos Bank was geometrically registered (RMS error = 14.5 - m, about one-half pixel) using 1:10,000 topographic maps of the region and Idrisi32 image processing software (Eastman 1999). Geometric registration warps the 2-dimensional satellite image of the 3-dimensional surface of the earth to make it coincide with mapping systems. A study area of 301 columns by 251 rows (68 km^2, 30 m resolution), including all of EHLCR, was selected from the registered sub-scene. Masks were applied to land, exposed sand, and deep-water, leaving submerged banks and reefs for spectral analysis.

For the pilot model, we used digital numbers (DNs) that measure at-sensor reflectance at the satellite rather than calibrated surface reflectance (i.e., corrected for atmospheric disturbance); the patterns for DN and surface reflectance should be closely correlated. Because water rapidly absorbs infrared radiation, most of the work done in this project utilizes visible light from Bands 1 (blue), 2 (green) and 3 (red).

Scatterplots were used to plot the reflectance of combinations of Bands for the entire image without reference to spatial location. Figure 2 shows the scatter plot for Band 3(red) versus Band 1(blue) reflectance.

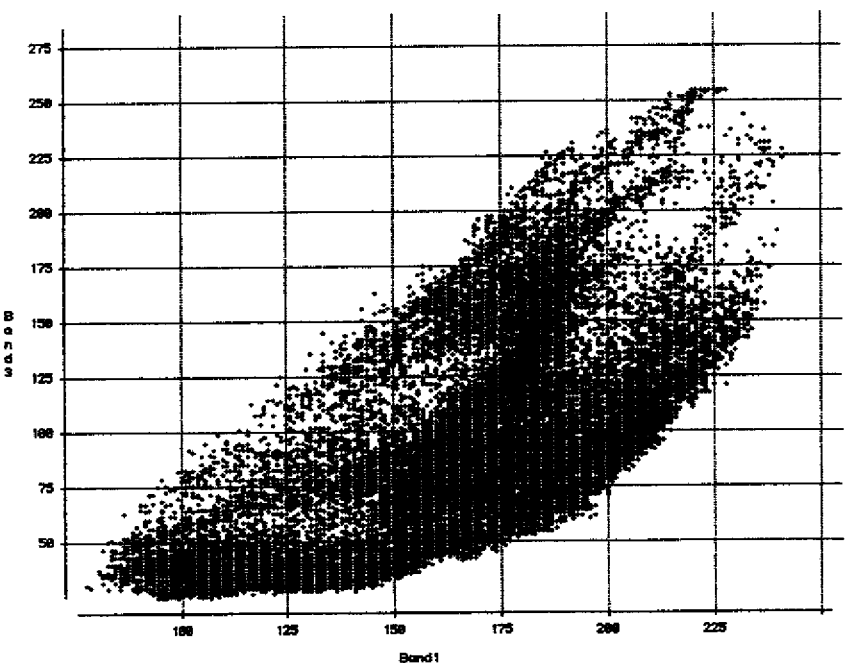


Figure 2. Scatterplot of Band 3 (red = light) versus Band 1 (blue = dark)reflectance as measured by digital numbers (DNs)

The use of scatterplots underlies Spectral Mixture Analysis (SMA) (e.g. Schweik and Green 1999). In SMA extreme 'end members' are defined – those points at the most extreme fringes of the scatterplots – as areas of 'pure' habitat type and used to classify other intermediate pixels as some linear combination of the end members. Using Datadesk software (Velleman 1997), it is possible to locate particular pixels or groups of pixels from the scatterplot in a spatial image of the study area, thus making it possible to associate particular habitat types with specific ranges of Bands 1 and 3 DNs. In our preliminary habitat classifications, we found that certain distinct habitat types tended to be closely grouped in the Band 3 vs Band 1 scatterplot. After exploratory analyses, we partitioned the scatterplot into 18 zones (Table 1), each of which is thought to represent a different type of habitat that is meaningful for the pilot ABM.

Fine-scale partitions in the areas of low reflectance were used to distinguish important differences between a variety of reef, seagrass and gorgonian-sponge habitats. The classification also shows algal plain and patches very well and distinguishes known fine-scale habitats crucial for conch nurseries and juvenile rearing (Danylchuk et al. in press). The classification will undergo further refinement and accuracy assessment in the near future.

Figure 3 shows a gray-tone image of the classified EHLCR study site. Each of the 75,551 pixels in the image was classified as one of the 18 habitat types or as masked area. This spatially referenced habitat data was exported from Idrisi32 to a text file, and subsequently imported into the Swarm modeling platform to construct the environmental base of the agent-based conch model.

Agent-Based Model Development using Swarm

The Swarm project was started at the Santa Fe Institute in 1994 and the first public simulation toolbox made available in 1995. Swarm is a collection of software libraries in the object oriented programming language, Objective-C, and now available for models written in Java. Swarm provides a platform for developing and documenting computer experiments that use collections of independent agents that interact in discrete space and time.

Diverse users in the natural and social sciences have developed the Swarm libraries, which can, according to Steffanson (1997), be broadly organized as classes of objects that:

i) Build spatial environments for agent interaction and handling information;
ii) Automate data collection and analyze data output visually or statistically;
iii) Maintain objects (e.g., conch, fishers) in structured collections (e.g., arrays) that can be readily manipulated (e.g., sorted, ranked, culled);
iv) Schedule periodic events at variable time-steps or to be triggered dynamically;
v) Probe simulation objects during simulations (e.g., how many conch are in a particular pixel grid) and adjust parameter values; and
vi) Generate random numbers that facilitate Monte Carlo analyses and random seeds that can be used to control the replicability of simulation runs.

Table 1. Partitions zones for scatterplot of Band 3/Band 1reflectance (measured by digital numbers, DN) and preliminary habitat type classifications

	Band 3 DN	Band 1 DN	Preliminary habitat type
1	10 ≤ B3 ≤ 32	10 ≤ B1 ≤ 116	Dense and/or deep seagrass
2	33 ≤ b3 ≤ 55	10 ≤ B1 ≤ 88	Medium-dense seagrass
3	44 ≤ B3 ≤ 55	89 ≤ B1 ≤102	Medium seagrass
4	33 ≤ B3 ≤ 43	89 ≤ B1 ≤ 102	Light seagrass (or deep reef)
5	33 ≤ B3 ≤ 55	103 ≤ B1 ≤ 116	Deep gorgonian-sponge
6	10 ≤ B3 ≤ 55	117 ≤ B1 ≤ 142	Shallow gorgonian-sponge
7	10 ≤ B3 ≤ 55	143 ≤ B1 ≤ 300	Mid-depth algal plain
8	56 ≤ B3 ≤ 104	10 ≤ B1 ≤ 116	Dense red algae
9	56 ≤ B3 ≤ 104	117 ≤ B1 ≤ 147	Red algae/shallow coral
10	56 ≤ B3 ≤ 104	148 ≤ B1 ≤ 175	Sand/algal plain
11	56 ≤ B3 ≤ 104	176 ≤ B1 ≤ 300	Shallow algal plain
12	105 ≤ B3 ≤ 188	10 ≤ B1 ≤ 161	Very shallow algal plain
13	105 ≤ B3 ≤ 130	162 ≤ B1 ≤ 200	Sand
14	105 ≤ B3 ≤ 130	204 ≤ B1 ≤ 300	Shallow sand 1
15	131 ≤ B3 ≤ 188	162 ≤ B1 ≤ 203	Shallow sand 2
16	131 ≤ B3 ≤ 188	204 ≤ B1 ≤ 300	Exposed sand
17	189 ≤ B3 ≤ 300 212 ≤ B3 ≤ 300 251 ≤ B3 ≤ 300	10 ≤ B1 ≤ 220 10 ≤ B1 ≤ 226 10 ≤ B1 ≤ 300	Exposed sand
18	189 ≤ B3 ≤ 211 212 ≤ B3 ≤ 250	221 ≤ B1 ≤ 300 227 ≤ B1 ≤ 300	Exposed sand/shell debris

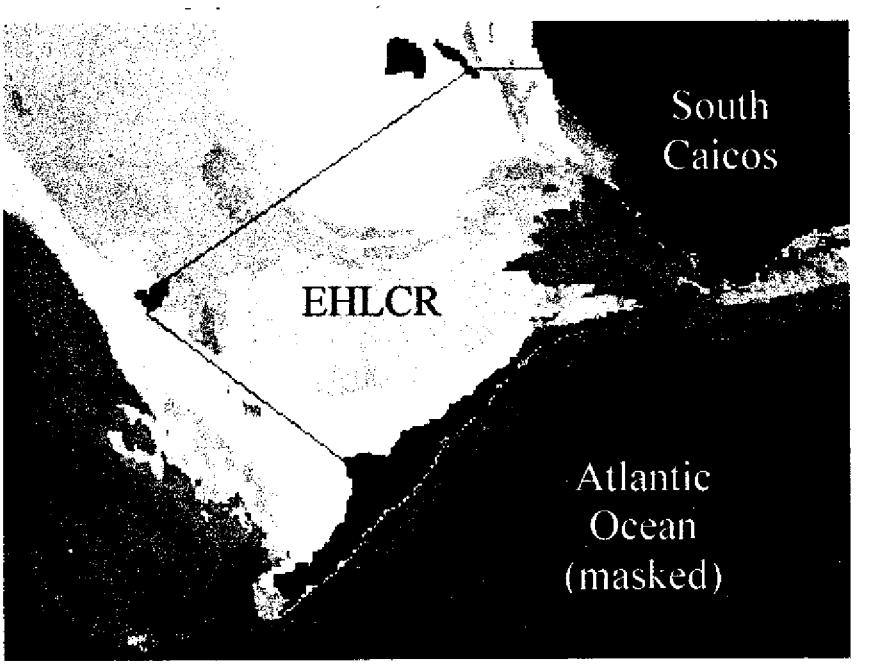


Figure 3. Gray-scale image of habitat classification (black = land/sea mask; classes 1 - darkest gray to 18 - white) at the South Caicos study site

In developing a Swarm model, the modeler's role is to define the types of objects and agents in the model, the behavior of each type of agent, and how the system is observed. Agent behaviors are designed following the recommendations of Railsback (2001), considering such issues as which behaviors should be forced to reproduce observed behaviors vs. emerging from a mechanistic representation of the causal processes. We attempt to capture the key processes driving agent behaviors using very simple representations of the processes. To date, only habitat cells and adult conch have been designed in detail. In the pilot conch model, we have defined the following important objects and agents.

Habitat Cells — are based on the 30-m ETM+ pixels described above. Habitats cells model food production and keep track of food consumption by conch and the resulting food availability; at any time step when food consumption by conch exceeds food production, food availability in the following time step is reduced. Predation risks also vary among habitat cells as a function of the relative predator abundance and quality of hiding cover for conch.

Conch — are the primary model agents. Larval dispersion and settlement are not currently modeled, although it would be feasible to integrate water flow, larval dispersal and habitat-specific settlement in the future. Conch behaviors that are simulated include feeding and growth, habitat selection, and mortality. Because conch traits change over their life cycle, three life stages of conch are simulated using different assumptions for each:

i) *Juveniles* — enter the model when they emerge after spending their first year buried in sand. Juveniles are vulnerable to predation by fish, and use all energy intake for growth. Habitat is selected to maximize the individual's probability of surviving to adulthood. This probability decreases in risky habitat and increases with growth rate because rapid growth reduces the time until adulthood is reached.

ii) *Adults* — are sexually mature conch not in the spawning period. Predation is assumed to be a negligible risk, so fishing mortality is the only important source of mortality. Energy intake is used for gamete production and habitat is selected to maximize gamete production. Adults decide when to become spawners by maximizing their expected reproductive success, a function of their probability of surviving until the next spawning season and the expected gamete production.

iii) *Spawners* — are conch during reproductive activity. Habitat is selected to obtain good spawning habitat and to maximize the probability of finding mates.

Fishers — are agents representing people that fish for conch. Fisher behavior is simple in the pilot model: we assume that fishers are simple profit maximizers that need only be concerned with conch harvests and variable operating costs (i.e., fuel). Much more complicated behaviors are possible in expanded models (e.g., accounting for risk preferences).

The Fishery Manager — is an agent that represents the agencies setting and enforcing fishery management rules. A number of potential management rules are easily modeled. For example, MPA boundaries can be changed to examine the effects of different MPA configurations on adult emigration of conch to adjacent commercial fishing grounds. In addition, policies such as TACs, minimum size limits, input taxes or subsidies, and export taxes can be modeled and compared. In addition, probes can be used to simulate field sampling programs, enabling the *fishery manager* to undertake virtual fishery science, setting policies to meet objectives with less than complete information.

Several tools are provided for observing the simulations. The main animation window shows all the habitat cells, colored by their habitat type. Individual conch (and, eventually, fishing boats) appear as dots but the resolution is too coarse to observe conch movement. A higher-resolution window can be opened to observe conch within a selected subset of habitat cells; in these windows cells are colored by food availability and conch are represented by line segments indicating their location,

size, and movement direction. In addition, summary information (e.g., total conch abundance by life stage; number of conch using each habitat type) can be obtained via output files or screen graphs.

Model Parameterization

Model parameterization is in process, and is based on a variety of scientific studies of feeding, movement and mortality (e.g., Stoner and Ray 1993, Stoner et al. 1995. Stoner and Glazer 1998). Key processes that seem important in modeling feeding include: larger conch can consume more food because they can move faster and forage over a wider path; conch adjust their feeding distance with the availability of food; and food competition can affect foraging behavior and intake. Three main sets of parameters need to be defined -- feed use and growth; movement; and mortality risk.

Feeding — Conch (1) use food (detritus, algae, seagrass) that is produced slowly, and (2) have limited movement compared to the 30 m grid cell size, thus making it unrealistic that they compete for food at a daily time step. The approach we are adapting is to assume a constant rate of food production, with accumulation and depletion of food over time, subject to constraints of a zero lower limit and some set upper limit. If the conch in a cell consume more food than is produced in a day, then food availability on the next day is lower. This allows food production and competition to occur over times longer than a one-day time step.

Movement — We assume that adult conch move a distance determined by the feeding model, and travel in the direction toward highest potential net energy intake. Avoiding mortality risks is not included in the movement decision because we assume in the pilot model that survival of adult conch does not vary with habitat.

Movement is simulated after feeding in the model's daily schedule. Therefore, the distance moved is a function of food availability in the habitat cell where the conch starts its movement. If food is relatively scarce, this distance will be equal to the variable *AdultForageSpeed* (m/d); if food is abundance and the conch can obtain its maximum daily food intake in less distance, then the distance needed to obtain maximum food intake is used.

Potential movement destinations are each of the eight cells adjacent to the conch's current cell, plus the conch's current cell. This approach assumes that adult conch are capable of sensing gradients in food availability in all directions. We do not necessarily assume that a conch "knows" habitat conditions in adjacent cells. We do assume that the conch can detect local gradients in habitat conditions, and that such local gradients are represented by the differences among adjacent cells.

The best destination is the cell offering the highest net energy intake. The conch calculates the net energy intake it would receive in each potential destination cell, using the feeding methods described above. If any of the eight adjacent cells offers

higher net energy intake than the conch's current cell, then that cell becomes the best destination; otherwise, the current cell is the best destination.

Mortality — We model natural mortality as a stochastic function of each conch's state and its habitat: the daily probability of survival is a function of conch state and habitat. On each simulation day, a random number is drawn from a uniform distribution between zero and one, for each type of mortality simulated. If the random number is greater than the survival probability, the conch is assumed dead of that type of mortality.

Following the evidence that natural mortality of adult conch is low (Appeldorn 1988), in the pilot model we simply assume a constant daily survival rate that is independent of habitat, energy status, and age. This daily survival rate is specified by the adult conch parameter *adultSurvivalProb*. A value of can be selected using *adultSurvivalProb* = 0.5[exp(1/(n*365))], where n is the mean survival time, in years, after conch achieve adulthood. We now use a mean survival time of 8 y, so *adultSurvivalProb* is 0.99976.

DISCUSSION AND CONCLUSIONS

A pilot ABM of queen conch in the EHLCR has been developed and is undergoing parameterization and calibration. The use of Landsat 7 ETM+ satellite imagery has allowed the classification of the 68 km^2 study area into 18 distinct habitat types based on spectral reflectance characteristics in the blue and red wavelengths. The 30 m resolution is useful as it allows differentiation of habitat zones as small as a few hectares, which may play particularly important roles in conch population dynamics within the MPA (Danylchuk et al. in press).

Methods for validating (testing the realism of) and analyzing (learning from) ABMs are quite different from the methods typically used for conventional fishery stock assessment models. Model validation and analysis are closely linked and focus on the question of whether the agent behaviors included in the ABM produce realistic patterns of individual- and system-level dynamics (Railsback in press). Agents must be shown to exhibit realistic behavior patterns before results for the entire fishery model can be considered valid.

Epstein (1999) argues for a criterion of generative sufficiency in ABMs. That is, are micro-level specifications (i.e., rules of behavior) sufficient to generate the macro-level outcomes of interest (i.e., conch distribution, age structure, etc.)? If more than one set of behavioral rules is sufficient to generate outcomes similar to those observed in the field, then the ABM can point to important experimental research questions that need to be addressed.

Behavior of model agents will be validated and analyzed by conducting a series of simulation experiments that examine the extent to which observed behavior patterns are reproduced. Alternative representations of key behaviors can be

compared to determine which best reproduce observed patterns. Examples of patterns that could be used for validation and analysis of conch behavior include:

i) Relative abundance of conch in various habitat types, and how it varies with conch life stage;
ii) Migration timing and direction in juveniles and spawners; and
iii) How conch ages and size at adulthood varies with food availability and growth.

The integration of the Swarm model and the Idrisi32 image processing and GIS software also offers the opportunity for model validation using advanced spatial statistics (e.g., Cressie 1993). Over 4.8 ha of EHLCR have been surveyed by CMRS using integrated line and belt transects (Danylchuk et al. in press). In addition, the Turks and Caicos Department of Environment and Coastal Resources (DECR) has engaged in extensive surveys farther afield in commercial fishing grounds using the same methodology (Clerveaux and Danylchuk in press). In total, over 400 field sites have been sampled to date, allowing for statistical comparisons of conch distribution in the field and in the ABM. The work underway in the TCI queen conch fishery should lead to new MPA modeling methodologies and insights as the model is further developed in the future.

ACKNOWLEDGMENTS

The government of the Turks and Caicos Islands provided funding for the pilot agent-based modeling project and SFS Center for Marine Resource Studies (CMRS) provided the Landsat satellite image. Steve Jackson, Jackson Scientific Computing, McKinleyville CA, coded the model. Jessica Hayes and Danielle Sacchetti assisted with image preparation. Thanks are especially due to Mark Day and Terry Smith (TCI Department of Environment and Coastal Resources) for supporting the project.

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Estimación de Densidad Abundancia y Biomasa de la Langosta Espinosa *P. argus* en el Arrecife Alacranes en los Años 1997-1999 con Aplicación de Sistemas de Información Geográfica

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RESUMEN

Como parte de las investigaciones realizadas sobre la pesquería de langosta espinosa (*Panulirus argus*) en el arrecife Alacranes, Yucatán, se hicieron 21 prospecciones entre abril de 1997 y diciembre de 1999, con el fin de obtener estimaciones de densidad que son utilizadas en los modelos de evaluación de la población o bien en la medición de la capacidad de repoblamiento natural del hábitat. En este trabajo se hacen estimaciones de densidad, abundancia y biomasa mensuales, se relaciona la presencia de langosta con los tipos de fondo y con base en estimaciones previas del área que tienen los tipos de fondo preferidos por la langosta se estima la abundancia y la biomasa, se observa el comportamiento de la densidad a través del tiempo. Los datos se obtuvieron mediante buceo libre durante prospecciones mensuales, en donde se llevaron a cabo transectos de 100 m x 10 m. Se registraron el número de langostas por transecto buceado, características del fondo, situación geográfica y el peso y longitud promedio de los organismos capturados. Para la estimación de densidades se usó un mapa de fondos obtenido del análisis de una imagen Landsat TM y sobre el cual se sobrepuso la información referida geográficamente utilizando un Sistema de Información Geográfica (SIG).

PALABRAS CLAVE: Arrecife Alacranes, langosta *Panulirus argus*, SIG

Spiny Lobster *P. argus* Biomass Abundance and Density Estimation on Alacran Reef During 1997 to 1999 Years with Geographical Information Systems Application

ABSTRACT

As part of the research efforts carried out on the spiny lobster fishery (*Panulirus argus*) in Alacranes Reef, Yucatan, 21 diving expeditions were made in order to obtain density estimations. Those estimations are important since they are used in stock assessment models and in measurement of natural stock restoring capacity in the habitat. In this study density and abundance estimations of spiny lobster are made during three fishing seasons (1997 - 1999), the results were related to lobster presence by bottom type, and based on previously estimates of the preferred areas by lobsters, the abundance is estimated. Density comparisons are made for different seasons. The data were obtained through monthly free diving expeditions using 100 m transects. Observations include number of lobsters, reef bottom characteristics, average abdominal length and weight of lobsters. The density estimators were calculated using a bottom map from a Lansat TM image analysis and overlapping the georeferenced information of the diving in a Geographical Information System (GIS).

KEY WORDS: Alacranes Reef, GIS, lobster *Panulirus argus*

INTRODUCCIÓN

El Arrecife Alacranes es un área natural protegida establecida oficialmente el 6 de junio de 1994 como Parque Marino Nacional Arrecife Alacranes. Debido a los cambios en la nomenclatura ecológica ahora es llamado simplemente Parque Nacional Arrecife Alacranes (PNAA).

De este PNAA se extrae entre el 15 y 25% de la captura de langosta (*Panulirus argus*) del estado de Yucatán, además de otras especies de escama de gran importancia comercial (meros: *Epinephelus morio, E. adscencionis, E. gutatus Micteroperca venenosa, M. bonaci, M. tigris*; pargos: *Lutjanus griseus, L. analis, L. synagris* y *L. jocu*; cojinuda *Caranx ruber*; Jurel *Trachinotus sp.;* sierra *Scomberomorus regalis y,* barracuda *Sphiraena barracuda),* tiburón-cazón y de manera furtiva caracol rosado (*Strombus gigas*).

El hecho de que en este Arrecife se desarrolle una gran actividad pesquera, hizo necesaria la elaboración de un Plan de Manejo. La primera versión de este Plan, que es la que se tiene en la actualidad, se sustenta en la información recabada de investigaciones aisladas, realizadas con anterioridad, tal vez con poco conocimiento del sistema, sus recursos y la actividad pesquera que ahí se realiza. En consecuencia, las zonas núcleo demarcadas en el Plan de Manejo para este Parque, se encuentran sobre gran parte de las áreas tradicionalmente explotadas. Esto ha dificultado la

disposición de los pescadores para llevar a cabo el Plan propuesto. También la falta de vigilancia es otra limitante en el cumplimiento de las medidas de conservación propuestas. Así que, aunque el Plan de Manejo existe, en la actualidad no se aplica.

Con el establecimiento del PNAA y las dificultades encontradas al elaborar el Plan de Manejo, algunos grupos de investigadores de varias instituciones mexicanas se han dado a la tarea de incrementar esfuerzos de investigación con diferentes objetivos que convergen en su interés por tener un mejor conocimiento del complejo arrecifal, sus recursos y la actividad humana desarrollada en el área. Por su parte, los pescadores hacen esfuerzos relacionados con la búsqueda de áreas y artes de pesca alternativas.

Una parte de los trabajos que se llevan a cabo en el PNAA es la investigación sobre la población de langosta y tiene como objetivo brindar conocimientos científicos que permitan aprovechar el recurso de una manera sustentable y disminuir la existencia de conflictos entre los actores sociales que participan en la pesquería, para esto es importante contar, entre otras cosas, con evaluaciones del tamaño de la población y de su capacidad de renovación. Con este fin se han explorado formas de muestreo y diferentes tipos de estimadores, para obtener los mejores indicadores de densidad, abundancia, biomasa, distribución y capacidad de repoblamiento del hábitat de langosta en el arrecife Alacranes (Ríos et al. 1998, Ríos 2000).

El cálculo de la densidad y abundancia pueden realizarse mediante el conteo de organismos en un área conocida, sin embargo en la mayoría de las poblaciones animales y en particular en poblaciones marinas esto es imposible y se tiene que recurrir al conteo de áreas pequeñas (muestras) y utilizando técnicas de estimación, inferir sobre áreas de interés (Seber 1982, Krebs 1989, Thompson 1992).

Recientemente las imágenes de satélite y los sistemas de información geográfica (SIG), han sido incorporadas exitosamente a la evaluación y elaboración de mapas de hábitats costeros y marinos para calcular la extensión del hábitat en que se distribuyen especies de importancia pesquera (Green et al. 1996). Esto ha permitido hacer estimaciones de la biomasa de especies que presentan una fuerte relación con un hábitat particular, como el caracol rosado (Jones and Endean 1977) y la tortuga verde (Menges et al. 1997).

Liceaga et al. (1998) prueban construir áreas de distribución de langosta en el arrecife Alacranes, relacionando imágenes de satélite clasificadas no supervisadas y datos de densidad del recurso, obteniendo mayores densidades para las clases espectrales localizadas hacia el centro del arrecife, sin embargo no fue posible relacionar esta información con hábitats particulares. En el trabajo de Bello (1998), los diferentes tipos de fondo del arrecife Alacranes fueron identificados mediante el análisis de imágenes de satélite Landsat TM, obteniéndose un mapa temático a un nivel general y en Bello et al. 2000 utilizan este mapa de fondos y se estima, densidad, abundancia y biomasa de langosta para los meses de julio de 1998 y febrero de 1999.

En este documento se hacen estimaciones mensuales de densidad, abundancia y biomasa de langosta durante el período abril de 1997 a diciembre de 1999 (1997 - 1999) en el PNAA que se basan en el conteo de organismos observados en

transectos, la estimación de hábitat preferencial para langosta y el mapa de tipos de fondo analizado por Bello, 1998 mediante imágenes de satélite Lansat TM y utilizado en Bello et al. 2000.

MÉTODO

Área de estudio

El Arrecife Alacranes constituye el complejo coralino más importante del Golfo de México. Se encuentra localizado a 66.4 millas náuticas al Norte de Progreso, Yucatán. entre los 22° 21´ 45´´ y 22° 34´ 55´´ LN y 89° 36´47´´ y 89° 47´53´´ LO (Figura 1).

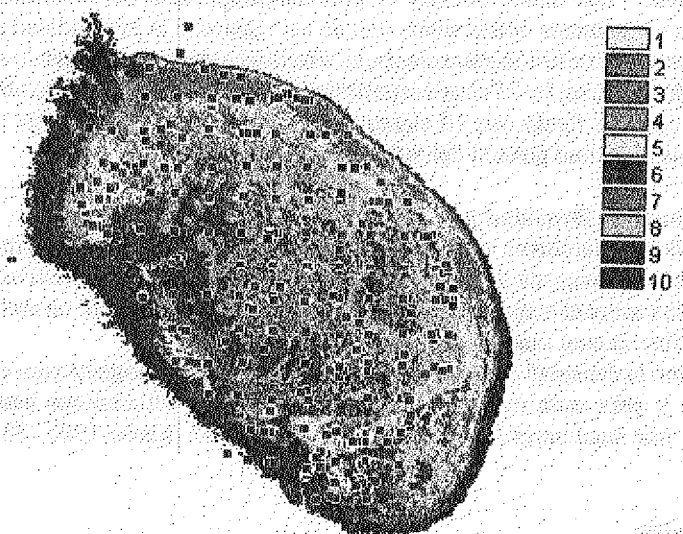


Figura 1. Mapa de tipos de fondo del Arrecife Alacranes

Colecta de Datos

Los datos utilizados en este trabajo se obtuvieron de 21 campañas de muestreo en donde se llevaron a cabo transectos de 100 m de largo por 10 m de ancho, a través de buceo libre y con compresor según la profundidad a la que se encontraba la estación de muestreo. El número de transectos por campaña realizada dependió de las condiciones del tiempo y fue variable, en cada transecto se registró la posición geográfica por medio de un geoposicionador (GPS), se contó el número de langostas observadas y se capturaron algunos organismos los cuales fueron medidos

y pesados con el fin de hacer una estimación del peso medio de las langostas observadas.

Mapa de Tipos de Fondo

Se usó un mapa de tipos de fondo obtenido del análisis de una imagen multiespectral Landsat TM por Bello (1998), quien describe el método. El análisis de la imagen incluyó la corrección geométrica de la imagen, el uso de contrastes y falsos colores para su análisis visual, la aplicación de un filtro de medianas a las diferentes bandas para reducir el "ruido", varias clasificaciones no supervisadas, que llevaron a una clasificación supervisada en 25 clases espectrales usando el algoritmo de máxima probabilidad y las bandas TM1, TM2 yTM3. Las semillas utilizadas en la clasificación supervisada, se generaron a partir del análisis de datos de campo provenientes de 168 estaciones realizadas en el arrecife usando estadística multivariada. Los datos incluían el porcentaje aparente de cobertura de los elementos visualmente dominantes, tipo de agregación y la profundidad puntual. Considerando la confusión entre clases, su similitud espectral y prestando atención al resultado temático, las 25 clases espectrales fueron reclasificadas para obtener un mapa de tipos de fondo con 10 clases temáticas (Figura 1). Para este mapa se reportó una exactitud general del 60% (Bello 1998, Bello et al. 2000).

Estimaciones de Densidad por Tipo de Fondo

Se elaboraron archivos vector de puntos, con las coordenadas de los transectos del muestreo de langosta de los meses en que se llevó a cabo, los archivos fueron desplegados sobre el mapa de tipos de fondo (Figura 1) y se obtuvo un archivo con la clase sobre la cual caían dichos transectos .

Se estimó la densidad promedio y el total poblacional de langosta para cada tipo de fondo y para cada mes muestreado. Se utilizaron estimadores basados en muestreo por cuadrantes (Seber 1987, Cochran 1987, Krebs 1989, Thompson 1992).

Estimadores

$$D_i = \frac{n_i}{a_i} \qquad D = \sum \frac{D_i}{nt}$$

$$S^2(\overline{D}) = \frac{\sum (D_i - \overline{D})^2}{nt - 1}$$

Donde,

D_i = Densidad en la estación i

n_i = Número de organismos observados en la iésima área muestreada

a_i = Área recorrida por el buzo

nt = Número de estaciones

Para estimar el total poblacional por mes y por tipo de fondo, se utilizó la tabla de áreas totales de tipos de fondo y áreas de hábitat preferencial para langosta en cada tipo de fondo del Arrecife Alacranes, construida por Bello et al. 2000 (Tabla 1).

La abundancia se estimó con:

$$N = D * A$$

$$Var(N) = \left(\frac{s^2}{am}\right) * A^2$$

Donde,

N= abundancia o número de organismos en cada tipo de fondo cada mes

A= Suma total de las áreas de hábitat preferencial en cada tipo de fondo que es = 7 460 hectáreas

am = área revisada en el muestreo cada mes

La biomasa estimada por tipo de fondo se obtuvo de:

$$B = N * \overline{W}$$

Donde,

B = Biomasa de langosta (kg de cola)

W = Peso medio de las langosta observadas = 250 g

El peso medio que se usó para estimar biomasa se calculó utilizando los pesos medios obtenidos para cada transecto.

Tabla 1. Área total y área de hábitat preferencial para langosta calculadas por Bello *et al.* 2000 y utilizadas en este trabajo para estimar totales poblacionales mensuales.

Clases o Tipos de Fondo	Área total mapeada (Ha)	Área de hábitat preferencial (Ha)
1	3 655	1 037.3
2	346	0.0
3	5 928	37.4
4	6 067	1 803.1
5	969	0.00
6	4 171	1 122.8
7	1 478	0.0
8	5 430	1 489.5
9	1 803	953.1
10	8 714	1 016.9
Total	38 561	7 460

RESULTADOS

En la Tabla 2 se puede observar el número de transectos realizados en cada prospección. Durante 1997 solo se realizaron dos prospecciones, mientras que en 1998 el muestreo fue más regular y se llevaron a cabo siete campañas de buceo y finalmente en 1999 se hicieron 11 prospecciones. El número de transectos realizados dependió en gran medida de las condiciones climatológicas y los mejores meses para hacer el muestreo fueron de abril a agosto.

Tabla 2. Número de transectos buceados por mes en el Arrecife Alacranes de Abril de 1997 a Diciembre de 1999

No. de Transectos	1997	1998	1999
Enero			8
Febrero			11
Marzo		18	8
Abril	32	27	8
Mayo		20	9
Junio		32	53
Julio		8	
Agosto			42
Septiembre		21	17
Octubre	21	19	8
Noviembre			13
Diciembre			8
Total	53	145	185

En la Tabla 3 se presentan las estimaciones de densidad en cada tipo de fondo. De las 10 clases que tiene el mapa temático solo apareció langosta en 8 de ellas. La clases que presentan mayores densidades son: clase 1 (Paredes y cabezas de coral duro y blando a profundidades menores de 2 m), clase 6 (Cabezas de coral duro y blando a profundidades entre 2 y 10 m) y clase 8 (Parches de coral duro y cubierto de algas a profundidades menores a los 2 m).

En las estimaciones de abundancia y biomasa que se presentan en la Tabla 4 y Figuras 2 y 3, los valores del mes de junio del 1997 son muy altos si los comparamos con junio de 1998 y junio de 1999. Para esta estimación se usaron datos de una prospección haciendo transectos de diferente tamaño.

En la Tabla 5 se presentan las capturas mensuales provenientes del PNAA que son desembarcadas en el puerto de Progreso Yucatán, y se grafican junto con la biomasa mensual estimada a partir de la abundancia para el tiempo en que se llevaron a cabo las prospecciones (Figura 4). En las capturas se da un comportamiento cíclico debido a la pesca y a la recuperación de la población durante la veda, no siendo tan evidente para las estimaciones de biomasa. Sin embargo se refleja un movimiento dinámico de la langosta aún dentro de los meses de veda y fuertes incrementos de la biomasa antes del inicio de la veda (junio).

Tabla 3. Estimaciones de densidad (número de organismos por Ha) para cada clase (tipo de fondo) de Abril de 1997 a Diciembre de 1999.

Fecha	Clases							
	1	3	4	6	7	8	9	10
Abril-97	0	0	12	2	0	0	0	0
Oct-97	0	0	0	0	0	0	0	0
Mar-98	0	0	0	0	0	0	0	0
Abr-98	0	0	3	7	4	0	5	
May-98		0	0	12	0	10		
Jun-98	20	7	10	35	18	40	0	0
Jul-98	0		0	0				0
Sep-98	5	4	15		0	0	10	0
Oct-98	45		2	0	15	0		3
Ene-99		0	10	0	0	35		0
Feb-99	3	5	0	0		0		0
Mar-99	10	0						0
Abr-99		0						10
May-99	10	5	30		0	20		20
Jun-99	24	7	13	41	0	45	19	10
Ago-99	0	0	26	0	0	0	0	3
Sep-99	13	3	0			0	0	0
Oct-99	0	30			0		10	
Nov-99	0	20	5		10	0		0
Dic-99	0	0	0		0	0		0

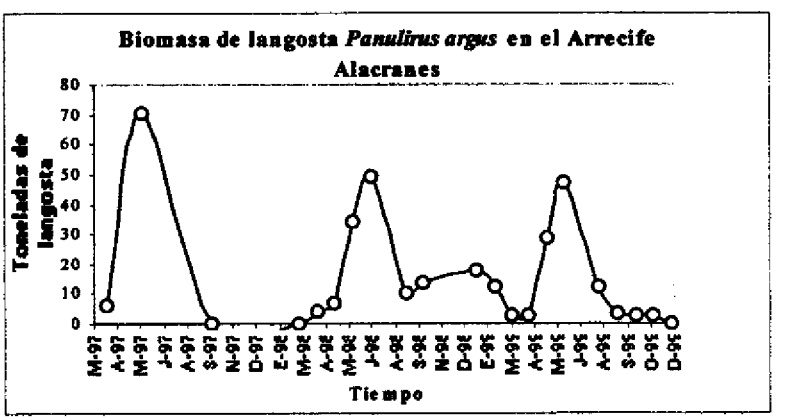


Figura 2. Fluctuaciones de la biomasa de langosta en el Arrecife Alacranes

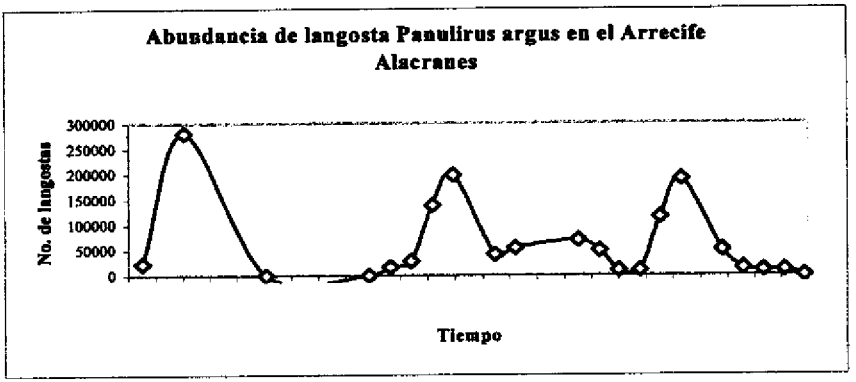


Figura 3. Abundancia de langosta en el área arrecifal somera del Arrecife Alacranes

Tabla 4. Estimaciones de abundancia, límites para el error de estimación para la abundancia y biomasa de langosta *Panulirus argus* para cada uno de los meses en los que se realizaron las campañas de muestreo.

Fecha	Abundancia en No. de organismos	Límite inferior para el error de estimación	Límite superior para el error de estimación	Biomasa (kg)
Abr-97	23883	19970	27796	5970.75
Jun-97	280,663	274,135	287,191	70,165.75
Oct-97	0			0.00
Mar-98	0			0.00
Abr-98	16759	12,847	20,670	4,189.66
May-98	27994	24,588	31,400	6,998.55
Jun-98	137903	131,257	144,549	34,475.74
Jul-98	197343	192,375	202,311	49,335.79
Sep-98	41904	38,376	45,432	10,475.97
Oct-98	53674	43,941	63,407	13,418.50
Ene-99	70162	40834	99489	17,540.46
Feb-99	49265	45947	52583	12,316.20
Mar-99	10373	7,084	13,662	2,593.23
Abr-99	10169	7,577	12,761	2,542.30
May-99	114780	110830	118730	28,695.09
Jun-99	189936	186215	193656	47 483.9
Ago-99	49932	44446	55417	12,482.91
Sep-99	13597	9491	17703	3,399.21
Oct-99	10651	6,839	14,463	2662,8
Nov-99	9763	6,741	12,785	2440,64

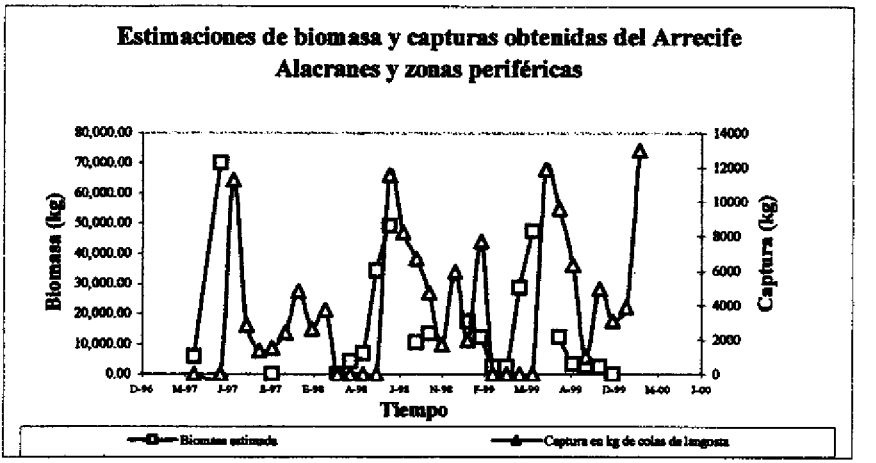


Figura 4. Captura de langosta (kg de cola de langosta) y biomasa estimada a partir de densidades y áreas de hábitat preferencial.

DISCUSIÓN

La temporada de pesca de langosta en Yucatán inicia el mes de julio y termina el mes de febrero. El esfuerzo de pesca en el arrecife tiene un comportamiento muy parecido cada temporada; al principio las embarcaciones se dirigen hacia la parte central del arrecife que presenta formaciones coralinas someras y con mayor probabilidad de brindar refugio a las langostas (Clases 1, 6, 8 y 9). Una vez agotado el recurso en el área central, esto es hacia mediados y final de la temporada de pesca, hay un desplazamiento de las embarcaciones hacia las zonas situadas al Noroeste y Sureste del arrecife, donde los refugios probables se encuentran más dispersos o bien a mayor profundidad (Ríos et al. 1998, Bello et al. 2000).

Esta dinámica espacial de aplicación del esfuerzo produce las mayores capturas al inicio de la temporada, una disminución paulatina de las capturas hacia mediados de la época de pesca y casi siempre un incremento al final de la temporada. Es decir, se aplica el esfuerzo en la zona más accesible, de mayores densidades y al agotarse el recurso en esta zona se recurre a los sitios menos accesibles pero que brindan esperanzas de captura. Este comportamiento cíclico de las capturas sugiere un proceso de disminución de la biomasa por la pesca y una recuperación durante la veda debida a dos procesos: crecimiento de las langostas pequeñas y repoblamiento de los hábitats debido a movimientos de organismos adultos desde zonas periféricas al Arrecife hacia la zona central.

Tabla 5. Serie de captura reportada para el puerto de Progreso, lugar en donde una gran proporción de la langosta desembarcada se trae de Arrecife Alacranes y zonas aledañas que conforman el Parque Nacional.

Temporalidad en la pesquería de langosta de Yucatán: V (veda) y P(Pesca).	Mes	Captura en kg de colas de langosta	Biomasa estimada
V	Abr-97	0	5,970.75
V	Jun-97	0	70,165.75
P	Jul-97	11,256	
P	Ago-97	2,840	
P	Sep-97	1,383	
P	Oct-97	1,527	0
P	Nov-97	2,385	
P	Dic-97	4,802	
P	Ene-98	2,630	
P	Feb-98	3,742	
V	Mar-98	0	0
V	Abr-98	0	4,189.66
V	May-98	0	6,998.55
V	Jun-98	0	34,475.74
P	Jul-98	11,565	49,335.79
P	Ago-98	8,239	
P	Sep-98	6,735	10,475.97
P	Oct-98	4,742	13,418.50
P	Nov-98	1,739	
P	Dic-98	5,949	
P	Ene-99	1,983	17,540.46
P	Feb-99	7,723	12,316.20
V	Mar-99	0	2,593.23
V	Abr-99	0	2,542.30
V	May-99	0	28,695.09
V	Jun-99	0	47,483.91
P	Jul-99	11,900	
P	Ago-99	9,616	12,482.91
P	Sep-99	6,346	3,399.21
P	Oct-99	1,043	2,662.80
P	Nov-99	4,946	2,440.64
P	Dic-99	3,098	0.00
P	Ene-00	3,891	
P	Feb-00	12,998	

Las estimaciones de densidad no muestran una regularidad tan clara, sin embargo, es notable un fuerte incremento de la densidad entre el lapso del final de una temporada de pesca y el inicio de la siguiente, al parecer las biomasas al inicio de la temporada de pesca es del orden de 50 toneladas en el área de estudio y se reduce durante ocho meses a alrededor de 2 toneladas. Entre septiembre y octubre de 1998 se puede observar un comportamiento anómalo con relación a la dinámica general ya que en plena temporada de pesca se incrementa la biomasa de un mes a otro y esto solo es explicable por un importante movimiento de organismos adultos hacia el interior del arrecife.

En realidad este comportamiento de repoblamiento de áreas que durante la temporada ya han sido explotadas es conocido por los pescadores quienes después de los nortes o frentes fríos (septiembre-octubre) regresan a los sitios donde al inicio o durante la temporada obtuvieron buenas capturas. La abundancia de langosta en una zona está ligada a la cantidad de refugio y alimento disponible, pero no es posible determinar el tiempo que tarda en ser ocupado un sitio que ha sido desocupado por efecto de la pesca; según los pescadores ocurre que en una temporada de pesca se puede visitar el mismo lugar varias veces en la temporada de pesca y encontrar nuevamente langosta poco tiempo después de haber sido cosechada o bien no encontrar nada en toda la temporada.

En términos del muestreo y estimadores se puede decir que en otras prospecciones realizadas en el Arrecife Alacranes y en la costa de Yucatán para evaluar a la langosta *Panulirus argus* se han utilizado transectos.de diferente tamaño (más largos y de diferente longitud y amplitud entre ellos) (Ríos et al. 1998, Ríos 2000, Bello et al. 2000), a diferencia de los transectos que se hicieron para obtener la información que se usa en este trabajo que son todos iguales (1000 m^2); como puede apreciarse en las estimaciones, los transectos de igual tamaño y de 1000 m^2, algunas veces arrojan resultados que son evidentes subestimaciones de la biomasa como ocurrió en octubre de 1997 en que las estimaciones de densidad dieron cero y la pesca ese mismo mes fue de más de una tonelada de colas. Esto sugiere la conveniencia de usar transectos de diferente tamaño que aunque presentan una mayor complicación en los métodos de estimación aparentemente producen resultados más confiables que los transectos como los usados en este trabajo (Seber 1982, Krebs 1989).

AGRADECIMIENTOS

Agradecemos al Instituto Nacional de la Pesca por el apoyo brindado para que el trabajo de campo pudiera ser realizado. A los pescadores de la Federación Regional de Sociedades Cooperativas de Producción Pesquera Centro-Poniente del estado de Yucatán por sus valiosos comentarios.

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An Investigation of the Effects of Increasing Fishing Efficiency on the Productivity of the Queen Conch (*Strombus gigas*) and Caribbean Spiny Lobster (*Panulirus argus*) Fisheries within the Turks and Caicos Islands

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ABSTRACT

Fishery management decisions throughout the world are often based on incomplete data, fortunately historical landing data exists for the Turks and Caicos Islands (TCI) dating back to 1887 (Sadler 1997). The fishery based upon Queen Conch (*Strombus gigas*) and the Caribbean Spiny Lobster (*Panulirus argus*) is typical of many fisheries because it is characterized by numerous increases, a leveling off and then a decline in catch landings. Lobster catch landings have gradually increased over the past century, from 90,700kg of whole lobster in 1947 to a maximum of 590,758 kg in 1992. Likewise, conch landings have increased from 117,550 kg in 1968 to the present total allowable catch (TAC) value of 736,960 kg.

Fishermen within the TCI have increased their fishing efficiency by acquired knowledge of the best fishing grounds as well as improving their fishing skills and developing new fishing techniques and technologies. The fishery within the TCI has transformed from one dominated by wind powered sailing sloops in the early 1900s to a fishery dominated by fishermen using 85-115 hp (three and four cylinder) engines with their fishing boats. Simultaneously, fishermen have switched from utilizing glass buckets to locate conch and lobster to free diving using mask, fins and snorkel. In the lobster fishery where nooses were used in the past, hooks are the main method now in use, however prohibited substances such as bleach are also used.

Several input and output mechanisms are being considered to manage the fishery. However, many of these mechanisms such as the maximum sustainable yield (MSY) are derived using catch per unit of effort (CPUE) data. Increases in fishing efficiency over time result in increased effective effort, although the nominal/apparent effort may seem to be unchanged. Hence, the CPUE may render misleading information on the economic and biological status of the fishery. To combat such, it is imperative that effort is standardized, and is reflected in local legislation to control technology creep.

KEY WORDS: Effective Fishing Effort, nominal/apparent fishing effort, technology creep

Investigación sobre los Efectos del Incrementos de la Productividad y la Rentabilidad en las Pesquerías de Caracol y Langosta en las Islas Turcos y Caicos

La administración de pesquerías en el mundo, se encuentra a menudo basada en informaciones incompletas. Afortunadamente, en las Islas Turcos y Caicos, existe información que data de 1904. La pesquería sobre caracol (*Strombus gigas*) y langosta espinosa (*Panulirus argus*) es la típica de muchas pesquerías, pues los desembarques se caracterizan por numerosos incrementos, estabilización y declinación. Para la langosta, las capturas tuvieron un incremento gradual durante el pasado siglo, desde 200 000 lbs. de langosta entera en 1947 a un máximo de 690 846 lbs. en 1998. De igual forma el caracol, aumento de 259 191 lbs. en 1968 a una captura permisible (TAC) actual de 1.6 millones de lbs.

Los pescadores de TCI han incrementado su eficiencia de pesca a través de las prácticas adquiridas en las mejores áreas de pesca así como mejorando sus conocimientos pesqueros y desarrollando nuevas técnicas y tecnologías. La pesca en TCI ha sido transformada desde un predominio de embarcaciones veleras en los inicios de los 1900 a una pesquería dominada por pescadores que utilizan motores de tres y cuatro cilindros (85-115 hp) en sus botes. Simultáneamente, los pescadores han cambiado el mira-fondo de vidrio para localizar la langosta y el caracol por la careta de buceo con snorkel y las patas de rana. En la pesquería de langosta donde el método principal fue el lazo en el pasado, el gancho es ahora el predominante para colectar la especie, sin embargo sustancias prohibidas como el peróxido son también usadas.

Diversos mecanismos de entrada y salida son actualmente utilizados para el manejo de la pesquería. Sin embargo, muchos de estos mecanismos como es el caso de el TAC para caracol, se derivaron de los datos de captura por unidad de esfuerzo (CPUE). El incremento de la eficiencia de pesca a través del tiempo resultó en un incremento efectivo del esfuerzo, no obstante el esfuerzo aparentemente parece no haber cambiado. Para enfrentar esto, es imprescindible que sea estandarizado el esfuerzo, y que esto se vea reflejado en una legislación local para controlar los cambios tecnológicos cambiantes.

PALABRAS CLAVES: Efectos del incrementos de la productividad y la rentabilidad, caracol, langosta

INTRODUCTION

The Turks and Caicos Islands are an archipelagic overseas territory of the United Kingdom located in the British West Indies (Figure 1). Scale fish are caught for subsistence usage as a by-product of the principle commercial fisheries of lobster and conch.

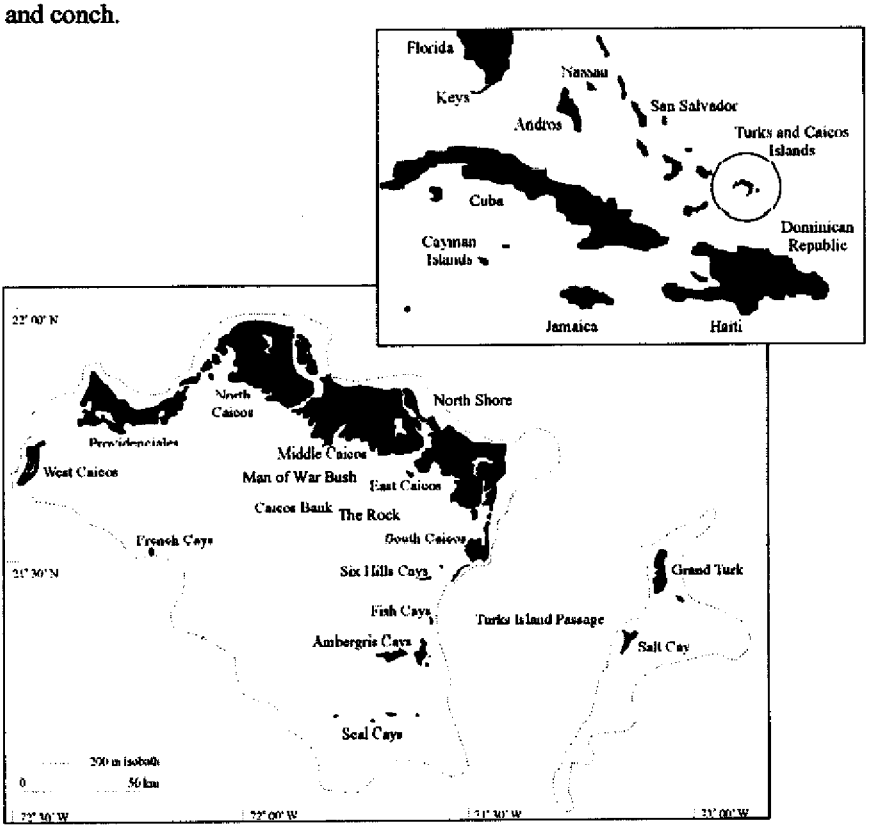


Figure 1. The location of the Turks and Caicos Islands in the British West Indies and the main fishing areas referred to in Table 2 later in this paper.

Effective management of any fishery that utilizes the MSY concept to predict fish stocks relies heavily upon often very basic input information to calculate yields through the use of surplus yield models. Such information is often merely catch and effort data (King 1995). It is well established that effort exerted within a fishery increases overtime for a number of reasons and that this 'technological creep' can mask detrimental changes in fish stocks (Pascoe1996, Cunningham 1980). It is this masking of increasing fishing effort within the TCI fisheries that is of interest and concern to those managing this fishery.

Technology creep occurs where fishermen increase their efficiency in catching fish through improvements in fishing gear over time. Unfortunately, technology creep is not reflected in the calculation of effort in most surplus production models. Increased efficiency of fishermen can occur through (Seijo 1998, Pascoe 1996, King 1995, Berg 1989):

i) The utilization and development of different fishing methods or gear,
ii) Changing the method of vessel propulsion thereby enabling fishermen to visit areas with more abundant fish stocks (generally those furthest away from fishing centers),
iii) Increased local knowledge regarding the location of fish stocks, and
iv) Increased skippers' skill.

When referring to fishing effort, it is wise to discern whether or not effective fishing effort or nominal/apparent fishing effort is being referenced. The difference, although appearing slight, is of utmost importance when determining if effort is increasing within a fishery. Eeffective fishing effort refers to the ability of a fisherman to remove a proportion of a mean population size, whereas nominal/apparent fishing effort reflects only the volume and not the effectiveness of resources devoted to removing a proportion of a fish population (Berg 1989, Cunningham 1980). For example, two fishermen in a five meter boat powered by a 150 hp outboard engine and utilizing hooks are far more effective at catching lobster than two fishermen in a four meter sail powered boat utilizing nooses. In this example it is clear that although the nominal fishing effort is the same (i.e. two fishermen and one boat) the effective fishing efforts exerted are disproportionate.

In fisheries where more than one species is fished at a time, effective effort exerted on a particular species can increase even though nominal effort remains unaltered as a result of a decline in a species abundance, forcing fishermen to fish other species, or the price returned on a particular species falls to such a level that it is economically unattractive to fish (Bēnē 2001). Effective effort has increased in the TCI conch fishery even though nominal effort has remained the same, because fishermen are now spending a larger proportion of their time fishing conch over lobster per day due to declining lobster stocks (Berg 1989, Olsen 1985). A TAC, based on MSY calculations and landing data, is currently used to manage the conch stocks within the TCI. It is believed that the TAC derived using a Schaefer biomass dynamic model (Medley 1999) is maintaining stable stocks. However, it is widely accepted that stock estimates derived from catch and effort data are inherently biased, since effort data is not adjusted to take into account changes in efficiency over time (Pascoe 1996). Nevertheless, the slight changes in efficiency over time within the conch industry do not seem to affect the results attained by the fishery dependent model, because the MSY has been corroborated by a recent visual stock assessment (Clerveaux and Danylchuk in press).

However, the lobster fishery is not managed by restrictions or limitations, and as such concerns are being aired by managers of this fishery. Their view is that lobster stocks are prone to overexploitation in the near future, based on anecdotal evidence that the fishery is in decline and effective effort is increasing (e.g. changes

in gear), although at present this is not reflected by decreased landings. In effect, fishermen are maintaining landings whilst masking potential overexploitation.

Historical landing data, in conjunction with effort records and interviews with active and retired fishermen, provide an insight to the fishing industry. Reliable data and historical records relating to the fishery will help to determine whether several periods of uncharacteristic landing figures are symptomatic of changes in effective fishing effort within the fishery or other variables such as environmental factors (e.g. water temperature and currents).

The Development of Gear Type and Efficiency

Pre-1958 wooden sailing sloops 10 - 12 m in length and drawing 1.5 - 2 m of water constructed of driftwood (Doran 1958) powered by sail were used to fish the conch and lobster grounds for up to a week. Each sloop acted as a mothership for two to four small wooden, oar-powered dinghies. The dinghies were 3 - 4 m dug outs sculled by 3 m oars worked in shallow oarlocks off center on the portside of the transom. Glass buckets (water glasses) were used to first identify conch and lobster by a bowman who carefully worked an 8 m long conch hook underneath the conch and then quickly lifted the animal to the surface (Berg 1989, Doran 1958). Lobsters, on the other hand, were 'bullied' using a small net on a pole, which was placed over the lobster and scooped into the small boat.

The fishery gradually transformed from non-diving to diving with the introduction of mask, fins and snorkel in the mid. 1950s. By the end of the 1950s free diving had increased in prevalence, although conch hooks remained in use until the mid. 1970s. As alternatives to the bully, the 'toss' (a flexible wire noose on a stick) and the 'grabber' (a spring-loaded snake catcher) were introduced to catch lobster. Diving also opened up previously unexploited areas of the fishery as it enabled deeper waters to be fished (Ninnes 1994, Olsen 1985). The grabber was quickly abandoned as it damaged the lobster, thereby resulting in a reduced economic return. These two methods of fishing were quickly replaced by a more efficient method of hooking (a shark hook attached onto a 1.5 m long flexible pole), which allowed fishermen to capture lobsters from within their dens where they aggregate during the day (Bĕnĕ 2001).

Free diving from fiberglass boats for conch and lobster aided by the use of the hook increased until it was the norm by the early 1980s (Table 1) (Nardi 1982). So far hooka and scuba which confer high fishing efficiencies, have not been used in the TCI. Their introduction is thought unlikely due to ease of enforcing these currently illegal methods of fishing.

Although changes in nominal fishing are more apparent than changes in effective effort, they have far less impact on the exploitation of a fish stock because of the law of diminishing returns (Pascoe 1996). Changes in gear on the other hand (from the use of a bully to a hook whilst fishing for lobster) and techniques (from non-diving to free diving) are believed to have increased fishermen's effectiveness to exploit the fishery.

Bënë (2001) noted that the shift to hooking is displayed by two distinct bionomic equilibrium's, resulting from two successive switches from conch to lobster and then from lobster to conch, which followed an almost perfect Cobb-Douglas indifference curve (Figure 2).

Table 1. The transition of gear in the Caribbean spiny lobster (*Panulirus argus)* and Queen Conch (*Strombus gigas)* fishery of the Turks and Caicos Islands since 1940.

Year	Prevalent Type of Fishing	Prevalent Gear Type	
		Lobster Fishery	Conch Fishery
1940s	Non-diving	Bully	Conch Hook
1956	Diving	Toss & Grabber	Hand Capture
Late 1950s	Diving	Toss & Hook	Hand Capture
1960s	Diving	Toss & Hook	Hand Capture
1970s	Diving	Hook	Hand Capture
1980s	Diving	Hook (Bleach)	Hand Capture
1990s - present	Diving	Hook (Bleach)	Hand Capture

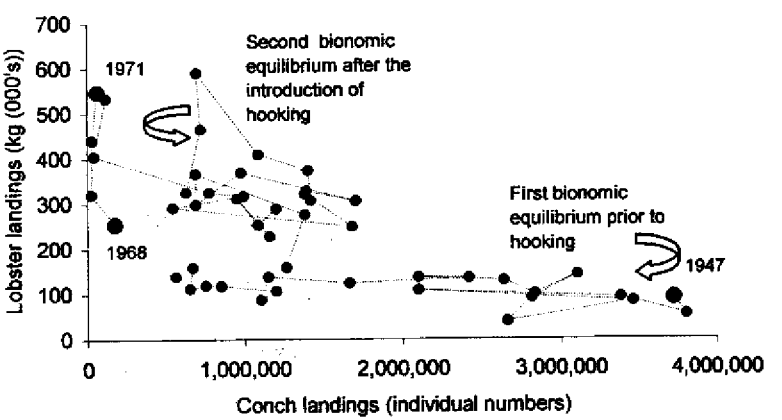


Figure 2. Phase diagram of the Caribbean Spiny Lobster (*Panulirus argus*) and Queen Conch (*Strombus gigas*) fisheries of the Turks and Caicos Islands showing two distinct bionomic phases before and after the introduction of the hook as a lobster fishing gear.

Development of Fishing Locations Over Time

Stocks are generally not evenly distributed along the seabed, and in many cases accessible areas of higher abundance are fished first to maximize return on investment (e.g. time, money) (Coppola 1996). Coppola also pointed out that fishermen have to extend their search for fish once areas of known abundance have been exploited to their full potential, venturing greater distances from port as a fishery is developed. Over time, fishing areas in the TCI have changed to reflect attempts by fishermen to increase or maintain their catches. Distant sites were explored and developed (Table 2). Until the introduction of high horsepower engines (> 40hp) in the mid. 1970s, fishermen, (in particular lobster fishermen) were restricted to fishing in close proximity to port (8 - 15 km) so as return the same day and land a high quality product. Conch fishermen, on the other hand, at times ventured further (e.g. Ambergris Cay from South Caicos) spending several days fishing and drying conch (Hesse 1977, Doran 1952).

Table 2. Fishing site development over time in the Turks and Caicos Islands Caribbean spiny lobster (*Panulirus argus*) and queen conch (*Strombus gigas*) fisheries.

	Six Hills Cay	Ambergris	Caicos Bank and the Rock	Southern Ambergris (Bush Cay)	Southern Seal Cays	Man Of War Bush	North Shore
Pre. 1970	STB/ D	U	U	STB	STB	U	U
Mid. 1970	D	LTB	U	LTB	STB	D	D
1980	D	D	D	LTB/ D	D	D_{DS}	LTB
Mid. 1980 - present day	D	D	D	LTB/ D	LTB/ D	D_{DS}	D
Distance from S. Caicos fishing community	8km	23km	31km	34km	37km	40km	40km

Key: D, Divers; U, Undeveloped; LTB, Large Trap Boats; STB, Small Trap Boats; D_{DS}, Diving still dominant but stocks are relatively depleted
Small trap boat; < 9m in length, 2 fishermen outboard engine
Large trap boat; > 9m in length, > 2 fishermen inboard engine
Divers; small boat, < 6m in length, 2–3 commercial fishermen

Since the introduction of outboard motor engines for commercial fishing vessels in the early 1950s, engine size and power have increased steadily over the years. By the middle of 1970, the sail powered sloops; seagull and low powered wooden dugout boats were replaced by vessels with fiberglass hulls with two and three cylinder engines, thereby allowing fishermen to venture further, quicker (Table 3). The increase in fishermen's fishing range and ability to carry large amounts of product increased effective fishing effort further allowing effective exploitation of the stocks. Apparent effort changed very little over time period of time.

Table 3. Fishermen of the Turks and Caicos Islands have increased their effectiveness over time at exploiting the fish stocks by changing hull composition and increasing engine size, allowing increased load capacity, speed and range.

Year	Prevalent Propulsion method	Hull material
1940	Sail/oars	Driftwood, dug out canoes
1950	2.5-6hp Seagull engine introduced	Locally made wooden boats, first imported fiberglass hull
1960	18hp	Wood/Fibreglass
1970	40hp	Wood/Fibreglass
1975	55hp	Wood/Fibreglass
1985	65-70hp	Wood/Fibreglass
1990	70-75hp	Wood/Fibreglass
1995	85-90hp	Wood/Fibreglass/buoyant foam
2000	85-90hp (lobster fishing)	Wood/Fibreglass/buoyant foam
2000	105-200hp (conch fishing)	Wood/Fibreglass/buoyant foam

Source: Department of Environment and Coastal Resources commercial fishing vessel licence application forms, historical records and interviews with commercial fishermen.

Effect of Increasing Fishing Efficiency

A simple surplus production model (Fox) was used to model the effects of increasing fishing efficiency using lobster catch and effort data from the mid. 1960s encompassing both pre- and post-hooking years (1966 - 2000) whilst also taking into account the changes in distance traveled from fishing centres over time. The data was then compared to the years when hooking was not as prevalent and there were no significant changes in fishing location (1966 - 1980).

The results indicate that a MSY of 491,650 kg would be obtained at an apparent effort level of 25,000 man-days, had effective fishing effort remained constant, as in pre-prevalent hooking years (1966 - 1980). However, an increase in effective effort causes a shift in the Fox model with the MSY rising more steeply and reaching a lower MSY value of 354,576 kg at 20,000 man-days of apparent effort (Figure 3). The ratio of fishermen to a fishing vessel was also investigated however there was no significant change in this ratio as the fishery developed. The implication here is that this potential area of increasing effective effort is actually static.

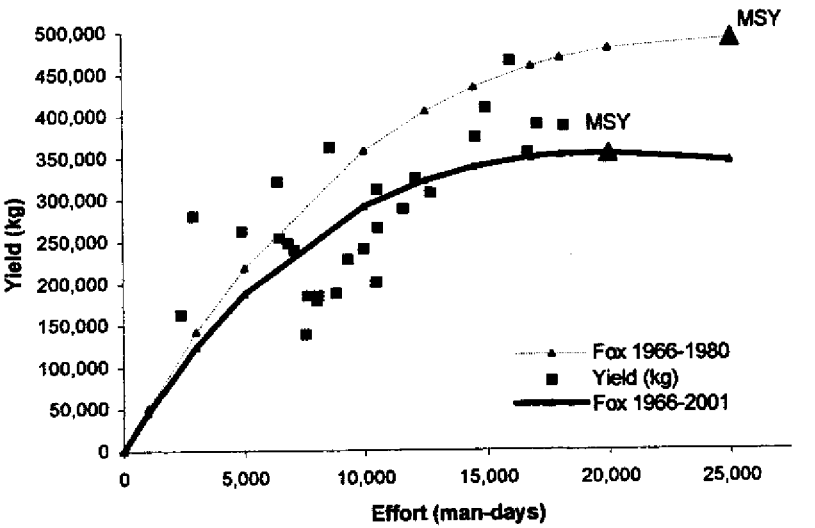


Figure 3. Maximum sustainable yield plot from a Fox surplus production model for the Turks and Caicos Islands Caribbean spiny lobster (*Panulirus argus*) fishery illustrating how a change in gear (the introduction of the hook in 1980) results in a decrease in the maximum sustainable yield which could also be attained by a reduced nominal effort (man - days).

DISCUSSION

Despite concerns which has been raised about surplus production models overestimating stocks and their unpredictability to identify potential changes of the catchability of inputs (Cunningham, 1980), surplus production models are commonly used as a management tool in many fisheries throughout the world (Coppola 1996; Sparre 1992). The reasoning for this is that in contrast to most analytical models, the data requirements are less demanding and can be met with reasonable yield and effort estimates/values being attained over several years (Sparre 1992).

An underlying assumption in the short run catch-effort relationship is that catch in one year is a linear function of effective fishing effort (Coppola 1996, Cunningham 1980) given by:

$$C = qEB$$

where C is the catch, q is the catchability coefficient, E is effort and B is the stock biomass.

A change in gear has the potential to increase both apparent and effective effort exerted upon a stock (Figure 2). The two binomial equilibrium observed in the fishery is a result of an increase in effective fishing effort (e.g. hooking), that led to

an increase in apparent effort (e.g. man-days). A shift to free-diving and hooking in the late 1950s and early 1960s increased the effectiveness of fishermen to catch lobsters, hence increasing profit and attracting more fishermen into the lobster industry. As the lobster stocks became depleted, fishermen diverted their effort to fishing conch, thereby producing the second bionomic equilibrium.

Furthermore, the change in fishing gear increased the level of the catchability coefficient (q) thereby increasing fisherman's effectiveness at exploiting the lobster stocks. However, lobster landings remained higher in the second bionomic equilibrium than previously, although apparent effort (man-days) declined to previous levels. This phenomenon may provide misleading CPUE information (i.e. abundance of the stock is high). The short-term benefit was the maintenance of high landings at a similar apparent effort level, but larger long-term MSYs were sacrificed.

There has been an increasing trend in the use of reference points for fisheries management, particularly with those that maximize yield (Caddy 1995) (e.g. effort at the MSY (E_{msy})). Increasingly, the use of fishing effort as a reference point would imply that at some point effort would be curbed at the reference level to provide optimum benefit to the resource users. One fishery management tool widely used to achieve this objective (effort reduction) is by exclusion (e.g. limiting the number of individuals allowed to enter the fishery).

The success of limited licence entry programs on a global scale has been quite variable (Austin 1986). Limiting the number of licensed fishermen itself may not prevent biological overfishing, as pointed out by Austin (1986), because only the apparent effort has been managed, and this in fact may have negligible impact on stock protection and management. Nevertheless, if used in conjunction with attempts to limit effective effort such as technology creep, limiting the number of licenses can assist in achieving biological and economic objectives.

It has been suggested that nominal or apparent fishing effort will only be a true reflection of fishing mortality so long as the catchability coefficient remains constant (Cunningham 1980):

$$F = qf$$

where F, is fishing mortality, q is catchability coefficient and f is nominal/apparent fishing effort. However, the catchability coefficient does not remain constant due to changes in efficiency, temporal and spatial scales (Tewfik 2000). As such, nominal/apparent effort would need to be periodically standardized and factored to take into account increasing effective effort within the fishery.

CONCLUSION

Effective and nominal efforts within the TCI fishery are significantly different. Technology creep has over time increased the effectiveness of exploiting the fisheries (e.g. the lobster stocks by shifting the MSY to a lower level of equilibrium). The

creep in effective fishing effort caused by changes in gear requires careful management to prevent over exploitation.

It is imperative that fishery managers have a good understanding of the levels of effective and nominal effort being exerted in their fisheries in order to choose the most appropriate manner in which to manage the fishery. If this is not the case, ineffective effort reduction schemes will do little to protect either the economic or biological sustainability of the fishery and may in actual fact be expensive and detrimental.

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Estimación de la Biomasa de Pepino de Mar (*Astichopus multifidus, Isostichopus badionotus y Holothuria floridana*) en dos Áreas de la Costa de Yucatán entre Octubre del 2000 y Marzo del 2001

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RESUMEN

Las especies potencialmente comercializables en las costas de Yucatán son tres. *Astichopus multifidus, Isostichopus badionotus y Holothuria floridana.* El objetivo de este trabajo es evaluar la biomasa de estas tres especies en dos áreas de las costas de Yucatán, durante el periodo Octubre del año 2000 a Marzo del año 2001. Las áreas de interés están ubicadas en la costa oriental y central del Estado de Yucatán. El área de la costa oriental tiene una superficie aproximada de 596,803 ha y el área de la costa central tiene una superficie aproximada de 581,197 ha. La evaluación de la biomasa se hizo tomando como base conteos de organismos de cada especie en transectos. Los conteos se realizaron durante los meses de Octubre Marzo (2000-2001). Se hicieron estimaciones de densidad en número de organismos por metro cuadrado y por hectárea; Las estimaciones de densidad en número de organismos por hectárea para el área de la costa oriental son: *Astichopus multifidus*: 5.92 , *Isostichopus badionotus*: 5.08, *Holothuria floridana*: 120, para la costa central son: *A. multifidus*: 32.18, *I. badionotus*: 25.29, *H. floridana*: 142.53. El peso medio en Kg de los individuos colectados de cada especie son: *A. multifidus*: 1.454 , *I. badionotus*: 0.790 , *H. floridana*: 0.118; la biomasa estimada para el área de la costa oriental en toneladas es: *A. multifidus*: 2 570 , *I. badionotus*: 1 196 *y H. floridana*: 1 016. la Biomasa estimada para el área de la costa central en toneladas es: *A. multifidus*: 13 600, *I. badionotus*: 5 806 y *H. floridana*: 1 968. Esta estimación de biomasa se realizó considerando que *A. multifidus* ocupa solo un 50% de cada área de interés, *I. badionotus* también un 50% y *H. floridana* ocupa solo un 20 % de cada una de las áreas.

PALABRAS CLAVES: Pepino de Mar, *Astichopus multifidus, Isostichopus badionotus y Holothuria floridana*

Sea Cucumber (*Astichopus multifidus, Isostichopus badionotus Y Holothuria floridana*) Biomass Estimation in Two Areas of Yucatan Coast between October of 2000 to March of 2001 Year

ABSTRACT

There are three sea cucumber species potentially marketed from the Yucatan Coast: *Astichopus multifidus*, *Isostichopus badionotus* and *Holothuria floridana*. The objective of this work was to get a biomass evaluation of these three species from two areas to Yucatan Coast during October (2000) to March (2001). The areas are located in the eastern and central coast of the Yucatan State, Mexico. The eastern coast area has an surface approximate of 596,803 ha, and the central coast area has an approximate surface of 581,197 ha. The biomass evaluation was made using counts of sea cucumbers of each specie in transects. The counts were made during October to March. Density were estimated in organism for square meters and organism for hectares. The density estimates in number of organism by hectare for the area of the eastern coast is: *Astichopus multifidus*: 5.92, *Isostichopus badionotus*: 5.08, *Holothuria floridana*: 120; for central coast are: *A. multifidus*: 32.18, *I. badionotus*: 25.29, *H. floridana*: 142.53. The average weight in kg. of the collected individuals of each specie is: *A. multifidus*: 1.454 , *I. badionotus*: 0.790 , *H. floridana*: 0.118; Biomass estimations for the area of the eastern coast in tons is: *A. multifidus*: 2,570, *I. badionotus*: 1,196 and *H. floridana*: 1,016. Biomass estimation for the area of the central coast in tons is: *A. multifidus*: 13,600, *I. badionotus*: 5,806 and *H. floridana*: 1,968. This biomass estimation was does considering that *A. multifidus* occupies only a 50% of each interest area, *I. badionotus* also a 50% and *H. floridana* occupies only a 20 % of each area.

KEY WORDS: Sea Cucumbers, *Astichopus multifidus, Isostichopus badionotus y Holothuria floridana*

INTRODUCCION

En Yucatán la pesca es una actividad económica de gran importancia, de ella dependen las comunidades de pescadores que habitan en la costa y durante la década pasada un gran número de campesinos se han integrado a la pesca. Esto dio como resultado un crecimiento considerable del esfuerzo pesquero de tal manera que en la actualidad se piensa que las pesquerías tradicionales como son la de mero, pulpo y langosta tienen un reducido margen de crecimiento si no es que ya han

alcanzado niveles de aprovechamiento pesquero que sobrepasan los niveles óptimos biológicos y/o económicos. Ante esta incapacidad de los recursos pesqueros tradicionales para soportar un crecimiento económico de la actividad, es posible hacer más eficiente el uso de la infraestructura pesquera existente, utilizándola en el aprovechamiento de recursos que hasta hoy no son sujetos a la pesca. Este trabajo es parte de un proyecto que tiene como objeto sentar las bases, mediante la adquisición de conocimientos científicos, para el aprovechamiento de un recurso pesquero con una gran demanda internacional y que en la actualidad no tiene mercado local ni nacional: el pepino de mar.

La primera fase del proyecto consistió en identificar las especies de pepino de mar de las costas de Yucatán que son potencialmente comercializables en el mercado internacional. Esto requirió una fase de prospección, colecta de ejemplares robustos y la identificación taxonómica, el trabajo fue realizado recientemente por Zetina et al. (2001) y el resultado fue la identificación de tres especies que son potencialmente comercializables: *Astichopus multifidus, Isostichopus badionotus* y *Holothuria floridana*. Otro aspecto importante que sirve como base para la definición de estrategias de aprovechamiento pesquero en un marco de sustentabilidad y manejo responsable, es la evaluación del tamaño y biomasa de las poblaciones.

Los métodos utilizados para la estimación del tamaño y biomasa de las poblaciones de pepinos de mar se basan en datos procedentes de las pesquerías o en observaciones directas como son el conteo de organismos en cuadrantes, transectos o métodos basados en mediciones de la distancia entre los organismos. La selección de la técnica depende de los objetivos y de las condiciones en que se harán las estimaciones, esto es: las características de distribución de la población en el ambiente natural y los recursos económicos disponibles, entre otras cosas (Conand 1986, Pérez-Ruzafa y Macos-Diego 1985). La mayor parte de las estimaciones de biomasa de pepino de mar realizadas en México, se han llevado a cabo en las costas del Pacífico y se refieren a *Isostichopus fuscus* e *I. parvimenses* (Fajardo y Vélez 1996). En el mar Caribe se han reportado algunas estimaciones de densidad, particularmente de la especie *Isostichopus badionotus* (Conde 1997). En las costas de Yucatán el único antecedente de estimación de la biomasa de pepinos de mar fue publicada por Ríos (2000) y no hace distinción entre las especies que conforman el recurso.

El objetivo de este trabajo es obtener una evaluación de la biomasa de tres especies de pepino de mar potencialmente comercializables (*Astichopus multifidus, Isostichopus badionotus* y *Holothuria floridana*.) en dos áreas de las costas de Yucatán situadas en las inmediaciones del puerto de San Felipe (área de la costa oriental) y Progreso (área de la costa central), Yucatán, durante el periodo Octubre del año 2000 a Marzo del año 2001.

METODO

Para obtener estimaciones de densidad se realizaron campañas de colecta utilizando como técnica el buceo libre, semi autónomo (con manguera y compresor) y autónomo (tanques). Al inicio de las campañas se midió el tiempo en que tarda un buzo en recorrer una distancia de 50 metros, estas mediciones sirvieron como base para calcular el recorrido de un buzo durante diferentes tiempos de buceo. El área revisada por un buzo se estimó utilizando los cálculos de la distancia recorrida (largo) y el ancho calculado por una estimación de la visibilidad durante la operación de búsqueda. En cada buceada se contaron los organismos de cada especie recolectando algunos para obtener estimaciones de peso promedio de los organismos de cada especie. En las dos áreas de interés se realizaron buceadas durante los meses de Octubre, Noviembre y Diciembre del año 2000, así como Enero, Febrero y Marzo del año 2001. Las buceadas tuvieron lugar en profundidades entre 1 y 20 metros de profundidad, casi siempre se iniciaron las buceadas en aguas profundas y se continuó con dirección a la costa hasta alcanzar las menores profundidades. En la costa oriental se recorrió un área de 30,716.7 m^2 y en la costa central se recorrieron 4 350 m^2.

El área de la costa oriente de Yucatán de interés en este estudio está comprendida en los cortes de la Costa de Yucatán con las longitudes 187° 35' Oeste y 88° 36' Oeste, el área de inferencia es de 596,803 ha. El área Central se ubica entre los cortes de la línea costera con las longitudes de 89° 16' y 90° 00' y el área de inferencia es de 581,197 ha.

Figura 1.- Area de estudio

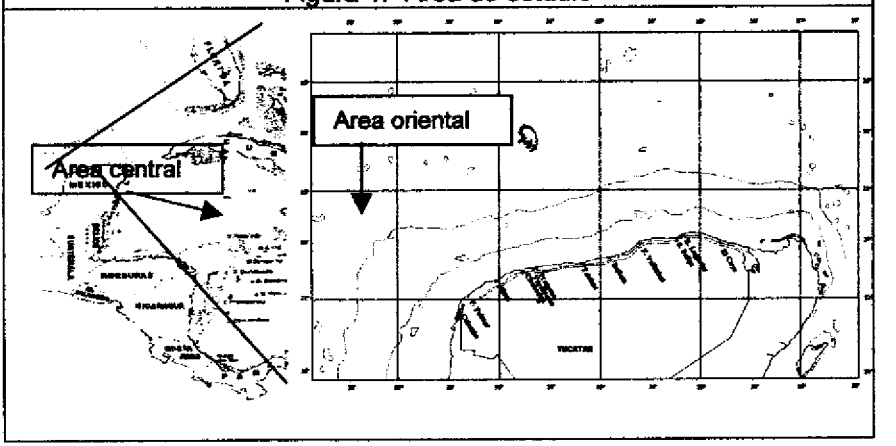


Figura 1. Area de estudio

La estimación de densidad para cada especie y área se obtuvo mediante la fórmula:

$$R = \frac{\sum n_i}{\sum a_i} = \frac{N}{A} \qquad (1)$$

Donde:
R= estimación de la densidad
n_i = Número de organismos encontrados en el transecto i
a_i = Area recorrida en el transecto i, medida en m^2 o en Ha
A= Area total recorrida durante las buceadas, medida en m^2 o en Ha
N= Número total de organismos encontrados

La varianza estimada para R es:

$$Var\,(\hat{R}) = \frac{\sum n_i}{\sum a^2{}_i} \qquad (2)$$

El cálculo del número total de organismos en cada área se calculó mediante la fórmula:

$$Norg(j) = R(j) * A(j) \qquad (3)$$

Donde:
Norg (j) = Número de organismos en el área j
R(j) = Densidad promedio en el área j
A(j) = Area j

La varianza de la estimación del número de organismos en el área es:

$$Var(\hat{Norg}) = Cf * (\sum (n_i)^2 + (R^2) * \sum (a_i)^2) - (2 * R * \sum (n_i * a_i)) \qquad (4)$$

Donde:
Cf es el factor de corrección por finictud.

$$Cf = ((Areacostera*(A-1))/(A*(A-1)) \quad (5)$$

Los límites para el error de estimación se obtuvieron en todos los casos por:

$$LPEE = \hat{e} \pm 1.96 \text{ Ö Var } (\hat{e}) \quad (6)$$

Donde:
LPEE = Límite para el error de estimación
ê = Estimación

La biomasa se calculó para cada especie multiplicando el número de organismos en cada j-ésima área por el peso promedio de los organismos encontrados. El peso fue medido en gramos de peso fresco y en tierra después de haber transportado a los organismos a los puertos:

$$B_{j,k} = N_{j,} * \bar{W}_k \quad (7)$$

Los límites para el error de estimación inferior y superior de las estimaciones de biomasa se calcularon multiplicando el peso el límite calculado para el número de organismos en el área por el peso medio de los organismos de cada especie (Krebs 1989, Seber 1982).

RESULTADOS

En las tablas siguientes se presentan las estimaciones realizadas con base en las observaciones realizadas en el campo. Las estimaciones de biomasa que se reportan en la Tabla 1 difieren de las que se reportan en la Tabla 4, esto se debe a que en esta última se considera que las especies no se distribuyen en toda el área de inferencia, sino solo en una fracción de ellas cuya aproximación se consiguió calculando el porcentaje de ocurrencias de las especies en los transectos.

La estimaciones del porcentaje de ocurrencia de cada una de las especies en los transectos, presentados en la Tabla 3 se utilizaron para calcular la biomasa en cada una de las áreas, esto permite estimaciones más conservadoras entre que se tienen mejores criterios para realizar las estimaciones como son el tipo preferido de fondo y las evaluaciones de las áreas que cubren.

Tabla 1. Estimación de densidades en organismos por metro cuadrado (Org/m^2) y por hectárea (Org/Ha) con estimaciones de varianza y límites para el error de estimación (LIPEE y LSPEE), totales poblacionales por área con cálculos de varianza y límites para el error de estimación, así como estimación de la biomasa en toneladas en el área y en kg por hectárea de *Astichopus multifidus, Isostichopus badionotus* y *Holothuria floridana* en la costa oriental de Yucatán.

Costa oriental			
Parámetro	*A. multifidus*	*I.badionotus*	*H. floridana*
Densidades Org/m^2	0.0006	0.0005	0.012
Densidad Org/Ha	6	5	120
Abundancia	3,535,365	3,030,313	71,616,396
Cf	252,526	252,526	1,377,238
Var(Ab)	4,836,570	8,649,742	2,060,349
LIPEE	3,531,055	3,024,549	71,527,430
LSPEE	3,539,676	3,036,077	71,705,363
peso medio (kg)	1.45	0.79	0.07
Biomasa (Toneladas)	5,140	2,393	5,085
LIPEE	5,134	2,389	5,078
LSPEE	5,146,688	2,398,501	5,091,081
Biomasa (kg/ha)	8.6	4.0	8.5

Tabla 2. Estimación de densidades en organismos por metro cuadrado (Org/m^2) y por hectárea (Org/Ha) con estimaciones de varianza y límites para el error de estimación (LIPEE y LSPEE), totales poblacionales por áreas con cálculos de varianza y límites para el error de estimación, así como estimación de la biomasa en toneladas en el área y en kg por hectárea de *Astichopus multifidus, Isostichopus badionotus* y *Holothuria floridana* en la costa central de Yucatán.

Costa central			
Parámetro	*A. multifidus*	*I. badionotus*	*H. floridana*
Densidades Org/m2	0.003218	0.002529	0.014253
Densidad Org/ha	32.18	25.29	142.53
Abundancia	18,705,198	14,696,942	82,837,307
Var(Ab)	50,047,164	44,285,527	450,620,771
LPEEI	18,691,332.5	14,683,898.2	82,795,700.2
LPEES	18,719,064.1	14,709,984.8	82,878,913.3
peso medio (kg)	1.45	0.79	0.12
Biomasa (Toneladas)	27,197.358	11,610.584	9,774.802
LPEEI	27,177	11,600	9,770
LPEES	27,218	11,629	9,780
Biomasa (kg/ha)	47	20	17

Tabla 3. Estimación del porcentaje de ocurrencia de cada una de las especies en los transectos.

Especie	Costa Oriental	Costa Central
Astichopus multifidus	43%	55%
Isostichopus badionotus	43%	55%
Holothuria floridana	19%	22%

Tabla 4. Estimación de Biomasa en kg. de tres especies comercializables de pepino de mar en las costas oriental y central de Yucatán. Este cálculo de la biomasa se basa en porcentajes aproximados de áreas de distribución de las especies en relación al área aproximada sujeta a solicitud o con permiso de pesca de fomento, la aproximación se basó en el porcentaje de ocurrencia de las especies en los transectos.

Area Costera	Area en Hectáreas	*A. multifidus* (50% del área solicitada)	*I. badionotus* (50% del área solicitada)	*H. floridana* (20% del área solicitada)
Oriental	596,803	2,570,133	1,196,591	1,016,953
Central	581,197	13,600,015	5,806,160	1,967,934

DISCUSION

En relación al método de conteo de organismos es importante señalar que el trabajo en transectos pequeños (50 m o menos) resulta inconveniente para el área de estudio, esto se debe a que las densidades de pepino de mar, inducen un gran número de transectos que no tienen organismos, por otra parte los costos asociados a muestreos utilizando transectos cortos se incrementan y lo más importante es que requiere de un mayor número de asensos e inmersiones de los buzos en áreas profundas (rebotes) lo que facilita la ocurrencia de accidentes de buceo. El usar transectos largos tiene el inconveniente de que se introduce cierta impresición en las mediciones o cálculo de las distancias, sin embargo en esta área de estudio en nuestra opinión los inconvenientes son menores que los causados por los transectos cortos.

Los métodos de estimación utilizados en este trabajo suponen que las observaciones fueron realizadas sin incertidumbre, es decir que las mediciones de áreas medidas y el conteo de organismos se hizo con un 100% de detectabilidad. Si bien en el futuro se utilizarán estimadores más apropiados, consideramos que los utilizados son más convenientes en esta primera aproximación ya que permiten estimaciones conservadoras. Algunas observaciones en las áreas de estudio realizadas durante la noche, mostraron densidades de *H. floridana* mucho mayores de las que se pueden observar durante el día. Durante la noche muchos organismos

enterrados en áreas fangosas emergen a la superficie del fondo del mar alcanzando densidades hasta de 15 organismos por metro cuadrado.

Las estimaciones de densidad que se obtuvieron en este trabajo son bajas en relación a las reportadas para otras especies de pepino de mar (0.59 a 0.03 organismos/m^2) del Pacífico mexicano reportados en el Libro de "Sustentabilidad y Pesca Responsable en México" y que proceden principalmente de las costas de la Baja California Sur (Aguilar et al. 2000), sin embargo es posible que las estimaciones del Pacífico se basen en conteos realizados sobre agrupaciones de organismos. En relación a las estimaciones reportadas por Ríos (2000), en el orden de 5.47 organismos/ha, las densidades de este trabajo son elevadas. Las explicación que tenemos a esta diferencia es que el trabajo de Ríos *op cit.* estaba orientado principalmente al conteo de langostas y los datos de pepino fueron secundarios, por otra parte a excepción de *A. multifidus*, las otras dos especies robustas comunes en las costas de Yucatán (*I.badionotus* y *H.floridana*) tienden a ocupar grietas o se entierran en el fondo de manera que su detectabilidad disminuye, además el estimador utilizado por Ríos incorpora una detectabilidad menor al 100% a diferencia de este trabajo. En relación a las densidades reportadas para *I. badionotus* en otras partes del Mar Caribe de 7.66 org/ha (Conde 1997), las densidades estimadas para el área oriental es similar y estadísticamente igual con un nivel de significancia de 0.05. Sin embargo, las densidades estimadas para la costa central son significativamente más altas.

Los resultados de este trabajo sugieren que la biomasa en las áreas y de las tres especies estudiadas, permiten realizar estudios de pesca en áreas definidas (modelos de decaimiento) y la evaluación de los tiempos de recuperación de la biomasa en dichas áreas.

CONCLUSIONES

Las técnicas de observación para la obtención de datos de densidad no pueden ser homogéneas para estudiar las especies de pepino de mar presentes en las costas de Yucatán. En algunas áreas y condiciones es necesario realizar adecuaciones en términos de tamaño de los transectos y modo de realizar los conteos. En trabajos subsecuentes es conveniente utilizar estimadores como los descritos por Ríos (2000).

Las estimaciones realizadas en el presente trabajo muestran densidades y biomas de pepino de mar que resultan adecuadas para el establecimiento de una pesquería, sin embargo para establecerla bajo un marco de desarrollo sustentable y pesca responsable, es necesario profundizar el estudio de características de la población como crecimiento individual y diferentes aspectos de reproducción y reclutamiento, así como otros tópicos de la biología y ecología de los pepinos de mar en la región.

AGRADECIMIENTOS

Agradecemos a CONACyT-SISIERRA, al Instituto Nacional de la Pesca, a la Facultad de Ingeniería de la UADY, a la S. C. de P. P. "Pescadores Unidos de San Felipe", a Mauricio Garduño, Ramón Díaz, Efraín Ortíz, Javier Rivas, Carlos Herrera, Domingo Addiego, José Luis Carrillo, Roberto Centeno, Francisco Duarte, Elba Castillo, Roger Méndez y Carlos Quintal por el apoyo económico, material y técnico manifestado, el cual hizo posible la realización de este documento.

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Premiers Resultats de Peches Experimentales de Crustaces Profonds en Guadeloupe (F.W.I.)

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RÉSUMÉ

L'exploitation intense des eaux du plateau insulaire de la Guadeloupe, implique de rechercher des solutions de redéploiement d'une partie des flottilles vers l'exploitation de nouvelles ressources. En ce sens, l'Institut Régional de Pêche et de Marine explore, depuis 1993, les possibilités d'exploiter les Crustacés profonds au casier.

Des pêches mobilisant différents types d'engins ont été réalisées entre -200 et -1500 m dans les eaux de la Guadeloupe et ont permis de compléter les inventaires faunistiques.

Ces travaux ont permis d'identifier certaines espèces d'intérêt économique potentiel : en particulier la langoustine *Eunephrops cadenasi* et des crevettes de la famille des Pandalidae (genres *Heterocarpus* et *Plesionika*). Quelques informations sur la biologie et sur la biométrie des espèces cibles ont pu être produites.

Un effort particulier a été consenti pour développer des engins et des techniques de pêche pour exploiter ces ressources de façon rentable économiquement tout en préservant leurs capacités de renouvellement. L'analyse des rendements économiques et des compositions des captures conduit à recommander l'emploi des casiers de très grand volume (20 m^3, mailles 38 mm ou supérieures) ou des casiers de petit volume de type « saint-martinois » (0.15 m^3, mailles 50 mm).

Les perspectives de développement de cette pêcherie sont également analysées.

MOTS CLEFS: *Eunephrops cadenasi*, Pêches, Ressources profondes

Firsts Results of Experimental Deep-sea Crustacean Fisheries in Guadeloupe (F.W.I.)

ABSTRACT

Overexploitation of stocks in Guadeloupe's continental shelf has led to consider other methods for fisheries in order to direct part of the fishery fleet towards unutilised or under utilised stocks.

For that reason, since 1993, IRPM has started exploring unutilized stocks of Crustaceans. Faunistic inventories has been completed through fishing experiments using different types of traps in waters from –200 m to – 1500 m. In this way, a few species with potential for exploitation have been identified: namely lobsters

Eunephrops cadenasi and few *Plesionika* and *Heterocarpus* shrimp species. Data including biological information on these stocks have been collected.

The development of fishing techniques to improve yields and monitoring in order to ensure the preservation and renewal of the stocks are necessary.

Yield estimates as well as analysis of capture composition have led us to recommend the use of very big traps (20 m^3 using 38 mm mesh) or smaller traps "Saint-Martin type" (0.15 m^3, mesh 50 mm).

The possibility of developing this fishery has also been analysed.

KEY WORDS: Deep-sea resources, *Eunephrops cadenasi*, fisheries

INTRODUCTION

Traditionnellement, la pêche guadeloupéenne s'est concentrée au niveau des zones peu profondes du plateau insulaire entraînant une surexploitation. Depuis une quinzaine d'années, l'Institut Régional de Pêche et de Marine (IRPM), conscient de cette situation, s'est efforcé de mener diverses actions en vue de permettre la diversification des pêcheries et le redéploiement d'une partie de l'effort de pêche vers l'exploitation de nouvelles ressources. Dans cette continuité, l'IRPM mène actuellement un programme intitulé "Optimisation de l'exploitation des ressources innovantes en Guadeloupe, ressources profondes et DCP". La rentabilité de d'exploitation ces ressources innovantes doit être étudiée en conditions d'exploitation commerciales en tenant compte de la nécessité de préserver les capacités de renouvellement des espèces.

Diverses techniques et engins de pêche sont expérimentées :

i) La palangre profonde ciblant particulièrement les requins,
ii) La pêche au filet profond ciblant principalement les Lutjanidés
iii) La pêche des grands pélagiques autour des DCP,
iv) La pêche aux casiers profonds ciblant les Crustacés.

C'est cette dernière technique qui fait l'objet des développements suivants. Les résultats présentés ici, sont issus de la première phase de mise en œuvre des casiers dans le cadre du programme. Les objectifs étaient de tester différents casiers et d'identifier les plus performants pour garantir une exploitation durable des ressources de Crustacés profonds. Il s'agissait de définir des montages qui seraient mis en œuvre pour la suite de la campagne expérimentale, dans une configuration d'exploitation commerciale

HISTORIQUE DES CONNAISSANCES SUR LES RESSOURCES EN CRUSTACÉS PROFONDS AUX ANTILLES FRANÇAISES

Les crustacés profonds sont exploités de manière anecdotique en Guadeloupe. Pourtant, plusieurs études menées dans le passé ont montré la présence de diverses espèces potentiellement exploitables.

En 1983, le Service de Développement et d'Aide Technique (SDAT, IRPM) est le premier à révéler l'existence de crevettes du genre *Plesionika* et *Heterocarpus*, et de langoustines *Eunephrops cadenasi* dans les eaux guadeloupéennes, en mouillant des casiers entre 250 et 520 m au large de Basse-Terre.

Des études de prospection complémentaires furent menées en 1989 et 1990 par le SDAT et l'Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER). Un premier inventaire des espèces de Crustacés profonds fut dressé à cette occasion. Lors de ces travaux, plusieurs types de casiers ont été expérimentés : les casiers "Paimpolais" à crabes utilisés par les pêcheurs européens ainsi que les casiers à crevettes de type "Bourrolle" et espagnol (Cot et Langlais 1990).

Une étude similaire fut menée en Martinique entre les mois de juillet 1991 et avril 1992 (Paulmier et Gervain 1994). En 1993, un ouvrage inventoriant l'ensemble des crustacés profonds capturés aux Antilles Françaises fut réalisé (Paulmier 1993). L'IRPM prit ensuite le relais de ces études en 1993 afin d'optimiser les engins et techniques de pêche. A cette occasion, l'inventaire des espèces a pu être complété dans un deuxième ouvrage "Faune marine profonde des Antilles françaises" (Poupin 1994). De plus, ces travaux permirent l'obtention de premières informations sur les rendements des captures ainsi que sur la structure de la population de langoustine *Eunephrops cadenasi*.

En 1994, cette recherche fut complétée par un programme réalisé par le pôle de Recherche Océanologique et Halieutique Caraïbe (François-Lubin 1994, 1995).

MATÉRIEL ET MÉTHODS

Le navire de pêche utilisé ("Polka") est un navire ponté d'une longueur de 12 mètres et d'une puissance de 192 CV, intégrant un équipement électronique de bord complet et plusieurs treuils puissants (puissance de levage de 1 tonne à 120 mètres par minute).

Engins de Pêche

Plusieurs types de casiers ont été mis en œuvre.

Les "Bourrolles" (BOUR) — Les "bourrolles" sont des casiers classiquement employés pour la pêche de la crevette. Ce sont des casiers cylindriques de 0,20 m^3 à doubles ouvertures latérales, avec un maillage hexagonal de 38 mm. Ils sont montés en filière d'une douzaine.

Les casiers "saint-martinois" (SM) — Les casiers de type "saint-martinois" sont traditionnellement utilisés pour la pêche à la langouste à Saint-Martin. C'est la première fois qu'ils sont mobilisés pour la capture de Crustacés profonds. Le matériau utilisé pour la confection des casiers "saint-martinois" est du grillage galvanisé découpé, plié et soudé pour l'obtention d'une forme parallépipédique avec entrée sur le dessus, pour un volume de 0,15 m^3. Les mailles sont carrées et

mesurent 50 mm. La particularité de ce casier réside dans le fait que l'entrée se situe sur le dessus. Ils sont également montés en filières d'une douzaine.

Les casiers "saint-martinois plastiques" (SMP) — Les casiers saint-martinois présentent l'inconvénient d'être lourds. Pour palier à cet inconvénient, de nouveaux casiers alliant la légèreté des casiers de type bourrolles, grâce à un grillage en plastique, et la forme des saint-martinois ont été confectionnés. Leur structure est maintenue par une armature en fer. Le goulot du casier a une forme d'entonnoir. Ils sont montés en filière d'une douzaine.

Casiers pyramidaux (PYR) — Les casiers pyramidaux sont inspirés de casiers employés pour la pêche à la crevette *Heterocarpus laevigatus* à Hawaii (Tagami et Barrows, 1988). Cinq engins de ce type ont été fabriqués, dans des dimensions ajustées au pont du navire. C'est la première fois qu'ils sont utilisés en Guadeloupe. Empilables, ils pèsent 50 kg et ont une capacité de 1,5 m^3. Le maillage de 19 mm est davantage destiné à la capture des crevettes, mais l'entrée, située au sommet, permet également la capture de plus grosses espèces comme les crabes et les langoustines. Ils sont travaillés individuellement ou par filière de deux casiers espacés de 150m.

Très grands casiers (TGC) — Ce sont des casiers à parloir et triple entrée, d'un volume de 20 m^3 et d'un poids de 225 kg ; Ils sont destinés également à la prospection des plus grandes profondeurs (1000 m et au-delà). La nappe est constituée de grillage de maille carrée de 19 mm Ils autorisent la capture de poissons et de Crustacés de grande taille. Initialement, seuls quelques casiers devaient être utilisés, avec des objectifs plutôt prospectifs pour les bathymétries supérieures. Des résultats de captures de langoustines intéressants ont conduit à confectionner un parc de casier plus important (10) de maille 38 mm.

Secteurs Exploités

Le secteur exploité est le sud de la Basse-Terre, en Guadeloupe. Les cartes caractérisant les zones profondes de la Guadeloupe sont peu précises. Grâce au logiciel de navigation embarqué, une cartographie des fonds est dressée en continu lors des déplacements du navire. Les informations recueillies permettent, par une meilleure connaissance des lieux de pêche, de diminuer les risques de perte de matériel par accrochage. De plus, les sites de pêche peuvent être choisis en fonction du type d'habitat de l'espèce cible (plaines sédimentaires, zones rocheuses accidentées...).

Informations Collectées

Pour chaque cale, les informations suivantes sont relevées : le type de casier, les positions, date et heure de cale, date et heure de levée, la profondeur. Les prises sont identifiées et dénombrées. Des mesures sont également réalisées : longueur

céphalothoracique (L_C) et longueur totale (L_T). Lorsque l'identification des espèces a été impossible, des spécimens ont été confiés à des spécialistes de l'Université des Antilles et de la Guyane ainsi qu'au Muséum National d'Histoire Naturelle.

Les langoustines, destinées à une commercialisation rapide sont pesées à bord du bateau à l'arrivée au port à l'aide d'une balance électronique. La pesée individuelle n'a été possible que pour une fraction réduite des pêches. Elle a été systématique pour les langoustines *Eunephrops cadenasi* ainsi que l'identification du sexe. Des collections de spécimens ont également été réalisées pour chaque espèce. La valeur commerciale des prises est également relevée.

Rendements

Les analyses et traitements visent à produire des informations comparables pour chaque type d'engin de pêche mis en œuvre. La multiplicité des techniques et engins a conduit à choisir le temps de travail de pêche de l'équipage associé à une technique comme numérateur de l'indicateur de rendement (unité d'effort). Cet indicateur devient alors polyvalent et autorise les comparaisons de rendements entre les différentes techniques et engins. Le temps de travail considéré est, dans le cas des casiers, l'addition des durées de filage et de levage de l'engin et de récupération et conditionnement des captures (hors travaux expérimentaux).

Pour chaque engin les rendements en effectifs, poids vif et valeur commerciale par temps de travail sont donc produits. Il devient alors possible de comparer les rendements obtenus pour chaque engin (en effectif, poids ou valeur commerciale par heure de travail).

RÉSULTATS ET DISCUSSION

Déroulement des Pêches

Dix-huit marées ont été réalisées du 14 mai au 10 juin. En tout, 43 stations ont été échantillonnées dans le secteur géographique du sud de la Basse-Terre, à des profondeurs allant de 200 m à 1500 m.

Seuls deux types de casiers ont balayé différentes tranches bathymétriques : le casier pyramidal à des profondeurs allant de 240 à 860 m, et le très grand casier de la tranche des 400 - 600 m, correspondant à la profondeur de pêche des langoustines jusqu'à des zones purement prospectives atteignant les 1500 m. Les autres casiers : bourrolles, saint-martinois, saint-martinois plastiques, ciblant la langoustine, ont été mouillés entre 400 et 600 m.

Diversité Spécifique des Captures

Crustacés — Vingt-six espèces de Crustacés ont été pêchées pour un effectif de 760 individus, hors bathynomes (*Bathynomus giganteus*). Ces résultats figurent dans le Tableau 1.

Tableau 1. Inventaire des Crustacés capturés (N : effectif ; Z : profondeur ; TGC : Très Grand Casier ; Pyr : casier pyramidal ; BOUR : casier bourolle ; SM : casier saint-martinois ; SMP casier saint-martinois plastique)

FAMILLES	Genres -Espèces	N						Z (m)
		TGC	PYR	BOUR	SM	SMP	Total	
ARISTEIDAE	***Benthesicymus bartletti*** (Smith)	25					25	926-1499
ATELECYCLIDAE	***Trichopeltarion nobile*** A. Milne Edwards,1880				1		1	500
CIROLANIDAE	***Bathynomus giganteus*** A. Milne Edwards,1879	641	131	46	35	12	865	470-1499
GALATHEIDAE	***Munidopsis sp***	2					2	652
	Munidopsis sp (2)	1					1	1329
GERYONIDAE	***Chaceon eldorado (quinquedens)***, Manning etHolthuis, 1989	2	3		1	2	8	513 -836
LEUCOSIIDAE	***Myropsis quinquespinosa*** Stimpson, 1971	1	1				2	240-926
LITHODAE	**Crabe sp (1)**	3					3	1202-1499
	Crabe sp (2)	2					2	1329-1499
	Crabe sp (3)	1	1				2	836-926
LYSSIANASSIDAE	***Stephonyx biscayensis*** (Chevreux, 1908)	1	1				2	790-1499
MAJIDAE	***Stenocionops spinosissima*** (de Saussure, 1957)		3				3	240
NEPHROPIDAE	***Eunephrops cadenasi*** Chace, 1939	59	21	17	89	80	266	465-572
	Nephropides caribaeus Manning, 1969		1				1	684
	Nephropsis aculeata Smith, 1881	1					1	652
PAGURIDAE	***Xylopagurus rectus*** A. Milne Edwards,1880		1				1	281
PANDALIDAE	***Heterocarpus laevigatus*** Bate, 1888	72	18				90	838-1015
	Heterocarpus ensifer A. Milne Edwards,1881		3				3	465-510
	Heterocarpus oryx A. Milne Edwards,1881	9					9	926-1015
	Plesionika edwardsii (Brandt, 1851)		28				28	240-281
	Plesionika ensis (A. Milne Edwards,1881)	148	12				160	510-520
	Plesionika laevis (A. Milne Edwards,1883)	14	115	2			131	470-652
	Plesionika longicauda (Rathbun, 1901)	3					3	500

Les bathynomes sont difficilement valorisables et ne présentent aucun intérêt commercial. De plus, ils constituent de très mauvais appâts. De ce fait, ils n'ont été comptabilisés que durant les deux premières semaines de pêche (865 individus dénombrés). Les bathynomes sont pêchés par tous les engins à des profondeurs allant de 470 à 1500 m. Toutes les classes de taille de 5 à 40 cm sont représentées.

Ensuite, ce sont les langoustines *Eunephrops cadenasi* qui avec 266 individus, constituent une part importante des captures.

La famille des Pandalidae, qui regroupe sept espèces de crevettes en deux genres principaux, *Plesionika* et *Heterocarpus*, est également bien représentée.

La prospection du crabe *Chaceon eldorado* dans les bathymétries supérieures n'a donné lieu à la capture que de 5 individus.

Deux espèces de crabes pêchées à quelques exemplaires semblent être inédites en Guadeloupe. Elles appartiennent vraisemblablement à la famille des Lithodae. De même, deux espèces de crevettes demeurent non identifiées dont une, capturée en un seul exemplaire à 1329 m. Des investigations ultérieures devraient permettre l'identification de ces espèces..

Lors des campagnes de 1994, 80 espèces de Crustacés avaient été dénombrées (Poupin 1994). Il faut cependant souligner que les profondeurs de pêche débutaient alors à 100 m contre 240 m pour l'actuelle campagne. A cela, il faut rajouter que les mailles 38 mm des casiers saint-martinois, saint-martinois plastique et bourrolles ne sont pas favorable à la prospection.

Autres espèces — D'autres espèces ont été capturées. Certaines n'ont pas pu être identifiés à ce jour et ont été confiées à des spécialistes. Globalement, leur intérêt commercial est mineur voire nul. Il s'agit des poissons osseux : *Antigonia capros, Trachonurus villosus, Myxine gluttinosa*...L'identification des murènes et congres a été confiée à des spécialistes. Les poissons cartilagineux sont représentés par l'espèce *scyliorhinus boa*. Enfin, des captures anecdotiques de Gastéropodes (dont *Murex beaui*), de Céphalopodes et d'Echinodermes (ophiures) ont été enregistrées. Les effectifs, poids totaux et valeur commerciales des prises par catégories figurent dans le Tableau 2.

Les langoustines *Eunephrops cadenasi* avec 33% des effectifs, 80% de la biomasse et 91% de la valeur commerciale (hors bathynomes) constituent sans conteste la principale espèce d'intérêt économique, ce qui rejoint les travaux précédents (François-Lubin 1994). Leur grande qualité gustative associée à leur effectif substantiel dans les captures en fait une espèce cible. Le prix de vente de cette espèce, localement, est de 21 USD/kg. Les crevettes constituent des captures annexes non négligeables présentant également un intérêt économique.

Tableau 2. Effectifs, poids et valeurs commerciales par espèces

Espèce	N	Poids total (kg)	valeur comm. (USD)	taille moy.(L-c)	Poids moy. (kg)
Eunephrops cadenasi	266	88,1	1835	78	0,340
Plesionika laevis	131	1,9	15	33	0,015
Heterocarpus laevigatus	90	3,2	9	38	0,035
Autres crevettes	245	7,6	95		0,031
Chaceon eldorado	8	9,8	50		1,2
Autres espèces non commercialisables	72		0		
TOTAL	812	110,6	2004		

Rendements Comparés des Différents Casiers

La Figure 1 illustre les comparaisons des rendements par casiers s'appuyant sur le poids commercialisable capturé et la valeur commerciale des captures. L'unité d'effort considérée est l'heure de travail de pêche.

Poids Commercialisable — Le casier saint-martinois est le plus productif, aussi bien en terme de biomasse totale (43 % du poids commercialisable total des captures) qu'en terme de biomasse rapportée à l'heure (5,36 kg/h). Les casiers bourrolles, avec 4 % du poids total commercialisable, produisent la plus faible biomasse sur l'ensemble de la période. En terme d'indice de poids commercialisable par heure de pêche, c'est le casier pyramidal qui est le moins rentable avec 1,2 kg produits par heure de travail.

Valeur Commerciale par Heure de Travail — Comme pour le paramètre précédent, le casier saint-martinois se détache avec 49 % de la valeur commerciale totale des captures, et 103 USD rapportés à l'heure de travail. Les casiers pyramidaux et bourrolles possèdent les plus faibles pourcentages de la valeur commerciale totale (5 % chacun). Le casier le moins rentable en terme de biomasse commercialisable par heure est le casier pyramidal avec 13 USD/h.

Il faut cependant nuancer les rendements du Très Grand Casier. En effet, pendant les deux premières semaines, il a servi exclusivement à la prospection. Ce n'est qu'après avoir été déployé à la profondeur des langoustines, que les poids et la valeur commerciale des captures se sont accrues. Ses rendements sont alors passé à 7,5 kg/h et 118 USD/h. Ces résultats sont alors supérieurs à ceux du casier saint-martinois qui apparaissait jusqu'alors comme l'engin de pêche le plus rentable.

Pertes d'engins — Les pertes d'engins subies durant cette période sont de 12,5 % pour les casiers pyramidaux, 1,8 % pour les casiers saint-martinois et 1,6 % pour les casiers saint-martinois plastiques. Aucune perte n'est enregistrée pour les Très

Grands Casiers ainsi que les bourrolles. Ces pertes affectent exclusivement les montages en filières en raison de l'augmentation du risque de croches liée à ces montages.

La médiocre efficacité des casiers bourolles et pyramidaux ont conduit rapidement à leur abandon.

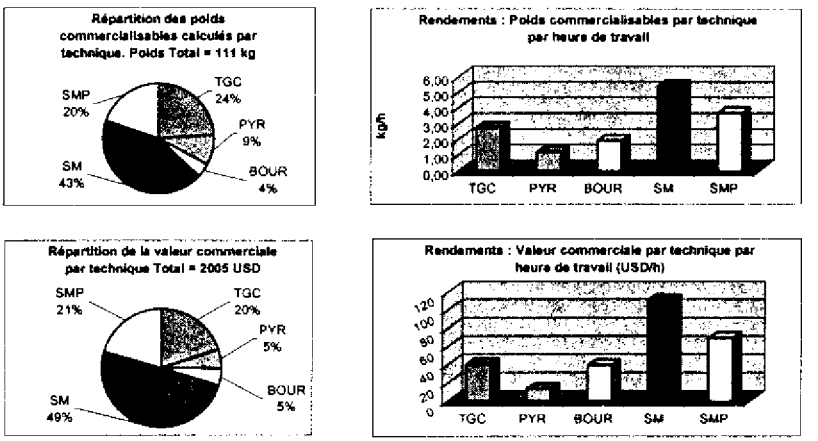


Figure 1. Rendements comparés des différents casiers (poids commercialisables et valeur commerciale)

La Langoustine *Eunephrops cadenasi*

Les informations concernant la biologie de l'espèce *Eunephrops cadenasi* sont peu abondantes. Sa répartition bathymétrique se situe entre 430 à 600 m (Poupin 1994). Son aire de répartition géographique s'étend des Bahamas à la Colombie. Sa présence a été confirmée dans l'ensemble de l'archipel guadeloupéen. Grâce à un film réalisé sur des fonds de 500 m par l'IRPM, il a été observé qu'elle vit dans des terriers sur des fonds meubles (Gervain, 1994). Les mâles atteignent des tailles très supérieures à celles des femelles.

Sur un échantillon de 227 individus, on obtient la répartition suivante (tableau 3) : 126 mâles et 101 femelles (dont 46 grainées). La taille maximum observée pour les mâles est de 114 mm de longueur céphalothoracique (LC), pour un poids de 1.12 kg. La taille minimum est de 48 mm LC pour un poids de 70 g. la moyenne se situe à 87 mm LC pour 488 g. Pour les femelles, la taille maximum observée est de 88 mm LC, pour un poids de 350 g. La taille minimum est de 42 mm LC pour un poids de 40 g. la moyenne se situe à 45 mm LC pour 170 g.

SEXE	N	TAILLES (LC en mm)			POIDS (kg)		
		Max	Min	Moy	Max	Min	Moy
Mâles	126	114	48	87	1,12	0,009	0,488
Femelles	55	84	42	68	0,3	0,04	0,17
Femelles grainées	46	88	49	68	0,35	0,07	0,18

Relations taille-poids — Pour les mâles, les relations taille-poids ont été calculées en se référant à la longueur du céphalothorax (LC) et à la longueur totale (LT ; du lobe orbitaire à l'extrémité du telson) de 77 individus. L'ajustement par une fonction puissance donne les résultats suivants :

$$P = 1.10^{-5}\, LC^{3.8374} \quad R^2 = 0{,}887$$
$$P = 8.10^{-10}\, LT^{3.7266} \quad R^2 = 0{,}880$$

Efficacité Comparée des Différents Casiers pour la Pêche de la Langoustine

La sélectivité du Très Grand Casier et des deux types de casiers saint-martinois ainsi que leurs rendements ont été analysés de manière à concevoir l'engin le plus performant pour un développement durable des pêches de langoustines profondes.

Analyse des Fréquences de Tailles — La comparaison des répartitions de fréquences de taille pour ces trois engins est illustrée sur la Figure 2.

i) Très grand casier : le plus petit individu mesure 48 mm LC, et le plus grand 108 mm LC. Le mode se situe à la classe [66;74[avec 31% d'individus.

ii) Casier saint-martinois : la longueur céphalothoracique minimale est égale à 71 mm, la taille maximale à 114 mm La moyenne se situe à 93 mm. La classe contenant l'effectif le plus important est la classe [90;98[avec 22% des captures de ce casier.

iii) Casier saint-martinois plastique : la taille moyenne est 70 mm LC avec un minimum à 49 mm et un maximum à110 mm. Le mode se situe à la classe [58;66[avec 36% des captures de ce casier.

Le très grand casier possédant le plus petit maillage (19 mm) est l'engin le moins sélectif ce qui explique que ses captures se répartissent entre toutes les classes. L'engin le plus sélectif est le casier saint-martinois qui grâce à son maillage de 50 mm ne retient que les plus gros individus. Le casier saint-martinois plastique de forme similaire a un plus petit maillage (38 mm) et un goulot plus étroit, ce qui se traduit par des captures de femelles supérieures au casier saint-martinois et une proportion réduite de grands mâles.

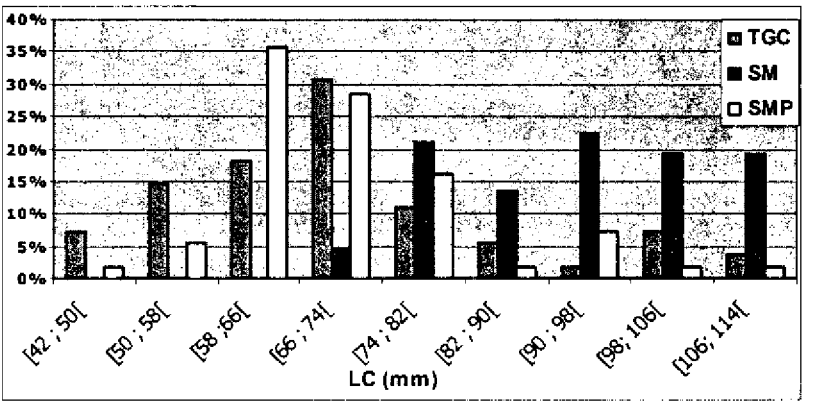


Figure 2. Histogrammes de fréquence de taille pour l'espèces *Eunephrops cadenasi* pour les trois casiers

Sex-ratios Selon les Casiers — La sélectivité de chaque engin se répercute au niveau de la sex-ratio comme le montre le diagramme suivant Ces résultats sont synthétisés sur la Figure 3.

i) Très Grand Casier : les proportions entre les mâles et l'ensemble des femelles semblent équilibrées puisque la somme des pourcentages des femelles non grainées et grainées (respectivement 29 et 22%) est sensiblement équivalente à la proportion de mâles qui atteint 49%.

ii) Casier saint-martinois : les captures sont dominées par les mâles qui représentent 79% des individus. Les femelles grainées sont les moins nombreuses avec 7% des captures.

iii) Casier saint-martinois plastique : les proportions sont de 38 % pour les mâles et des pourcentages proches pour les femelles non grainées et grainées avec respectivement 30 et 32%. Les femelles dans leur ensemble dominent donc les captures de ce casier.

Ces proportions peuvent s'expliquer par le dimorphisme sexuel chez cette espèce. Le très grand casier, peu sélectif avec ses petites mailles, capture autant de mâles que de femelles, alors que le casier saint-martinois capture une plus grande proportion de mâles. La faible proportion de mâles observée pour les casiers saint-martinois plastiques est à imputer au diamètre du goulot, plus réduit que celui du saint-martinois et qui semble être un obstacle à la pénétration de grands mâles.

Le choix d'un type de casier adapté à la pêche de la langoustine doit tenir compte de la capacité de renouvellement de l'espèce. Le très grand casier semble être l'engin le moins intéressant car il est le moins sélectif. Par conséquent, il pêche de très petits individus qui ne se sont pas encore reproduits.

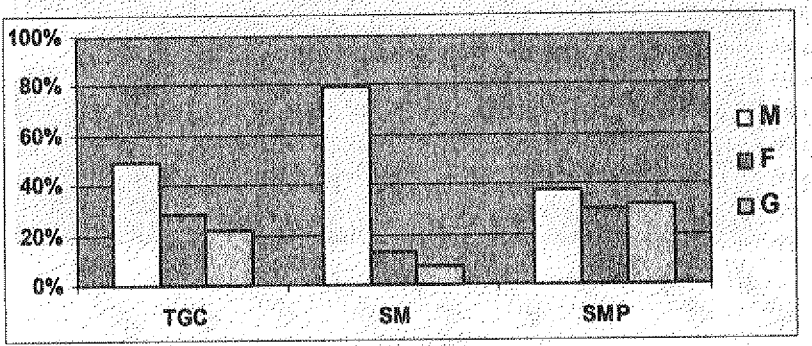


Figure 3. Sex-ratios selon le type de casier (M : mâles ; F : femelles ; G : femelles grainées)

Bien que le casier saint-martinois plastique soit plus sélectif que le très grand casier, il semble tout aussi, sinon plus, nuisible à la préservation de l'espèce. En effet, le maximum de ses captures se situe dans les classes correspondant aux tailles moyennes des femelles grainées et non grainées. Ceci pourrait s'expliquer par sa maille dont la taille est inférieure à celle du casier saint-martinois. Cependant, alors que sa forme est similaire à celle du casier saint-martinois, le casier saint-martinois plastique pêche beaucoup moins de gros individus. Ceci pourrait être du à la forme des goulots en entonnoir. Ce montage, initialement prévu pour réduire l'échappement des captures, paraît avoir une influence sur la capacité de pénétration à l'intérieur du casier des gros mâles. De telles observations avaient été réalisées à l'aide de caméra vidéo par l'IRPM en 1994 (Gervain 1994). Ces images instructives montraient une langoustine mâle essayant vainement de pénétrer dans un casier. Les casiers saint-martinois sont les casiers qui semblent nuire le moins à la population de *Eunephrops cadenasi*. En effet, ils pêchent de très gros individus dans lesquels on compte peu de femelles en phase de reproduction.

Captures Annexes D'intérêt Commercial — Les captures commerciales annexes sont constituées essentiellement de crevettes des genres *Plesionika* et *Heterocarpus* et, dans une moindre mesure du crabe *Chaceon eldorado*. L'ensemble des crevettes représente 11 % des poids capturés (hors bathynomes) et contribuent pour 6 % de la valeur commerciale. Les crevettes sont surtout présentes dans les casiers de petites mailles comme le casier pyramidal et le très grand casier. Parallèlement, de tels maillages sont ceux qui semblent nuire à la langoustine, principale espèce cible. Si l'on veut pêcher les crevettes qui vivent aux même profondeurs que la langoustine, comme *Plesionika laevis*, il faudrait imaginer un casier sélectif pour cette espèce mais, alors, les seules captures de crevettes paraissent difficilement pouvoir être rentables.

CONCLUSIONS

La langoustine *Eunephrops cadenasi* semble être la principale espèce à privilégier pour une pêche rentable des Crustacés profonds aux casiers, en Guadeloupe. Les engins de pêche ciblant cette espèce doivent à la fois être rentable économiquement mais aussi préserver le renouvellement de la population. Le casier saint-martinois paraît être l'engin qui intègre le mieux cet équilibre. Cependant, ce type de casier est cher à la construction (environ 100 USD) et des pertes de près de 2 % liées au montage en filière ont été enregistrées. Les très bons rendements obtenus avec le très grand casier sont également à prendre en considération. Cet engin présente en plus la possibilité de pouvoir être travaillé sur des temps de cales longs, qui autorisent la pratique d'autres types de pêches profondes dans l'intervalle.

Au vu des résultats de cette étude, de nouveaux casiers ont été confectionnés pour la poursuite du programme de recherche. Ils allient le volume important du très grand casier et les mailles du casier saint-martinois plastique (38 mm). Ces nouveaux engins ont, à ce jour, permis de réaliser des pêches de langoustines de plus grandes tailles. C'est avec un parc de ce nouveau type de casiers que la campagne de pêches expérimentales est entrée dans une configuration d'exploitation à caractère davantage commercial. La taille de la maille, correspondant au minimum autorisé pour les pêches sur le plateau continental, permet également leur mobilisation dans des eaux moins profondes.

Les analyses de la rentabilité de cette pêche seront produites à la fin de l'année 2001 et comparées avec la rentabilité de l'exploitation d'autres ressources profondes en Guadeloupe : pêches des poissons profonds à l'aide de filets ou de palangres.
Un autre axe d'investigation poursuivi concerne l'estimation de la ressource. Des essais d'estimation de la densité d'individus à partir de transects vidéos et du dénombrement des terriers sur images est en cours. Il s'agit d'adaptations des protocoles expérimentaux d'estimation de la biomasse mis au point pour l'espèce *Nephrops norvégicus* en Europe (Bayley, comm. pers.).

Une meilleure connaissance de la biologie de cette espèce est souhaitable, notamment concernant sa croissance et sa reproduction : tailles à la première maturité des mâles et des femelles, saisonnalité de reproduction...

L'absence de telles informations incite à une approche précautionneuse de l'exploitation de ces stocks. Si les résultats de l'étude confirment la rentabilité de l'exploitation de la langoustine, l'effort de pêche qui pourrait se développer devra être contrôlé et l'analyse des captures réalisée

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Understanding the Influence of Selected Variables on the Travel Patterns of Saltwater Anglers

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ABSTRACT

Understanding how often individuals fish and where they fish should be of concern for fishery managers, as well as those responsible for marketing particular destinations. This research examined location preferences of a statewide population of saltwater anglers in Texas, and how various aspects of angling behavior influenced their travel decisions. Using data collected from a sample of Texas saltwater anglers, angling behavior and attitudes were hypothesized to influence the location an individual fished most often in the previous 12 months. Using information concerning the locations where inshore anglers fished most often, and offshore anglers accessed the Gulf of Mexico, distance measures were calculated using a Geographic Information System (GIS) and used as a surrogate for distance traveled for a "typical" fishing trip for each angler. These measures were then used as the dependent variable in subsequent analysis.

KEYWORDS: Recreation specialization, saltwater anglers, travel behavior

Entendimiento de la Influencia de Variables Seleccionadas sobre los Patrones de Recorrido de los Pescadores de Agua Salada

Concierne a los responsables del manejo de la pesca y a los que comercializan los productos en lugares específicos, el entendimiento de la frecuencia y el sitio de pesca de los pescadores de agua salada. Si un área es sobreutilizada, pueden surgir varios problemas que incluyen el agotamiento del recurso y conflictos con otros usuarios del recurso. Esta investigación examina las preferencias de sitio de pesca de la población de pescadores de agua salada del estado de Texas y como varios aspectos del comportamiento de los pescadores pueden influir sobre esas preferencias. Usando datos de una muestra de pescadores de agua salada del estado de Texas, se relacionaron las actitudes y el comportamiento de los pescadores con el sitio en que pescaron mas frecuentemente en los últimos 12 meses. Con información de los sitios de pesca mas frecuentes de los pescadores de bahía y de aquellos por los cuáles los pescadores de mar abierto accesaron el Golfo de México, se obtuvieron medidas de distancia usando un Sistema de Información Geográfica (SIG) como indicador de las distancias recorridas en un viaje "típico" de cada tipo de pescador. Se calcularon ecuaciones de regresión para cada sitio de pesca usando como variables independientes varias medidas del comportamiento, tales como

motivaciones para la pesca y limitaciones para participar en la pesca. Enseguida, se hizo un esfuerzo para diferenciar sitos de pesca por las características de las personas que ahí pescan con mas frecuencia. Se obtuvieron conclusiones en relación con aspectos característicos de cada sitio y diferencias entre sitios.

PALABRAS CLAVES: Pescadores de agua salada, aspectos del comportamiento de los pescadores

INTRODUCTION

Studies of anglers have been conducted for a variety of purposes, which include providing information for fisheries managers, marketing, and general scholarly knowledge. Encompassing a wide range of topics, these studies generally focus on regional patterns of participation (U.S. Department of Interior and U.S. Department of Commerce 1997), demographic characteristics (Murdock et al. 1996), expenditure levels, angler attitudes, and angler preferences (Hunt and Ditton 1996). While these studies do provide insights into the behavior of anglers, they do little to provide information as to how this behavior affects real world phenomena such as traveling. Once an angler has made the decision to go fishing, the next logical choice that he/she must make is where to go fishing. While we may understand the rational thought process behind this decision, we do not understand how the previous behavior of an individual angler will affect the choice of a fishing destination.

One of the most often used concepts to explain angler behavior is that of recreation specialization. The classical definition of recreation specialization is "a continuum of behavior from the general to the particular, reflected by equipment and skills used in the sport and activity setting preferences" (Bryan 1977). An angler's specialization level is thought to be reflected by his or her avidity to the activity and fishing experience. Certain behaviors are thought to be influenced by an angler's specialization level, including catch preference and travel patterns.

Problems with the original concept of specialization led to a modification of the theory. Ditton et al. (1992) recognized that Bryan (1977) had defined specialization (a behavior) by observing the behavior of anglers. This led them to develop a new definition based upon the social worlds perspective. They defined specialization as:

> "1) a process by which recreation social worlds and subworlds segment and intersect into new recreation subworlds, and 2) the subsequent ordered arrangement of these subworlds and their members along a continuum" (Ditton et al. 1992).

More importantly, they identified testable hypotheses based upon the concept, and empirically measured anglers behavior using the hypotheses in the study, thus strengthening the concept of specialization.

Specialization has been used to explain behavior in other outdoor recreation activities besides fishing; however, the results from these studies should be applicable to all outdoor recreations including fishing. Of particular interest is that specialization has been shown to influence the setting in which an activity takes place (Virden and Schreyer 1988, Schreyer and Beaulieu 1986).

Many different methods have been used to measure specialization. Among the variables that have been shown to influence a person's specialization level are resource-related motives, skill, and experience (Chipman and Helfrich (1988; Hammit et al. 1989; Fisher 1997).

This research replicated the methods used by Fisher (1997) to group anglers according to six specialization variables. Once angler groups were formed, the groups were compared using their mean travel distance as the dependent variable. It is thought that as an angler's specialization level increases, the angler will travel greater distances to his or her fishing destination.

METHODS

The sampling frame consisted of 2,073 licensed Texas anglers who indicated they fished one or more days in saltwater in the 1998 statewide survey. Standard mail survey methodology (Salant and Dillman 1997) was used to collect additional data from these anglers on their saltwater fishing activity and preferences. 1,005 questionnaires were returned in a usable form providing an effective response rate of 56.5% (excluding nondeliverable mailings).

Six variables were used to determine specialization level:

i) Total years of saltwater fishing experience,
ii) Total days saltwater fishing in the previous year,
iii) Importance of number of fish caught,
iv) Importance of catching "something;"
v) Importance of size of fish caught, and
vi) Disposition of catch.

Total number of days fishing was skewed; therefore the data were transformed with the natural logarithm into a normal distribution. The last four items are measures of an angler's attitude towards keeping fish; a detailed explanation of the items used for these measures is available in Fedler and Ditton (1986) and Hunt (2000).

Four hierarchical clustering methods were used to determine the number of groups present in the data. All data were standardized to mean 0 and variance 1 before clustering took place. The purpose of using of four methods was to validate the findings of the number of clusters present in the data. The number of clusters is indicated by a plot of the cubic clustering criterion versus the number of clusters (Aldenderfer and Blashfield 1984). Once the number of groups was determined, nonhierarchical (k-means) cluster analysis was used to determine the size of each group. Clusters were then ranked according the sums of the standardized means of the six specialization variables.

Each angler was asked to identify the location where "they fished most often since this time last year" or "accessed the Gulf most often since this time last year" from a list of seven Texas bays (Sabine Lake, Galveston Bay, Matagorda Bay, San Antonio Bay, Aransas Bay, Corpus Christi Bay, Upper Laguna Madre, Lower Laguna Madre) or eight Texas ports (Port Arthur, Galveston, Freeport, Port O'Connor, Rockport, Port Aransas, Port Mansfield, Port Isabel/South Padre Island). Since the above items were crucial in this study, those anglers that did not indicate where they fished most often, or left out one of the items used to determine specialization level, were removed from the sample (n = 772).

The responses to the angler's fishing destination were linked to the angler's address where available or, if the address was not available, to the center of the respective ZIP code. A GIS was used to calculate the straight line distance from the angler's location to the geographic location of the response.

ANOVA was used to test for differences among angler groups and their respective travel distances. Fisher's LSD was used to test for differences between specific angler groups.

RESULTS

Statistics were calculated to check the reliability of each subdimension of the consumptive attitude scale (number of fish = 0.68, disposition of catch = 0.74, size of fish = 0.70; importance of catching "something" = 0.73). These scores indicated that each item is a reliable measure of the subdimension it was designed to measure (Cronbach 1951). For each subdimension, a high score indicates that the angler places high importance on that item. A high score on the "disposition of catch" subdimension indicates the importance an angler places on releasing fish.

Plots of the number of clusters versus the cubic clustering criterion indicated that seven groups were present in the data (See Figure 1). The value at the leftmost point is indicative of the number of clusters present in the data (Everitt 1977). All methods indicated that there were seven clusters, providing evidence that the true number of clusters is seven.

The mean characteristics of each angler group are presented in Table 1. Group 5 anglers had the greatest number of days fishing in the past 12 months, while group 4 anglers had the lowest days fished. However, group 4 anglers had the most experience of all groups, and group 2 had the least experience. Group 7 placed the most importance on the number of fish caught as well as the importance of catching "something." Group 1 anglers placed the least importance on the number of fish caught, size of fish caught, and catching "something." Group 6 anglers placed the most importance on releasing fish. Most surprising is that group 7 anglers placed the least importance on releasing fish. It appears that both group 6 and group 7 could be considered highly specialized, but differ on this one aspect of the recreational fishing experience.

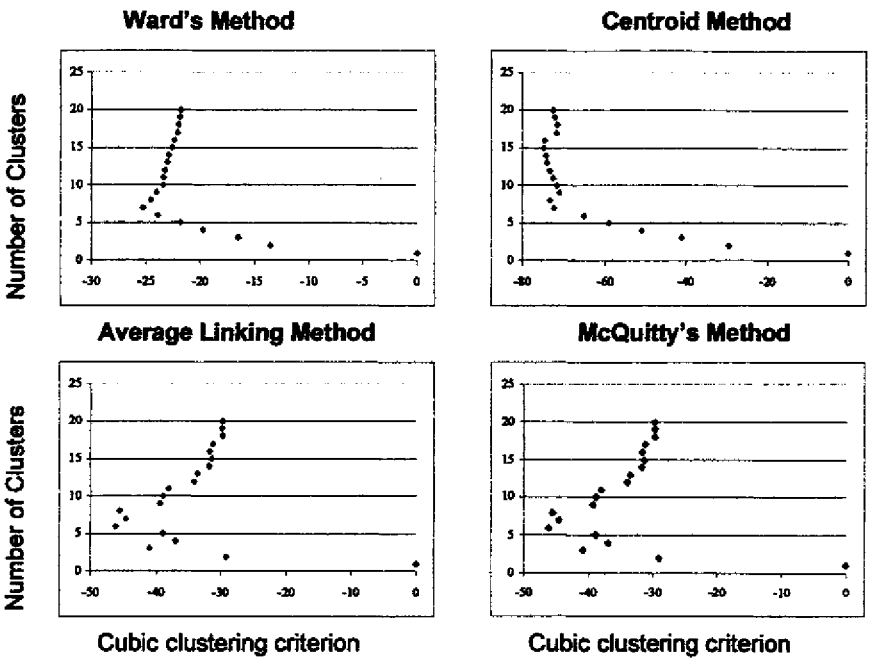


Figure 1. Results from cluster analysis. All methods indicated seven groups of anglers

Other behaviors that are thought to be indicative of an angler's specialization level include tournament participation and club membership. These variables were analyzed to see if the groups formed by the cluster analysis are consistent with specialization theory (Table 2). Group 5 had the highest participation in tournaments and club membership. The lowest participation rates were found in group 2 for fishing tournaments and group 3 for club membership.

There is little effect of an angler's specialization level on the location that they fished at most often. While group 6 anglers, considered to be more specialized, did have the greatest mean travel distance, group 2 anglers had the second highest mean travel distance (Table 3).

Table 1: Mean (SE) Values of the Six Variables Used In Cluster Analysis and Travel Distance by Angler Group

Angler Group	Days fishing in the past 12 months	Years of fishing	Number of fish	Size of fish	Disposition of catch	Catching "something"
1 (N = 119)	31.71 (2.58)	21.06 (1.14)	-1.27 (.06)	-0.99 (.07)	0.60 (.07)	-0.97 (.06)
2 (N = 115)	7.32 (0.49)	13.8 (0.70)	0.06 (.07)	-0.08 (.07)	-0.14 (.06)	0.08 (.08)
3 (N = 94)	40.63 (2.71)	25.54 (1.26)	0.15 (.08)	-0.89 (.07)	-0.93 (.06)	0.21 (.07)
4 (N = 106)	6.97 (0.46)	39.44 (0.77)	0.11 (.07)	-0.13 (.08)	-0.18 (.08)	0.03 (.07)
5 (N = 120)	52.83 (4.4)	35.25 (0.87)	-0.34 (.07)	0.51 (.06)	0.19 (.07)	-0.53 (.07)
6 (N = 120)	34.53 (2.91)	15.96 (0.92)	0.54 (.07)	0.79 (.07)	1.01 (.06)	0.17 (.08)
7 (N = 98)	29.57 (2.84)	30.14 (1.24)	0.97 (.06)	0.70 (.07)	-0.96 (.09)	1.29 (.08)

Table 2. Percentages of anglers participating in fishing tournaments and fishing clubs, by specialization group.

Angler Group	Participation in Fishing Tournaments (%)	Participation in Fishing Clubs (%)
1	17.7	16.1
2	13.2	14.8
3	15.1	10.6
4	16.2	12.3
5	35.0	29.7
6	19.3	24.8
7	19.0	11.3

Table 3. Mean distance traveled by angler group. Group means with the same letter are significantly different ($p < .05$).

Angler Group	Mean Distance Traveled
1	86.5 (7.7) [A,B]
2	113.6 (9.4) [A,C,D,E]
3	80.2 (8.9) [C,F]
4	85.2 (8.8) [D,G]
5	81.6 (8.0) [E,H]
6	117.2 (11.3) [B,F,G,H,I]
7	91.2 (9.0) [I]

DISCUSSION

These results may be consistent with specialization theory. It was originally hypothesized that as an angler's specialization level increases, their travel distance will increase also. While Bryan (1977) did originally relate the effect of specialization on travel, the relationship was twofold. First, he thought that an angler's vacation patterns are a result of their specialization level, i.e. a highly specialized angler will plan vacations specifically to fish in a prime location. He also thought that highly specialized anglers may choose to alter their lifestyle to be in proximity to prime fishing locations. This may be what is shown by the results of this study. Groups 6 and 7, the most specialized of the angler groups, differed from the overall mean of the entire population. It could be that these groups are

exhibiting this difference in lifestyles. Group 7 anglers could have altered there lifestyles to be closer to the fishing experiences they are seeking, i.e. they have moved closer to the coast. Unfortunately, the wording of the question regarding their "most often used fishing destination" does not indicate differences on this aspect of an angler's travel patterns. It may be possible that anglers fished as a collateral activity on a vacation to the coast of Texas and identified this location as the area where they fished most often since this time last year.

The management implications from this study are many. First, the results support the conclusions that Fisher (1997) reached regarding the heterogeneity of the angling population. Different anglers seek different experiences, and managers are able to control many aspects of the fishing experience. Second, fishing destinations can use the results as a tool for planning strategies to increase the angling clientele that visits their location. Furthermore, an area can market itself with particular characteristics to attract the specific clientele that they feel would be most interested in their destination. For instance, an area can market particular aspects of the fishing experience to attract certain anglers, i.e. marketing a "trophy" fishery will attract anglers in groups 5, 6, and 7.

In the future, this sort of research should be replicated with data on an angler's complete travel record for the previous 12 months, i.e. both their fishing destination as well as the number of trips to this location. This will provide a more complete picture of an angler's travel patterns. Furthermore, the variables in this research considered to represent an angler's specialization level may have no effect on the decision of where to fish. Future research could be directed at identifying those aspects of recreation specialization that do influence an angler's decision of where to fish.

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Spawning and Nursery Habitat of Blue Marlin, *Makaira nigricans*: Cooperative Research in the Vicinity of Exuma Sound, Bahamas

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ABSTRACT

We describe a two-phased project that examines "essential fish habitat" for blue marlin, *Makaira nigricans*. It builds on previous work and constitutes an international cooperative research effort involving government and university scientists and recreational and commercial fishers. Neuston sampling during July 2000 and July 2001 in the vicinity of Exuma Sound, Bahamas, yielded some of the highest densities of *circa* 2 - 17 day old blue marlin larvae ever reported. This indicates that the waters directly upstream of the Sound served as blue marlin spawning grounds and that the Sound itself may be an important nursery area, at least during the summer. These results have prompted implementation of the second phase of the project: "pop-up" satellite tagging of adults at locations both upstream and downstream of the Sound during the peak of the next spawning season (i.e., June, 2002) followed by additional, larval sampling in the vicinity of the Sound during July, 2002. This work may provide valuable insight into the nursery role of Exuma Sound relative to open-ocean environments as well as into the extent of adult movement during the peak of their spawning period. Concurrent with our work are three other studies that will complement our research:

i) An effort to combine genetic and traditional methods for identifying even badly damaged billfish larvae to species;
ii) An effort to age larval blue marlin from their otoliths; and
iii) An effort to determine the sex and reproductive status of tagged adults from a small sample of muscle tissue.

Collectively, these ongoing investigations may provide critical information for the protection of spawning and nursery habitats for Atlantic blue marlin and possibly other billfishes in the region. A future application for this work, if the study is expanded spatially and a time series is developed, is to assess whether abundances of larval blue marlin can be used as a fishery-independent index of spawning stock biomass.

KEY WORDS: Blue marlin, essential fish habitat

INTRODUCTION

The term "billfish" refers to fishes of Family Istiophoridae which includes the marlin, sailfish and spearfish species that inhabit the coastal and offshore waters of all tropical and subtropical seas (Nelson 1994). Of the 11 billfish species that roam the world's oceans, four occur in the Atlantic Ocean and Caribbean Sea: blue marlin (*Makaira nigricans*), white marlin (*Tetrapturus albidus*), longbill spearfish (*Tetrapturus pfluegeri*), and sailfish (*Istiophorus platypterus*) (Robins and Ray 1986). The blue marlin is the largest species in its family with individuals capable of attaining up to 910 kg and 4.5 m. Its size, beauty and spectacular fighting ability make it the most sought-after gamefish among saltwater anglers around the globe (de Sylva 1972). These apex predators support multi-million-dollar sportfishing industries throughout their range, especially along the U.S. east coast, in the Gulf of Mexico and in the Caribbean Sea (IGFA 1996). Unfortunately, man's activities have led to significant declines in billfish stocks, particularly those of Atlantic blue and white marlin. In recent work by the International Commission for the Conservation of Atlantic Tunas (ICCAT) and the National Marine Fisheries Service (NMFS) both Atlantic marlins are characterized as overfished (NMFS 2000; ICCAT 2000). Concerns over Atlantic billfish exploitation rates have led to restrictions on commercial and recreational fisheries and the promotion of catch-and-release programs among recreational anglers. However, despite these measures, indices of marlin population sizes suggest declines to low levels. For example, the most recent Atlantic blue marlin stock assessment suggested that the population biomass is currently at about 40% of the level needed to provide maximum sustainable yield (MSY) and that overfishing has been taking place for about three decades (ICCAT 2000). Moreover, fishing mortality is currently about four times the level that would support MSY. The situation is even more dire for the white marlin.

These trends stress the need for rapid and appropriate action. However, a major barrier to effective management is the dearth of fundamental biological knowledge on these highly-evolved oceanic predators and the dynamics of their "blue water" environment. Because adult billfish are large, pelagic, and highly-migratory, scientific observations and data on them are especially difficult to obtain (Prince and Brown 1991). The available quantitative scientific stock

assessment information derives mainly from fisheries statistics with the majority of data on billfish being recorded as bycatch and/or discards. In contrast, fishery-independent data on the earliest life stages is extremely limited and knowledge of spawning activity, especially in a spatial context, is, at best, anecdotal. This study seeks to improve our knowledge of biology and ecology of blue marlin larvae and to use this knowledge to guide research on the spawning behavior of adults. In addition to increasing our knowledge of what constitutes essential fish habitat for these large pelagic fishes, the larval sampling component of this study may have a future role in stock assessment. Specifically, the abundance of blue marlin larvae may have utility as fishery-independent index of spawning stock biomass (*sensu* Scott et al.1993), provided that the study area is expanded and a time series is developed.

BACKGROUND

The present study examines Exuma Sound and adjacent waters as nursery and spawning grounds for blue marlin. It builds on research conducted in July 2000 and July 2001, whereby we sampled for istiophorid larvae throughout the Sound's surface waters as well as in the adjacent, open waters of the Atlantic Ocean (Serafy et al., in review). One of the most compelling aspects of this work is that it resulted in the highest catch rates reported for this species. Specifically, we collected larvae at rates of 8.06 and 4.05 larvae/hour of towing in July 2000 and July 2001, respectively. Both rates appear to greatly exceed those obtained in other studies. For example, sampling in the Indo-Pacific, Jones and Kumaran (1962) collected blue marlin larvae at a catch rate of 0.26 larvae hr^{-1}; in the southwestern Atlantic (Bartlett and Haedrich 1968) catch rate was 0.38 larvae/hour; in the central Pacific (Masumoto and Kazman 1974) catch rate was 0.003 larvae/hour; plankton sampling throughout the Atlantic, Pacific, and Indian Oceans (Nishikawa et al. 1985) obtained catch rates of 0.08, 0.45, 0.58 larvae/hour, respectively. Our blue marlin catch rates are of the same order as the 2.4 larvae/hour obtained by Leis et al. (1987) in the Coral Sea, but less than that obtained for sailfish larvae by Post et al. (1996) in the Straits of Florida off Miami, Florida, USA. Their catch rate was 27.4 sailfish larvae/hour.

Other major findings of our Exuma Sound sampling effort were that:

i) Unlike most previous studies, we collected a preponderance (~90%) of blue marlin larvae as opposed to early stages of other istiophorid species,

ii) Patterns of distribution and density of the larvae were strongly related with physical and hydrodynamic features of the Sound (i.e., larval abundance was highest within the two regions where exchange with the Atlantic is greatest),

iii) Mean length of larvae tended to increase in the direction of mean flow from 7.9 mm at the Sound's mouth to 13.5 mm at its upper reaches,

iv) The probable age of the larvae ranged from 2.2 to 17.2 days (*sensu* Prince et al. 1991), and
v) Given our age estimates, and assuming passive, surface transport, spawning likely occurred in waters within or near the "triangle" of Rum Cay, San Salvador and Conception Islands.

In addition, our limited sampling just outside Exuma Sound, in the Atlantic Ocean proper, also yielded blue marlin larvae. These findings beg at least two questions: Do blue marlin consistently use Exuma Sound and surrounding waters as spawning and nursery areas? Do larvae entrained in the semi-enclosed Sound gain growth and/or survival advantages relative to those entrained in the open waters of the Atlantic Ocean proper?

OBJECTIVES

Given that larval sampling has yielded such high concentrations of very young blue marlin in two consecutive years, the second phase of the project will be implemented. The objective here is to collect data on adult blue marlin movement during the peak of the reproductive season. From these data we hope to gain insight into the spatio-temporal nature of spawning behavior. This will entail "pop-up" satellite tagging of adults during the peak of the next spawning season (i.e., June, 2002) at three locations in Caribbean waters:

i) Caicos Passage, about 370 km upstream (southeast) of the Sound's mouth,
ii) Off San Salvador Island, from 0 to 150 km upstream (southeast) of the Sound's mouth, and
iii) Off Great Abaco Island, about 300 km downstream (northwest) of the Sound's mouth.

Tags will be programmed to release 60 to 90 days after deployment. Pop-up tagging will be followed by downstream larval sampling (i.e., during July, 2002). Described below are the methodologies we will use for the sampling of larvae (during 2001 and 2002) and the tagging of adults (during 2002 and beyond).

METHODS

Larval Collection

Study objectives will be pursued during July 2002 by following the same seven transect sampling protocol of 2000 plus the 4 transects sampled in adjacent, open-ocean waters sampled in 2001. The sampling larval vessel will be a US-owned recreational sportfishing boat (17-m long) with experienced captain and crew. Blue marlin larvae will be sampled with a 2 m^2 rectangular neuston net with 1 mm-mesh and flow meter. The net will be towed off the side of the sampling vessel at a speed of approximately 3.5 knots. At the beginning and end of each 10-minute tow, location coordinates will be obtained with a global

positioning system with differential beacon. During each tow, surface water temperature, dissolved oxygen, and salinity will be measured using a multi-probe water quality instrument (Hydrolab); water column depth will be logged by ship-board sensor. Each neuston sample will be stored in ethanol for complete processing in the laboratory. All istiophorid larvae will be identified to the lowest possible taxonomic level and measured for standard length. Abundance and size distributions of collected larvae will be mapped in both time and space, correlated with concurrently-collected physical, chemical and biological measurements and compared with previous results. Inclusion of the open ocean transects will increase total effort to approximately 100 total neuston samples. It will also provide the opportunity for the density, growth and condition of larvae found in open waters to be compared with those developing in the semi-enclosed waters of the Sound.

Adult Tagging

Electronic tagging of adults will be attempted in late May to early June 2002, well in advance of the peak of spawning in July. Marinas on San Salvador Island and Great Abaco Island (Marsh Harbour) will serve as bases for blue marlin fishing during June, 2002. At both locations, we will engage 5 - 10 fishing crews who are especially experienced fishers to conduct cooperative, scientific research from their sportfishing vessels. These boats will "fan-out"each fishing day in search of adult blue marlin and stay in radio contact with one another. One vessel carrying scientific crew and electronic tagging equipment will fish centrally with respect to the entire fleet to minimize the time involved in the tagging process should another boat hook an appropriate fish. Concurrently, a longlining vessel will be leased that is stationed in Caicos Passage with a third scientific crew and equipment to deploy pop-up tags. The electronic tag to be used is the latest generation of Wildlife Computers' pop-up archival satellite tag. Each tag will be programmed to measure and store water temperature and location data every two hours and "pop-up" after 60 to 90 days. Hooked fish will be brought to the boat, quieted and secured and a satellite tag and conventional (streamer) tag will be deployed. Large fish will be subdued along boat-side with the aid of a snooter, a tool that allows a steel wire loop to be fastened around the upper bill, and secured to a cleat on the vessel (Graves et al. in press). The tags will be implanted using a stainless steel tag applicator modified to accomplish placement to a depth of about 10 cm into the dorsal musculature, about 5 cm below the base of the fifth dorsal spine. Hook location as well as observations on foul-hooking (tissue damage, bleeding, etc.) will be noted at the time of hook removal. Before release, fish that are unable to maintain their body position in the water column will be resuscitated as necessary. After 60 (or 90) days, the positively buoyant tags are designed to release from the fish, float to the surface, and begin transmitting data to satellites of the Argos system. Position information and portions of the temperature and inclinometer data will be captured with each satellite pass and transmitted to a ground station and ultimately to the

investigators via the internet. Data will be analyzed to determine net movement from the point of release to the point of first transmittal following pop-up. Water temperature and depth estimates will be determined from temperature and pressure sensor readings using calibration equations provided by the manufacturer.

COMPLEMENTARY RESEARCH

Though beyond the scope of the present study, three additional lines of research are in progress or planned that will greatly complement the activities described herein. First, very small and/or damaged larval istiophorids can pose significant species identification problems, even for experts. In this regard, the ongoing work of University of Miami Ph.D. candidate Ms. Stacy Luthy is relevant. Working closely with JEG and Dr. William Richards (NOAA/NMFS), she is addressing these problems by a combination of genetic and traditional methods. Second, accuracy of larval age estimates is important for hindcasting probable spawning times and locations as well as for making diet, growth rate and condition comparisons. One University of Miami proposal (co-authored by Dr. Su Sponaugle) has been funded in which Exuma Sound billfish larvae will be aged by counting and measuring otolith microincrements. Finally, adult spawning behavior is undoubtedly related to the sex and the reproductive condition of the animal in question. An immunologist, Dr. Duane Schultz, at the University of Miami medical campus has received funding to develop molecular "field-kits" to determine sex, and possibly reproductive status, from a small sample of muscle tissue or blood. These samples could be obtained just prior to release of all electronically and/or conventionally tagged individuals with little or no harm to the fish. Reliable tools for determining sexual identity could significantly improve stock assessments if they were incorporated into ongoing fishery monitoring programs that sample billfish carcasses at fishing ports and bycatch/discards at sea.

SIGNIFICANCE

The present study represents the first fieldwork-based research project that directly examines "essential fish habitat" for blue marlin in the Atlantic Ocean. Our approach of sampling larvae for information on nursery habitat and electronic tagging of adults upstream for information on potential spawning behavior has not been attempted before. The project's success depends on the cooperative efforts of multi-national group of fisheries scientists, managers and commercial and recreational fishers. Research of this type may serve as a "first-step" towards the ultimate protection of habitats that are critical for blue marlin, and possibly other highly-migratory, pelagic fishes. Furthermore, the larval sampling component of this study may also have a future role in the management of the Atlantic blue marlin stocks by providing data for an index of spawning

stock biomass. These represent important new lines of investigation on a valuable, heavily exploited pelagic resource.

ACKNOWLEDGMENTS

Financial support was provided by Perry Institute for Marine Science (Project No. CMRC-99-ORJY-01-00A), the American Institute for Marine Studies, Tim Choate, Artmarina, Inc., and the National Marine Fisheries Service. The editorial comments of William Richards and Gerald Scott greatly improved this paper. This is the Southeast Fisheries Science Center's Sustainable Fisheries Division Contribution No. SFD-01/02 - 20011110.

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Demographics, Motivations, and Participation Patterns of Sport Divers in the Flower Garden Banks National Marine Sanctuary

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ABSTRACT

To establish whether a potential marine protected area (MPA) is an area of special national significance requires knowledge of the area's resource, ecological, historical, cultural, and archeological qualities. Socio-economic understandings include the public benefits to be derived from recreational use and tourism activity. Managers at the Flower Garden Banks National Marine Sanctuary (FGBNMS) are required to facilitate all public and private uses of sanctuary resources (not otherwise prohibited) "to the extent compatible with the primary objective of resource protection". This paper provides estimates of the total economic impacts of FGBNMS sport divers on the Texas coastal community where they boarded their dive charter boats (Freeport, Texas). FGBNMS managers wanted a baseline understanding of the extent of new money entering the local and state economy as a result of the marine sanctuary. We sent an 11-page mail questionnaire to a sample of 1,059 sport divers using dive charter boats along the Texas coast; 528 were returned for a response rate of 56%. FGBNMS divers spent an average of $259 in the local community and $94 "elsewhere in Texas" on their last diving trip. Most (74%) of local expenditures were made for charter dive boat fees. We estimated the expenditures of non-local Texas residents in the Freeport area at between $363,079 and $407,344. Non-residents of Texas spent an additional $204,068 to $407,346 in the local community. Using a multiplier of 1.8169 (number of times money is spent and re-spent before leaving the local economy), diver direct expenditures resulted in $1,030,450 to $1,155,800 of total economic output in the local area. This level of economic output also generated 21 to 24 jobs. The total value-added (or income and taxes that remain in the local community) was estimated at between $653,921 and $733,467. Various uses of economic impact data will be discussed.

KEY WORDS: Human dimensions, marine sanctuary, Scuba diving

Impacto Económico del Buceo Deportivo en el Santuario Marítimo Nacional Flower Garden Banks

RESUMEN

Para determinar si un area marítima protegida (MPA) es de especial importancia nacional, se requiere del conocimiento de sus recursos ecológicos, históricos, culturales y arqueológicos. El entendimiento socio-económico incluye los

beneficios públicos derivados del uso recreativo y de la actividad turística. Los responsables del manejo del Flower Garden Banks National Marine Sanctuary (FGBNMS) deben permitir el acceso a los recursos del santuario para su uso público o privado (usos no prohibidos) "hasta donde este uso sea compatible con el objetivo prioritario de proteger los recursos". Este artículo reporta estimaciones del impacto económico del buceo deportivo en el FGBNMS en la comunidad costera de Texas, donde los buzos abordan las embarcaciones que arrendan (Freeport, Texas). Los responsables del manejo del FGBNMS deseaban conocer la cantidad de dinero que ingresa a la economía local y estatal por efecto de estas actividades en el santuario. Enviamos por correo un cuestionario de 11 páginas a buzos deportivos que rentan embarcaciones en la costa de Texas; se recibieron 528 cuestionarios contestados por lo que la respuesta fue del 56%. En su último viaje, los buzos que visitaron el FGNMS gastaron en promedio $259 USD en la localidad y $94 USD "en cualquier otra parte de Texas". El 74% de los gastos realizados en la localidad fueron dedicados al pago de la renta de las embarcaciones. Estimamos que la derrama económica en el área de Freeport por parte de visitantes del estado de Texas estuvo en el rango de $363,079 a $407,344 USD. Adicionalmente, los visitantes de otros estados gastaron en la localidad entre $204,068 y $407,346 USD. Utilizando un multiplicador de 1.8169 (número de veces que el dinero es gastado antes de salir de la economía local), los gastos directos de los buzos deportivos produjeron en la localidad una salida económica total de $1,030,450 a $1,155,800 USD. Este nivel de respuesta económica además generó entre 21 y 24 empleos. El valor agregado total (o ingresos e impuestos que se quedan en la localidad) se estimó entre $653,921 y $733,467 USD. Se discuten varios usos de la información sobre impacto económico.

PALABRES CLAVES: Impacto Económico del Buceo Deportivo, Santuario Marítimo Nacional Flower Garden Banks

INTRODUCTION

The Flower Garden Banks National Marine Sanctuary (FGBNMS) is one of 13 National Marine Sanctuaries managed under the National Marine Sanctuaries Act (16 U.S.C. 1431- 1445b). The FGBNMS, including the East and West Flower Garden Banks, was designated a Sanctuary in 1992 and is located about 120 nautical miles from shore, almost directly south of the Texas/ Louisiana border. These two banks constitute the northernmost living coral reefs on the U.S. continental shelf. Stetson Bank, which lies 70 miles south of Galveston, Texas, was added to the FGBNMS in 1996. Overall, all three banks encompass about 42.5 square miles and are soon to be administered as a single unit by the Sanctuaries and Reserves Division of the National Oceanic and Atmospheric Administration (NOAA).

The three banks sit atop salt domes that rise above the 300-foot sea floor to within 55 or 65 feet of the surface. Typical recreational dives at the Flower Gardens range from 60 to 80 feet with visibility often exceeding 100 feet. Although not as

biologically diverse as tropical reefs in the Caribbean, the FGBNMS serves as a regional reservoir of shallow-water Caribbean reef fishes and invertebrates in the Gulf of Mexico. This, in addition to protecting the coral reef from damage caused by anchoring, was the basic rational for designating the Flower Gardens as a National Marine Sanctuary. The main attraction at the Flower Gardens is the high diversity reef (55 –140 feet deep) offering large pelagics and 23 species of coral, most of which are star, brain, and fire corals. At the Stetson Bank where the water is slightly cooler, sponges account for most of the growth coverage.

Sanctuary managers are concerned with many of the same human-induced impacts experienced at other coral reef marine protected areas, namely, shipping traffic, oil and gas operations, fishing (commercial and recreational), and recreational diving activity. Because of their offshore location, they have not been as impacted as near shore reefs. The major impacts to date have been from ship anchors. In 2001, the International Maritime Organization (IMO) designated the FGBNMS as a "no-anchoring zone." Mooring buoys had previously been installed to reduce the anchoring impacts associated with recreational diving and fishing boats.

Overall, there is little known about the extent of various recreational uses of the FGBNMS and their physical and ecological impacts. The FGBNMS staff monitors the annual number of boat trips and divers taken to the Sanctuary by live-aboard dive boats offering overnight trips to FGBNMS. However, they currently have no scientific knowledge of the sport diver population using these charter boats to access the FGBNMS. Previous studies of Texas divers (Graham and Ditton 1975, O'Reilly 1982) and divers elsewhere (Graham 1975, Holecek and Lothrop 1980, Roberts and Thompson 1983, McCawley and Teaff 1995) have profiled this group of recreational participants to some extent. Two studies of Texas divers pointed to the popularity of the Flower Garden Banks as a dive site even before it was designated a National Marine Sanctuary (Graham and Ditton 1975, O'Reilly 1982). With designation as a National Marine Sanctuary and an overnight stay required to access the FGBNMS for diving purposes, we would expect this area to attract a more geographically diverse, better educated, higher income, more dedicated, and more non-consumptively oriented clientele than the general sport diver population.

The objective of this paper was to profile recreational divers who use charter dive boats to access the FGBNMS for sport diving purposes. By understanding the socio-demographics of divers, their level of previous experiences, and their particular reasons for diving at the FGBNMS, managers should have a greater appreciation for this clientele group, and as a result, be more effective in its outreach and education programs. By providing support for this investigation of one of its Sanctuary user groups, the FGBNMS is recognizing that National Marine Sanctuary management is to a great extent user management. In order to protect the coral reef ecosystems at FGBNMS, managers must not only know about coral reef resources but they must know something about their various clientele groups to ensure recreational uses are conforming and experience outcomes are being realized.

METHODS

We used a stepwise approach for learning about sport divers in Texas marine waters and their participation patterns. First, an inventory of dive charter boat operators was completed in 1997 (Ditton et al. 1995). Operators were asked to provide data on the number of dive charter trips taken offshore in the previous 12 months as well as the number of divers carried overall on these trips. In some cases, estimates were made; in others, we accessed their records to count their number of trips and customers. Second, we invited dive boat operators to cooperate in a survey of their customers; we needed to access their customer lists in to select a random sample of divers. And third, we used a mail questionnaire to collect data from sport divers.

With initial funding support from the Texas Parks and Wildlife Department, the goal of this study was to learn about the sport diver population that used agency-managed artificial reefs as well as other artificial and natural reefs in Texas offshore waters (Ditton et al. in press, Ditton et al. 2002). The diver sample was derived from the population of charter dive boat operators who were asked to provide a list of their customer names and addresses. The goal of the diver survey was to sample 1,200 sport divers: 600 divers from boats known to take divers to the FGBNMS and 600 divers from boats using mostly manmade dive resources along the Texas coast. Actual sizes of the FGBNMS and artificial reef diver samples were 614 and 445, respectively.

An 11-page self-administered mail questionnaire was used to solicit information from divers regarding their diving activity and experience, their overall level of involvement in the social world of sport diving, diving participation in Texas offshore waters, other dive destinations frequented, and information about their last diving trip to the Texas coast. Finally, a demographic profile of sport divers was sought with questions regarding age, gender, race, ethnicity, education, income, and residence location. Survey questions were based on those proven effective in previous studies of sport divers, birders, and anglers conducted by the Human Dimensions Lab at Texas A&M University and were modified as necessary through a pre-test of members of the Texas A&M University Scuba Diving Club. This study employed the highly personalized survey methodology advocated by Salant and Dillman (1994). Each diver was sent four mailings by first class mail as necessary over a five-week period with an expectation of a 60% response rate.

Two questions on the survey helped identify two groups: those whose total number of trips in Texas offshore waters in the previous twelve months were solely to the FGBNMS and those who went diving at the FGBNMS as well as other places off the Texas coast. Of the total 528 divers who responded to the survey, 461 had been diving in the previous twelve months. Of those, 333 (10 were deleted because they were minors) divers reported they went diving at the Flower Gardens in the previous twelve months; 186 of these went diving only at the FGBNMS (henceforth called FGBNMS only divers) and the remainder went diving at the Flower Gardens as well as other dive sites along the Texas coast (henceforth called FGBNMS plus divers). This paper will focus on the social and demographic information derived

from the diver survey for the two groups identified.

Responses to all questions were tested for statistically significant differences between FGBNMS only divers (n = 186) and FGBNMS plus divers (n = 147). Differences between groups for interval-scaled variables were tested using t-tests. For variables with ordinal measures (scale items), the Kruskal-Wallis test was used. For nominal variables, chi-square tests for independence were used. All tests were conducted using SAS Version 8 and level of statistical significance was set at = 0.05. Results will only be presented where significant group differences exist; otherwise aggregated results will be presented.

Of the 1,059 questionnaires mailed to divers, 528 were returned usable for an overall effective response rate of 56.2%. This response rate was lower than expected from Salant and Dillman (1994) and lower than reported for most other outdoor recreation surveys. A check on non-respondents was planned to test for significant differences between respondents and non-respondents on selected variables but could not be completed due to a lack of phone numbers for divers. In other previous studies of outdoor recreation participants, non-respondents had fewer years of experience and participated less frequently than respondents; the activity probably has less salience for the former group possibly explaining their non-response to the survey (Filion 1980). Therefore, we would expect survey respondents to report more days of diving experience in the previous 12 months, more years of diving experience, more charter dive boat trips in the previous 12 months, and more trips to the FGBNMS than non-respondents.

RESULTS

FGBNMS divers traveled an average of 201.6 one-way miles for this diving trip (Table 1). There were no significant differences between FGBNMS only divers and FGBNMS plus divers regarding the distance traveled to their point of embarkation from the Texas coast (Freeport). Most (73.6%) of the sport divers visiting the FGBNMS were residents of Texas, and resided mainly in larger metropolitan areas: 44.5% Houston, 13.9% Austin, 8.2% San Antonio, 4.9% Ft. Worth, 4.1% Beaumont, and 4.1% Dallas. Twenty-six (26.4%) percent of FGBNMS divers resided out of state.

Of the individuals who reported diving at the FGBNMS (n = 333), nearly three-quarters (74.5%) were male and the remainder (25.5%) were female. Most divers classified themselves as Anglo (92.4%), with remaining divers classifying themselves as "other" 5.6%, African-American 1%, and Asian 1%. When asked about their ethnic origin, 4.2% indicated they were of Spanish/ Hispanic origin. Divers ranged in age from 18 to 68 years with a mean of 39. The median household income category of FGBNMS divers was $120,000 - $149,000 with a correspondingly high level of education with an average of 16 completed years of school (or essentially, the completion of a four-year degree). Only 1.2% of these divers had not completed high school. Sixteen years was also the median indicating that 50% of the divers had

post-graduate schooling.

Table 1. Frequency Distribution of Divers by Distance Traveled to the FGBNMS

Distance Traveled (miles)	Total	
	Number	Percent
0 - 100	119	39.8
101 - 200	69	23.1
201 - 300	61	20.4
301 - 400	29	9.7
401 - 500	6	2.0
501 - 600	5	1.7
600+	10	3.3
Total	299	100.0

Sixty-one (60.8%) percent of FGBNMS divers subscribed to one or more diving magazines with a mean of 2.2 magazines. The most commonly subscribed magazines were *Skin Diver* (35.0%), *Deep Tech* (30.0%), and *Rodales* (22.8%). Most divers did not belong to a diving club; only 21.4% answered in the affirmative when asked if they belonged to a dive group. The most common dive groups cited by these divers were the Houston Underwater Club (23.4%) and the Bay Area Divers (10.6%). The most common group with whom FGBNMS divers went diving in saltwater most often was friends (54.2%), followed by family and friends together (22.3%), family (11.9%), and club members (11.6%).

When asked to compare sport diving with their other outdoor activities, most (57.2%) reported that diving was their most important outdoor activity. While seventeen percent (17.4%) listed diving as their second most important activity, twenty-one percent (21.1%) of FGBNMS divers indicated that scuba diving was only one of many outdoor activities in which they participated. Divers reported they had been certified for an average of 8.5 years; most received certification through PADI and NAUI (Table 2). Of these 8.5 years of diver certification, nearly all (7.9 years) were spent diving saltwater. About one-quarter (26.2%) of FGBNMS divers indicated their highest level of certification as basic open water; thirty-one (30.5%) percent indicated they achieved advanced open water; fifteen (15.2%) percent achieved divemaster status; fifteen (14.6%) percent achieved the status of dive instructor; and thirteen (13.4%) percent classified themselves as a "specialty" diver (cave, wreck, conservation, navigation, photography, etc.).

In the previous 12 months, FGBNMS divers spent an average of 3.9 days diving in freshwater and 12.9 days diving in saltwater. These divers made between one and four trips specifically to the FGBNMS in the previous twelve months with an average of 1.3 trips. They also indicated making an average of 0.3 trips specifically targeting artificial reefs (including standing oil and gas rigs) in Texas waters in the previous twelve months. Of the total days spent saltwater diving in the past twelve months, FGBNMS divers spent an average of 5.1 days diving in Texas, 0.7 days diving in Florida, 2.0 days diving in Mexico, 3.3 days diving in the Caribbean, and 2.1 days diving elsewhere.

Table 2. Frequency Distribution of FGBNMS divers according to where they received their certification.

Certification	Number	Percent
NAUI	98	22.2
PADI	222	50.4
SSI	50	11.3
YMCA	30	6.8
Other	41	9.3
Total*	441	100.0

* Total number of diver certifications is greater than the total number of divers because divers could have received certification from more than one group

Most FGBNMS divers reported that they participated in night diving (89.5%), underwater photography (58.9%), and marine identification (57.4%); followed closely by wreck diving (44.1%). Only a minority of divers participated in spear fishing. FGBNMS only divers (14.7%) participated significantly less ($P<0.05$) in spear fishing than FGBNMS plus divers (26.1%). Additionally, significantly more ($P<0.05$) of the FGBNMS plus divers participated in wreck diving (51.6%) than FGBNMS only divers (39.0%). This was the same pattern for cave diving (13.1% FGBNMS plus divers; 6.3% FGBNMS only divers). However, when divers were asked about the type of diving activity they participated in most often, there were no significant group differences: underwater photography (31.5%), marine identification (28%), and night diving (17.5%).

FGBNMS divers were given a list of fifteen reasons why people dive in saltwater and asked to rate the importance of each scale item on a five-point scale ranging from "not at all important" to "extremely important." A majority of divers rated 12 of 15 reasons for diving as either "very important" or "extremely important" (Table 3). In addition to a low rating of importance for the family recreation reason for sport diving, the standard deviation was highest for this item indicating there was low agreement on this item among divers. Whereas both groups indicated that "for the experience of spearing fish" was not an important reason why they went diving in saltwater, there were significant group differences. Significantly more ($P < 0.05$) of the FGBNMS plus divers indicated that the spearing of fish to eat was either very important or extremely important (12.2%) compared to FGBNMS only divers (7%) (Table 3).

Overall, on a five-point scale ranging from 1 ("not satisfied") to 5 ("extremely satisfied"), most FGBNMS divers indicated they were either "very satisfied" (48.0%) or "extremely satisfied" (33.9%) with their trip.

Table 3. Frequency Distribution of FGBNMS divers by importance of reason for diving on this trip.

Reason for Diving	Not at All Important 1	Slightly Important 2	Moderately Important 3	Very Important 4	Extremely Important 5	Mean	S.D.	Median
	Values given are percentages							
For family recreation	28.5	14.2	16.4	22.9	18.0	2.88	1.49	3.0
To learn more about the underwater environment	1.2	5.5	24.6	38.6	30.1	3.91	0.93	4.0
To experience unpolluted natural surroundings	0.9	2.75	13.5	37.9	44.95	4.23	0.85	4.0
To look at fish and other aquatic life	0.0	0.6	2.4	30.1	66.9	4.63	0.56	5.0
To be outdoors	1.8	5.5	19.9	35.8	37.0	4.01	0.98	4.0
For relaxation	3.03	2.73	10.9	40.0	43.33	4.18	0.95	4.0
To experience adventure and excitement	1.5	4.24	12.7	31.8	49.7	4.24	0.94	4.0
To get away from the demands of other people	8.8	10.9	20.1	25.5	34.7	3.66	1.29	4.0
To experience tranquility underwater	1.2	3.95	8.8	28.3	57.75	4.37	0.89	5.0
To be with friends	3.35	9.15	27.1	37.5	22.9	3.67	1.03	4.0
For the exercise	16.1	24.2	33.3	17.3	9.1	2.79	1.16	3.0
To develop my diving skills and abilities	3.6	7.0	25.45	35.15	26.8	3.78	1.05	4.0
To get away from the regular routine	5.2	8.5	17.0	36.8	32.5	3.83	1.13	4.0
To experience new and different things	2.1	6.1	14.3	34.35	43.2	4.10	1.00	4.0
For the experience of spearing fish to eat*								
Flower Gardens Only	83.6	4.9	4.9	3.3	3.3	1.38	0.96	1.0
Flower Gardens and Other Places in Texas	71.1	11.3	4.9	5.6	7.04	1.67	1.23	1.0

* Significant difference at the $P < 0.05$ level between groups

DISCUSSION

Like sport divers elsewhere, FGBNMS divers were mostly Anglo males, residents of major metropolitan areas, well educated with four or more years of higher education, and had above average household incomes. FGBNMS divers had notably higher education (Holecek and Lothrop 1980, Vrana 1992, McCawley and Teaff 1995) and income levels (when adjusted to current dollars) (Holecek and Lothrop 1980, Vrana 1992) than other diver samples studied previously. This seems consistent with their propensity for dive-related travel. In terms of age, FGBNMS divers are older than divers in other studies, but this is likely due to the effects of the aging "baby boom" population.

There were few differences overall between the two FGBNMS diver groups. Aside from an overlap between groups for testing purposes, the lack of differences is likely due to the challenges of sport diving in offshore waters that require a certain level of training and diving experience. However, spear fishing with the intent to harvest fish was less of an attraction for the FGBNMS only anglers, indicating they might have been much less interested in visiting the sanctuary for consumptive reasons. Likewise, there was less interest among FGBNMS only divers in underwater environments dominated by manmade structures as evidenced by their lower rate of participation in wreck diving and number of trips to artificial reefs.

When FGBNMS and artificial reef divers were compared, they shared many of the same social and demographic characteristics (gender distribution, age, race and ethnicity, and years of formal education), but there were notable differences in household income, annual diving frequency, and diving resources used most frequently in Texas offshore waters (Ditton and Baker 1999). First, the median household income category of FGBNMS divers was twice that of artificial reef divers ($60,000-$69,000) (Ditton and Baker 1999). Second, artificial reef divers averaged more days (26) of diving annually than FGBNMS divers (17). Third, there were a higher percentage of FGBNMS only divers (55%) than artificial reef only divers (40%). More FGBNMS divers appear to concentrate their activity at the FGBNMS than artificial reef users do at artificial reefs. This may be due to differences in household income and their preference for the FGBNMS. Also, in terms of use frequency, FGBNMS divers made fewer trips over a twelve-month period to the FGBNMS (1.3) than did artificial reef divers to artificial reefs (3.25). This is best explained by the cost differences in diving near shore artificial reef sites compared to the FGBNMS, which is much farther from shore. FGBNMS divers appear willing to dive less frequently than artificial reef divers and at a higher cost at their distant location just to be able to dive there.

Besides understanding FGBNMS diver characteristics and participation patterns, other social science perspectives would be useful to management efforts. First, to what extent are there constraints to diving at the FGBNMS besides time and money? These would be worth knowing about so they can be dealt with in diver training and sanctuary education programs. Second, additional insights into FGBNMS diver attitudes and opinions regarding the marine environment and

current and proposed management regulations would provide an important source of user feedback prior to initiating the rulemaking process. Third, managers should know whether sport divers consider other dive sites in the region to be substitutes (where a substitute provides the same diving enjoyment and satisfaction at a similar cost) for the FGBNMS. This would help explain whether the FGBNMS diving experience is viewed as unique and why some divers concentrate their Texas diving activity here. Based on where FGBNMS divers reside and the extent and quality of other dive sites on the Texas coast, we expect there are few, if any, other dive sites on the Texas coast that would be viewed as substitutes for the FGBNMS. If there were no substitutes, FGBNMS divers would be an even more important stakeholder group for the National Marine Sanctuary, one that would likely support future rulemaking efforts that maintain the ecological integrity of the area.

A constraint to future studies of recreational users of the FGBNMS and probably most other National Marine Sanctuaries in the U.S. is the lack of an annual sampling frame or list of users. This can be overcome with a no-cost special use permit for all recreational users accessing the FGBNMS. Such a permit could be made available via the Internet and would provide a database of user names and addresses for follow-up research purposes. This approach is used routinely by the National Park Service and U.S. Forest Service for survey sampling purposes in support of its backcountry and wilderness management responsibilities so that they can monitor users.

ACKNOWLEDGEMENTS

We appreciate the financial support of the Texas Parks and Wildlife Department; they fully supported the costs of the 1997 Texas Sport Diver Survey, which focused on all diving activity in Texas offshore waters accessed by dive charter boats. In particular, we want to recognize Hal Osburn, Director of the Texas Artificial Reef Program at the time, for his foresight in allowing us to design this study beyond their particular interest in artificial reefs. We also appreciate the support of the NOAA Flower Garden Banks National Marine Sanctuary, which enabled this focus on study results of interest to the FGBNMS. Without the cooperation and assistance provided by Gary Rinn, this paper would not have been written. Additionally, Troy Baker deserves special recognition for his efforts to coordinate and carry out the sport diver survey "against all odds"

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The Economic Impacts of Sport Divers Using the Flower Garden Banks National Marine Sanctuary

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ABSTRACT

To establish whether a potential marine protected area (MPA) is an area of special national significance requires knowledge of the area's resource, ecological, historical, cultural, and archeological qualities. Socio-economic understandings include the public benefits to be derived from recreational use and tourism activity. Managers at the Flower Garden Banks National Marine Sanctuary (FGBNMS) are required to facilitate all public and private uses of sanctuary resources (not otherwise prohibited) "to the extent compatible with the primary objective of resource protection". This paper provides estimates of the total economic impacts of FGBNMS sport divers on the Texas coastal community where they boarded their dive charter boats (Freeport, Texas). FGBNMS managers wanted a baseline understanding of the extent of new money entering the local and state economy as a result of the marine sanctuary. We sent an 11-page mail questionnaire to a sample of 1,059 sport divers using dive charter boats along the Texas coast; 528 were returned for a response rate of 56%. FGBNMS divers spent an average of $259 in the local community and $94 "elsewhere in Texas" on their last diving trip. Most (74%) of local expenditures were made for charter dive boat fees. We estimated the expenditures of non-local Texas residents in the Freeport area at between $363,079 and $407,344. Non-residents of Texas spent an additional $204,068 to $407,346 in the local community. Using a multiplier of 1.8169 (number of times money is spent and re-spent before leaving the local economy), diver direct expenditures resulted in $1,030,450 to $1,155,800 of total economic output in the local area. This level of economic output also generated 21 to 24 jobs. The total value-added (or income and taxes that remain in the local community) was estimated at between $653,921 and $733,467. Various uses of economic impact data will be discussed.

KEY WORDS: Economic Impact, human dimensions, SCUBA diving

Impacto Económico del Buceo Deportivo en el Santuario Marítimo Nacional Flower Garden Banks

Para determinar si un area marítima protegida (MPA) es de especial importancia nacional, se requiere del conocimiento de sus recursos ecológicos, históricos, culturales y arqueológicos. El entendimiento socio-económico incluye los beneficios públicos derivados del uso recreativo y de la actividad turística. Los

responsables del manejo del Flower Garden Banks National Marine Sanctuary (FGBNMS) deben permitir el acceso a los recursos del santuario para su uso público o privado (usos no prohibidos) "hasta donde este uso sea compatible con el objetivo prioritario de proteger los recursos". Este artículo reporta estimaciones del impacto económico del buceo deportivo en el FGBNMS en la comunidad costera de Texas, donde los buzos abordan las embarcaciones que arrendan (Freeport, Texas). Los responsables del manejo del FGBNMS deseaban conocer la cantidad de dinero que ingresa a la economía local y estatal por efecto de estas actividades en el santuario. Enviamos por correo un cuestionario de 11 páginas a buzos deportivos que rentan embarcaciones en la costa de Texas; se recibieron 528 cuestionarios contestados por lo que la respuesta fue del 56%. En su último viaje, los buzos que visitaron el FGNMS gastaron en promedio $259 USD en la localidad y $94 USD "en cualquier otra parte de Texas". El 74% de los gastos realizados en la localidad fueron dedicados al pago de la renta de las embarcaciones. Estimamos que la derrama económica en el área de Freeport por parte de visitantes del estado de Texas estuvo en el rango de $363,079 a $407,344 USD. Adicionalmente, los visitantes de otros estados gastaron en la localidad entre $204,068 y $407,346 USD. Utilizando un multiplicador de 1.8169 (número de veces que el dinero es gastado antes de salir de la economía local), los gastos directos de los buzos deportivos produjeron en la localidad una salida económica total de $1,030,450 a $1,155,800 USD. Este nivel de respuesta económica además generó entre 21 y 24 empleos. El valor agregado total (o ingresos e impuestos que se quedan en la localidad) se estimó entre $653,921 y $733,467 USD. Se discuten varios usos de la información sobre impacto económico.

INTRODUCTION

The Flower Garden Banks National Marine Sanctuary (FGBNMS) is one of 13 National Marine Sanctuaries in the U.S. It is managed under the National Marine Sanctuaries Act (16 U.S.C. 1431- 1445b), where the U.S. Congress found that "special areas of the marine environment will contribute positively to marine resources conservation, research, and management." The goal of the U.S. Marine Sanctuaries Program is to "enhance public awareness, understanding, appreciation, and wise use of the marine environment". Much like national park legislation in the U.S., the National Marine Sanctuaries Act seeks to facilitate "to the extent compatible with the primary objective of resource protection", all public and private uses of the resources of these marine areas (not otherwise prohibited). The FGBNMS was designated as a Sanctuary in 1992 because of its biodiversity of Caribbean reef fishes and invertebrates, its reputation as a sport diving area of national significance, and to provide a means for protecting the coral reefs from damage due to anchoring.

There are many considerations involved in National Marine Sanctuary designation in the U.S. First, the area needs to be of special national significance due to its resource or human-use values. Second, existing state and Federal management

authorities must be found to be inadequate for ensuring coordinated and comprehensive management of the marine area. In addition to having knowledge of an area's resource, ecological, historical, cultural, and archaeological qualities and significance, present and potential uses of the area that depend on these qualities should be well understood (16 U.S.C. 1431, 1433). To establish whether the marine environment in question is an area of special national significance, socio-economic understandings are required as well. These include an understanding of the public benefits to be derived from Sanctuary status with an emphasis on protecting those resources that generate tourism activity and the overall socio-economic effects of Sanctuary designation.

Economic benefits generally fall into two categories: economic impact and economic value. Economic impacts at the local, regional and state level result from participation in an outdoor recreation activity like sport diving at the FGBNMS. These impacts are measured in jobs, sales, income, and tax revenues and are derived from the expenditures made by sport divers (i.e., the cost of going diving) prior to and following their diving activity. Economic value, on the other hand, addresses how much resource users value the opportunity to use a particular resource like the FGBNMS. The extent to which sport divers value the resource is partially expressed by their expenditures for sport diving as well as an additional value they would pay in a market situation before foregoing the opportunity to go sport diving at the FGBNMS. This paper will focus solely on economic impact concerns. Since economic impact assessments do not measure willingness to pay (they do not measure the economic benefit to individuals), they are not suitable for benefit-cost analyses (Propst and Gavrilis 1987, Edwards 1991). They nevertheless provide answers to many of the questions posed by local, state, and federal officials.

The objective of this paper was to provide estimates of the total economic impacts of FGBNMS divers on the Texas coastal community where they boarded their dive charter boats (Freeport, Texas) as well as at the statewide level. This involves making estimates of sport diving-related expenditure by divers who reside in the coastal community, elsewhere in Texas, and out-of-state with the multiplier effects on the economy. In particular, FGBNMS managers were interested in demonstrating the extent sport diving and related tourism activity impacts the local economy of Freeport, Texas as well as the state of Texas. At the local community level, it is important to know the extent and distribution of new money entering the local economy as a result of sport diving activity at the FGBNMS. Likewise, FGBNMS managers wanted some baseline understanding of the extent to which out-of-state sport divers bringing new money into the state's economy used FGBNMS.

METHODS

This study employed a stepwise approach to learn about sport divers in Texas marine waters and diving activity at the FGBNMS, in particular. First, an inventory of dive charter boat operators was completed in 1997 (Ditton et al. 1995). Twenty-three operators were identified and asked to provide data on the number of dive

charter trips taken offshore in the previous 12 months as well as the number of divers carried overall on these trips; only 10 responded. In a follow-up effort in1997, the one charter dive boat operator making dive trips to the Flower Garden Banks National Marine Sanctuary reported 77 boat trips in the previous 12 months to the Sanctuary; these trips accounted for 2,350 diver trips. This information was derived directly from logs and databases maintained by the operator. Additionally, this dive boat operator along with others on the Texas coast were asked to provide us with access to their customer lists so we could send a mail questionnaire to their customers.

This research was facilitated by a study initially funded by the Texas Parks and Wildlife Department to learn about the sport diver population that used agency-managed artificial reefs as well as other artificial and natural reefs in Texas offshore waters (Ditton and Baker 1999, Ditton et al. (a) in press, Ditton et al. (b) 2002). The diver sample was derived from the population of charter dive boat operators who provided names and addresses of their customers. The goal of the diver survey was to sample 1,200 sport divers overall: 600 divers from boats known to take divers to the FGBNMS and 600 divers from boats using mostly manmade dive resources along the Texas coast. Actual sizes of the FGBNMS and artificial reef diver samples were 614 and 445, respectively.

An 11-page self-administered mail questionnaire was used to solicit information from divers regarding their diving activity and experience, their overall level of involvement in sport diving, their diving participation in Texas offshore waters as well as other dive destinations, and information about their last diving trip to the Texas coast. Additionally, the survey included several economic questions, including those designed to gain information about personal expenditures made in the coastal community on their "last trip to the coast to go sport diving in offshore Texas waters" as well as elsewhere in Texas. Direct expenditure results taken with estimates of the number of sport diver days at the FGBNMS are essential ingredients for calculating the total economic impact of sport diving at the National Marine Sanctuary. Finally, a demographic profile of sport divers was sought with questions regarding age, gender, race, ethnicity, education, income, and residence location. Survey questions were based on those proven effective in previous outdoor recreation studies completed in our Human Dimensions Lab at Texas A&M University and modified, as necessary, as a result of a pre-test of members of a local diving club. We employed the survey methodology advocated by Salant and Dillman (1994), which entailed four, personalized, first-class mailings over a five-week period with an expected response rate of 60%.

Of the 528 divers who responded to the survey, 461 had been diving in the previous twelve months. Using two survey questions, we identified those divers whose total number of trips in Texas offshore waters in the previous twelve months were made solely to the FGBNMS and those who made trips to the FGBNMS as well as other places off the Texas coast. Of the 461 divers who had been diving in the previous twelve months, 333 (10 were deleted because they were minors) reported they went diving at the Flower Garden Banks in the previous twelve

months; 186 of these went diving only at the FGBNMS (henceforth called FGBNMS only divers) and the remainder went diving at the Flower Garden Banks as well as other dive sites along the Texas coast (henceforth called FGBNMS plus divers). This paper will focus on the economic impact information derived from each group of divers.

Responses to all questions were tested for statistically significant differences between FGBNMS only divers (n = 186) and FGBNMS plus divers (n = 147). Differences between groups for interval-scaled variables were tested using t-tests. For variables with ordinal measures (scale items), the Kruskal-Wallis test was used. For nominal variables, chi-square tests for independence were used. All tests were conducted using SAS Version 8 and level of statistical significance was set at = 0.05. Results will be presented in aggregate form, since there were no significant group differences between the two groups (FGBNMS only and FGBNMS plus divers) regarding their expenditures made in the local community where they boarded their dive charter for the FGBNMS (Freeport, Texas) or elsewhere in Texas.

Utilizing the data provided by survey respondents for their expenditures in the local community and elsewhere in the state of Texas, we estimated direct economic impacts at each of these respective levels. Direct expenditures, however, are only one portion of the total economic impact of sport diving. Direct impacts, combined with other indirect and induced impacts represent the full economic impact of sport diving at FGBNMS to both local and state economies. Indirect impacts include the economic activity that is created among businesses and organizations that supply goods and services to the businesses that directly sell products to visiting sport divers. Induced impacts refer to the effects of generated economic activity resulting from increased incomes as a result of divers' overall expenditures. It is the combination of the direct, indirect, and induced effects that results in total economic output. Through the use of an input-output model, we can determine the changes in total output, income, value-added, and employment that reflect the economic importance of an industry and the habitats and resources that generate tourism activity (i.e. sport diving at the FGBNMS) to the coastal community and state economies.

Economic impacts of sport diving at the coastal community and state levels were estimated using economic impact multipliers for the Texas coast and statewide, derived by Tanyeri-Abur et al. (1998). Through their understanding of the total impacts of recreation activities on the Texas coast, they concluded that each dollar of expenditure resulted in an average of $1.81 total output in the coastal community, $0.75 in personal income, and $1.15 in value-added to the Texas coastal economy. Based on their calculations, they reported that 37 jobs were generated per $1 million of expenditures. At the state level, Tanyeri-Abur et al. derived an economic multiplier of $1.91 of total economic output, $0.78 in personal income, and $1.20 in value-added to the state economy with 38 jobs created per $1 million of expenditures.

RESULTS

Of the 333 individuals who went diving at the FGBNMS, 248 (75%) were male. Most divers classified themselves as Anglo (92%), with remaining divers classifying themselves as "other" 6%, African-American 1%, and Asian 1%. When asked about their ethnic origin, 4% indicated they were of Spanish/ Hispanic origin. Divers ranged from 18 to 68 years of age with a mean age of 39 years. The median annual household income of the FGBNMS divers was between $120,000 and $149,000 with a corresponding average 16 years of school completed.

FGBNMS divers traveled an average of 201.6 one-way miles to reach Freeport, Texas for their last sport diving trip in offshore Texas waters. Most (73.57%) of the sport divers visiting the FGBNMS resided in Texas, particularly larger metropolitan areas: 44.5% Houston, 13.9% Austin, 8.2% San Antonio, 4.9% Ft. Worth, 4.1% Beaumont, and 4.1% Dallas.

The FGBNMS divers spent an average of 3.9 days diving in freshwater and 12.9 days diving in saltwater in the previous 12 months. They also made between one and four trips, specifically, to the Flower Gardens Banks National Marine Sanctuary in the previous twelve months with an average of 1.3 trips.

FGBNMS divers spent an average of $259 in the local coastal community (Freeport, Texas) and $94 "elsewhere in Texas" on their last diving trip, resulting in a total trip expenditure of $354 (Table 1). Seventy-four (74%) percent of local expenditures were made for charter dive boat fees, 7% were for tips, 5% were for auto transportation, and 5% were for restaurant meals. Most (74%) expenditures made "elsewhere in Texas" were for dive boat fees and automobile transportation. Overall, including the local community and "elsewhere in Texas", seventy (70%) percent of the total diver expenditures were for dive charter fees; 6% for tips; 7% for transportation; 5% for restaurant meals; and 2% for lodging. Dive charter fees included the costs of transporting them to and from the FGBNMS, as well as overnight accommodations onboard at the sanctuary.

In order to understand the total economic impacts that sport diving at the FGBNMS has on the local and state economies, it was necessary to separate the divers into three groups: local residents, non-local Texas residents, and non-residents (out-of-state). This was done because impact depends upon having "new" money coming into the area of particular concern, not including money that would have been spent by residents regardless of whether they went diving at the FGBNMS or not. If they could not go diving for some reason, they would have made expenditures for other items in the local economy, for example. Therefore, only non-locals and their expenditures were counted when calculating local economic impact. Similarly, only non-residents of Texas and their expenditures were counted when calculating the state level economic impact of sport diving at the FGBNMS. Since there were no "local" divers in the study from the Freeport area, no one was deleted for purposes of calculating the local economic impact of sport diving at the FGBNMS. Two hundred forty-five FGBNMS divers (74%) were non-local Texas residents and eighty-eight (26%) were non-residents from out-of-state.

Table 1. Number and Percent of FGBNMS Divers Making Dive Trip Related Expenditures on Their Last Dive Trip to the Texas Coast; Average Expenditures for Those Making Each Expenditure and Overall

Expenditure Category	n	Percent of Divers with Expenditure on Item	Average Expenditure per Diver Who Purchased Item	Average Expenditure for Item for All Divers n=270
Amount in the Coastal Community:				
Automobile transportation to the Texas coast (fuel, rental car, taxi, etc.) *	190	57.1	22.09	12.72
Other transportation to the Texas coast (airplane, etc.)	7	2.1	353.29	1.46
Dive boat fees *	197	59.2	293.75	192.14
Tips *	223	67.0	27.69	19.18
Lodging *	39	11.7	77.08	6.00
Restaurant meals *	172	51.7	25.09	12.23
Groceries, drinks, ice *	135	40.5	13.88	4.43
Rental of diving gear	34	10.2	38.53	3.81
Anything else for this diving trip *	28	8.4	42.46	7.51
Total			$893.86	$259.48
Amount Elsewhere in Texas:				
Automobile transportation to the Texas coast (fuel, rental car, taxi, etc.) *	165	49.5	26.16	13.04
Other transportation to the Texas coast (airplane, etc.)	12	3.6	197.58	2.57
Dive boat fees *	50	15.0	306.30	56.81
Tips *	44	13.2	27.84	3.37
Lodging *	17	5.1	72.24	0.57
Restaurant meals *	95	28.5	32.54	3.99
Groceries, drinks, ice *	61	18.3	16.67	2.43
Rental of diving gear *	34	10.2	45.03	6.84
Anything else for this diving trip	24	7.2	55.25	4.73
Total			$779.61	$94.35

* Indicates extreme outliers have been eliminated from data

Non-local FGBNMS divers who were Texas residents spent an average of $235 in the local coastal community on their "last trip to the coast to go sport diving in offshore Texas waters". These divers spent an average of 2.39 days diving on their overall trip of 2.79 days, resulting in an expenditure of $99 per diving trip day. They also spent an average of $98 "elsewhere in Texas," resulting in an additional expenditure of $41 per diving trip day. Non-resident FGBNMS divers spent an average of $369 in the coastal community on their last trip to the Texas coast (5.14

days) during their 3.13 days of sport diving. This resulted in an average expenditure of $118 per sport diving trip day in the coastal community. These same divers also spent $104 "elsewhere in Texas," yielding an additional $33 per sport diving trip day. Whereas out-of-state divers spent nearly $134 more in the coastal community than Texas residents, the former only spent about $20 more per dive trip day.

From a review of the diveboat operators' log books, there were 77 diver boat trips made by two vessels to the FGBNMS, and 2,350 divers taken offshore to FGBNMS or approximately 30.5 persons per vessel per trip. This number is slightly greater than the average number of divers (excluding captain and mate) on board the dive boats (27.2) as reported by FGBNMS divers in their questionnaire responses. This would have resulted in a total of 2,094 diver trips to the FGBNMS.

The range of diver trips was multiplied by the average trip expenditures for non-local Texas residents to estimate a range of total expenditures (direct economic impact) made in the Freeport area ($363,079 and $407,346) (Tables 2 and 3). Non-residents of Texas spent an additional $204,068 to $228,792 in the local community. These divers also made expenditures ranging between $57,236 and $64,170 elsewhere in the state on their way to and from Freeport.

Table 2. Total Expenditures (Direct Economic Impact) Made by FGBNMS Divers by Residence Location Using Data Provided by FGBNMS Survey Respondents (n = 2,095)

Residency	Dollars spent in coastal community	Dollars spent elsewhere in Texas	Total
Coastal community residents	0.00	0.00	0.00
Texas residents (not coastal community)	363,079.32	151,486.08	514,565.40
Non-residents	204,068.06	57,235.50	261,303.56
Total	567,147.38	208,721.58	775,868.96

Table 3. Total Expenditures (Direct Economic Impact) Made by FGBNMS Divers by Residence Location Using Data Provided by Dive Boat Charter Operators (n = 2,350)

Residency	Dollars spent in coastal community	Dollars spent elsewhere in Texas	Total
Coastal community residents	0.00	0.00	0.00
Texas residents (not coastal community)	407,345.80	169,955.20	577,301.00
Non-residents	228,792.40	64,170.00	292,962.40
Total	636,138.20	234,125.20	870,263.40

Calculated based on data provided by one dive charter boat operator for number of trips taken offshore for sport diving and number of divers carried offshore in 1996.

Estimated total expenditures made by non-local residents and non-residents in the Freeport area as a result of their trips to FGBNMS ranged from $567,147 to $636,138. Using the 1.8169 multiplier (number of times money is spent and re-spent before leaving the local economy) calculated by Tanyeri-Abur et al. (1998), these direct expenditures resulted in $1,030,450 to $1,155,800 of total economic output, respectively, in the local area. This level of economic output also generated 21 to 24 jobs. The total value-added associated with this level of output was estimated between $653,921 and $733, 467. Value-added represents only the amount of income and taxes that remain in the local community, and therefore, is smaller than the level of total output. Personal income is a component of the total value-added impact of sport diving activity on the local community.

Since only 26.4% of FGBNMS divers were non-residents of Texas, the state level economic impacts resulting from sport diving activity at the FGBNMS were, as expected, less than the economic impacts on the local community. Using a multiplier of 1.9099, the total economic output contributed by this group of FGBNMS divers to the state of Texas ranged between $498,933 and $599,382 with 10 to 11 jobs. Total statewide impacts from indirect and induced spending are likely to spread well beyond sport diving jobs and include a wide range of sectors including manufacturing, retail, and services sectors. The total value-added dollars generated by the increased level of output was estimated to be between $313,617 and $351,613.

Using the number of dive trips and number of divers per trip as provided by dive charter boat operators, the total economic output (direct, indirect, and induced economic impacts) of FGBNMS divers for the Freeport area ($1,151,410) was nearly double that of divers using artificial reefs in offshore Texas waters in all coastal communities in Texas ($581,994) (Ditton et al. 2002). In terms of new money being brought to the state by divers, the total economic output of non-resident sport divers using the FGBNMS ($559,558) greatly exceeds that of divers coming to Texas to dive artificial reefs ($166,349) (Ditton et al. 2002). When the number of divers per trip as reported by respondents is used, the picture is not quite as clear. Accordingly, total economic output of artificial reef divers on coastal communities ($1,745,559) is nearly twice that of the FGBNMS divers on one community ($1,026, 537) with total economic output at the state level being roughly the same for both diver groups (Table 4).

DISCUSSION

Economic impact data can be used to inform current businesses as well as local and state officials about the economic contributions of sport diving. From the results provided here, the community of Freeport, Texas should have a better understanding of the importance of this activity vis-à-vis others in the local economy, and as a result may want to develop strategies to increase the extent of local FGBNMS-related economic impacts. Taking a different perspective, if the two current boats operating charter trips to the FGBNMS were to cease operations for

some reason, the loss of $600,000 in diver expenditures in the local area would have an estimated total impact of $1,086,000 on the Freeport economy. The data presented should allow the FGBNMS to calculate the economic impact effects of additional charter dive boats using the marine sanctuary.

Table 4. Coastal Community and Statewide Impacts of FGBNMS Divers by Economic Impact Variable

	Total Impacts			
Economic Impact Variable	Local		State	
	Low	High	Low	High
Direct Impact	$567,147.38	$636,138.20	$261,303.56	$292,962.40
Output	$1,026,536.76	$1,151,410.14	$499,089.80	$559,558.18
Personal Income	$425,360.54	$477,103.65	$203,816.78	$228,510.67
Value-Added	$652,219.49	$731,558.93	$313,564.27	$351,554.88
Employment	21	24	10	11

The total economic output (direct, indirect, and induced impacts) of sport diving using a dive charter boat in offshore Texas waters (diving at the FGBNMS and artificial reefs) at the state level (new money to Texas) is estimated at $725,907 if we rely on party size data provided by boat operators; it is even higher if we rely on data provided by respondents ($998,003). Several points should help put these results in perspective. First, the two estimators for boat party size at the FGBNMS were much more congruent; as a result, the difference in high-low estimates of economic impacts is much less than it is for artificial reefs (Ditton et al. (b) in press). Second, the total economic output of non-residents using dive charter boats to access one dive site (FGBNMS) (Table 4) is almost as high as that of the entire statewide charter fishing fleet in Texas ($667,836) (Sutton et al. 1999). This is best explained by the finding that only 3% of the charter fishing trips in Texas are taken by non-residents of the state compared to some other Gulf states (e.g., 62% in Mississippi, 57% in Alabama) (Sutton et al. 1999). Due apparently to the high costs of accessing the Texas coast from out-of-state in comparison to fishing in their home states, Texas does not attract charter-fishing parties from out of state. Perhaps due to its National Marine Sanctuary status and national significance as a dive site, a higher percent (26%) of FGBNMS divers were attracted from out of state and made expenditures in Texas. Only 19% of artificial reef divers in Texas were from out-of-state, suggesting less draw power for artificial reefs than for one of the thirteen National Marine Sanctuaries. As divers around the U.S. and elsewhere in the world learn about the FGBNMS and the nature of the diving experience there, the percent of out-of-state divers should increase and with it, additional economic impacts at the state level and community level.

Future research needs to focus in a number of areas. First, we chose not to include private-boat sport divers in the study because there was no reliable way to

identify a list of private boats in Texas used one or more times in the previous 12 months for offshore diving purposes. Even if we had been able to do so, it is unclear to what extent their use would have contributed to state level economic impacts (new money to the state of Texas). Unless private boats were being operated inappropriately as dive charter boats, we would have expected them to carry mainly state residents. Second, we need to better understand the use and non-use benefits associated with the FGBNMS. This involves knowing how much sport divers value the opportunity to use the FGBNMS above dive trip costs and how much the public values the existence of the FGBNMS and the option to use it one day for diving purposes. These economic valuation methodologies are well-established (Edwards 1990; Loomis and Swanson 1996; Loomis and Walsh 1997) and need to be applied at the FGBNMS so the value of the sanctuary is well understood among other marine resources and uses.

This paper presents a social science approach and methodology that is readily transferable elsewhere. However, there are particular challenges that need to be overcome first, such as developing a sampling frame or list of divers using a particular resource, achieving the confidence and full cooperation of dive charter boat operators, and building support among the diver community to respond to the survey. Results should be useful to dive site managers in that they will have a better understanding of local and regional stakeholders and how their interests may be affected by policy-making efforts. Likewise, they should also be useful to local communities and their leaders for better understanding how their economy is tied to a marine protected area. As communities evolve from consumptive and utilitarian activities to appreciative and non-consumptive activities, economic impact results can help communities to see which are sustainable and in their best long term interests.

ACKNOWLEDGEMENTS

We appreciate the financial support of the Texas Parks and Wildlife Department; they fully supported the costs of the 1997 Texas Sport Diver Survey, which focused on all diving activity in Texas offshore waters accessed by dive charter boats. In particular, we want to recognize Hal Osburn, Director of the Texas Artificial Reef Program at the time, for his foresight in allowing us to design this study beyond their particular interest in artificial reefs. We also appreciate the support of the NOAA Flower Garden Banks National Marine Sanctuary, which enabled this focus on study results of interest to the FGBNMS. Without the cooperation and assistance provided by Gary Rinn, this paper would not have been written. Additionally, Troy Baker deserves special recognition for his efforts to coordinate and carry out the sport diver survey "against all odds".

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The TCI Experience:
Pros and Cons of Developing Eco-tourism Related Activities

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ABSTRACT

Trail systems and programs have been developed in the Turks and Caicos Islands (TCI) to augment and entice eco-tourism related activities. The Little Water Cay Rock Iguana Trail Program was the first such endeavor, developed in 1996 to aid in the protection of the endangered TCI rock iguana, *Cyclura carinata*. Two underwater snorkel trails (Smith's Reef and Bight Reef) were developed in 1997 in an effort to help protect nearshore reefs and in 1998, the Middle Caicos Eco-tourism Project was initiated with the development of the historical Crossing Place Trail. An experiential review of the mechanisms for the development, design, funding and implementation of these programs are discussed, as well as the pros and cons experienced while undertaking each of these endeavors.

KEY WORDS: Turks and Caicos Islands, eco-tourism projects

INTRODUCTION

The standard set by the Ecotourism Society describes eco-tourism as "responsible travel that conserves natural environments and sustains the well-being of the local people" (Kalosh 1993). The parameters that define eco-tourism are directly linked to the reasons for initiating environmentally related activities. Overall, the basic eco-tourism concepts are either one or a combination of the following aspects:

i) A management tool to help protect and preserve the environment;
ii) Promotion of the ecological facets of a tourist destination;
iii) Increasing visitor and local environmental awareness;
iv) Increasing the economic gain of the tourism industry through sustainable use of the natural environment
v) Spreading the tourism dollar to areas other than the main commercial districts utilizing the natural environment as the attraction.

Ultimately, every project must ensure the continued sustainable use of the environment, otherwise, there will be no further eco-tourism activity. It is here that most programs incorporating nature fall short.

The next step is to define what makes a particular eco-tourism project a success. In simplified terms, a successful project is one that manages to keep the environment in tact and keeps the tourists coming year after year. But accomplishing those goals are not so simple or straight forward. As there are many components to developing

programs of this nature, it is important to evaluate the effectiveness of each individual item in perpetuating the overall goals.

The Turks and Caicos have developed several nature trail projects that are currently marketed as part of their eco-tourism trade. Of these, this paper will examine three of the projects using a case study approach. The evaluations will include the details of developing the TCI trail systems and highlighting the pros and pitfalls experienced along the way. In this manner, it is hoped that others may garner pertinent information from these experiences that will help them to develop their own successful eco-tourism programs.

RESULTS

The three nature trail programs described in the following text are all projects initiated through the Turks and Caicos National Trust (TCNT). The Department of Environmental and Coastal Resources (DECR) has also lent support for these projects within the governmental framework, with funding contributions coming from both external and local resources. The author of this paper acted as the TCNT Project Coordinator for the following projects and was involved in all aspects of the projects from proposal preparation, design and implementation, and initial project management and maintenance.

The following is a brief background and summary of the individual programs, with the pros and pitfalls noted for each. Included in each case study are the following aspects of the development process: funding sources, reasons for design specifics, types of interpretive elements utilized, marketing techniques, maintenance needs, forms of income generation, training programs and/or environmental education aspects.

The Little Water Cay Rock Iguana Nature Trail Program

Background — The Little Water Cay Rock Iguana Nature Trail Program was the first eco-tourism project initiated through the Turks and Caicos National Trust. Little Water Cay (LWC) is a small island adjacent to the east side of Providenciales and is inhabited by a healthy population of the endangered rock iguana, *Cyclura carinata*. For many years, residents and visitors have visited the nearby cay for picnics and the experience of seeing the rock iguanas. As tourism began to grow on Providenciales, visits to LWC became more frequent and the associated impacts increased. Most disconcerting was the destruction of the burrows and nesting areas of the rock iguanas as visitors tread over the dunes and burrowing areas and began to explore the interiors of the cay. A second problem was the inappropriate feeding of the animals, causing possible illness and the disruption of their role within the food chain. Harassment of the docile creatures also became more frequent, especially from residents bringing their animals to the cay.

In 1995, a solution was proposed by the Turks and Caicos National Trust (TCNT) and the Department of Environmental and Coastal Resources (DECR).

Proposals were written to seek funds for the development of a multi-faceted nature trail program. Outside funding was secured through the RARE Center for Tropical Conservation and matching funds from the MacArthur Foundation. Once funding was secured, two boardwalk nature trails were developed on the island in the areas most accessed by humans. The boardwalks would keep visitors from crushing burrows and nesting sites, while localizing impact to the given areas. Interpretive elements would help to educate the visitors, complete with "iguana etiquette", on why and how they could help protect the endangered iguanas. This was followed by training sessions for the water sports operators in their role as self-policing wardens of the cay.

Brochures about the cay were produced to enhance the educational component as well as act as a marketing aid. Magazine articles and press releases were also written (Pardee Woodring 1996). Posters were made for marketing and placed in the airports, at all tour desks, and at water sports operators outlets. An income generation mechanism was initiated that would raise funds for the maintenance and upkeep of the cay facilities. An iguana button was produced, which acted as the ticket for accounting purposes and also as a souvenir in exchange for the tourists' $3 fee. Any excess income not used to operate and maintain the cay was transferred into a conservation fund controlled by the water sports operators and the National Trust to initiate other projects of this nature.

Pros and Pitfalls — A large bonus to the LWC Nature Trail Program was the initiation of the RARE funded Environmental Education Project that focused specifically on the endangered rock iguana. Through this program, residents and locals of all ages throughout the islands were made aware of the country's own special endemic endangered species. This program helped to set the stage for island wide acceptance and pride in the newly developed Little Water Cay Nature Trail Program.

Albeit, the biggest hurdle to overcome with the development of the LCW Nature Trail Program was the user conflicts and acceptance by the people that made money running tours to the cay. Many of the water sports operators felt their freedom to use the island for tours was being taken away from them, and they were opposed to their visitors having to pay a fee. Many meetings and training sessions were held prior to the opening, and eventually the operators agreed to cooperate with the project. Operators were promised that funds collected above and beyond program maintenance fees would be held in a separate account for use on other conservation projects of their choosing. A special committee was formed through the local Watersports Association that would vote on the appropriation of those funds.

Once opened, the new trail system did prove beneficial to the operators despite their initial opposition. Tours increased to the cay, and the tourists were quite pleased with the trail system. As of March, 1999, the trails were grossing over $50,000 dollars per year, with approximately 17,000 tourists visiting the cay (Pardee Woodring 1999). Excess funds have been used to hire an iguana specialist for

additional monitoring LWC, to put in mooring buoys on dive and snorkel sites, to lend support to the Underwater Snorkel Trails and Middle Caicos Project, and to finance numerous other small conservation related projects.

The author of this paper relinquished the management role in 1999 and therefore cannot report fully on the progress of the program since that time. A number of changes have occurred over the past two years, including posting a warden on the cay for periodic policing and checking for payment of user fees. Prior to this, the cay was self policed by the operators who went there. In 1999, there was a change in the structure of the LWC committee that decided on fund allocations, limiting the power of the operators in controlling those funds and their involvement in the project. Local sentiment suggests that with this reduction in involvement, the operators have lost some of their interest and have reduced their efforts to comply.

Feeding iguanas has also been a problem from the outset, and initially specifically formulated food was purchased for the operators that felt their guests still needed to feed the iguanas. Eventually many operators gave up on the prepared feed and discontinued feeding practices completely. Unfortunately, several operators continue to feed less appropriate items, but the incidents are far less frequent.

Tidal surge and winter storms are also a problem for the trails, but the boardwalks were designed to be removable and built in small 4ft manageable sections. If the shoreline begins to wash away, the sections can be removed in those areas. When sand accretes through tidal surge, the boardwalk is easily jacked up again with the use of a few strong boards. Otherwise, maintenance to the trail system is minimal.

Aside from the small problems and growing pains that every project suffers, the Little Water Cay Nature Trail Program has made a huge mark for eco-tourism in the Turks and Caicos Islands. In 1998, the program received a Finalist position in the Islands Magazine Eco-tourism Awards. This accomplishment alone has put the TCI on the map in terms of those searching for eco-tourism destinations.

The Smith and Bight Reef Underwater Snorkel Trails

Background — The second eco-tourism project was in fact inspired by the same water sports operators who helped develop LWC, due to their concern of the apparent demise of two near-shore snorkeling reefs. Smith's Reef and Bight Reef are both located along the north coast of Providenciales and are accessible from the shore. The increase in tourism was escalating the level of impacts to the reefs at a rapid rate. Unlike the offshore reefs where water sports operators have the chance of educating and policing visitors on the rules of reef etiquette, beachgoers to these reefs were on their own. It was decided that snorkel trails would be placed around both reefs. The purposes of the trails were two-fold: to lead snorkelers along a path of sufficient water depth where they could not easily damage the corals or themselves (which would also tend to localize the area of impact), and to educate the snorkelers through interpretive information given on the trail markers and beach

signs.

A unique design was decided for the underwater trail markers. The base of the trail marker is a LoPro size ReefBall™ that will eventually become part of the living reef. The marker portion is a handmade tile with original artwork and information embedded into the glazed surface. These individual artworks were then sold to increase local community awareness in the project with the names of the donor or donor agency embedded into the tile for deployment on the underwater sites. Meetings were held with all operators that frequented the reefs to advise them of the new system and ask for their assistance in helping to police the areas.

As it was deemed impossible to set up an income generating mechanism directly from day to day users of the trails, alternative methods were offered. Colorful laminated trail cards with educational information included were produced for sale through the tour desks and water sports operators. A complimentary courtesy card was also developed for the hotels, to be placed in the individual rooms. The card consisted of an underwater scene on front with drawings pictographically representing the "NOs" of reef etiquette for international interpretation. No marketing was deemed necessary to attract visitor's to the trails, but magazine articles were published to advise snorkelers of the reef trails and their role in helping to preserve the environment (Pardee Woodring 1997).

Pros and Pitfalls — The Underwater Snorkel Trail Project has overall, been very well received by all that enter the waters off Providenciales. The community interest and assistance with initial funding needs and subsequent maintenance has been positive for the trails. International interest has been shown through several news releases in other countries.

Maintenance of the trails has been from voluntary sources since their completion in 1997, with bimonthly cleaning of the tiles and checks on general conditions. To date, these voluntary efforts have been for the most part sufficient in keeping the trail markers maintained.

Thus far, no storms have managed to wreak havoc with the underwater mounts or markers. Their weight, design, and additional screw anchor and cabling has kept them in place. Some scouring around the bases has occurred, but they are easily repositioned with the aid of divers. Only two tiles have been broken to date. The first was attached to a buoy that was obviously used as a mooring by mistake. Since that time, less resistant markers, such as plastic bottles are used for marking outer boundaries, and they are attached to separate screw anchors. The second tile broken was located in shallow waters and likely used to stand upon or bumped by a passing boat.

Coral growth on the trail mounts has been slow, but at least three species of corals are now apparent with a fair coating of primary algal species and other encrusting organisms. This is to be expected in the highly oligotrophic waters in this area.

Unfortunately, the funding mechanisms devised to assist with maintenance have not been fully utilized nor have the recipient funds been returned to assist in this

maintenance. Fortunately, there have been little need to maintain the project as is, and those needs have been covered by volunteer services and donations.

The biggest pitfall of the project is that no continuous monitoring system has been put in place to monitor the health of the corals on the reefs, nor the effect of the trails as an aid in reducing the impacts. Observations suggest that people tend to follow the trail markers and that some are obviously absorbing the interpretive information on the markers and beach signs.

Additional impact control has been added to Bight Reef in the form of roping off the interior shallow reef sections. An artificial reef program has been initiated as well that should further dilute impact by providing another nearshore reef site. Proposals have now been submitted for monitoring the reefs and obtaining user impact information.

The Middle Caicos Eco-tourism Project

Background—The Middle Caicos Eco-tourism Project began with the resurrection of the Crossing Place Trail, a historical trail that leads along the coast of Middle Caicos to a "crossing place" between the islands of Middle and North Caicos. Aside from reinstating one historical aspect of the islands culture, the trail provides easier, yet limited, access to some of the impressive natural surroundings. By instituting the official trail site, coastal access for this area is guaranteed as development begins to escalate. Economic gain to the local island economy through guided tours, meals, taxis, local crafts, and other services are further benefits to the project.

A portion of the trail is suitable for hiking only, while another segment can be accessed with bicycles. There are plenty of snorkel sites along the way and magnificent views from many stops. Two caves are included on or near the trail with ruins from the Loyalist era scattered about. Flora and fauna abound on this barely developed island.

Interpretive signs include large scale artistically drawn maps at the beginning of each trail section as well as maps and interpretive information for the cave sites. Handmade "cameo" tile trail markers mark the way, with directional signs at key points. Brochures have been produced with information on Middle Caicos and contact numbers. Magazine articles were written to aid in marketing (Pardee Woodring 1998). A marketing booklet filled with color photos and text describing the highlights of the island and trail was produced and given to all tour operators and in some cases, villa rental agencies. Keychains with the MC Cameo logo are sold at local craft outlets and to those visiting the island to help with trail maintenance fees.

All aspects of design, construction, and implementing stages of the project included interviews, participation and assistance from many of the elders of the community. The official opening of the Crossing Place Trail took place in December 1998, with cultural shows, crafts, and foods sold by the local community, and other proceeds going to the augment the trail program.

Pros and Pitfalls — In terms of local support, acceptance, and pride in the project, the Middle Caicos Eco-tourism Program is a prime example of a how a community can work together to make the project unique. Since the opening of the Crossing Place Trail, there has been a resurgence in local interest for Middle Caicos and their local handicrafts.

Outside eco-tourism has increased at an island style pace. The biggest pitfall in the process is access to Middle Caicos and the cost of doing so. The water sports operators do run excursions to Middle Caicos but the roundtrip ride is sometimes a grueling 2.5 hours in rough weather, and the boats are limited in time by the receding tides. Plane services, although the best option for extending the day, are not guaranteed to run daily, and special charters have to be arranged. Either way, the cost per person per day is minimally at a rate of $130. Many tourists ensconced in all inclusive resorts are not willing to spend that amount for a tour, regardless of its eco-tourism appeal.

Another problem with the trail portion of the program is the limited funds available for maintenance. The five-mile hiking portion of the trail has to be brush-cut seasonally for upkeep. A private donor guaranteed initial funds for the first few years of operation as the program took hold, but few funds are left now for continued maintenance. The ticketing mechanism has not been fully utilized, and the limited tours that have paid are not enough to maintain the trails and interpretive elements. Again, voluntary services have been required to keep the trail in operation.

DISCUSSION

Overall lessons learned while developing the three nature trail projects are compiled below. The key points have been categorized by the various aspects involved in project development.

Funding Sources

For large budgeted projects, it is often necessary to seek regional or international funding, particularly in small island nations. Securing outside funding can not only help to market the program internationally, but also establishes a good "credit rating" with other funding agencies and the potential for future assistance. Utilizing local sources for funding helps to build community involvement and awareness and is well worth the effort it takes to do so as it often results in continued moral and financial support.

Design and Construction

The infrastructure design and construction of a particular nature trail project depends upon several factors beyond the physical and biological characteristics of the site and conservation needs. One must consider the number of visitors expected, their levels of physical ability, safety and health precautions, waste disposal, accessibility to transport, security, food and water, time allocations, and trail

guidance needs to name just a few. Seasonal climatic conditions, tides if located near water, and pests such as mosquitos or more lethal organisms should all be addressed when designing the project.

Lo-tech construction, use of locally found durable materials, and low visibility structures that blend with the environment are preferable for all the right reasons, i.e. typically lower costs and less maintenance. Any cultural features or representations of native culture should be utilized to highlight more unique qualities. Employment opportunities and interviews with as many local counterparts as possible will help to create local vested interest, acceptability and pride in the project.

Interpretive Elements

Interpretive elements are often the defining features that make the individual project stand out from all other trail programs. It is here that the opportunity lies to relate to visitors what is unique not only about the particular environment, but the efforts of the Turks and Caicos government and citizens to protect it. Typically, the role of interpretive elements is to relate environmental information, but is often coupled with protective measures needed to help conserve the environment. To be successful, the interpretive information must be presented in a way that catches not only the eye, but the mind and memory of the visitor.

Income Generation

Income generation is important for ongoing maintenance and operations. If a user fee is used, the ticketing mechanisms should be simplified as much as possible in terms of how to collect and disperse the tickets and funds. Instituting a ticket form that also acts as a souvenir gives visitors an added bonus to their fee, one that serves to remind them of their special eco-tour. This mechanism can also help to promote the program as other potential tourists inquire about the souvenir. Be prepared to work with the tour operators and desks to assist them in getting the fee mechanism in place and functioning to their benefit as well as the programs.

Marketing

The eco-tourism marketing program needs to extend from local, to national and international levels. The most difficult problem in local marketing is that tourists are new every week, and the marketing devises chosen must be continuously supplied and updated. Assistance on the international level is usually available through the government's Tourism Board. Posters, magazine articles, press releases, and advertisements in marketing booklets or road maps are good tools in spreading information. Apply for international recognition of your projects through the many eco-tourism awards offered.

Training and Environmental Education

Training and environmental education programs need to extend not only to the tour guides and trail guides, but to taxi drivers, water sports operators, tour desks, travel agents, hotel management, and any other persons directly or indirectly related

to the project. Instituting environmental awareness programs in schools and other community arenas will help to further the pride and preservation of the project.

CONCLUSION

In all three case studies, the biggest problem has been one of continuity. Almost all projects start off with a bang and then slowly dwindle into obscurity. As that happens, enthusiasm tapers off, upkeep of the environment becomes less of a priority, program maintenance suffers, and local pride and support abate. Of all the lessons learned from the three TCI nature trail projects, the following key factors have been deemed the most important in developing successful eco-tourism programs.

Continuous Protection and Preservation of the Environment

Without the environment, there is no opportunity for eco-tourism activities. Protecting and preserving the environment that is chosen for the eco-tourism activity involves careful consideration when designing the project, and monitoring during construction and operation phases to ensure that the surrounding environment sustains minimal impacts. Interpretive elements are also important as educational components that inform visitors of how to assist in preserving the environment. Through training and environmental awareness programs, residents will also learn an appreciation and awe for their local environment, furthering the preservation efforts.

Continuous Local Acceptance, Involvement and Support

The increased attraction of tourist through eco-tourism programs can offer opportunity to many people throughout the community, whether it be taxi drivers, boat operators, tour desks, local craftsmen, hotel and restaurants, or rental villas to name just a few. Although outside marketing is important in initially getting tourists to a destination, it is the local support and acceptance of the project that is key to the program's continuing success. If a sense of pride for the project can be manifested throughout the community, this sentiment will be reflected in numerous ways to the tourists. The local community will be the force that makes the eco-tourism activity a truly special experience. In metaphorical terms, the environment you wish to preserve and protect may be the heart of the matter, yet the soul comes from the people who embrace it.

How does a project succeed in garnering this local support? By involving as many people in the community as possible in all the different phases of project development and ongoing operations. Some examples used in the TCI projects include holding community meetings about the project, getting funding or service donations, employment opportunities, utilization of local artisans and craftsmen, training and education programs for all ages, and establishing working groups or committees involved in the disbursement of funds or other activities. Their involvement will constitute an investment of sorts, one in which they will have

vested interest in seeing the program become and remain successful.

Continuous Maintenance

Maintenance typically refers to just the physical maintenance of whatever type of trail is constructed. Although important, the physical structures are only a small portion of the overall program that needs to be maintained. Other facets include interpretive and marketing elements, training and education programs, administration / accounting, and public forums for continued community involvement. Continual maintenance of all these facets will result in the continued promotion of the program.

Beyond the physical facilities, a few examples for continued maintenance include interpretive elements that must be updated for changes and in the case of brochures and handouts redistributed on a regular basis. Marketing elements require the same, and time must be spent maintaining good relations with the travel agents and writers, tour operators and tourism desks, and any other persons related to the enterprise of the project. Training and local education programs need to run continually to ensure the ongoing enthusiasm of local counterparts. Keeping up with administration and accounting if working a fee paying trail can be key to determining the highs and lows of the project and to prepare financially for upcoming needs. This information needs to be reported to the community and local user groups to keep them in contact and a part of your project.

How does a project succeed in providing ongoing maintenance? It is accomplished primarily through some form of income generation which supplies the needed funds to a) hire staff to coordinate and keep up with ongoing needs and b) supply the finances for the material aspects. Income generation does not necessarily have to be in the form of a user fee, but does require some consideration in terms of creating a fairly constant cash flow of funds for maintenance. Even if the project is fairly simple and easily maintained in the beginning, long term wear and tear will eventually require funds for replacement of physical or material implements. Voluntary services should only be considered a bonus to any project, and volunteers do require a certain amount of coordination and appreciation for their roles.

In summary, continuity is the key to an ongoing successful eco-tourism operation. Developing the program is only the first step. Continued protection and preservation of the environment, continued local support, and ongoing program maintenance are the real challenges of any successful eco-tourism operation. Keep those facets in tact and the tourists will come back.

ACKNOWLEDGEMENTS

The author would like to acknowledge the Turks and Caicos National Trust, Department of Environmental and Coastal Resources and all those who have contributed financially, provided voluntary services or given local support during the development of the TCI Nature Trail Programs. Special thanks to my colleagues in the Island Group, Kathleen Wood (terrestrial consultant), Barbara Young (graphics specialist) and Pamela Leach (artist) for their contributions to the success

of the programs.

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Red Snapper (*Lutjanus campechanus*) Diet in the North-Central Gulf of Mexico on Alabama Artificial Reefs

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ABSTRACT

Red Snapper, *Lutjanus campechanus*, is a highly exploited reef fish in the Gulf of Mexico (Gulf) that occupies both natural hard-bottom and artificial habitats. Despite its importance, little is known about its feeding habits. Toward this end, we examined the size-specific diet of red snapper collected for stomach content analysis from artificial reefs in the north-central Gulf off Alabama between May 1999 - April 2000. Thirty-nine to 86 stomachs per month were removed and prey items were identified to the lowest possible taxonomic level. The relative contribution of prey items was determined using percent composition by weight, percent composition by number, percent frequency of occurrence, and index of relative importance (IRI). Results suggest that snapper are feeding on organisms not associated with reefs, such as mantis shrimp and portunid crabs. Diet changes seasonally, with crabs being most important (38% and 43% by IRI) in summer and fall, while mantis shrimp dominate in winter (42% IRI). Pelagic zooplankton was the greatest by percent weight in the diet in spring (60% IRI). Fish also contribute to each season, but they are not the principal prey items in any season (28% - 30% IRI). These diet data ultimately will be used in combination with a bioenergetics model to estimate prey demand of snapper on Alabama artificial reefs.

KEY WORDS: Artificial reefs, diet analysis, *Lutjanus campechanus*

INTRODUCTION

Red snapper, *Lutjanus campechanus*, is a highly exploited finfish in the Gulf of Mexico (Gulf). It has been harvested both commercially and recreationally since the late 1800s (Moseley 1966, Goodyear 1995, Schirripa and Legault 1997). Thus, stocks declined throughout the Gulf until the early 1990s (Szedlmayer and Shipp 1994). Since then, regulations enacted by the National Marine Fisheries Service, including size and bag limits and total allowable catches, have led to some recovery of the stock (Schirripa and Legault 1997, Patterson 1999).

This recovery also has been attributed in part to an increase in structure in the form of artificial reefs and oil and gas platforms. The Alabama shelf has the largest artificial reef program in the nation with over 4000 km^2 of reef permit area (Shipp

1999). Perhaps as many as 20,000 artificial reefs have been deployed in the permitted areas off the Alabama coast (Patterson 1999); these structures support red snapper and other reef associated species. However, the role that artificial reefs play in trophic dynamics is largely unknown; some have suggested that they may actually be energy sinks (Bortone 1998).

In addition, there has been a growing recognition that interacting species, such as those found on artificial reefs, cannot be managed individually. This idea has led to the development of multispecies ecosystem models, which has generated the need for more information about the food consumed by the communities of reef fish (Munro 1987). This study examines the role that artificial reefs may play in red snapper trophic dynamics, focusing on seasonal changes in diet.

METHODS

Red snapper were collected by hook and line from artificial reefs in the northern Gulf off the coast of Alabama between May 1999 and April 2000. Most fish were caught by recreational fishermen in the Hugh Swingle General Permit Area. However, some were collected in July 1999 and 2000 from local fishing tournaments. Knowing that red snapper are prone to regurgitation (Parrish 1987), approximately 39 to 86 fish were collected per month to ensure a significant number of fish with full stomachs. All snapper were weighed to the nearest 0.01 kg, and their total length (TL) and fork length (FL) determined to the nearest mm before their stomachs were removed. Stomachs were severed at the esophagus and duodenum below the pyloric sphincter, slit to allow complete preservation, and then preserved in 10% formalin for at least 48 hours. They then were transferred to 70% isopropyl alcohol until they could be sorted. Preserved stomachs were opened and contents removed and sorted to the lowest possible taxonomic level. Prey items were then weighed by taxon to the nearest 0.01g.

The relative contribution of each of several prey categories was determined using four methods:

i) Percent composition by weight,
ii) Percent composition by number,
iii) Percent frequency of occurrence, and
iv) Index of relative importance.

The index of relative importance (IRI) was calculated as: IRI = (%N +%W) x %FO, where N = number, V = volume, and FO = frequency of occurrence (Pinkas 1971, modified by Hacunda 1981). Percent IRI (% IRI) also was calculated by dividing the IRI value for each prey category by the sum of the IRI values and multiplying by 100. These indices were used to describe overall diet, as well as to evaluate diet on a seasonal basis (summer = June, July, and August; fall = September, October, November; winter = December, January, February; and spring = March, April, and May). The identifiable contents of all stomachs combined were divided into six major prey categories: fish; crabs; adult mantis shrimp; penaeid shrimp; squid; and, 'others'. The 'other' category was further subdivided into

pelagic zooplankton and demersal/benthic associated species, with the exception of larval fish, which were included in the fish category and crab megalopae and zoea, which were included in the crab category. The diet also consisted of an 'unidentified' category, however it was not included in all of the analyses because IRI cannot be determined for this category.

To further analyze the diet data, the PRIMER statistical package (Clarke and Gorley 2001) was used to calculate Bray-Curtis similarity coefficents, which then were used to assess the extent of similarity between the weight proportions of the prey items for each red snapper stomach with prey. The non-parametric permutation procedure ANOSIM (Analysis of Similarities, PRIMER) (Clarke and Warwick 1994) was used to test for significant differences between seasons. Which prey categories that most contributed to the observed differences between season were elucidated with BVSTEP, a stepwise procedure that attempts to determine influential species "whose among sample relationships capture nearly the same multivariate pattern as the full species set" (Clarke and Gorley 2001). SIMPER (Similarity Percentages, PRIMER), a multivariate multiple permutations test was used to examine the contribution a prey group made to the average within group similarity and between group dissimilarity. Descriptive indices then were used to further examine the SIMPER results by breaking down three of the major categories (i.e. fish, crab, and pelagic zooplankton) further, to examine the specific species that contributed to the observed trends (Table 1).

RESULTS

Stomach contents of 656 red snapper ranging from 207 to 913mm FL were examined. Of these, 268 stomachs contained identifiable prey (40.8%), 262 were empty (39.9%), 63 contained only bait (9.6%), and 63 contained only unidentifiable prey (9.6%).

The 'unidentified' prey category made up the largest proportion of the diet by %W. After exclusion of the unidentified category, fish, pelagic zooplankton, and crab were the principal components of red snapper diet when all stomachs were combined (Figure 1). However, no single group was largest by all indices. Pelagic zooplankton dominated by % FO (39.3%) and % N (30.2%), whereas fish dominated by % IRI (30.9%) and % W (28.7%). Unidentified fish, larval fish, fish of the families Ophicthidae (shrimp eels), and Triglidae (sea robins) contributed largely to the fish portion of the diet, whereas crabs of the family Portunidae and unidentified crabs were important in the crab category. Pelagic zooplankton consisted primarily of larval mantis shrimp, amphipods, and pteropods (*Cavolinia* sp.).

Table 1. Three major diet categories broken down into their component species for each season using percent weight for 300 - 499mm FL fish only.

Prey Type	Percent by Weight in Season Encountered			
	Summer	Fall	Winter	Spring
Fish				
Unidentified fish	50.0	30.8	53.8	44.5
Ophicthids	12.5	0	23.1	4.8
Syngnathids	0	0	0	4.8
Pinfish	0	0	0	0
Anchovy	6.2	0	0	0
Sea robin	0	30.8	0	0
Scad	0	0	0	0
Cusk eel	0	0	7.7	3.0
Haemulids	0	7.6	0	0
Fish larvae	31.3	30.8	15.4	42.9
Pelagic zooplankton				
Larval mantis shrmp	67.6	45.7	85.6	29.5
Amphipods	6.1	25.1	0.1	55.4
Pteropods	21.1	0	0	13.7
Isopods	5.2	0	0	0
Sergestid shrmp	0	1.0	0	0.6
Mollusk larvae	0	25.7	0	0
Chaetognath	0	2.4	0	0.1
Copeopods	0	0.1	0	0
Euphausids	0	0	14.3	0
Mysids	0	0	0	0.3
Palaemonidae	0	0	0	0.4
Crabs				
Unidentified crabs	80.0	29.4	30.5	64.3
Portunids	20.0	58.8	49.3	14.3
Calappids	0	5.9	0.7	0
Parthenopids	0	0	19.5	0
Crab mega. and zoea	0	5.9	0	21.4

An examination of gut contents by season for all stomachs (%W) indicates that while fish was present in red snapper diet in all seasons (comprising between 25 - 34%W), it did not contribute the greatest amount by weight in any season (Figure 2). The diet in summer and fall was comprised predominately of crabs (31.4%W in summer and 36.3%W in fall). Winter diet was comprised predominately of adult mantis shrimp (33.3%W) and spring of pelagic zooplankton (39.1% W). Demersal crustaceans (crabs and adult mantis shrimp) were present in all seasons, comprising approximately 50% by weight of the diet in summer, fall, and winter. During the spring, red snapper fed on high numbers of pelagic zooplankton, which were present at some level in all seasons. However, the numbers of pelagic zooplankton consumed appeared to be inversely related to numbers of demersal crustaceans eaten by red snapper.

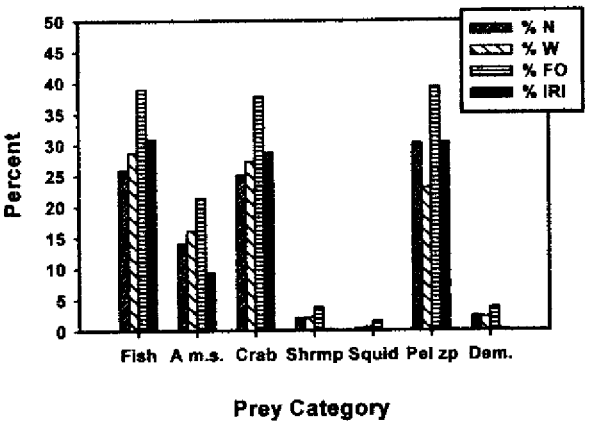


Figure 1. Indices of diet composition for all stomachs (N=268). (A.m.s. = adult mantis shrimp, Pel. zp. = pelagic zooplankton, and Dem. = demersal species)

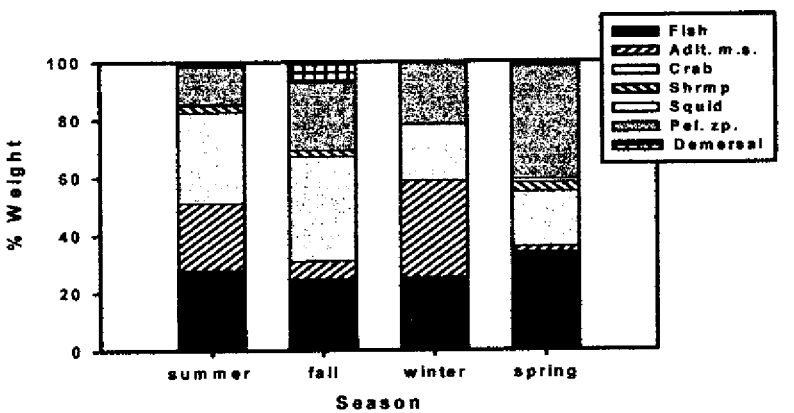


Figure 2. All stomachs (includes fish of all sizes) broken down by season by % weight (N = 268). (Adlt. m.s. = adult mantis shrimp and pel. zp. = pelagic zooplankton)

Because red snapper > 600mm FL were collected almost exclusively in summer and fish 200 - 299mm FL were primarily collected in fall and winter, we were concerned that the results described above may be confounded by red snapper size effects. To eliminate this concern, we reanalyzed the seasonal data using fish only between 300 - 499mm FL, as sufficient numbers of fish in this size range (N = 452) were collected in all seasons. Results based upon the descriptive indices for the 300 - 499mm size group were similar to results pooled over all sizes. For this sub-set, diet was comprised primarily of pelagic zooplankton according to all 4 indices (%N, %W, %FO, % IRI). The next most important diet item was fish, then crabs, followed closely by adult mantis shrimp. Compared to the larger data set pelagic zooplankton (27% W) and adult mantis shrimp (18% W) made up a larger portion of the diet. Fish again were present in all seasons, comprising between 24.5 - 31.8% by weight of red snapper diet (Figure 3). Demersal crustaceans, such as crabs and adult mantis shrimp comprised between 44% and 54% of the diet of 300 - 499 mm FL red snapper in summer, fall, and winter and, as previously noted, when demersal species decreased, they were replaced by pelagic zooplankton. However, in the data subset, adult mantis shrimp contributed the most by weight in summer (33% W) and winter (34.4%), while crabs still contributed the most in fall (37% W) and pelagic zooplankton in spring (39% W).

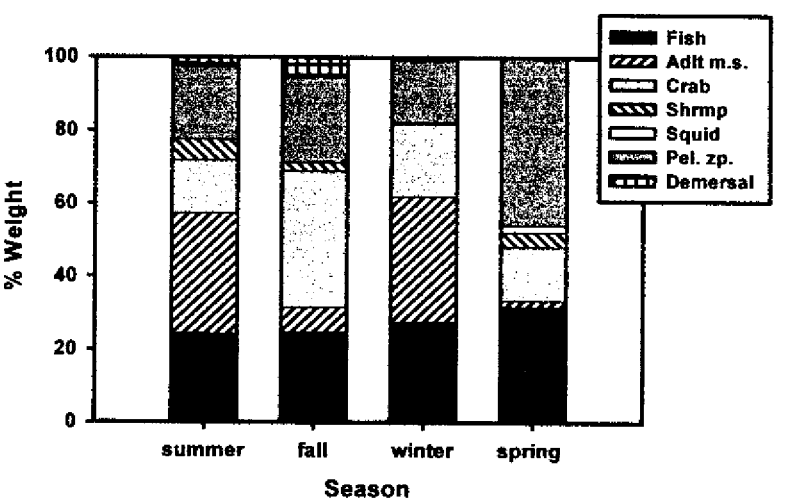


Figure 3. The 300-499mm FL fish broken down by season by % weight (N=172) (Adlt. m.s. = adult mantis shrimp and Pel. zp. = pelagic zooplankton

With seven prey categories (fish, adult mantis shrimp, crab, shrimp, squid, pelagic zooplankton, and demersal/benthic associated species) included in the test for significance for the 300 - 499mm snapper, ANOSIM found a significant difference between the weight proportion data for season ($P = 0.001$). Examination of the BVSTEP results reveal that these differences appear to be attributable to four influential prey types: fish, crab, adult mantis shrimp, and pelagic zooplankton. There was a 99.5% correlation between these four variables and the overall pattern in the samples. SIMPER results reveal the degree to which these four prey types contributed in different seasons (Table 2). All four categories contributed to within winter similarity, however only two or three of the prey types contributed within the other seasons. In winter, adult mantis shrimp contributed the most (45.6%) to within group similarity, followed by fish, crab, and pelagic zooplankton. In summer, adult mantis shrimp also contributed significantly (46.9%) to within season similarity, followed by fish and pelagic zooplankton. In fall, crab contributed the most to within season similarity (54.0%) followed by fish and pelagic zooplankton. Spring was typified by pelagic zooplankton and fish, with pelagic zooplankton contributing over 63% to within season similarity.

Table 2. SIMPER results of species contributions to within season similarity

Season	Species	Avg. Similarity	% Contribution	% Cum. Contribution
Summer		24.70		
	Adult mantis shrimp	10.43	46.91	46.91
	Fish	5.91	25.59	73.50
	Pelagic zooplnkton	3.76	16.91	90.41
Fall		24.94		
	Crab	13.47	54.02	54.02
	Fish	5.83	23.36	77.38
	Pelagic zooplnkton	5.13	20.58	97.97
Winter		24.70		
	Adult mantis shrimp	11.26	45.59	45.59
	Fish	7.25	29.34	74.93
	Crab	3.64	14.75	89.68
	Pelagic zooplnkton	2.55	10.32	100.0
Spring		33.17		
	Pelagic zooplnkton	20.97	63.21	63.21
	Fish	9.95	29.98	93.20

A pairwise comparison between each season revealed about the same amount of dissimilarity between each (75 - 81%), but with summer and fall diets being the most dissimilar, and winter and summer diets being the most similar (Table 3). Results further indicate that over 73% of the dissimilarity between summer and fall was contributed by crab and fish, thus they are good discriminating species for these two seasons. Winter and summer are the most similar seasons (least dissimilar) with adult mantis shrimp and fish contributing the most (81.7%) to their dissimilarity.

Table 3. SIMPER results of species contributions to between season dissimilarity (sm = summer, f = fall, w = winter, sp = spring)

Season	Species	Avg. Dis-similarity	% Contribution	% Cum. Contribution
w vs sm		75.13		
	Adlt mantis shrmp	22.31	26.69	26.69
	Fish	19.02	25.31	55.01
	Pelagic zooplktn	15.13	20.14	75.14
	Crab	14.26	18.97	94.12
sp vs f		75.30		
	Pelagic zooplktn	23.75	31.54	31.54
	Crab	20.48	27.19	58.73
	Fish	20.29	26.94	85.68
	Adlt mantis shrmp	4.15	5.51	91.19
w vs f		79.08		
	Crab	21.16	26.76	26.76
	Fish	19.22	24.31	51.07
	Adlt mantis shrmp	18.28	23.11	74.18
	Pelagic zooplktn	16.23	20.52	94.70
w vs sp		79.42		
	Pelagic zooplktn	23.58	29.69	29.69
	Fish	20.71	26.07	55.76
	Adlt mantis shrmp	17.47	21.99	77.76
	Crab	14.28	17.98	95.74
sp vs sm		79.44		
	Pelagic zooplktn	23.57	29.67	29.67
	Fish	20.09	25.29	54.96
	Adlt mantis shrmp	16.76	21.09	76.05
	Crab	12.31	15.49	91.54
sm vs f		81.04		
	Crab	20.47	25.26	25.26
	Fish	18.42	22.73	47.99
	Adlt mantis shrmp	17.64	21.77	69.76
	Pelagic zooplktn	16.97	20.93	90.69

Descriptive indices were used to further examine the SIMPER results for season, by first breaking down three of the major prey types, fish, pelagic zooplankton, and crab, into more specific prey types (Table 1). Thus, when these categories contributed to within season similarity, the specific species that contributed to the larger category can be ascertained. Fish contributed to every season's within season similarity, however the types of fish that made up this category changed seasonally. Unidentified fish was the largest category in every season (between 44.5-53.8% W), except fall where unidentified fish tied with larval fish and sea robins (all 30.7% W). Larval fish also were present in every season making up between 15.4-42.8% W. In winter, Ophicthids and cusk eels also were present. Ophicthids also contributed 12.5% by W to summer and 4.5% by W to the spring diet. Spring diet also included Syngnathids (4.7% W) and cusk eels (3.1% W).

Similarly, pelagic zooplankton also contributed to every season's within season similarity. In winter pelagic zooplankton was comprised of larval mantis shrimp (85.6% W) and euphausids (14.2% W). Larval mantis shrimp were prevalent in all seasons except spring (contributing between 45.7% - 85.6% W), which was comprised primarily of amphipods (55.4% W). Besides larval mantis shrimp, fall diet also consisted of mollusk larvae (25.6% W) and amphipods (25.1% W). In summer, pteropods, amphipods, and isopods also were observed in the diet. Crabs contributed to the within season similarity of winter and fall. In winter Portunids (49.3% W), unidentified crabs (30.5% W), and *Parthenope granulata* (19.5%) made up the crab category. Likewise in fall, the crab category was varied and was composed of Portunids (58.8% W), unidentified crabs (29.4% W), crab zooplankton (megalopae and zoea) (5.8% W), and Calappids (5.8% W).

DISCUSSION

The combined results show seasonal shifts in red snapper diet on Alabama artificial reefs. These findings are similar to most other studies of red snapper diet including another off Alabama (Bailey 1995) (Table 4). However, Bradley and Bryan (1974) found fish to be the largest category in fall, winter, and spring, but crabs contributed the most to the summer diet. In this study, fish were found in all seasons, but they were never the largest category by percent weight. Parrish (1987), in his literature review of snapper and grouper diet's stated that the principal food groups of snapper in most studies are fish and decapod crustaceans, which was consistent with the current study. Anguilliform fishes, like the Ophicthids that were found, were common and fairly abundant in the snapper diets he examined. Parrish found crabs were the second most abundant prey category, specifically with Portunid and Calappid crabs mentioned in several reports, and shrimps and other crustaceans (especially stomatopods) were the next largest diet category. He also stated that snappers often ate large plankton, which were an important part of the diet for some Lutjanid species he reviewed, specifically pteropods, which were found in our study to make up 13 - 21% W of the diet in spring and summer. Larval mantis shrimp, which were also found in the current study in large amounts in all seasons (highest in summer and winter) are thought to form large swarms in tropical waters (Morgan and Provenzano 1979). Randall (1967) found that they made up a considerable portion of the diet of reef fishes in the West Indies.

Many of the crustaceans we found in the diet are sand/mud inhabitants of the shelf. The Portunid crabs (swimming crabs such as *Portunus gibbesii*) as well as the mantis shrimp (*Squilla empusa*) inhabit mud or sand substrates (Williams 1984, Wenner and Wenner 1989, Manning and Heard 1997). Hildebrand (1954 cited in Williams 1984) found *S. empusa* to be the third most abundant crustacean in the Gulf of Mexico offshore trawl fishery only following *Penaeus* sp and *Callinectes* sp. On the Alabama shelf, *S. empusa* can be collected year-round from mud bottom areas, and are the most abundant stomatopod on the Alabama shelf (Aronson, pers. comm.). Rouse (1970) (cited in Williams 1984) stated that *P. gibbesii* was the most

often collected Portunid in the Gulf. Other of the Portunids found in the stomachs, such as *P. spinicarpus*, *P. ordwayii*, and *C. sapidus* were also cited by Williams (1984) as being found either on mud bottoms or a variety of bottoms, but not on reefs. Most of the crustaceans we found in the stomachs are associated with mud bottom and are abundant in the Gulf.

Table 4. Literature review of red snapper diet studies relevant to the present study.

Source	Location of study	Fish size	# stomachs examined (# w/ food)	Description of Results
Moseley 1966			712 (187)	
	Louisiana	juvenile	(28)	30% FO of crustaceans, another sample had 60% *Squilla* (night sample), unidentified fish made up 27% of this sample
		adult	(46)	44% fish in one sample, 80% fish and rest crustaceans in another
	Texas	juvenile	(45)	41% crustaceans in one sample, 89% crustaceans in another
		adult	(68)	Fish dominated the diet in all samples (40-69%), crustaceans were present in small numbers
Bradley and Bryan 1974	Texas	juvenile and sub-adult	575 (258)	Summer ate shrimp and crabs, spring and winter ate squid. Mantis shrimp made up portion of diet in summer, winter had most varied diet
		adult	1139 (190)	Primarily ate fish, but in fall and winter ate more crustaceans. In spring 13% of diet was tunicates. Summer had largest variety and winter the smallest variety
Bailey 1995	Alabama	330-691 mm TL	98	Principal prey items in summer were rock shrimp and crabs, also ate some eels and unid. fish
Lee 1998	Alabama	10-280mm SL	1652 (792)	Reef associated red snapper fed on reef assoc. species; fish (*Halichoeres* sp., *Serranus* sp. and *Centropristis* sp.) and shrimp (*Lysmata* sp. and *Synalpheus* sp.) and squid

The seasonal trends we observed differed slightly in the reduced (300 - 499mm FL) data set. Differences such as predominance by crabs in summer in the complete data set compared to more mantis shrimp in the smaller data set, were probably due to size differences of red snapper. For example, many of the red snapper > 600 mm FL collected in summer contained crabs, thus influencing the summer results. Otherwise results derived from the data sub-set were similar to all size-classes combined.

Red snapper foraging does not appear to be associated with the reef structure, and they may be gaining little nutritional support from the reef. Rather, red snapper diet was focused primarily on benthic organisms, such as Portunid crabs, adult mantis shrimp, Ophicthid fishes, sea robins, and cusk eels. These organisms are associated with mud or sand substrates, thus foraging is probably occurring more over the nearby bottom than over the reef itself. The prey species that are abundant on Alabama artificial reefs, such as tomtates, sea basses, and grunts (Andy Strelcheck, pers. comm.), were not found in the diets of red snapper in this study, although they did eat in smaller numbers some organisms that are associated with structure such as Syngnathids (pipe fish and sea horses) and pinfish. Starck (1968) also lists species that have an affinity to reefs, such as lizardfish, gobies, and wrasses, which would be expected in the diet, but these fish were not found in the stomachs of the red snapper we sampled. Thus, we infer that red snapper are selectively or preferentially feeding on non-reef habitat.

Other studies of red snapper diet describe foraging habits that support this claim. Moseley (1966), in a red snapper diet study off of Texas and Louisiana, found that red snapper do not always feed on reef associated species. He stated that "Based on food habits, there seems to be no particular reason why red snappers should congregate on reefs or rocky areas...". Parrish (1987) states that snapper probably remain within a few meters of the bottom because most of their prey needs to be captured from the substrate. He classifies *L. campechanus* as an intermediate depth feeder, which means they forage anywhere from relatively shallow water up to 100 meters. He states that such feeders probably forage widely from shelter over soft bottom to gain food, or either forage by "patrolling up to several meters off the bottom for nektonic prey as well as periodically foraging on substrate for fully benthic prey." Supporting this idea, this study found that snapper consumed some organisms that reside higher in the water column, such as larval mantis shrimp, fish larvae, amphipods, and pteropods, and other assorted pelagic zooplankton as well as mud associated species. Davis and Birdsong (1973) describe coral reefs and other "habitat interfaces" as rich in diversity saying they "represent 'cross roads' between foraging and refuge areas". Artificial reefs can be seen in much the same context, as snapper seem to supply their energetic demands from habitats other than reefs. It is still unclear if red snapper are simply leaving a reef to forage on nearby mud bottom, or if they are feeding during their transit between reefs, or both. In contrast, Lee (1998) found snapper over artificial reefs ate reef associated prey, such as fish (*Halichoeres* sp., *Serranus* sp. and *Centropristis* sp.) and shrimp (*Lysmata* sp. and *Synalpheus* sp.) (although he examined snapper smaller (100 – 230 mm standard

length) than what we studied). Perhaps smaller red snapper, such as the ones Lee examined, are more reef dependent than their larger counterparts.

There has been debate about how to analyze diet data. Indices alone are inadequate for making statistical comparisons (Ferry and Cailliet 1996). The fact that diet data is usually proportional and is dominated by zero values has presented problems. Multivariate techniques have been recommended, but the data often does not meet the heterogeneity of variance assumption (Ferry and Cailliet 1996). In the recent past, nonparametric techniques have become the norm in diet studies. However, some of these techniques still fall short of adequate quantitative analyses. The PRIMER statistical package (Clarke and Gorley 2001) allows multivariate analyses with very few assumptions about the data (ANOSIM), as well as determination of which prey categories or which species are responsible for groupings in the data found *a posteriori* or identified *a priori* (MDS, SIMPER, BIOENV, and BVSTEP). Thus, we support that it is widely applicable for many different types of diet analysis, such as comparing diets of numerous species found in concert (for example see Deudero 2001) or analyzing the diet of a single species, such as in the present study. PRIMER allows for hypothesis testing of the entire community at one time, a technique often impossible in diet studies in the past.

The data from this diet study will be used along with information on red snapper diel feeding patterns, and the caloric content of the prey species to present a complete picture of the foraging habits of red snapper off of Alabama. That data will then be used along with information on growth rates of snapper on artificial reefs as well as metabolism values in a bioenergetics model to obtain a first order estimate of the prey demand of a red snapper population on a reef.

ACKNOWLEDGEMENTS

This study was funded by a Mississippi-Alabama Sea Grant Fellowship and the Alabama Department of Conservation, Marine Resources Division. Special thanks to Julie Prerost for her help in identifying the invertebrates in this study.

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Artificial Reefs for Submerged and Sub-aerial Habitat Protection, Mitigation, and Restoration

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ABSTRACT

Artificial reefs traditionally have been used for environmental enhancement, and more recently, as mitigation for damages to natural reef areas. This paper presents recent methods for using artificial reefs for habitat protection, mitigation, and restoration. These methods include the use of artificial reefs for protection of existing natural reefs, environmental and eco-tourism enhancement, mitigation for damaged reefs, and shoreline stabilization. Examples of these methods, their unique design aspects, and their performance are presented so that they may be used to benefit other areas of the world.

To protect existing natural reefs, artificial reef units can be used to increase reef area, thereby decreasing the stresses on natural reefs. Artificial reefs provide areas for fishing, diving, snorkeling, and other activities, and as mitigation for damaged reef areas, so that the reef areas can recover. Artificial reefs also can be used as obstructions for ships and nets to prevent shipping or fishing in protected areas, or as underwater trail markers to safely guide snorkelers and divers around shallow natural reefs, while also providing information and education on the reefs and their inhabitants. These artificial reefs enhance the underwater environment for both the natural species and eco-tourism.

Just as natural reefs can provide calm areas in their lee, providing protection from wave attack and beach erosion, artificial reefs can be used for shoreline stabilization. This requires the reef structure to serve as a submerged breakwater, with the crest of the reef in close proximity to the water surface. This exposes the reef to much greater wave forces and other important design considerations. The performance of artificial reefs designed for wave attenuation and shoreline stabilization are presented, using several examples from the United States and the Caribbean. The designs and performance of these artificial reef/submerged breakwaters are evaluated in terms of the wave attenuation and shoreline stabilization provided, special design considerations for safety and stability, and the environmental enhancement provided by these structures.

KEY WORDS: Artificial reefs, habitat enhancement

INTRODUCTION

This paper presents methods for using artificial reefs to provide protection of existing natural reefs, mitigation of damages to natural reefs, and restoration and enhancement of marine and shoreline areas. Artificial reefs have been used for centuries for creating underwater habitat and increasing biological activity (Duedall and Champ 1991). More recent applications of artificial reefs include the protection of existing natural reefs, environmental and eco-tourism enhancement, repair and mitigation of damaged reefs, and shoreline stabilization (Harris 1995). Examples of these applications, their unique design aspects, and their performance are presented.

PROTECTION OF NATURAL REEFS

Artificial reefs can provide protection to natural reefs in several ways, including:

i) Increasing the amount of hardbottom habitat,
ii) Reducing stresses on existing reefs,
iii) Acting as obstacles to provide a deterrent for ships and nets, and
iv) Serving as guideposts for snorkel and diver trails.

To protect existing natural reefs, artificial reef units can be used to create new reef areas, providing additional hardbottom areas to increase the available habitat. With additional reef areas provided, stresses on the natural reefs can be decreased. Artificial reefs also can be used as obstructions for ships and nets to prevent shipping or fishing in protected areas.

Shallow, nearshore reefs are particularly susceptible to damages from boats and novice snorkelers. Surface markers can be used to mark the reef locations so that boaters can avoid reef areas, but snorkelers enjoying the underwater environment may inadvertently cause damages to the reefs by breaking off reef pieces with fins when swimming across shallow regions of the reef. For reef protection as well as eco-tourism enhancement, artificial reef units used as underwater snorkel trail markers can safely guide snorkelers and divers around shallow natural reefs, and provide habitat while also providing information and education on the reefs and their inhabitants.

REEF PROTECTION EXAMPLES IN TURKS AND CAICOS ISLANDS

The use of artificial reefs for protection of natural reefs has been demonstrated in two different ways in the Turks and Caicos Islands. The first example utilizes the artificial reefs as trail marker mounts along underwater snorkel trails. The second example is the creation of a new reef in the nearshore areas. In both cases, environmental education and awareness are part of the protection plan.

Both projects were developed in an effort to decrease impacts to the limited nearshore reef areas. Although many small coral outcroppings do exist in the Grace Bay, Providenciales area, there are only two larger reefs that can be easily accessed from the shore. Locally known as Smith's Reef and Bight Reef, these reefs

experience the brunt of the impact from numerous tourists that stay in the Grace Bay area. Without any simple means to regulate or control the access to these reefs, alternative plans were devised.

Underwater Snorkel Trails

The first plan of action was to create snorkel trails surrounding the two reefs. The trails were designed to lead the snorkelers along a path that would be "safe" for both the snorkelers and the coral, i.e. in areas where the depth and distance precluded the snorkelers from coming in contact with the coral. Like most trails, the effect tends to also localize what impacts do occur to a given area. Secondly, the trail markers included educational information that advises snorkelers on the rules and reasons for "reef etiquette" along with other interesting information on reef ecology and ecosystems.

The snorkel trails are unique in that the base portion or mount for the markers is a medium size Reef Ball™ artificial reef unit. Eventually, the mount will overgrow with corals and other benthic organisms, becoming an extension of the natural reef. The marker portion is also unique to the underwater trail world with the use of hand made tiles with graphics embedded within the glaze coats (Figure1). The smooth surface helps to minimize fouling and is fairly easily cleaned.

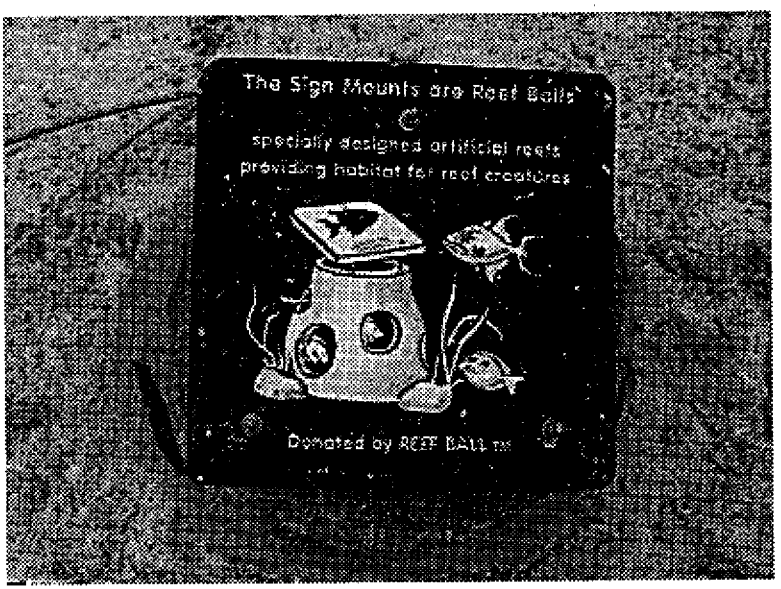


Figure 1. Snorkel Trail Sign Mounted on Reef Ball™ Artificial Reef Unit

Since 1997, growth has occurred on the artificial reefs, albeit slowly as expected in these oligotrophic waters. Initial sets of the corals *Favia fragum*, and *Millepora* species were noted after one year of submersion. Within the past year, small sets of *Porites* species (probably *P. astreiodes*) has also occurred. Other benthic encrustation includes primary algal growth, calcareous tube worms, bryozoans, tunicates, and anemones. Inhabitation by numerous species of fish occurred within minutes of the reefs being in place, and the reefs have continued to attract the motile species.

The total effect that the trails have had in reducing impacts to the two reefs has not been fully evaluated, but many tourists have been observed following the underwater trails and reading the information provided along them. Tourism has continued to escalate in the area since the trails were created in 1997, and a definite increase in the number of snorkelers to the two reefs has occurred. In particular, the Bight Reef sustains most of the impact with large numbers of tourists from nearby Beaches Resort and a new condominium development built directly onshore of the reef. An additional measure of a buoy line exclusion area has been added to that site to help protect the inner, more shallow regions of the reef. Further studies have been proposed to evaluate the impact to these and other snorkeling reefs in the area, which would include user statistics to assist in determining an appropriate carrying capacity. Once determined, management efforts can be made to further limit access if necessitated.

New Artificial Reef Areas

To augment these initial efforts, it was suggested to create an artificial reef site as an additional nearshore snorkeling site. The location of this reef was key to the plan if to be utilized effectively, and the site chosen is located directly across from the National Environmental Center (NEC) currently under construction. The NEC will act in part as a Visitor's Center, complete with environmental educational information and displays. The site is also located within walking distance of the Bight Reef to the west, with Smith's Reef located further down and to the east.

The design of the artificial reef incorporates a series of Bay Ball size Reef Balls™ grouped together in pods of 8 - 10 balls each. These pods are located in a string-like series that leads the snorkelers from shore and around a loop that encircles some natural coral heads before heading back to the beach. To date, three pods have been added to the chain, with a total of 26 reef units. The artificial reefs were deployed during the summers of 1999 and 2000, with growth similar to that found on the underwater snorkel trails, with the exception of the initial sets of *Favia fragum*. Figure 2 shows one pod consisting of seven Reef Ball™ units.

To date, funds and labor to construct the reef have been derived entirely through educational participant programs and voluntary services. The Reef Ball Coalition has spearheaded the efforts in organizing the participant programs. The first two programs included high school students from all over the United States that participated in a Living Classrooms Foundation Reef Restoration Program. The two

week courses taught students fundamentals of marine ecology as well as participating in the fabrication and deployment of the artificial reefs. Four local students were also sponsored to participate in the programs.

Future programs include assistance from University of Georgia students that will arrive in the spring of 2002, and plans are being made for next summer's marine ecology programs. It is hoped that when the NEC is operational, further interest will be sparked through the Visitor's Center. The Center provides an opportune outlet for further environmental awareness materials on reef ecology and etiquette, while the new artificial reef gives tourists the opportunity to see a reef in its initial growth stages. It is hoped that the combined efforts of the two projects well help to protect and alleviate the pressure on the natural reef systems, while educating tourists on their role in reef preservation.

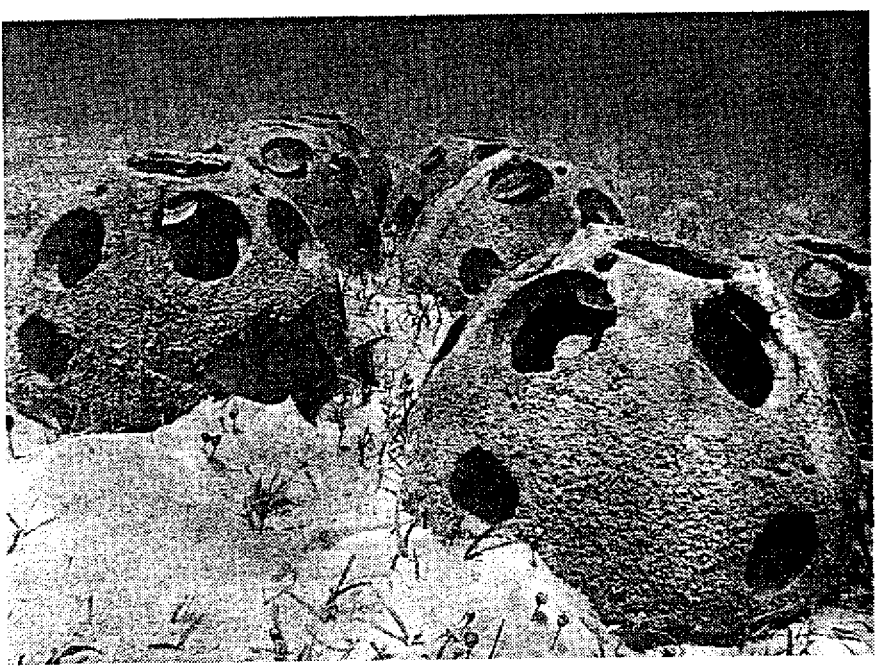


Figure 2. Reef Ball™ Artificial Reef Offshore Visitor's Center

MITIGATION REEFS

Natural and anthropogenic activities including storms, ship groundings, anchoring, dredging operations, beach restoration projects, and pollution can cause severe damages to existing natural reef areas. Artificial reefs can be used for repairing natural reefs once damages have occurred, and for mitigating for damages that will occur due to construction projects. This can be accomplished using custom

designed artificial reef units or waste materials, often referred to as "material of opportunity" (Harris et al. 1996).

Figure 3 shows the use of concrete bridge rubble as artificial reef material for the nearshore mitigation reefs offshore Martin County, Florida in 5 to 6 meters of water depth. This mitigation reef was required to compensate for the nearshore reef areas that were covered over by a beach nourishment project. The demolition of a nearby bridge being replaced provided the materials for the reef, and the bridge contractor also provided the funds for the deployment of the reef materials as an economical method of waste disposal.



Figure 3. Concrete Bridge Rubble as Nearshore Artificial Reef

Typical damages to natural reefs include the breaking off of individual reef pieces, with more severe damages resulting in the destruction of the reef substrate. Repair techniques include substrate repairs using underwater concrete to restore the reef foundation, artificial reef units to replace damaged reefs, and re-attachment of broken pieces of coral. Figure 4 shows coral transplants on Reef Ball™ artificial reef units located offshore of the Island of Mustique.

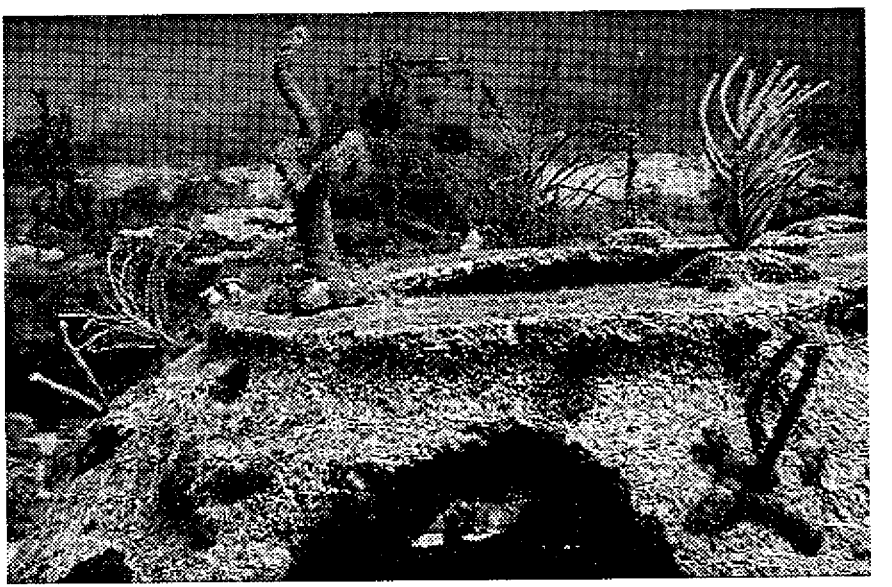


Figure 4. Coral Transplants on a Reef Ball™ offshore of the Island of Mustique

SHORELINE STABILIZATION

Just as natural reefs can provide calm areas in their lee that are protected from wave attack and beach erosion, artificial reefs can be used for shoreline stabilization. This requires the reef structure to serve as a submerged breakwater, with the crest of the reef in close proximity to the water surface. This exposes the reef to much greater wave forces and other important design considerations (Harris 1998).

The design and performance of artificial reefs as submerged breakwaters are evaluated in terms of the wave attenuation and shoreline stabilization provided, with special design considerations for safety and stability and the environmental enhancement provided by these structures.

Submerged Artificial Reef Breakwater Example

Approximately 450 Reef Ball™ artificial reef units were installed offshore of the Gran Dominicus Resort on the southern Caribbean coast of the Dominican Republic during the summer 1998 to form a submerged breakwater for shoreline stabilization, environmental enhancement, and eco-tourism (Harris 2001). The individual units used for the breakwater were 1.2 m and 1.4 m high Reef Ball™ units, with base diameters of 1.8 meters. The breakwater system consisted of three segmented breakwater sections, using three rows of Reef Ball™ units for each segment (Figure 5 and 6). The breakwater was installed in water depths of 1.6 m to 2.0 m, so that

the units were 0.2 m to 0.8 m below the mean water level (the tide range in the project area is approximately 0.4 m).

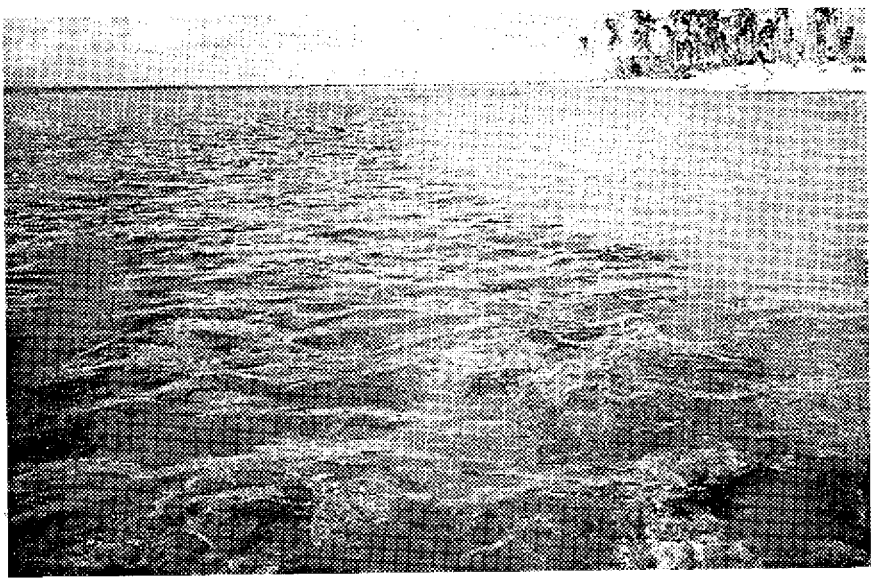


Figure 5. Submerged 3-row Reef Ball™ Breakwater

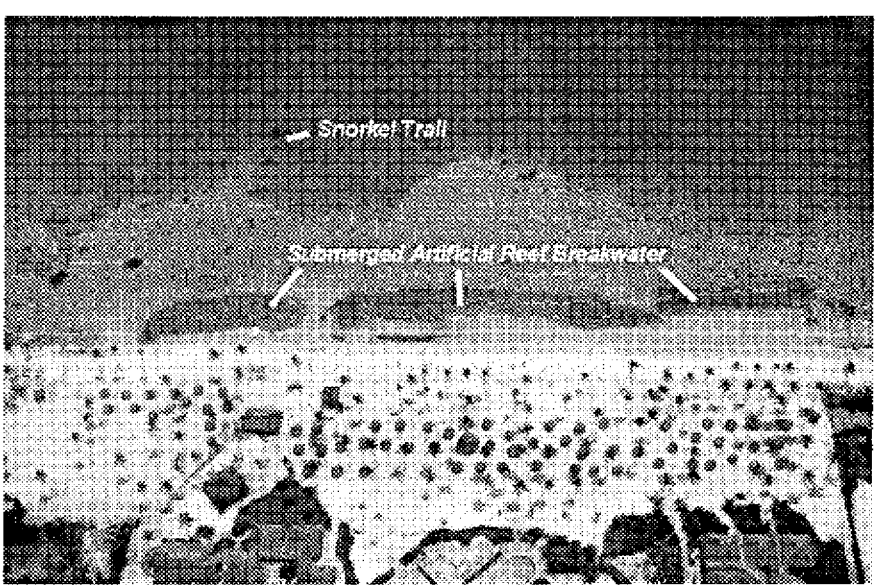


Figure 6. Reef Ball™ Artificial Reef Submerged Breakwater.

Survey data taken in April 2001 is compared to that taken in February 1999 after project installation and hurricane impacts of the previous fall. Figure 7 displays the plotted beach profile data, which show a shoreline advance of 10 meters and a large gain in sand volume due to the wave reduction in the lee of the submerged artificial reef breakwater. The effects on adjacent beaches must be considered in the design of submerged breakwaters, to avoid increased erosion of adjacent shorelines. The beaches adjacent to this project showed stability during this same time period, but with minimal accretion. Habitat for the smaller species was provided by adding small rocks in the hollow centers of the artificial reef units.

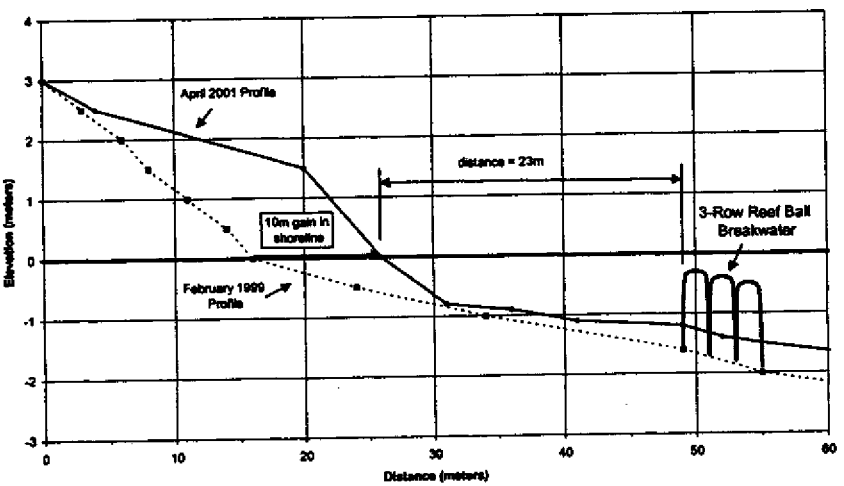


Figure 7. Artificial Reef Breakwater - Beach Profile Changes

The artificial reef submerged breakwater project presented in this paper demonstrates the technology available to provide shoreline stabilization due to wave attenuation at a site with a low tidal range and low to moderate wave climate (except during tropical storms and hurricanes). In addition, the use of artificial reef units for the breakwater also provides habitat enhancement for the marine life, which can be enjoyed by divers and snorkelers.

CONCLUSIONS

This paper presents some new uses of artificial reefs, in addition to the traditional uses of artificial reefs for providing increased hardbottom habitat. Artificial reefs can be utilized to protect existing natural reefs and shorelines by increasing available hardbottom, providing obstacles to boats and nets, serving as guideposts for snorkelers, providing repair and mitigation for damaged reefs, and providing shoreline stabilization through wave attenuation. Examples are presented in this paper that can be employed at other locations.

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Introduction to the Turks and Caicos Islands Bonefish Research Project Tagging Program

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ABSTRACT

Bonefish, *Albula vulpes*, are the focus of both a small-scale commercial and a recreational sport fishery in the Turks and Caicos Islands, yet there is currently no management plan in place to help conserve bonefish stocks. In 1992, Bell Sound Nature Reserve was created with bonefish noted as a species of interest, however it remains unclear as to whether this reserve is an effective management tool. The Turks and Caicos Islands Bonefish Research Project was established to provide a better understanding of bonefish on the Caicos Bank and form the basis of a management plan. The first part of the project is a tag and recapture program designed to assess the movements of bonefish. To date, 120 bonefish have been tagged. One fish tagged in Bell Sound Nature Reserve was recaptured north of the reserve. Although additional tagging and recaptures are necessary, these results suggest that other management tools may be required to conserve local bonefish stocks.

KEY WORDS: Bonefish, *Albula vulpes*, movement, Turks and Caicos Islands,

INTRODUCTION

Bonefish, *Albula vulpes*, are an important resource in the Turks and Caicos Islands (TCI). For generations, bonefish have been the focus of a subsistence/small-scale commercial fishery with catches being sold to individuals or small restaurants in local communities. Currently, a sport fishery for bonefish is also developing in the TCI, and is strongly supported by the government that depends on tourism for the majority of its revenue. Recreational anglers commonly practice catch and release (Kaufmann 2000), increasing the potential value of each fish returned to the water as opposed to being consumed.

Despite the importance of bonefish to the economy in the TCI, there is currently no management plan in place for either the subsistence or sport fishery. This, to a large part, is due to the lack of scientific information regarding bonefish populations both globally and in the TCI (Mojica et al. 1995, Crabtree et al. 1997). For example, aside from daily tidal migration patterns, little is known about the habitat preferences or long-term movements of bonefish (Colton and Alevizon 1983). In addition, although Crabtree et al. (1996, 1997, 1998) have provided a good understanding of the life history and feeding habits of bonefish in the Florida Keys,

it is uncertain as to whether the information obtained from these studies is transferable to other populations in the region.

Bell Sound Nature Reserve (BSNR) was established near South Caicos in 1992 with bonefish noted as a species of special interest, even though little information exists for bonefish inhabiting this area. As such, it remains unclear whether BSNR is effective in conserving local stocks. Moreover, other management tools may be necessary to protect local stocks in light of the growing use of monofilament nets for the harvest of bonefish. Anecdotal information from sport fishing guides indicates that monofilament nets are being deployed across tidal creeks resulting in the mortality of large numbers of smaller, juvenile bonefish, as well as the by-catch of other important species such as marine turtles. In response, the Turks and Caicos Islands Bonefish Research Project (TCI-BRP) was initiated to gather information necessary to form a management plan for bonefish in the TCI, leading to the conservation of local stocks. The first part of the TCI-BRP is a conventional tag and recapture study used to assess movement of bonefish on the Caicos Bank including the waters in and around BSNR.

MATERIALS AND METHODS

The TCI are located at the southern end of the Bahamian archipelago, about 180 km north of Hispaniola. South Caicos is situated on the eastern side of the Caicos Bank with BSNR (approximately 12 km^2 in size) abutting the northern side of the island (Figure 1).

Two methods are being used to collect bonefish for the purpose of tagging and recapture. Students from The School for Field Studies – Center for Marine Resource Studies are tagging and recapturing bonefish near South Caicos and in BSNR, using a traditional method of capture known as 'hauling'. A large, nylon seine (1.8 m x 60 m, 38 mm mesh) is stretched out in relatively shallow water when a school of bonefish is spotted, and the ends of the net are brought together to encircle the fish. The second method of capture is by sport fishers using hook and line. Several sport fishing charters on various islands are participating in the project by tagging bonefish caught by their clients, and by recording the recapture or sighting of any previously tagged fish.

When landed, each bonefish is measured (total length (TL) and fork length (FL) to the nearest cm), weighed if a scale is available, and the habitat type where caught is recorded. The fish are tagged on the left side just under the dorsal fin using a T-bar anchor tag (Floy Tag model FT-68B with ¾" monofilament base between the vinyl tubing and the anchor end). Each tag is individually numbered and includes details regarding the project (project name and phone number). Tags are also color-coded according to one of five designated areas on the Caicos Bank. Brightly colored tags are used so tagged fish can be visually identified in shallow water, which can provide information on movement even if a fish is not recaptured. In addition, each of the five designated fishing areas is subdivided into smaller fishing zones to allow anglers and guides to indicate a general location as to where a fish

was tagged or recaptured without giving away details of their fishing locations. When a fish is recaptured, tag number and color, fish length and weight, habitat type and fishing zone are recorded.

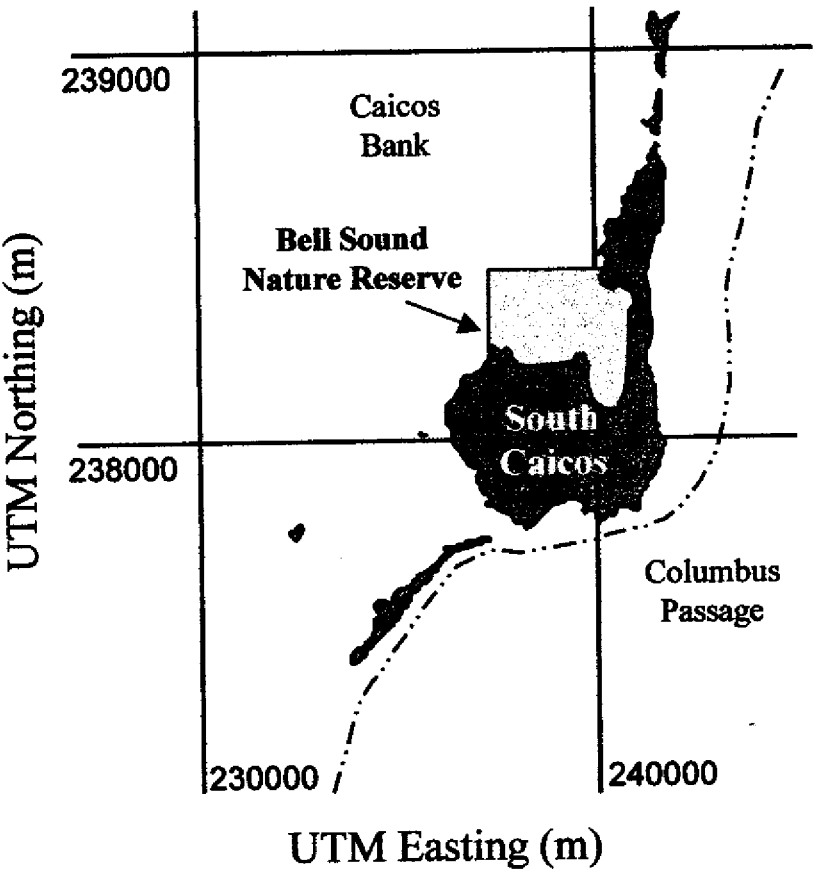


Figure 1. Bell Sound Nature Reserve, South Caicos, BWI. Coordinates are for the Universal Transverse Mercator (UTM) metric grid system in Zone 19N.

RESULTS AND DISCUSSION

To date, 120 bonefish have been tagged on the Caicos Bank, ranging in size from 28 to 72 cm TL (Figure 2). Preliminary assessment of the data suggests that the average size of bonefish increases from west to east across the Caicos Bank. Information obtained from anglers indicates that larger individuals caught were solitary or a part of small schools (< 5 fish), whereas smaller fish were from larger schools.

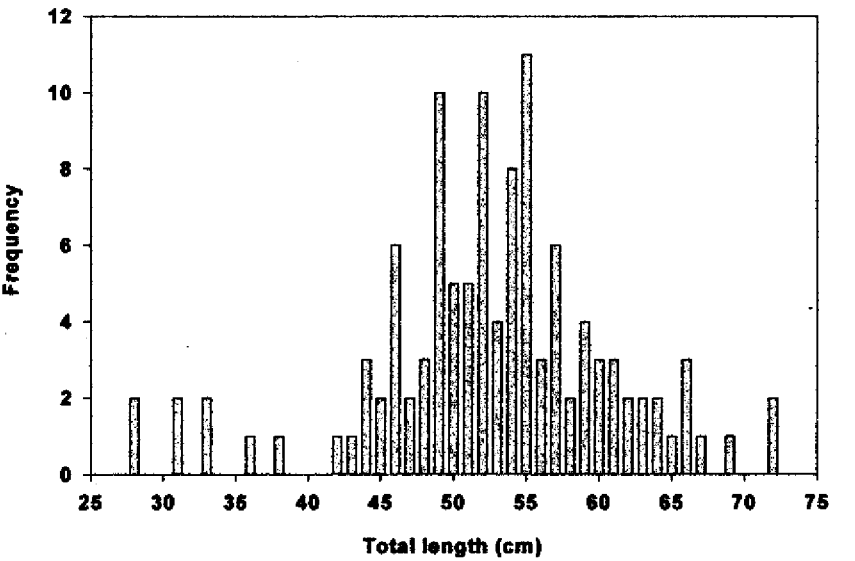


Figure 2. Length-frequency distribution of tagged bonefish on the Caicos Bank.

One tagged bonefish has been recaptured. It was originally tagged in BSNR on 30 November 2000, and was recaptured on 20 March 2001 by a local commercial fisher approximately 2 km north of the reserve. The fish had grown approximately 1 cm between the time of tagging and recapture. A second tagged fish was sighted by a local sport fishing guide, and the tag color indicated that the fish had been tagged in the same area of the Caicos Bank.

Results thus far indicate it is likely that bonefish travel in and out of BSNR making them susceptible to harvest by local fishers. As such, the use of this no-take reserve may not be entirely effective as a management tool for local bonefish stocks. The continuation of the tag and recapture program, and the addition of life history studies should provide the information about bonefish on the Caicos Bank needed to develop a management plan, which will aid in the conservation of local bonefish stocks.

ACKNOWLEDGEMENTS

We gratefully acknowledge the key financial and logistical support of The School for Field Studies Center for Marine Resource Studies. We would also like to thank the following organizations and individuals for their logistical, financial, or technical support: Mark Day, Wesley Clervaeux, and Duncan Vaughan (TCI Department of Environment and Coastal Resources), Ganger Lockheart and Bibo Jayne (Beyond the Blue Charters), Barr Gardiner (Bonefish Unlimited), Skooter Gardiner (SilverCreek Adventures), Robert Humston and Gerry Ault (University of Miami), Bill Foster, Stanley Jennings, Floy Tag and Redington. This is contribution SFS/CMRS 055.

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Harvest of Settlement Stage Reef Fish for Small-scale Grow-out or Stock Enhancement: A Feasibility Study on the Family Haemulidae

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ABSTRACT

Mortality rates of reef fishes are typically very high in the first few weeks after settlement. Capture, rearing, and release of reef fish before or shortly after settlement may provide an opportunity to increase survival. Increasing survival at this stage could be a sustainable way of increasing fisheries resources. Visual censuses of juvenile grunts (Haemulidae) during settlement pulses from January to March 2001 and July to September 2001 in Tortola, British Virgin Islands were used to estimate local post-settlement mortality rates on a back-reef, seagrass/sand halo area. Concurrently, settling haemulids were captured from another location and reared in aquaria and sea cages. For fish smaller than 15 mm TL, aquarium-based rearing trials were used to compare the efficacy of feeding with wild-caught plankton or feeding with brine shrimp nauplii. Internally lit sea cages were tested against a plankton-pump food-delivery system for fish larger than 15 mm. Fish growth rates were rapid and mortality rates in sea cages were low for fish greater than 15 mm in size. Results are discussed in relation to potential applications for stock enhancement or mariculture.

KEY WORDS: Post-settlement mortality, post-larval fish feed, settlement-stage reef fishes.

INTRODUCTION

There now exists a wealth of information on the settlement and post settlement stages of coral reef fishes. In particular, the evidence demonstrating the population-limiting role of settlement stage mortality is considerable (Doherty et al. in press, Roberts 1996 and references therein, Shulman et al. 1987, Watson et al. in review). Exceptionally high mortality rates of many reef fish species during early settlement has led to interest in development of interventionist management strategies (Doherty 1994, Hair et al. 2001, Watson et al. in review). Harvest of fish before or shortly after settlement may provide an opportunity to increase the resource output from the settlement period. Capturing fish before they are subject to post-settlement mortality, and transferring them to rearing programs, has the potential to yield over 90% more fish than capture of the same cohort two weeks after settlement (Watson

ICLARM Contribution No. 1647

et al. in review). Preliminary experiments, rearing settlement-stage lutjanids with light attracted plankton, showed that high survival rates and rapid growth is possible (Watson et al. 2001). If significant numbers of settlement-stage fish can be reared successfully with low mortality, using low-technology systems, they may be a valuable source of "seed" for small-scale mariculture operations, or localized stock enhancement projects (Doherty 1994). While the economics of such an approach may not be appropriate for application in many commercial fisheries, the method may have application as a fisheries management tool in discrete, over-exploited artisanal fisheries.

This paper examines the mortality rates of haemulids shortly after settlement and the potential use of cheap and simple technology for rearing these fish to a size where mortality rates are much lower. As the recently settled fish are generally very fragile, and have restrictive food requirements, answers to the following questions are needed to assess the feasibility of early harvest and the use of simple rearing systems: What is the level of post-settlement mortality in the wild? Can it be reduced in captivity? How many fish settle each month? Is harvest of low-cost zooplankton food possible? Is it suitable for rearing haemulid fish?

Different species of haemulids often settle together and are indistinguishable from each other at this stage, however post rearing identification revealed that approximately 80% of settlement shoals were French grunt (*Haemulon flavolineatum*). White grunt (*H. plumieri*), Blue-striped grunt (*H. sciurus*), and Tomtate (*H. aurolineatum*) made up most of the remaining 20%. Fish of this family possess the following biological features which make them ideal candidates for such a study.

i) They settle in large numbers virtually all year round (McFarland et al. 1985), ensuring a constant supply of fish for small-scale grow-out or stock enhancement.

ii) Cohorts settle onto the same habitats and do not appear to move for two weeks, thereby providing an opportunity to quantify post-settlement mortality rates within this time period.

iii) Haemulids are planktivorous throughout most of their juvenile life phases, making them ideal candidates for rearing with simple and inexpensive plankton-attraction rearing systems. In addition, later juveniles will readily feed on chopped fish.

iv) Juvenile haemulids have been found to exhibit high site fidelity to daytime resting locations (Helfman et al. 1982), a feature which would considerably simplify any stock enhancement experiments, and

v) Adult haemulids are of moderate economic value to small-scale artisanal fishers (Gaut and Munro 1983)

The disadvantages and challenges of working with haemulids lie in the small size of settling individuals (around 8.5 mm total length) (Helfman et al. 1982). Fish this size present considerable challenges in rearing, as they are fragile and require very small, live food. They are also extremely sensitive to water temperature, chemistry, parasites and pathogens (Olla et al. 1998, Montgomery-Brock et al. 2001). Also,

haemulids do not appear to be attracted to light (Watson and Munro, in review) and therefore have to be harvested after settlement. This means that some post-settlement mortality occurs prior to collection, reducing the scope for increasing production compared to species that can be caught in light traps prior to settlement.

MATERIALS AND METHODS

Mortality Rates of Settling Fish in the Wild

This study focused on shallow habitats within the channel between Tortola and Beef Island in the British Virgin Islands because previous censuses showed that settlement-stage haemulids were present in large numbers between sand halo and seagrass habitats adjacent to back reef areas. A 170 m strip of back reef habitat which was bordered to the east and west by land was selected. About 200 m to the north, the fore reef dropped to island shelf at a depth of 20 m. To the south, it was bordered by dense seagrass at a depth of 1 - 3 m extending from the back reef for 50 m and ending in a sandy channel 5 m deep (Figure 1). A pilot visual census was carried out for two weeks in December 2000 to determine likely settlement sites. Based on observations during the pilot survey, a 10 x 6 m grid of 4 m^2 quadrats was laid out spanning the sand halo/seagrass interface, so that a line of five 4 m^2 quadrats covered each of three habitats; seagrass, seagrass/sand-halo interface and sand-halo (upper inset, Figure 1). Numbers of fish on the grid were counted by visual census daily from January to April and July to September 2001 with few interruptions, giving 116 days of observations. Haemulid fish sizes were estimated and grouped into the following categories: 5 - 15 mm, 16 - 20 mm, 21 - 25 mm, 26 - 30 mm, > 30 mm. In addition, the observations from July to September 2001 were extended to cover the whole back-reef area (170 m). Observations from the grid and wider back reef survey were used to generate mean settlement mortality estimates for the 5 - 15 mm and 16 - 20 mm size classes. The assumption was made that, if one of the three habitat categories was preferred, then any post-settlement movement of fish was likely to increase observed numbers on the preferred habitat, rather than decrease observed numbers. Thus estimates of mortality from this study may be conservative.

A one-way ANOVA, and post hoc Tukeys test, were used to test the null hypothesis: that there was no difference between the numbers of haemulids settling in sand-halo/seagrass interface habitats and in sand-halo or seagrass habitats.

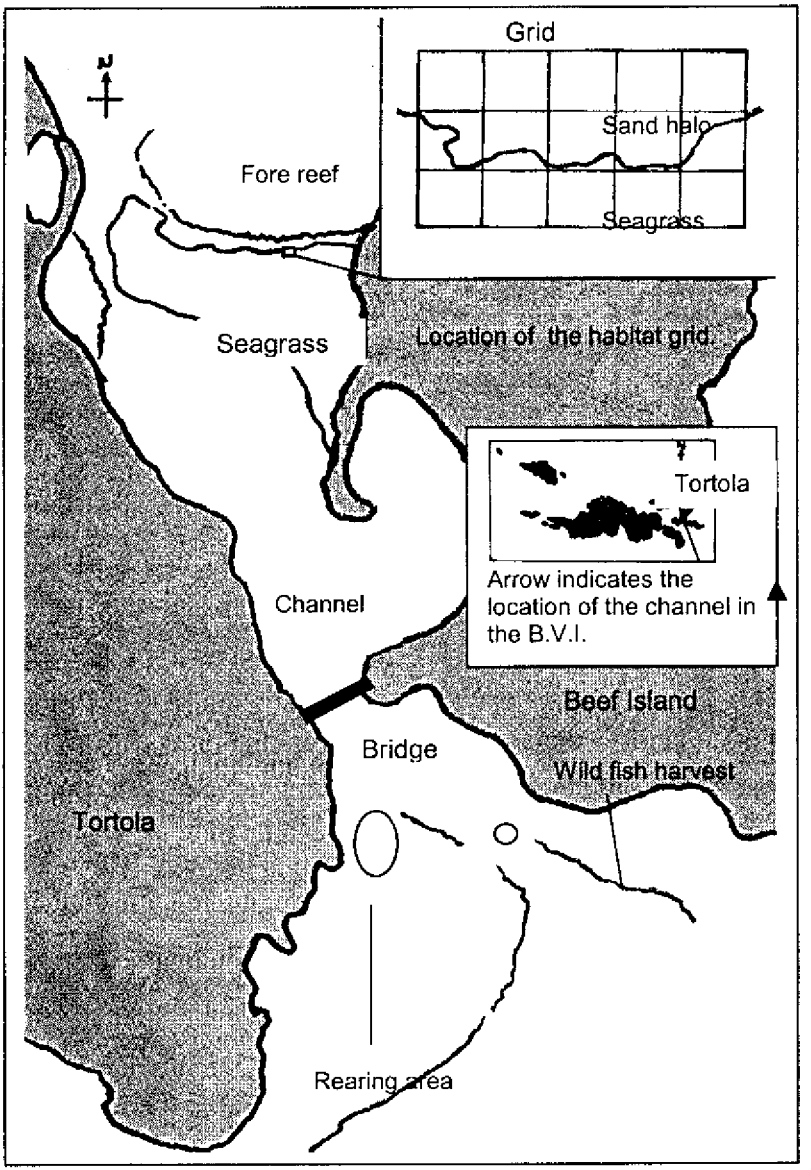


Figure 1. Map of the channel showing location of wild mortality study, rearing site for sea cage experiments, and wild fish harvest site

Growth and Mortality Rates of Fish Fed with Brine Shrimp Nauplii and Plankton

Haemulids which had settled over-night were carefully captured from a sand patch, 2.5 m deep, 500 m to the south of the settlement study site (Figure 1). Fish of 6 - 15 mm could be captured easily by gently herding them towards a 0.3 mm mesh funnel net with a 1 m^2 aperture, which ended in a glass jar. All 'in water' movements of fish this size were done slowly and with great care being taken not to startle or stress the fish (earlier attempts at capture using a 1 mm mesh sweep net resulted in 98% mortality within the first two days). Once inside the glass jar, the fish were slowly brought to the surface and placed in a blue plastic bucket of fresh seawater. Fish were then transferred into a 95 L aquarium set up to simulate the sand-halo/seagrass habitat, with substrate and plants taken from the capture site (stocking density 1.58 fish/L). The aquarium had an under-gravel filter and was divided by a piece of plexiglass fitted with a 0.3 mm mesh window. This allowed for circulation and ensured that microbe content and water chemistry of both sides of the aquarium remained the same.

Fish in one side of the aquarium were fed brine shrimp nauplii whereas those on the other were fed live plankton harvested overnight by a plankton-attraction feeding-system (Power and Watson in review). Prior to feeding the plankton was screened for parasitic isopods. Fish were fed until feeding behaviour ceased, morning, noon and evening. Aquarium water was exchanged with fresh seawater at a rate of ¼ tank/day. This experiment was run five times, twice for 8 days and three times for 16 days. Treatments were randomly swapped between sides of the aquarium each time. The aquarium was cleaned and reset with fresh substrate between the two, 8-day replicates, but left with the same substrate for the 16-day replicates. Fish were removed at the end of each experimental period, counted and measured against markings on the bottom of a transparent container. They were then transferred to the sea cage rearing experiments (see below). Thus, different fish were used for each of the five trials.

Growth and Mortality Rates of Fish Reared in Sea Cages

To avoid some of the water quality and intermittent feeding problems associated with rearing the fish in aquaria, fish were also placed in small (6 l) "sea cages" fitted with the plankton pump system described by Power and Watson (in review). The plankton pump minimised water quality problems by providing a flow of water for half an hour of every hour on a 24-hour cycle. This flow of water not only reduced the buildup of waste and microbe populations within the cage, but was also likely to contain small quantities of suspended food during daylight hours to supplement the zooplankton attracted to the light at night. The pump also offered the opportunity to filter plankton before it reached the fish without severely restricting the flow of water through the cage.

Sea cages were situated over 2 m deep seagrass beds adjoining a channel (Figure 1). Experiments were designed to test a variety of rearing strategies that may have potential for extensive application. The first sea cage experiment used fish that had

been in aquaria for 8 days. Three treatments were set up, each with three 6 l cylindrical sea cages of 1mm mesh. Each sea cage was stocked with haemulids (mean TL 17.8 mm) at a density of 3.3 fish/L. The first treatment was designed to supply and retain plankton filtered by 1 mm mesh, at night, as well as exchange water and supply ambient plankton during the day. The outflow pipes from a plankton pump were fitted with 1mm filter bags and the sea cages were lined with ultra-fine mesh (<0.01mm). The cages were secured so that the outflow pipes delivered filtered plankton directly to the fish. The second treatment was designed to supply filtered plankton at night and exchange water and ambient plankton during the day, without any retaining mechanism. A second plankton pump was fitted with 1mm filter bags and cages as in the first treatment. The third treatment, a control, was designed to attract plankton to a light inside each sea cage, where fish could feed on them at night. This treatment had no water exchange or mechanism to retain plankton or supply it during the day. Three 1 mm mesh sea cages were each fitted with an internal light source (9W, 115V, 0.1 A) before being sealed and suspended one meter below the surface. These treatments were spaced 20 m from each other and run concurrently for a period of eight days.

A second sea cage experiment was designed to investigate the potential for cheap automation of rearing newly settled haemulids. Fish were caught and transferred to nine 6 l cylindrical sea cages of 1 mm mesh, at a density of 1.6 fish/L. These cages were split evenly between three experimental treatments. The first treatment was designed to provide the correct size food for the smallest of the fish and retain it throughout the night and day. For this treatment, three outflow pipes from a plankton pump were each fitted first with 1mm and then 0.3 mm mesh filter bags. The three sea cages, which had been lined with ultra-fine mesh (< 0.1mm) before being stocked with fish, were then secured to the outflow pipes so that filtered plankton of <0.3 mm diameter was delivered directly to the fish. The second treatment was designed to supply plankton which had passed through a 1mm filter, retain it at night with light attraction, as well as exchange water and ambient plankton during the day. A second plankton pump was fitted with 1mm filter bags and three sea cages with internal lights (9W,115V, 0.1A). In the third treatment, three sea cages were each fitted with an internal light source (9W, 115V, 0.1 A) before being sealed and suspended one meter below the surface. The lights attracted plankton through the 1 mm mesh, where fish could feed on them during darkness. This treatment had no water exchange or mechanism to retain or supply plankton during the day. All treatments were run concurrently for a period of eight days and spaced 20 meters from each other.

Planktonic Food Supply

Plankton pump output for the months February to December 2000 was sampled at full moon and new moon. A 200 µm plankton net and collection jar was attached to one of the outflows of the plankton pump, operated for half an hour each hour, throughout the night. Mean flow from each output was 0.85 L/minute. The volume of plankters collected each night was estimated from ten 1% sub-samples using a

grid marked out with 1 mm squares. Plankters were grouped into the following categories: Copepoda, Mysidacea and unidentified crustacean larvae (after Todd and Laverack 1991). All other plankton forms were excluded from this investigation on the basis of their absence from fish stomach contents. Data were split between new moon and full moon samples and then further split into seasons, defined as the following periods: February-April, May-August and September-December. A two-way ANOVA was used to test the null hypothesis that there were no differences in the supply of plankton between seasons and within lunar cycles.

RESULTS

During a pilot visual census of the area, settlement-stage haemulids were observed in large numbers where the sand halo bordered the seagrass and on small sand patches within the seagrass. Numbers of fish observed further into the sand halo and in dense seagrass were minimal. Mean monthly settlement on the grid for January to June and August was 89.5 (± 204; max = 716) fish. Settlers showed a highly significant preference for the sand-halo/seagrass interface habitat ($p = < 0.001$), accounting for 70.9% of total number of settlers recorded on the grid. Any movement of fish generally occurred within this habitat with shoals moving <2m overnight. Mean natural mortality after six days, calculated from the relative abundances at each settlement peak, was 65% (SD = 17.3). This correlated well with natural mortality calculated from the 37 day survey of the whole back reef area, which gave a mortality of 58.4% five days after peak settlement and 70% after six days. In addition, after 14 days a conservative mortality estimate of 67% was calculated by addition of surviving numbers of settlers to the subsequent peak in numbers for the succeeding size class (16 - 20 mm).

Table 1 gives a summary of the most significant results from the aquarium rearing experiments. The lowest mortality after 8 days was 10% for fish fed on brine shrimp and 25% for fish fed on plankton. Fish feeding behaviour between the two treatments appeared to differ little in duration. However, fish appeared to feed selectively on plankton, with prey being expelled after 29% of strikes. In contrast, fish rarely hesitated to consume brine shrimp. Mean mortality for both treatments was lower than 30% with no significant difference in sizes of fish by the end of the trial ($p = 0.32$). Mortality in the 16-day treatments was much higher than for 8 days, with the mortality rate increasing with each successive replicate. Forty percent of dead fish, removed from the final plankton-fed replicate, had spined crustacean larvae lodged in their throats.

Stomach contents analysis of eleven plankton-fed fish (9.7 mm, mean TL ± 1.03) contained 22% copepoda, 34% unidentified crustacean larvae and 44% mysids. Mean volume of stomach contents at satiation was 0.8 mm^3.

Table 1. Summary of results from aquarium rearing experiments with haemulid fishes caught from the wild, shortly after settling.

Fish size	Treatment	Period	Feed time	Mean % mortality	Lowest % mortality	No. replicates	Rearing density (fish/L)
6-10 mm	Fed brine shrimp nauplii	8 days	Day	14 +/- 5.7	10	2	1.6
6-10 mm	Fed harvested plankton	8 days	Day	27 +/- 2.9	25	2	1.6
6-10 mm	Fed brine shrimp nauplii	16 days	Day	61 +/- 29.6	27	3	1.6
6-10 mm	Fed harvested plankton	16 days	Day	65 +/- 13.3	66	3	1.6

The lowest mortality rates from sea cage rearing experiments were achieved with the simple internally illuminated 1 mm mesh sea cage (Tables 2 and 3). Mean mortality rates of settlement size fish (Table 2) did not decrease when they were provided with filtered plankton or when plankton was retained during the day, although one replicate had 10% mortality. Mean mortality rates of fish pre-reared in aquaria (Table 3) and fed filtered plankton from the plankton pump was very high in the treatment where no retaining mechanism was provided, and not significantly lower than the wild mortality where food was retained.

Planktonic food supply varied throughout the year with significantly greater numbers of copepods and unidentified crustacean larvae being caught from September-December ($p = < 0.001$ and < 0.001, respectively), while mysid volumes were four times higher during May-December than in February - May. Differences in volumes of plankton between full moon and new moon were not significant for crustacean larvae ($p = > 0.9$), but were significant for copepods and mysids ($p = < 0.001$ and $< 0.00,1$ respectively) with higher volumes at full moon. Interaction between moon phase and season was highly significant ($p = <0.001$). Comparison of mean volumes of plankton output for the three categories present in fish stomachs (Figure 2), with mean volume of stomach contents, gave a crude estimate for the number of fish that may be reared with a plankton based diet from each plankton pump output (four to each pump). This estimate was based on fish feeding to satiation four times in an eight hour feeding period; double the feeding rate used for hatchery rearing lutjanid postlarvae (Turano et al. 2000). This capacity was estimated at between 270 and 280 fish (9.7 mm mean TL).

Table 2. Summary of results from sea cage rearing experiments with haemulid fishes caught from the wild, shortly after settling.

Fish size	Treatment	Period	Feed time	Mean % mortality	Lowest % mortality	No. replicates	Rearing density (fish/L)
6-10 mm	Fed plankton: light inside cage	8 days	Night	29 +/- 25.4	7	3	1.6
6-10 mm	Fed plankton: Plankton pump, ultra fine mesh & 0.3mm filter.	8 days	Night & Day	60 +/- 45.8	10	3	1.6
6-10 mm	Fed plankton: Plankton pump, 1mm filter & light in cage.	8 days	Night	50 +/- 20	30	3	1.6

Table 3. Summary of results from cage rearing experiments with haemulid fishes which were pre-reared in aquaria for 8 days.

Fish size	Treatment	Period	Feed time	Mean % mortality	Lowest % mortality	No. replicates	Rearing density (fish/L)
16-20 mm	Fed plankton: light inside cage	8 days	Night	0	0	3	3.3
16-20 mm	Fed plankton: Plankton pump, ultra fine mesh & 1 mm filter.	8 days	Night & Day	83 +/- 10.4	75	3	3.3
16-20 mm	Fed plankton: Plankton pump, 1mm filter.	8 days	Night	92 +/- 2.8	90	3	3.3

DISCUSSION

The greatest mortality of haemulid post-larvae in the wild occurs during the first six days after settlement, with only ~30% of fish surviving beyond 14 days. Whilst we cannot entirely rule out the effects of movement from this calculation it would appear that these results are consistent with estimates from other studies of settlement mortality (Doherty et al. in press, Sulman and Ogden 1987, Roberts 1996 and references therein, Watson et al. in review).

The results (Table 1) from feeding with brine shrimp nauplii and filtered plankton in aquaria show that the survival of recently settled haemulids can be increased substantially by rearing them in captivity. The best results from a combination of rearing strategies show that 10% mortality at 14 days can be achieved using a combination of feeding with brine shrimp nauplii and subsequent rearing in sea cages. Rearing fish in sea cages from settlement yielded 7% mortality. Mean mortality rates from each treatment present a slightly different picture with projected mortality at 16 days of around 30%. Even so, this still represents a large potential increase in production compared to natural rates of mortality. The high survival (100%) of fish reared from 8 -16 days with internally illuminated sea cages, indicates that subsequent grow-out is likely to have low mortality. The same cannot be said for wild cohorts, where an average of 5% may reach maturity (Sulman et al. 1987). Preliminary extended rearing trials of up to 40 days show mortality lower than 5% between day 16 and day 40 is possible, but observations indicate that interspecific aggression may increase with size. It would be advisable, therefore, to separate species as early as possible. The appropriate age for release of reared fish has yet to be determined. However, Helfman et al. (1982) suggest that juveniles between 40 and 120 mm TL which have succeeded in learning the appropriate gregarious forage and resting behaviour, are far less likely to be preyed upon than smaller fish. If reared fish can be habilitated in a predator free environment with wild individuals at this size (Olla et al. 1998), their mortality may be similarly low. Some of the results point to areas for improvement and problems with the use of plankton as a cheap food. The fact that dead fish were found with spined crustacean larvae lodged in their throats appears to point to a breakdown in the normal prey selection behaviour. It is possible that early morning delays in supplying plankton to fish may disrupt their natural dawn feeding behaviour and result in hasty and inappropriate prey selection. While plankton supplies were variable, samples always contained more than enough food of the right size and variety. Interestingly, attempts to improve early sea cage rearing with various plankton filtering and retaining mechanisms, proved far less effective than a 1 mm mesh 6 L sea cage with an internal light. There appeared to be no adverse effects to fish from the reversal of the natural daylight feeding behaviour. Results from this rearing method may be improved by taking measures to control external parasites with techniques like hydrogen peroxide dips (Montgomery-Brock et al. 2001).

This study shows that there is considerable potential for increasing the survival of fish at settlement, thereby creating a way to improve fisheries production by

growing-out the additional fish in small-scale mariculture operations or in stock enhancement programs.

ACKNOWLEDGEMENTS

This work was completed as a component of the ICLARM Marine Protected Areas Project, funded by the United Kingdom Department For International Development. Special thanks to John Munro, Zolt Sary and Ivor Williams for assistance with experimental design and editing of the manuscript. Thanks also to Vanessa Bertenshaw, Karen Bech, Zsolt Sary and Newton Erihstee for assistance with fieldwork.

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An Assessment of the Aquaculture Potential of the Caribbean Spiny Lobster, *Panulirus argus*

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ABSTRACT

There is strong demand for spiny lobsters (family Palinuridae) in international seafood markets and this is generating interest in the development of aquaculture for these species. However, a previous assessment of the economic feasibility of commercial land-based culture of a spiny lobster species in the temperate waters of New Zealand indicated that the prospects were poor unless input costs could be reduced and productivity increased dramatically. This earlier assessment recommended that the potential for culturing tropical species of spiny lobsters deserved closer examination, as these species generally have much more rapid growth. Consequently, this present study reviewed information on a tropical species, *Panulirus argus,* from Florida and the Caribbean.

Overall, this review indicates that the prospects for farming *P. argus* profitably are more likely than for temperate spiny lobster species, due to the greater availability of wild seed lobsters and more rapid growth rates. Sea-cage culture or land-based tank culture are probably both feasible, with the former technique being less capital intensive. However, further research and development is required to identify efficient land-based and sea-cage aquaculture systems. Research will also be required to establish the densities and feeding methods for these new grow out systems. A cost effective feed for *P. argus* is probably the most important obstacle to commercial aquaculture development of this lobster on a large scale. Some preliminary work has been done in the Caribbean and in the United States on artificial feeds, and indications are that there is excellent potential for rapid development of a cost effective artificial diet for commercial aquaculture. An important early step toward this goal would be establishing a reference diet that can be used to assess the performance of new diet formulations.

KEY WORDS: Aquaculture, spiny lobster, *Panulirus argus,* Caribbean

INTRODUCTION

In the past few years the early experimental and commercial scale aquaculture of spiny lobsters has begun in a many countries, including Australia, Japan, Croatia, Vietnam, Indonesia, Philippines, Singapore, Taiwan, South Africa, India, Sri Lanka,

Tahiti and New Zealand. This development has been driven by the high market value of spiny lobsters and the limited global supply from wild fisheries (FAO 1997).

A previous assessment of the economic feasibility of the commercial land-based culture of spiny lobsters in the temperate waters of New Zealand indicated that the economic prospects were poor unless input costs could be reduced and productivity increased dramatically (Jeffs and Hooker 2000). Consequently, the study recommended that the economic potential of culturing tropical species of spiny lobsters deserved closer examination as these species have more rapid growth.

The tropical species of spiny lobster for which there is the most available aquaculture information and strongest interest in aquaculture is *Panulirus argus* (Ingle and Witham 1968, Tamm 1980, Miller 1983, Ryther et al. 1984, Oesterling and Provenzano 1985. D'Abramo and Conklin 1985, Ryther et al. 1988, Lellis, 1990, 1991, Sandifer 1991, Sandifer 1998). This lobster has an extensive natural range from North Carolina to Brazil and is found throughout the Caribbean (Lellis 1991). The growth rates of this species both in the wild and under captive conditions have been recorded in a number of studies (Travis 1954, Warner et al. 1977, Lellis and Russell 1990, Forcucci et al. 1994, Sharp et al. 2000) and some initial research into artificial diets has been conducted (Pardee and Foster 1992, Sjoken 1999). While there has been very little research into commercial scale hatchery rearing of lobster larvae from eggs (Provenzano 1968, Kittaka 2000), there have been numerous studies into experimental capture of post-larval lobsters, or pueruli, from the wild using a variety of techniques (Little 1977, Gutierrez-Carbonell et al. 1988). This latter source of seed lobsters has considerable potential for extensive commercial scale aquaculture until effective hatchery techniques can be developed.

Therefore, the aim of this study was to review the existing research related to aquaculture of *P. argus* and identify those areas requiring further research and development to expedite the commercial aquaculture of this lobster.

SEED SOURCE

Panulirus argus, like most spiny lobsters, has a long and complex larval development, which proceeds through many stages and is thought to last for at least a year in the wild. Like many species of spiny lobster, the larval biology and ecology of this species is very poorly understood (Yeung and McGowan 1991). Larval development ends in a settling post-larval stage known as the puerulus, which molts to become a benthic dwelling juvenile lobster. Unlike other species of spiny lobster for which there is commercial aquaculture interest, there has been relatively little research into the hatchery production of *P. argus* pueruli (Robertson 1968, Provenzano 1968, Ingle and Witham 1968, Moe 1991, Booth and Kittaka 2000). However, there is a large and accessible supply of pueruli and early juveniles of *P. argus* available for harvest from the wild. Unfortunately, the commercial harvest of the early stages of *P. argus* for aquaculture is currently not permitted anywhere within the natural range of this species, as it is for spiny lobsters in other nations.

Ecological research indicates that pueruli collectors only remove a small proportion of the available pueruli from the wild, and that very large numbers or pueruli and early juveniles are lost to the wild fishery mainly through predation (Butler and Herrnkind 1988, Bannerot et al. 1988, Ryther et al. 1988, Butler and Herrnkind 1989, Forcucci et al. 1994).

Large numbers of wild pueruli and juveniles have been caught for research at a great many locations using a variety of simple and low cost techniques, such as floating and submerged habitats, dip nets, artificial benthic habitats as well as zooplankton nets suspended in tidal currents, towed behind boats or pushed through shallow water (Witham et al. 1964, Calinski and Lyons 1983, Reid et al. 1991, Field and Butler 1994, Phillips and Booth 1994). Suction dredges and benthic trawls have been shown to be an ineffective method of catching early lobsters (Sweat 1968). A great variety of floating and submerged artificial habitats have provided reliable catches of pueruli. Although these artificial habitats have taken many forms, they all provide an abundance of fine scale structural complexity for the pueruli to hide in. These include folded sheets of fibrous material in the Witham collector (Witham et al. 1968), masses of tassels of synthetic fibers in the GuSi collector (Gutierrez-Carbonell et al. 1992) and a modified Phillips (Phillips 1972) collector consisting of a triangular frame of aluminum and PVC sheets holding artificial seaweed (Cruz et al. 1991, 1995).

The geographical and temporal extent of the use of these collection techniques suggest that provided the collectors are placed in suitable areas they will reliably catch pueruli, although the numbers will often vary markedly with location, season and lunar phase (Little 1977, Bannerot et al. 1987, Coton and Nijean 1987, Monterrosa, 1987, Briones-Fourzan and Gutierrez-Carbonell 1988, Butler and Herrnkind 1988, Bannerot et al. 1991, Heatwole et al. 1991, Aguilar et al. 1992, Bannerot et al. 1992, Quinn et al. 1992). For example, nearly 23,000 seed lobsters were taken in less than a year in Antigua using only 28 very small floating collectors (Bannerot et al. 1988). Lellis (1991) estimated that a single floating pueruli collector would trap an average of 300 to 400 pueruli a year in Florida and Antigua. In 185 hours of nighttime sampling using a lantern and a dip net from a dinghy 2,751 pueruli were taken in a shallow bay in Granada (Calinski and Lyons 1983).

The efficiency of these techniques could readily be improved for commercial scale seed lobster collections for aquaculture as they have been in Australia and New Zealand (Jeffs and Hooker 2000). Bannerot et al. (1988) estimated it would cost around US$75,000 to collect around 23,000 pueruli using basic research techniques and including salary for two scientists, scientific equipment, house rental, office and vehicle. Commercial scale collections would be significantly more efficient and could be expected to provide large numbers of pueruli at an estimated cost of US$0.05 to $0.30/seed lobster, which is substantially less than the cost of seed lobsters previously collected for aquaculture in New Zealand (Jeffs and Hooker 2000). Collected pueruli and early juveniles can be transported considerable distances to grow out locations provided they are carefully packed to create the correct conditions (Witham 1970, Lellis and Russell 1990).

GROW OUT

Land-based Culture

Small-scale grow out of lobsters for research in Florida and the Caribbean has been comprised of a variety of seawater systems including flow through, semi-recirculation and full recirculation systems with few problems being encountered (Travis 1954, Ting 1973, Witham 1973, Warner et al. 1977, Quackenbush and Herrnkind 1981, Lipcius and Herrnkind 1982, Ryther et al. 1988, Glaholt 1990, Lellis and Russell 1990, Pardee 1992a, 1992b, Pardee and Foster 1992, Field and Butler 1994, Sjoken 1999, Sharp et al. 2000). Likewise, these studies report lobsters being experimentally grown in a range of tank environments including glass aquaria, as well as fibreglass, plastic and concrete tanks, with and without shelters. Possible differences between tank design and holding conditions have not been explored in detail and may not make a great deal of difference in the growth and mortality of cultured lobsters.

Spiny lobsters, including *P. argus*, are naturally gregarious, however, high tank stocking rates have been shown to inhibit growth in a number of other spiny lobster species (Childress and Herrnkind 1994, Geddes et al. 2001). In addition, limited or poor quality feed is known to induce extensive cannibalism in *P. argus* especially among early captive juveniles. Information of appropriate stocking densities over a range of juvenile sizes for *P. argus* have not been experimentally determined although good growth rates have been obtained at potential commercial densities in experiments designed to test other grow out factors. Increases in stocking densities, equivalent to 266, 533 and 666 juvenile lobsters per m^2 of tank floor were found to produce corresponding decreases in survival due to cannibalism (Díaz-Iglesia et al. 1991). High mortalities of 22-33% over nine weeks at much lower experimental densities of 17.4 and 34.8 juvenile lobsters per m^2 of tank floor were encountered in another study suggesting that improvements in food availability and quality will be a necessary prerequisite for establishing high density grow out systems (Pardee and Foster 1992).

Sea-cage Culture

Only a few studies have investigated the cage culture of *P. argus*, a method that is showing considerable promise in other parts of the world for commercial grow out (Jeffs and James 2001). A 500 m^2 sea-cage was stocked with 15,000 wild caught juvenile lobsters taken from the Brazilian fishery and some growth was recorded after 60 days of holding (Assad et al. 1996). Wild-caught juvenile lobsters (200 - 250 g) apparently performed well in terms of growth when they were stocked into sea-cages at 1.1 per m^2 over 30 days in a shallow canal in the Bahamas (Brown et al. 1995, 1999). Seafloor cages (3 x 3 x 1 m) have also been used in Mexico for holding and feeding juveniles (40 - 81 mm CL) taken from the fishery in an attempt to increase biomass yield (Lozano-Alvarez 1996). However, the overall biomass in every experimental treatment did not increase due to high mortality, probably related to the high stocking densities used (up to 18 kg of biomass per m^2 and up to 88

lobsters per m^2). Other studies have also attempted to increase the biomass of harvested lobsters through impounding and feeding with mixed results (Creswell 1984). Lobsters have also been experimentally cultured from early juveniles in seafloor cages in Puerto Rico (Ting 1973). The cages (0.9 x 1.2 x 1.8 m with 25 x 38 mm plastic coated wire mesh) were stocked at around 25 lobsters per cage and over two years the lobsters grew rapidly to 250 - 300 g in the second year, and to 750-900 g in the third year.

Water Quality Parameters

Water quality and flow rates required for cultured juvenile *P. argus* have not been precisely determined, but they are likely to be very similar to other species of spiny lobster, especially the tropical species *Panulirus cygnus* from Australia (Geddes et al. 2001). The oxygen consumption rates of early juvenile *P. argus* has been recorded and found to increase crepuscularly, during premolt and postmolt, and with increasing water temperature up to 30°C and was at its lowest at a salinity of 35ppt (Brito Pérez and Díaz-Iglesia 1987a, Brito et al. 1991). Mean oxygen consumption at 27°C for large juveniles of 50 - 340g at rest was 0.09 - 0.12 ml (about 0.13 - 0.17 mg)/g body weight/h) and was lethal at some value below 1.95 ml (2.79 mg)/l (Maynard 1960, Buesa 1979). There is also an indication that *P. argus* may avoid waters with high silt loadings, which may be an important consideration in siting aquaculture developments (Herrnkind and Butler 1988).

A number of studies have examined growth rates in relation to water temperature. Maximum growth of early juveniles was found to be at 29 to 30°C, but feed conversion was higher at 27°C (Lellis 1991). Likewise, growth of lobsters from pueruli was greater for animals reared at 30°C than for animals reared at 24, 27, or 33°C, and experimental lobsters at 33°C had lower survival and lower feed conversion than lobsters held at 30°C (Lellis and Russell 1990). Similar results were found in a study in Cuba where the best economic return was estimated to be at a grow out temperature of 28°C (Díaz-Iglesia et al. 1991). Witham (1973), however, found the most rapid growth among juveniles was at lower temperatures of 25 - 27°C, and that they were unable to survive when held at temperatures below 15.6°C or above 32.2°C. He also found that early postlarval lobsters were more likely to die at temperature extremes than larger juveniles.

In the wild early juvenile *P. argus* are frequently found in areas of lowered salinity such as mangroves and upper Florida Bay and are therefore able to withstand low salinity conditions (as low as 19 ppt) as well as fluctuations from ideal (32 - 36 ppt) to as low as 25 ppt (Witham et al. 1968; Buesa 1979, Acosta and Butler 1997, Field and Butler 1994). Tolerance to altered salinities also appears to be greatly reduced by extremes in holding water temperatures (Field and Butler 1994).

Photoperiod and Ablation

A number studies have investigated eyestalk ablation and the manipulation of photoperiod as a means of increasing growth rates of cultured juvenile *P. argus*, however, neither techniques have produced improvements in growth that would be

useful for commercial scale grow out (Maynard and Dingle 1963, Maynard and Yager 1968, Maynard and Sallee 1970, Lipcius and Hermkind 1982, Brito Pérez and Díaz-Iglesia 1983, Quackenbush and Hermkind 1983, Brito Pérez and Díaz-Iglesia 1987a, 1987b, Díaz-Iglesia et al. 1987, Lipcius and Hermkind 1987, Brown et al. 1995, 1999).

Diet

Most spiny lobster species perform well in culture when provided with a diet of fresh molluscs (Geddes et al.,2001) and the same pattern has been found for *P. argus*. For example, Ting (1973) found the Caribbean beach clam, *Donax denticulatus*, was an ideal food for captive lobsters. Likewise, a number of other studies have used molluscs, and other seafood material such as fish and prawn waste as food for juvenile lobsters (Assad et al. 1996, Lozano-Alvarez 1996, Díaz-Iglesia et al. 1991, Sjoken 1999). Brine shrimp have been used for experimental culturing of early juvenile lobsters, however, the results indicated that this diet was inadequate as mortalities were high on live brine shrimp. The mortalities were higher again for treatments fed frozen brine shrimp (Pardee 1992a, 1992b, Pardee and Foster 1992). Sjoken (1999) evaluated three artificial diets including a commercial Homarid lobster feed for growth, survival and biomass on juvenile *P. argus* and found that none of the artificial feeds performed nearly as well as the natural food. A range of artificial diets based on soybeans were found to produce good growth in juvenile lobsters, however, mortalities and a control diet were not reported from the study making their effectiveness difficult to assess (Brown et al. 1995, 1999). Lellis (1992) assessed the feasibility of using two reference diets from the American lobster, *Homarus americanus*, for early juveniles of *P. argus* and found that neither was suitable because mortality was high and growth poor. These results confirm other findings which strongly suggest that the metabolism and dietary requirements of spiny lobsters are markedly different to other groups of crustaceans and will require separate development (Crossland 1988).

Growth Rates

A wide range of growth rates of *P. argus* in culture have been reported and are summarised in Figure 1. The growth rates of this species both in the wild and under captive conditions have been recorded in a number of studies (Travis 1954, Olsen and Koblic 1975, Warner et al. 1977, Lellis and Russell 1990, Forcucci et al. 1994, Sharp et al. 2000) and some initial research into artificial diets has been conducted (Pardee and Foster 1992, Sjoken 1999). Very rapid growth rates are achievable in culture, for example male lobsters have been grown from first instar juveniles to 450 g in 12 months and 1.4 kg in two years (Lellis and Russell 1990, Lellis 1991).

Disease

There are few reports of disease in *P. argus*, although a small number of disorders have been reported in spiny lobster species elsewhere. A number of these such as fungal infections are likely to be widespread and capable of rapid

proliferation in the preferred temperature range of *P. argus* (Evans and Brock 1994, Porter et al. 2001). More recently a lethal and highly contagious virus has been reported among wild and captive juvenile lobster in the Florida Keys, however, it would seem that this disease can be prevented in land based grow out through relatively simple water treatment systems (T. Matthews and M. Butler IV pers. comm.).

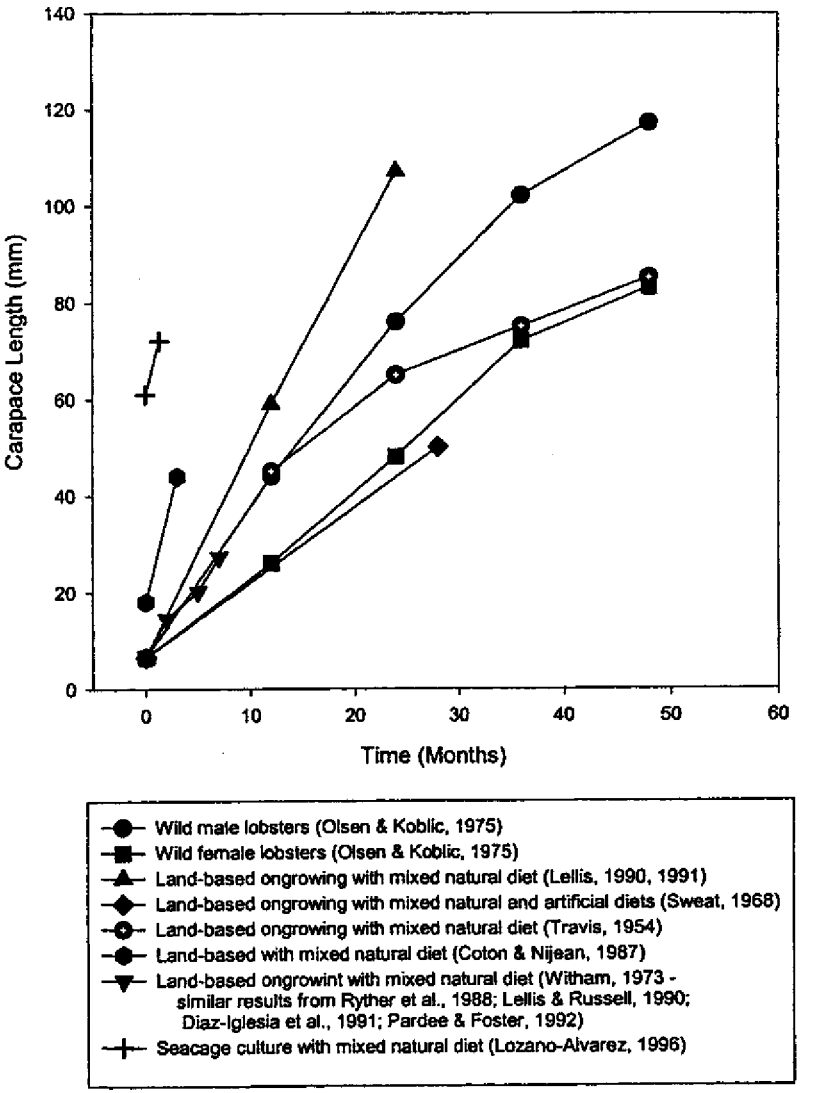


Figure 1. Growth rates for spiny lobster, *Panulirus argus*, under captive conditions. Sizes are reported in carapace length (mm).

DISCUSSION

Overall, this review indicates that the prospects for profitably farming this species of spiny lobster are excellent and far more likely than for temperate species, due to the greater availability of wild seed lobsters and more rapid growth rates (Booth and Kittaka 2000). Sea-cage culture or land-based tank culture are probably both feasible, with the former technique being less capital intensive. However, further research is required to design and develop efficient grow out systems especially in relation to stocking densities, provision of shelters, and feeding regimes. Previous studies have indicated that feed is likely to make up more than 25% of the production cost of cultured spiny lobsters (Jeffs and Hooker 2000). Therefore, a cost-effective feed for *Panulirus argus* is probably the single most important obstacle to large-scale commercial aquaculture development of this species. Some preliminary work has been done in Cuba and in the United States, and there are strong indications that there is excellent potential to rapidly develop an effective artificial diet. A number of commercial diets for spiny lobster are currently available in the USA, however, grow out studies by the authors indicates they are less than optimum. Considerable work is now underway in New Zealand and Australia on artificial grow out diets for different species of spiny lobsters and it is likely that this research will result in advanced formulations that can also be effectively transferred to the culture of *Panulirus argus*.

ACKNOWLEDGEMENTS

This research was supported by an OECD Fellowship and a NZ/USA STC CSP Programme Award to the first author. The project also received funding support from the Foundation for Research, Science and Technology for accessing the extensive literature required for this research. We are also very grateful to Mark Butler, John Hunt, Sarah Pausina, and NIWA librarians for providing support to this project. Harbor Branch Oceanographic Institution contribution number 1484.

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Captive Breeding for the Gastropod Conch (*Strombus* spp.)

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ABSTRACT

A captive breeding program for three non-restricted Caribbean *Strombus* conch species: *S. raninus*, *S. alatus*, and *S. costatus*, as well as the commercially threatened *S. gigas* was established at Harbor Branch Oceanographic Institution in June 2000. A total of 24 adult conch were collected from the Florida Keys: five *S. costatus* (3 female, 2 male), seven *S. raninus* (5 females, 2 males), eight *S. alatus* (4 females, 4 males) and four *S. gigas* (1 female, 3 males). They were placed in a circular tank (4.5 m dia) that was divided into four equal quadrants (4.1 m^2). Egg masses from the breeding tank were measured for size, number of eggs, and egg capsule and strand diameter. In 40 weeks, 426 egg masses were collected. A total of 341 egg masses were collected from the five *S. raninus* females. The four *S. alatus* females laid 58 egg masses, the three *S. costatus* females laid a total of 23 egg masses, and the single *S. gigas* female laid 4 egg masses in mid-February. The viability of several eggs from all four species was confirmed by successfully hatching and culturing the larvae to the juvenile stage. The breeding success of these species holds promise for the establishment of a commercial captive breeding program, and may provide alternative conch species for the food markets and the aquarium trade.

KEY WORDS: Conch, spawning, *Strombus*

INTRODUCTION

For years conch belonging to the Family Strombidae have been harvested as a food source, building material, and decoration. There are seven *Strombus* species in the Caribbean and Florida region: *Strombus gigas*, *S. costatus*, *S. raninus*, *S. alatus*, *S. pugilis*, *S. gallus*, and *S. goliath* (Abbott 1974). Of these species, *S. gigas*, the queen conch, holds the highest commercial value as a subsistence and commercial fisheries product (Brownell 1977, Berg 1976). Beginning in the 1970s, the *S. gigas* fishery became impacted by overfishing, which eventually led to the enactment of several regulations (Appledoorn 1994). However, management strategies alone cannot keep up with the fishing pressures of today. Captive breeding and larval rearing are now promising means of raising juvenile *S. gigas* for the market and for restocking efforts (Davis 2000).

Today, scientists still rely upon wild adult populations of *S. gigas* for egg masses. Often it can be difficult to find egg masses in the wild due to limited spawning aggregations, low copulation frequency, and seasonal breeding. Establishing a captive breeding program would alleviate the need to collect egg masses from the wild and possibly extend the breeding season. Prior to this

experiment, there have been no commercial captive breeding programs. However, spawning and egg-laying in captivity has been observed for *S. costatus*, *S. pugilis*, a close relative to *S. alatus*, and *S. raninus*, but only on a small, research scale (Bradshaw-Hawkins 1982, Davis et al. 1993, Reed 1995a, Reed 1995b).

The purpose of this experiment was to document the breeding activities for four *Strombus* species: *S. raninus, S. alatus, S. costatus*, and *S. gigas*. The number of egg masses laid per female on a weekly and daily basis was recorded, the size and number of eggs per mass was determined, and the viability of the eggs laid in captivity was assessed through larval and juvenile rearing. The results from this study will assist in developing a permanent captive breeding program at Harbor Branch Oceanographic Institution in Fort Pierce, Florida USA.

MATERIALS AND METHODS

The captive breeding study was conducted at Harbor Branch Oceanographic Institution (HBOI), Ft. Pierce, Florida from June 15, 2000 – March 22, 2001. Four Florida and Caribbean *Strombus* species: *S. raninus*, *S. alatus*, *S. costatus*, and *S. gigas*, were used in the study. A total of 24 adult conch were collected from the Florida Keys: five *S. costatus* (3 female, 2 male), seven *S. raninus* (5 females, 2 males), eight *S. alatus* (4 females, 4 males) and four *S. gigas* (1 female, 3 males). The *S. gigas* adults were hatchery-reared conch from the Florida Fish and Wildlife Conservation Commission (Glazer, unpubl. data). The sex of each conch was determined, by examining the external sex organs. The males and females were then numbered with fluorescent enamel paint (Shawl and Davis, in prep). The adult conch were covered with towels moistened with seawater and transported to HBOI in coolers.

Based on the availability of broodstock, the conch were stocked at varying densities and sex ratios: *S. gigas* were held at 0.98 conch/10 m^2 and a 1:3 female:male ratio, *S. raninus* conch were held at 1.7 conch/10 m^2 and a 3:1 ratio, *S. alatus* were stocked at 2 conch/10 m^2 and a 1:1 ratio, and *S. costatus* were held at 1.2 conch/10 m^2 and a 1:1 ratio. The broodstock were fed a total of 550-650 g of koi chow and *Ulva* gel diet daily (Shawl and Davis, in prep). Approximately 21 g were fed per day to each *S. raninus*, 19 g fed per day per *S. alatus*, and 50-70 g fed per day to each *S. costatus* and *S. gigas* conch.

The 4.5 m dia (0.9 m high) breeding tank at HBOI is on a recirculating system (Figure 1, 2). The initial and replenishment water (30 L/hr) for the system is pretreated water from a shallow salt water well. For this experiment, the breeding tank was divided into four equal areas (4.1 m^2) using 30 cm high polypropylene mesh (2.5 cm openings) (Figure 2). The breeding tank is designed to be a subgravel filter (Figure 1). Approximately 10 cm of sand is supported 15 cm above the bottom of the tank. The Bahamian aragonite sand (1 - 3 mm dia) is the substrate for the broodstock and also acts as the biofilter for the system. The water depth above the sand substrate is 45 cm. The recirculating water enters the tank both through angled spray bars and under the substrate (Figure 1). The water filters through the sand and

returns to the pump from the bottom of the tank. The water goes through a sand filter prior to being pumped into the breeding tank. This filter is backwashed every two weeks.

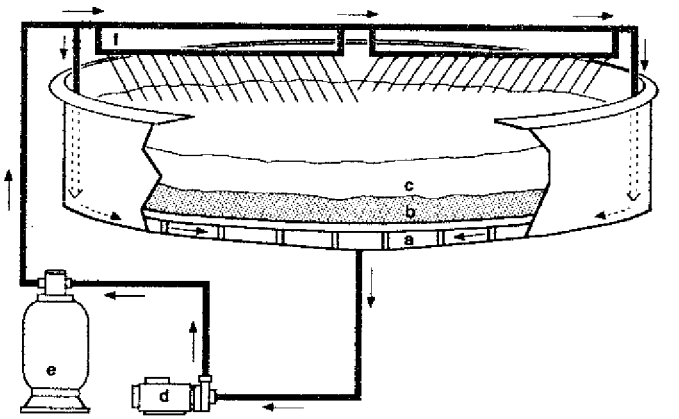


Figure 1. The Strombidae broodstock tank at HBOI: a) undergravel support, b) sand substrate, c) water column, d) pump, e) sand filter, and f) spray bars (drawing by Jackie Arosan).

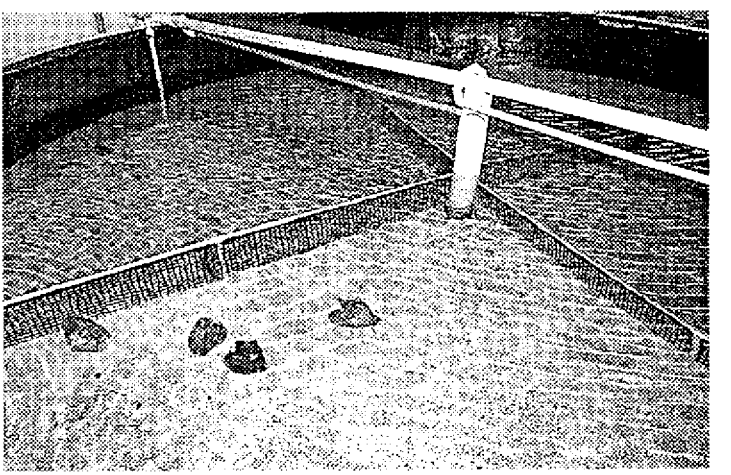


Figure 2. Strombidae broodstock tank at HBOI shows sand substrate and four breeding areas for *S. gigas*, *S. costatus*, *S. raninus*, and *S. alatus*.

Temperature, salinity, and pH were recorded daily and ammonia was determined weekly. Water temperature in the warmer months was 27.5 - 28.5°C, average salinity was 32 ‰, average pH was 8.0, and ammonia was 0.06 - 0.10 mg/L (Table 1). The breeding tank is inside a shaded greenhouse. Along with natural light, a small amount (250 watts) of artificial lighting is used above the tank for a 12 hour cycle (8am – 8pm). The tank water was heated during the winter months using a 4000 watt heater, to increase the ambient temperature to 24 - 27°C.

When an egg mass was found, it was removed with either a net or by hand and placed onto a wet table for measurements (length, width and height). Several egg masses were stretched to determine total length of the egg strand and the number off eggs per mass (n =13 for *S. raninus*, n =10 for *S. alatus*, and n =10 for *S. costatus*). Strand length was not determined for *S. gigas* masses because the eggs were used for culture. The strand diameter (µm), egg capsule diameter (µm), the number of eggs per mm of strand length, and newly hatched veliger size (µm) were also recorded using a compound microscope (40 X) equipped with a 1 mm micrometer. In order to determine whether or not the eggs were fertilized, several batches of each specie was hatched and cultured through juvenile stage using techniques described by Davis (1994, 2000) and Davis and Shawl (in review).

Table 1. Water quality records for the broodstock tank (June 2000 - March 2001) and the replenishment water (June 2000). The number in parentheses represents the number of samples.

	Tank Water	Replenishment Water
Temp (°C)	27.4 ±2.11 (277)	28.3
Salinity (‰)	33.5 ± 1.25 (255)	33
Ammonia (mg/L)	0.1 ± 0.02 (39)	0.08
pH	8.1 ± 0.28 (242)	7.7
Nitrite	0.009 ± 0.006 (6)	NA
Ca+ ion Concentration	429 ± 12.7 (2)	403
Dissolved Oxygen	6.2 (1)	4.09
ORP	203.1 (1)	195

RESULTS

From June 15, 2000 – March 22, 2001 (282 days), a total of 426 egg masses were collected. The *S. raninus* females spawned persistently through November and again in March, and laid 341 egg masses. The four *S. alatus* females laid 58 egg masses, the three *S. costatus* females laid a total of 23 egg masses, and the single *S. gigas* female laid 4 egg masses beginning in February. During the first 22 weeks, each *S. raninus* female laid approximately 2.8 egg masses per week. They ceased egg production for 15 weeks (November – February), and then began to lay again during weeks 38 and 39 at 0.42 egg masses per female per week. The *S. alatus* females laid egg masses on a regular basis for the first 15 weeks, with each individual female laying roughly 0.48 eggs masses per week. The *S. alatus* females then underwent a period of quiescence from week 16 (October) until week 30 (January), and then began to spawn again, during weeks 31 thru 40, at a frequency of 0.44 egg masses per female per week. Each *S. costatus* female laid approximately 0.3 egg masses per week during the first 10 weeks. After this date, the *S. costatus* females did not lay eggs again until weeks 30 (January) thru 40 (March) at a frequency of 0.25 egg masses per female per week. The *S. gigas* female laid four egg masses from weeks 35 thru 40. Temperature records show an increase in temperature in January (week 31) and again in February (week 37) which corresponded to the start of egg-laying for *S. gigas* and initiated egg-laying activity for *S. raninus*, *S. alatus*, and *S. costatus* again (Figure 3).

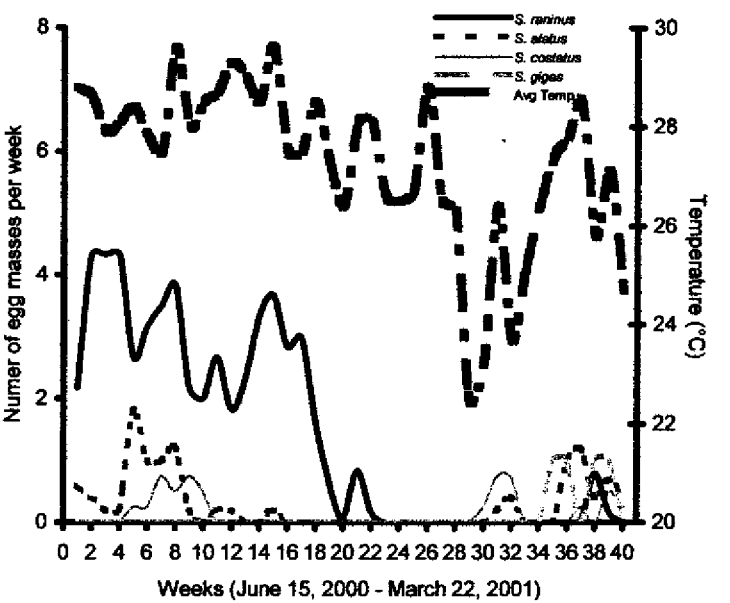


Figure 3. Average number of egg masses collected from each female conch on a weekly basis in comparison with weekly average temperatures for the duration of the breeding experiment at HBOI (June 15, 2000 – March 22, 2001).

The egg strand measurements obtained in this experiment were compared to published literature (Table 2). All four species laid viable eggs in captivity, and the veligers were successfully raised through metamorphosis to the juvenile stage. The larvae were cultured according to Davis (1994, 2000), and metamorphosis was induced using the hydrogen peroxide procedure (Boettcher et al. 1997). Once the post larval conch reached 3 – 4 mm shell length (SL), they were placed on sand trays in a recirculating system at a density of 3200 conch/m^2 (Davis and Shawl, in review) (Figure 4).

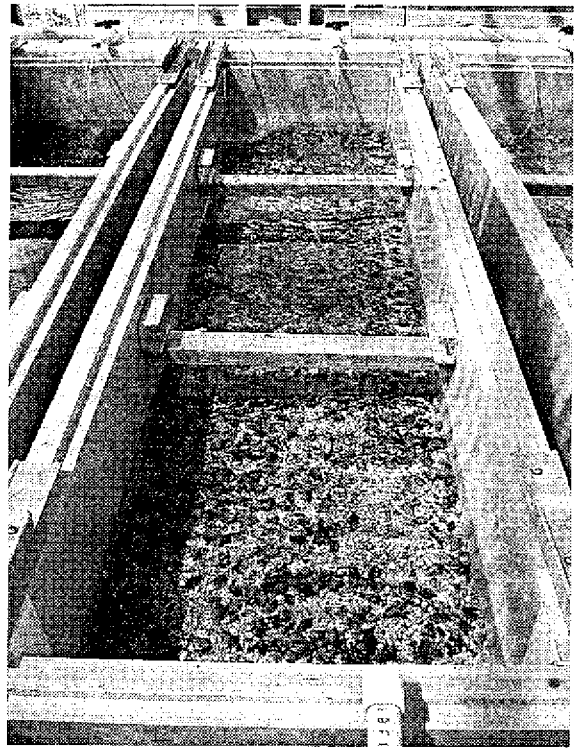


Figure 4. Sand tray for juvenile conch (3 – 40 mm SL).

Table 2. Summary of egg mass and veliger data from this experiment (bolded numbers) shown in comparison to published data. The numbers in parentheses indicate the number of samples.

Variables	*S. raninus*	*S. alatus*	*S. costatus*	*S. gigas*
Length of egg mass (cm)	**3.5 - 15.5 (315)** *4 - 7 (4)*[c]	**4.5 - 9 (30)**	**9.5 - 30 (10)** *6 - 10 (2)*[c]	**9 (1)** *8 - 15 (9)*[c]
Diameter of egg strand (µm)	**351 ± 24 (40)*** *321 ± 20 (10)*[c]	**509 ± 41 (20)*** *600*[b]	**825 ± 56 (9)*** *761 ± 18 (10)*[c]	**798 ± 18 (2)** *785 ± 44 (10)*[c]
Length of uncoiled strand (m)	**7.0 ± 2.0 (13)** *20*[a]	**10.8 ± 21.4 (10)** *10.7*[b]	**19 ± 9.7 (9)**	**N/A** *22.6*[a]
No. eggs/mass	**91,000-250,000 (13)** *206,000 - 245,000 (2)*[c] *400,000 - 460,000*[a]	**76,000-182,00 (10)** *92,000 (2)*[b]	**87,000-440,000 (9)** *185,000 - 210,000*[a]	**N/A** *313,000 - 485,000*[d]
No. egg capsules per mm	**15 - 34 (40)** *21 - 25 (15)*[c], *20 - 23*[a]	**11 - 15 (20)** *8.6*[b]	**10 - 13 (9)** *12 - 14 (10)c*	**12 - 15 (3)** *14 - 16 (10*[c]
Egg capsule diameter (µm)	**123 ± 10 (40)** *140 ± 4 (30)*[a]	**181 ± 11 (20)** *170*[b]	**250 ± 9 (9)** *262 ± 6 (20)*[c]	**233 ± 11 (2)** *225 ± 17 (20)*[c]
Newly hatched veliger SL (µm)	**205 ± 10.5 (10)** 197 ± 8 (20)[c]	**298 ± 14.2 (10)**	**370 ± 10.5 (10)** 388 ± 14 (20)[c]	**198 ± 14 (2)** *354 ± 15 (20)*[c]

[a] Robertson (1959) [b] D'Asaro (1986) [c] Davis et al. (1993) [d] Randall (1964)

DISCUSSION

The Florida and Caribbean *S. gigas* fishery stocks are threatened today and alternative conch species for the queen conch market need to be identified. Although there have been efforts to cultivate *S. gigas* as well as replenish their populations in the wild, only one commercial queen conch farm exists, and large-scale restocking efforts have not been attempted. This experiment examined the feasibility of a captive breeding program for S. *gigas* as well as for alternative, non-threatened *Strombus* species. All four species reproduced and spawned viable eggs in captivity. A total of 426 egg masses were collected in 40 weeks. There are two possible explanations for this success. First, the male and female conch were aggregated, as they tend to do in the wild (Berg 1975, Robertson 1959), which increases the likelihood that reproduction would occur. Secondly, the conch were provided with a stable breeding site that was devoid of predators, had optimal water quality conditions, had a consistent supply of food, and a sand substrate. In early January, the water temperature in the breeding tank spiked (from 23°C to 28°C) due to a warm front and *S. alatus* and *S. costatus* females laid egg masses again after two months of quiescence. Similarly, the *S. gigas* female spawned on February 12, 2001, which is not typical of this seasonal summer breeder. This supports the studies that show temperature and photoperiod control reproductive activity (Stoner et al. 1992).

This experiment was successful in demonstrating that spawning and egg-laying for four *Strombus* species can be achieved reliably in captivity. The breeding tank at HBOI is now being used to commercially produce *S. alatus* egg masses for production of juveniles for the aquarium trade. Future captive breeding studies for *S. alatus* and *S. gigas* at HBOI will include diet, temperature, photoperiod, and sex ratio manipulations. Determining these parameters will enhance the productivity of a captive breeding program and will alleviate the need to collect egg masses from the wild. Production of *S. gigas* and alternative *Strombus* species will take the pressure off the fisheries and provide juveniles for food and aquarium markets, as well as stock enhancement programs.

ACKNOWLEDGEMENTS

The authors would like to thank the following individuals for their contributions to this experiment: Richard Greenfield, Jr. from CaribSea, Inc., Buddy and Joe Pinder from the Keys Marine Conservancy, Bob Glazer from the Florida Fish and Wildlife Conservation Commission; and Tom Smoyer, Brian Cousin, Jackie Arosan, Tina Powell, Riccardo Russo, and The Link Foundation from Harbor Branch Oceanographic Institution, Inc. This is Harbor Branch Oceanographic Institution, Inc. contribution #1460.

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La Larvicultura de *Strombus gigas* en el Laboratorio de Biología Marina del CINVESTAV IPN Unidad Mérida

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RESUMEN

El presente trabajo resume los resultados obtenidos a lo largo de 10 años de investigación sobre la larvicultura de *Strombus gigas*, realizado en el laboratorio de Biología Marina del CINVESTAV IPN Unidad Mérida.

Durante los diferentes cultivos se ha empleado la misma metodología: temperatura de 29° ± 1°C, densidad de 200 larvas por litro, alimentación con *Tetraselmis suecica* a una concentración de 1,000 células algales por mililitro.

El sitio de muestreo para la obtención de las masas de huevos ha sido el Arrecife Alacranes. Se realizaron 22 cultivos durante los meses de marzo, abril, mayo, junio, julio, agosto y septiembre.

El tiempo de eclosión varió entre 92 y 96 horas con una media de 94 ± 1.51 horas después de la ovoposición.

La longitud sifonal al momento de la eclosión fue de 300 ± 6.17 µm (n = 1980 larvas).

Al eclosionar las larvas de los meses de junio, julio y agosto, presentaron cuatro lóbulos del velum y 2.0 vueltas de espira de la concha (n = 810 larvas), mientras que las de marzo, abril, mayo y septiembre mostraron dos lóbulos del velum y 1.5 vueltas de espira (n = 1 170 larvas).

Las larvas alcanzaron al momento de la metamorfosis una longitud sifonal entre 867 y 893 µm, con una media de 879 ± 1.23 µm, para los meses de junio, julio y agosto, mientras que las larvas del otro grupo de meses lograron una longitud sifonal entre 879 y 902 µm, con un promedio de 879 ± 5.28 µm.

Los resultados obtenidos muestran que las larvas de los primeros meses de la temporada de reproducción en el Arrecife Alacranes tienen un desarrollo más lento en relación con las larvas de los meses intermedios de dicha época, sin embargo el crecimiento en similar para ambos grupos de meses.

PALABRAS CLAVES: *Strombus gigas*, larvicultura, Yucatán

The Larviculture of *Strombus gigas* in the Marine Biology Laboratory of CINVESTAV IPN Unidad Mérida

The present work summarizes the results obtained throughout 10 years of investigation on the larviculture of *Strombus gigas*, made in the laboratory of Marine Biology of CINVESTAV IPN Unit Mérida.

During the different cultures the same methodology has been used: temperature of 29° ± 1° C, density of 200 larvae/L, feeding with *Tetraselmis suecica* at a concentration of 1 000 algal cells/ml.

The site of sampling for the obtaining of the masses of eggs has been the Alacran Reef. Twenty two cultures were made during the months of March, April, May, June, July, August and September.

The time of appearance varied between 92 and 96 hours with a 94 average of ± 1.51 hours after the ovoposition. The shell length at hatching was of 300 ± 6.17 µm (n = 1980 larvae).

At hatching the larvae of the months of June, July and August, presented four velar lobes and 2.0 shell whorls (n = 810 larvae), whereas those of March, April, May and September showed two velar lobes and 1.5 shell whorls (n = 1 170 larvae).

The larvae reached at the time of the metamorphosis a shell length between 867 and 893 µm, with a 879 average of ± 1.23 µm, after the months of June, July and August, whereas the larvae of the other group of months obtained a shell length between 879 and 902 µm, with a 879 average of ± 5.28 µm.

The obtained results, nevertheless, show that the larvae during the first months of the season of reproduction in the Alacran Reef had a slower development in relation to the larvae of the intermediate months; the growth was similar for both groups of months.

KEY WORDS: *Strombus gigas*, larviculture, Yucatan, laboratory

INTRODUCCION

El caracol reina *Strombus gigas*, es uno de los más importantes recursos demersales de la región del Caribe. Actualmente en la mayoría de los países donde se distribuye, sus poblaciones se encuentran sobre-explotadas, a pesar de existir diversos programas de manejo, con regulaciones que van desde el cierre total de la pesquería, hasta el uso de tallas límite de captura, períodos de veda y cuotas de captura (Appeldoorn y Rodríguez 1994).

En México, la producción del caracol reina o rosado, *S. gigas*, ha caído drásticamente, habiéndose decretado una veda permanente para su explotación a partir del año 1988 (Diario Oficial de la Federación), con lo cual se dañó la economía de pescadores que vivían únicamente de la explotación de éste recurso (de Jesús Navarrete 1999).

economía de pescadores que vivían únicamente de la explotación de éste recurso (de Jesús Navarrete 1999).

El empleo de la maricultura y de la cría en el laboratorio desde el huevo hasta la metamorfosis para restaurar las poblaciones agotadas *de S. gigas*, ha sido propuesto por numerosos investigadores (Berg 1976, Berg 1981, Ballantine and Appeldoorn 1983, Davis and Hesse 1983, Creswell and Davis 1991, Davis et al., 1993). Aunque el cultivo pueda no ser una ayuda directa a la pesquería como lo ha determinado Chanley (1983), constituye un mecanismo de repoblación en apoyo a las poblaciones reproductoras.

El desarrollo de las técnicas orientadas hacia su cultivo se ha debido a la dedicación que investigadores de instituciones gubernamentales, universidades y empresas privadas han realizado sobre el recurso. Se han hecho contribuciones significativas hacia el logro del cultivo de *S. gigas* en un esfuerzo por restablecer las poblaciones naturales afectadas y permitir el nacimiento de la industria de su acuicultura en las naciones del Caribe y Latinoamérica. El intercambio cooperativo de información e ideas ha facilitado el desarrollo de su maricultura (Creswell 1994).

En este sentido en el laboratorio de Biología Marina del CINVESTAV IPN Unidad Mérida, se han realizado investigaciones durante 10 años, sobre la factiblidad de realizar el cultivo de *Strombus gigas*, empleando la tecnología desarrollado por Instituciones del Caribe, los resultados obtenidos son presentados en éste trabajo.

MATERIALES Y METODOS

En el presente trabajo se resumen los resultados obtenidos a lo largo de 10 años de investigación sobre la larvicultura de *Strombus gigas*, realizado en el laboratorio de Biología Marina del CINVESTAV IPN Unidad Mérida.

El sitio de muestreo para la obtención de las masas de huevos fue el Arrecife Alacranes (Figura 1). La colecta fue realizada siempre de hembras que se encontraban en ovoposición. Las masas fueron colocadas en termo-recipientes de plástico con agua de mar para su transporte al laboratorio de Biología Marina del CINVESTAV IPN Unidad Mérida.

Una vez en el laboratorio cada masa de huevos fue colocada sobre un tamiz de 300 µm de luz de malla, sumergida en un recipiente de plástico con capacidad de 25 litros con agua de mar filtrada a 2 µm y esterilizada con luz U.V. La temperatura de incubación fue de 29° ± 1°C. Los recambios de agua y de tamiz se realizaron cada 24 horas hasta el momento de la eclosión.

Las larvas velígeras recién eclosionadas se cultivaron en recipientes de plástico inertes con capacidad de cuatro litros a una densidad de 200 larvas/L. Las larvas fueron alimentadas con la microalga *Tetraselmis suecica* a una concentración de 1 000 cél/ml, realizando cambios de agua y alimentación cada 24 horas. El alimento fue proporcionado una sola vez al día por la mañana.

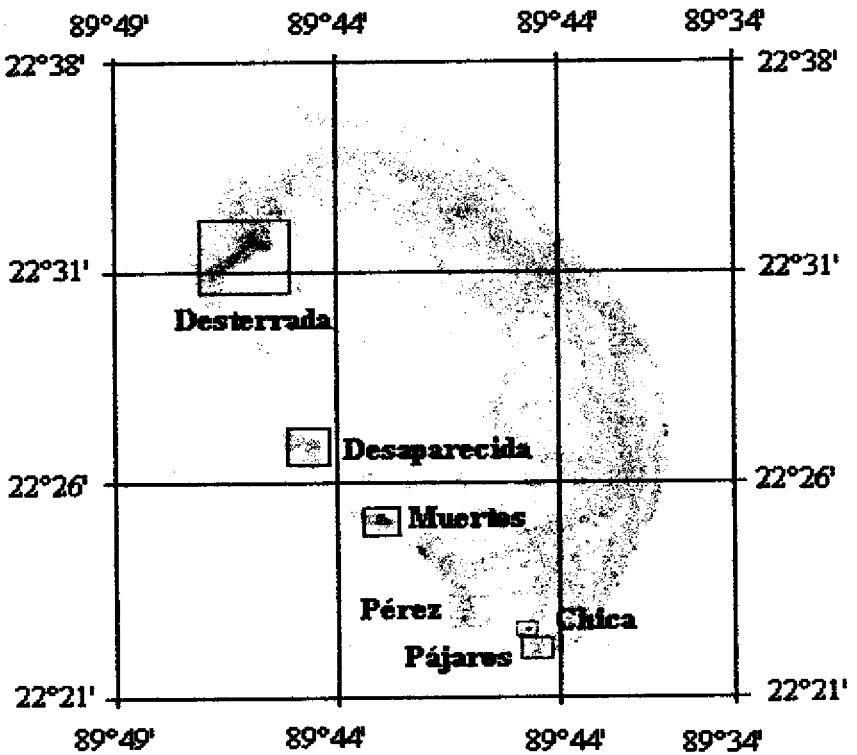


Figura 1. Arrecife Alacranes, sitio de muestreo durante los 10 años de investigación.

RESULTADOS

Desarrollo

El tiempo de eclosión para las larvas de las 22 masas de huevos empleadas en los cultivos, varió entre 92 y 96 horas con un promedio de 94 ± 1.51 horas después de la ovoposición. En la Tabla 1 se presentan los tiempos de eclosión para las masas obtenidas durante los siete meses de muestreo.

De los resultados obtenidos a lo largo de las investigaciones, se dividieron a las larvas en dos grupos de meses, (un grupo que incluye los meses de marzo, abril, mayo y septiembre y otro grupo en el cual se encuentran los meses de junio, julio y

agosto), de acuerdo a las similitudes que presentaron en relación al desarrollo y crecimiento observados, sin tomar en cuenta el año del muestreo, dado que no existieron diferencias a lo largo de los años estudiados.

Tabla 1. Tiempos de eclosión en horas para las masas de huevos obtenidas durante los meses de muestreo en el Arrecife Alacranes.

Meses	Horas	Promedio	Desviación estándar
	92		
	94		
Marzo	94	93	1.15
	92		
	96		
	96		
Abril	96	96	0.0
	96		
	96		
	92		
Mayo	92	93.6	2.19
	92		
	96		
Junio	94	94	0.0
	94		
	92		
Julio	94	93.3	1.15
	94		
Agosto	94	94	0.0
	94		
Septiembre	94	94	0.0
	94		

En la Tabla 2 se presentan las características morfológicas que desarrollaron las larvas de marzo, abril, mayo y septiembre, independientemente del año en que se realizó el muestreo.

Al momento de la eclosión las larvas de los meses de marzo, abril, mayo y septiembre, tenían dos lóbulos del velum, 1.5 vueltas de espira de la concha y pedúnculo derecho (Tabla 2), mientras que las larvas de los meses de junio, julio y agosto, presentaron cuatro lóbulos del velum, 2.0 vueltas de espira de la concha y pedúnculo derecho (Tabla 3).

Para el día 11 las larvas de los dos grupos de meses desarrollaron 4 ó 6 lóbulos del velum con 3.5 vueltas de espira de la concha, corazón adulto, así como también dio inicio la formación pedúnculo izquierdo. La única diferencia encontrada entre las

características desarrolladas, fue el porcentaje en el que se presentaban en cada mes (Tablas 2 y 3).

Tabla 2. Descripción de las características morfológicas desarrolladas por las larvas de los meses de marzo, abril, mayo y septiembre (n = 1 170 larvas).

Días de cultivo	Características morfológicas (marzo, abril, mayo y septiembre)
1	2 lóbulos y 1.5 vueltas, pedúnculo derecho
3	2 lóbulos y 1.5 vueltas, pedúnculo derecho
5	4 lóbulos y 2.0 vueltas, pedúnculo derecho
7	4 lóbulos y 2.0 vueltas, pedúnculo derecho
9	4 lóbulos y 2.5 vueltas (48%), 4 lóbulos y 3.0 vueltas (52%), pedúnculo derecho
11	4 lóbulos y 3.0 vueltas (25%), 4 lóbulos y 3.5 vueltas (75%), corazón adulto (18%), inicia formación pedúnculo izquierdo (22%)
13	4 lóbulos y 3.5 vueltas (43%), 6 lóbulos y 3.0 vueltas (57%), corazón adulto (67%), pedúnculo izquierdo (72%), migración de los ojos (19%)
15	6 lóbulos y 3.0 vueltas (12%), 6 lóbulos y 3.5 vueltas (88%), corazón adulto (74%), pedúnculo izquierdo (82%), migración de los ojos (43%)pigmentación del pie y del manto (15%)
17	6 lóbulos y 3.5 vueltas (88%), 6 lóbulos y 4.0 vueltas (12%), corazón adulto, pedúnculo izquierdo, migración de los ojos (81%), pigmentación del pie y del manto (73%)
19	6 lóbulos y 3.5 vueltas (11%), 6 lóbulos y 4.0 vueltas (89%), corazón adulto, pedúnculo izquierdo, migración de los ojos, pigmentación del pie y del manto, aparece la probóscis (17%).
21	6 lóbulos y 4.0 vueltas, corazón adulto, migración de los ojos, pigmentación del pie y del manto, probóscis (68%)
23	6 lóbulos y 4.0 vueltas (72%), 6 lóbulos y 4.5 vueltas (28%), corazón adulto, pedúnculo izquierdo, migración de los ojos, pigmentación del pie y del manto, probóscis (81%), aparece la rádula (22%).
25	6 lóbulos y 4.0 vueltas (20%), 6 lóbulos y 4.5 vueltas (80%), corazón adulto, pedúnculo izquierdo, migración de los ojos, pigmentación del pie y del manto, probóscis, rádula (49%).
27	6 lóbulos y 4.5 vueltas, corazón adulto, pedúnculo izquierdo, migración de los ojos, pigmentación del pie y del manto, probóscis, rádula (66%).
29	6 lóbulos y 4.5 vueltas, corazón adulto, pedúnculo izquierdo, migración de los ojos, pigmentación del pie y del manto, probóscis, rádula (96%).
30	6 lóbulos y 4.5 vueltas, corazón adulto, pedúnculo izquierdo, migración de los ojos, pigmentación del pie y del manto, probóscis, rádula (velum prácticamente reabsorbido).

Las características desarrolladas por las larvas de los meses de junio, julio y agosto, al día 15 de cultivo fueron: 6 lóbulos y 3.5 vueltas, corazón adulto, migración de los ojos, pigmentación del pie y del manto (Tabla 3).

Para las larvas de marzo, abril, mayo y septiembre, la metamorfosis se inició al día 30, cuando éstas presentaban: 6 lóbulos (prácticamente reabsorbidos) y 4.0 ó 4.5 vueltas de espira de la concha, corazón adulto, migración de los ojos, total pigmentación del pie y del manto, probóscis y rádula funcionales.

Al día 27 momento de la metamorfosis para las larvas de los meses de junio, julio y agosto, las larvas presentaron las siguientes características morfológicas: 6

lóbulos y 4.5 vueltas, corazón adulto, pedúnculo izquierdo, migración de los ojos, pigmentación del pie y del manto, probóscis y rádula completamente funcionales y reabsorción total del velum.

Tabla 3. Descripción de las características morfológicas desarrolladas por las larvas de los meses de junio, julio y agosto (n = 810 larvas).

Días de cultivo	Características morfológicas (junio, julio y agosto)
1	4 lóbulos y 2.0 vueltas, pedúnculo derecho
3	4 lóbulos y 2.0 vueltas, pedúnculo derecho
5	4 lóbulos y 2.5 vueltas, pedúnculo derecho
7	4 lóbulos y 3.0 vueltas, pedúnculo derecho
9	4 lóbulos y 3.0 vueltas (62%), 4 lóbulos y 3.5 vueltas (38%), pedúnculo derecho
11	4 lóbulos y 3.5 vueltas (82%), 6 lóbulos y 3.5 vueltas (18%), corazón adulto (44%), inicia formación pedúnculo izquierdo (39%)
13	4 lóbulos y 3.5 vueltas (28%), 6 lóbulos y 3.5 vueltas (72%), corazón adulto (79%), pedúnculo izquierdo (81%), migración de los ojos (37%)
15	6 lóbulos y 3.5 vueltas, corazón adulto, pedúnculo izquierdo (94%), migración de los ojos (62%), pigmentación del pie y del manto (33%)
17	6 lóbulos y 3.5 vueltas (22%), 6 lóbulos y 4.0 vueltas (78), corazón adulto, pedúnculo izquierdo, migración de los ojos, pigmentación del pie y del manto, probóscis (52%)
19	6 lóbulos y 4.0 vueltas, corazón adulto, migración de los ojos, pigmentación del pie y del manto, probóscis (92%).
21	6 lóbulos y 4.0 vueltas (61%), 6 lóbulos y 4.5 vueltas (39%), corazón adulto, pedúnculo izquierdo, migración de los ojos, pigmentación del pie y del manto, probóscis, rádula (43%).
23	6 lóbulos y 4.0 vueltas (5%), 6 lóbulos y 4.5 vueltas (95%), corazón adulto, pedúnculo izquierdo, migración de los ojos, pigmentación del pie y del manto, probóscis, rádula (81%).
25	6 lóbulos y 4.5 vueltas, corazón adulto, pedúnculo izquierdo, migración de los ojos, pigmentación del pie y del manto, probóscis, rádula.
27	6 lóbulos y 4.5 vueltas, corazón adulto, pedúnculo izquierdo, migración de los ojos, pigmentación del pie y del manto, probóscis, rádula, reabsorción total del velum
29	6 lóbulos y 4.5 vueltas, corazón adulto, pedúnculo izquierdo, migración de los ojos, pigmentación del pie y del manto, probóscis, rádula, reabsorción total del velum.
30	6 lóbulos y 4.5 vueltas, corazón adulto, pedúnculo izquierdo, migración de los ojos, pigmentación del pie y del manto, probóscis, rádula, reabsorción total del velum.

Crecimiento

La longitud sifonal promedio para las larvas de las 22 masas de huevos incubadas al momento de la eclosión fue de 300 ± 6.16 µm (n = 1 980 larvas).

En la Figura 2 se presenta la evolución de las longitudes sifonales promedio alcanzadas por las larvas a lo largo de los cultivos realizados, durante los años de estudio.

La longitud máxima promedio alcanzada por las larvas al momento de la eclosión (día 30) fueron: en el mes de marzo 879 ± 1.33 µm, en abril 884 ± 1.94 µm, para las larvas de mayo 867 ± 1.33 µm y para el mes de septiembre 902 ± 1.33 µm, en éste grupo de meses no se encontraron diferencias estadísticas significativas ($P > 0.05$). En la Tabla 4a se presenta el resultado del ANOVA realizado.
Para el otro grupo de meses, al momento de la eclosión (día 27), las longitudes promedio alcanzadas fueron para el mes de junio 879 ± 1.33 µm, para julio 893 ± 1.82 µm y para agosto 902 ± 1.19 µm, no se encontraron diferencias significativas, entre las longitudes alcanzadas por las larvas ($P > 0.05$) (Tabla 4b).

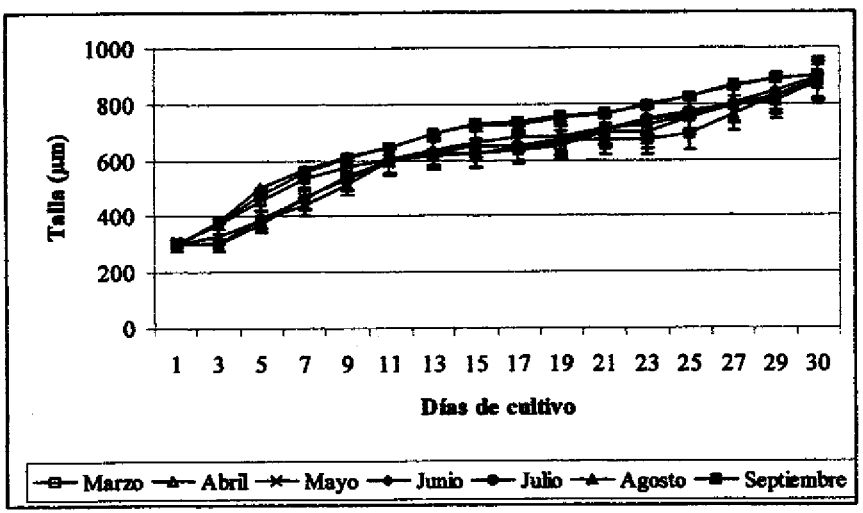


Figura 2. Longitudes sifonales alcanzadas por las larvas al momento de la metamorfosis, para los cultivos realizados durante los meses de marzo, abril, mayo, junio, julio, agosto y septiembre.

DISCUSION

Los resultados encontrados a lo largo de éstos 10 años de cultivo en el laboratorio de Biología Marina del CINVESTAV IPN Unidad Mérida, con el caracol rosado *Strombus gigas*, demuestran que es posible realizar la larvicultura de ésta especie, siempre y cuando se cuente con las condiciones y herramientas adecuadas.

Tabla 4a. Resultados del Análisis de varianza aplicado al crecimiento de las larvas del grupo de meses de marzo, abril, mayo y septiembre.

RESUMEN

Grupos	*Cuenta*	*Suma*	*Promedio*	*Varianza*
Columna 1	1080	3840	3.55555556	3.8059932
Columna 2	1080	954539	883.832407	167.694778

ANÁLISIS DE VARIANZA

Origen de las variaciones	*Suma de cuadrados*	*Grados de libertad*	*Promedio de los cuadrados*	*F*	*Probabilidad*	*Valor crítico para F*
Entre grupos	418439161	1	418439161	4879735.03	0.5	3.84576992
Dentro de los grupos	185049.332	2158	85.7503857			
Total	418624211	2159				

Tabla 4b. Resultados del Análisis de varianza aplicado al crecimiento de las larvas del grupo de meses de junio, julio y agosto.

RESUMEN

Grupos	*Cuenta*	*Suma*	*Promedio*	*Varianza*
Columna 1	840	4200	5	0.57210965
Columna 2	840	744205	885.958333	166.600169

ANÁLISIS DE VARIANZA

Origen de las variaciones	*Suma de cuadrados*	*Grados de libertad*	*Promedio de los cuadrados*	*F*	*Probabilidad*	*Valor crítico para F*
Entre grupos	325956786	1	325956786	3899651.17	0.5	3.84700627
Dentro de los grupos	140257.542	1678	83.5861393			
Total	326097043	1679				

A pesar de que el laboratorio de Biología Marina del CINVESTAV, se encuentra ubicado a 30 km del Puerto de Progreso, lo que implica el carecer del agua de mar recién obtenida, dado que al laboratorio llega por medio de pipas y es almacenada en cisternas, los resultados obtenidos en el presente trabajo, en términos generales son similares a los obtenidos por diversos autores.

En relación al desarrollo para las larvas de los meses de marzo, abril, mayo y septiembre, los resultados son similares a los reportados con el número de espiras de la concha de larvas recién eclosionadas por autores como Davis et al., (1993) quienes encontraron que las larvas de *S. gigas* y *S. costatus* poseen dos lóbulos del velum y 1.5 vueltas de espira al momento de la eclosión, el mismo número fue reportado por Brownell (1977) para larvas de *S. gigas*, *S. costatus* y *S. pugilis*. En el otro grupo de meses (junio, julio y agosto) se encontró que las larvas al momento de la eclosión presentaron un velum con cuatro lóbulos y 2.0 vueltas de espira de la concha, característica que los autores antes señalados encontraron a los cuatro días posteriores a la eclosión.

La aparición del pedúnculo izquierdo en las larvas de los dos grupos de meses, ocurrió al día 11, característica que Davis et al., (1993) observaron entre el quinto y sexto día de cultivo. Sin embargo, la migración de los ojos a los pedúnculos oculares en las larvas de éste trabajo se produjo a los 13 días, mientras que en el trabajo ya mencionado se llevó entre 21 y 23 días.

El desarrollo morfológico que presentaron las larvas de *S. gigas* en éste estudio en los diferentes cultivos realizados, fue comparado con los datos de la literatura para otras especies de *Strombus*. Brownell (1977) encontró que la aparición de la probóscis se presenta al día 25 para larvas de *S. gigas* y *S. costatus*, mientras que en las larvas de esta investigación apareció entre el día 17 y el 18 en todos los cultivos.

Con respecto a la longitud sifonal presentada por las larvas al momento de la eclosión fue similar al reportado por autores como D'Asaro (1965), Brownell (1977), Ballantine and Appeldoorn (1983), Laughlin y Weil (1983) y Davis (1994) quienes reportaron que las larvas recién eclosionadas tienen una longitud sifonal de 300 µm.

La longitud máxima alcanzada a la metamorfosis de los cultivos larvarios fue similar a lo reportado por Ballantine (1981) el cual reportó una longitud de 900 µm para larvas de *S. gigas*, Aldana Aranda et al. y Heyman et al. (1989) encontraron una longitud de 900 µm para larvas de S. costatus y S. gigas, respectivamente. García Santaella y Aldana Aranda (1994), reportaron una longitud sifonal máxima de 800 µm para larvas de *S. gigas*. En este trabajo la longitud sifonal máxima alcanzada fue de 879 ± 1.33 µm, 884 ± 1.94 µm, 867 ± 1.33 µm, 879 ± 1.33 µm, 893 ± 1.82 µm, 902 ± 1.19 µm y 902 ± 1.33 µm, para los meses de marzo, abril, mayo, junio, julio, agosto y septiembre, respectivamente.

AGRADECIMIENTOS

Al Fondo Yucatán del Gobierno del Estado de Yucatán por el financiamiento otorgado, al Gobernador Constitucional del Estado de Yucatán C. Patricio Patrón Laviada, por su decidido apoyo hacia los jóvenes investigadores Yucatecos, mil gracias. Al CONACyT por la beca de doctorado 90032.

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Potential for Queen Conch Grow-out Facilities

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ABSTRACT

A study was conducted to assess the feasibility for establishment of queen conch, *Strombus gigas*, grow-out facilities. Hatchery seed (1.5 cm) for pond culture and juveniles (8 cm) for cage or pond culture are available through the Caicos Conch Farm, TWI Ltd., a commercial scale culture facility. In addition, markets for conch ranging in size from 2.5-16 cm have been established. Grow-out system cost and yields estimates for both pond and cage culture were determined. These included evaluations for capital requirements, scale of production, size of unit at input, stocking densities, and final market product. Current standing as well as future research and development needs are addressed.

KEY WORDS: Aquaculture, Grow-out, *Strombus gigas*

RESUMEN

Se ha llevado a cabo un plan de producción para valorar el establecimiento de viveros de reina concha, *Strombus gigas*. Se dispone de la simiente de cultivo (1.5 cm) por cultivo de estanque y juveniles (8 cm) por jaula o cultivo de estanque, a través de la Granja de Concha de Caicos, TWI Ltd., un vivero a escala comercial. Además, se han establecido mercados de concha que varían en tamaño de 2.5 a 16 cm. El costo del sistema de crecimiento y su rendimiento, tanto para estanque como para el cultivo de jaula, fueron determinados. Estos incluyeron evaluaciones para requerimientos de capital, escala de producción, tamaño de la unidad en "stock", densidades de"stock" y mercado de producto final. Tanto la situación actual como el desarrollo y la investigación futuros necesitan ser tratados.

PALABRAS CLAVES: Acuicultura,caracol reina, *Strombus gigas*

INTRODUCTION

The queen conch, *Strombus gigas*, supports one of the most important benthic fisheries in the Caribbean region second only to the spiny lobster (Hahn 1989, Appeldoorn 1994). However, due to increases in fishing pressure, most stocks are overexploited and the historical range of the queen conch has been significantly reduced (Creswell 1994). As a result, both commercial and research culture facilities have been established, serving a dual role of supplementing the declining

fishery and as seed source for replenishment efforts (Appeldoorn and Rodriguez 1994). The Caicos Conch Farm, TWI Ltd., Turks and Caicos, BWI is currently the only full-scale commercial facility involved in the culture of the queen conch. The Caicos Conch Farm was established in 1984 and raises *S. gigas* from the fertilized egg mass through the adult stage. Their hatchery produces one and a half million juveniles per year for both pond and cage culture. The Caicos Conch Farm has developed a high value niche market for which they produce specific size conch. To expand this opportunity to grow-out farmers, they have proposed to sell hatchery produced seed as well as guarantee buy back of the product for marketing through their established wholesale distribution network.

A financial feasibility study was undertaken to compare the relative costs of producing various market size juvenile conch in pond and cage culture. Production costs were compiled from actual annual costs for pond operation at the Caicos Conch Farm, and cage costs were estimated from ongoing cage grow-out studies. Operating costs, gross revenues, net profits per cycle, average yearly profits, and investment needs were compared for the two systems, and a series of scenarios were generated to examine maximized pond and cage use with a base production facility of 20 ponds or cages. A sensitivity analysis considered the effect of changes in the cost of shipping, feed, fuel and labor as well as the effect of differences in survival rates.

RESULTS AND DISCUSSION

Market Potentials

As described above, the Caicos Conch Farm has established a high value market for conch ranging in size from 6.5 – 16 cm. They will sell potential grow-out farmers hatchery-produced seed, provide technical support, and buy back end products for processing and marketing. The Caicos Conch Farm will sell 1.5 cm grow-out seed for $0.16 (US) each and larger 6.5 cm seed for $0.24 (US) each (shipping paid by farmer). They will buy back the product at a rate of $0.45 (US) for 8-10 cm conch and $2.00 (US) for 16 cm conch (shipping paid by the Caicos Conch Farm). Product sold direct to the retail market would be expected to garner a price of approximately 40% over wholesale.

Ninety five percent of the Caicos Conch Farm's past two years of sales have been in the Island Princess (IP, 8 - 10 cm) market category for live and shucked product. Aquarium (AQ, 3 cm) and Ocean Escargot (OE, 6.5 cm) conch constitute the majority of the rest of the sales products. There is a large demand for the Caribbean Queen (CQ, 16 cm), but the Caicos Conch Farm has only been able to produce a small continuous supply of this product to date. The 2002 season will see an expansion in this market potential. For these reasons, the following projections have concentrated on production from grow-out (GO, 1.5 cm) and OE size seed to IP and CQ markets.

Operating Costs for Ponds *vs.* Pens

Operating costs for ponds, including the variable costs of labor, feed, supplies, and fuel were estimated at $273 (US) per pond per month. The cost does not incorporate interest on the operating capital or any fixed depreciating costs, taxes, etc. Similarly, cage costs were estimated at $100 (US) per cage per month.

Feasibility Analysis

With the given pond and cage operating cost information, several production feasibility scenarios were generated to determine the most cost effective use of a 20 pond or 20 cage culture facility. Of the multiple scenarios tested, only five have been included for discussion purposes. Again, no costs were included for capital acquisition, depreciation, debt service, nor were return on investments calculated. However, average yearly profits, maximum investments (from cash flow analysis), and basic capital needs are given to allow for further interpretation. Each of the five scenarios details the number and size of the conch produced for market and the length of the particular grow-out cycle (Table 1). Optimal densities, as recommended by the Conch Farm, have been used and vary throughout the course of the production cycle depending upon the size of the conch. Survival rates, provided by the Caicos Conch Farm, in both ponds and pens vary between 95-100%. For the purpose of the current analyses, all scenarios were run with the assumption of 100% survival. Three of the scenarios (two 19 month and one 6 month) were calculated for growth in cages versus ponds, using a 20-unit facility and stocking with 6.5cm (OE) seed. A fourth scenario (29 month mixed sales) incorporated 1.5 cm (GO) seed as stock. This scenario requires the use of a combination of ponds and cages to allow for the production of OEs needed for stocking into cages. The fifth scenario looked at producing OEs from GOs as an onshore alternative for cage production or further pond production. Only two ponds are needed in this scenario (Table 1). For all four scenarios in which ponds and cages are compared, the average yearly profit for cages was significantly higher than that for ponds (Table 1). This coupled to the fact that maximum investment and capitol costs are lower for the cages makes them an obvious choice for grow-out facilities where offshore operations are viable. The highest average yearly profits for ponds were seen for the 29-month mixed sales scenario (Table 1).

Table 1. Feasibility analysis of various market scenarios for queen conch grow-out, based on a 20 pond or cage facility. The 29 month Mixed Sales scenario includes the addition of 4 ponds to the 20 pens and stocks both GO (1.5 cm) and OE (6.5 cm) seed, while the OE scenario stocks GO seed and utilizes two ponds for production.

Scenario	Culture Unit	Operating Costs ($)	Gross Revenue ($)	Net Profit per cycle ($)	Avg. Yearly Profit ($)	Max. Investment ($)	Capital ($)
CQ Sales							
50,000 CQ	Cages	36,667	100,000	63,333	39,999	34,667	40,000
19 months	Ponds	76,457	100,000	23,543	14,869	70,997	120,000
Mixed Sales							
150,000 IP	Cages	87,668	167,500	79,832	50,420	56,201	40,000
50,000 CQ	Ponds	141,254	167,500	26,246	16,576	68,294	120,000
19 months							
Mixed Sales							
600,000 IP	Cages/ponds	193,487	370,000	176,512	73,039	77,293	64,000
50,000 CQ	Ponds	274,997	370,000	95,003	39,311	84,904	120,000
29 months							
IP Sales							
200,000 IP	Cages	66,666	90,000	23,334	46,668	64,667	40,000
6 months	Ponds	87,427	90,000	2,573	5,146	81,967	120,000
OE Sales							
50,000 OE	Ponds	12,116	13,667	1,551	1,861	23,570	12,000
10 months							

Sensitivity Analysis

The sensitivity analyses for pond culture reflect actual changes in feed and fuel costs based on improved technology used during the current year (2001) at the Caicos Conch Farm. The amount of feed used (i.e. cost) was increased over past years to reflect more appropriate feeding needs, while fuel costs were lowered through the addition of a more efficient pump. Values for cage culture are based on values from an ongoing experimental study and show cost changes under a variety of conditions (Table 2). Variable feed, fuel, shipping, and labor costs may all impact the potential success of a grow-out facility and will be, in part, site dependent (Table 2). Manual labor costs provide an example of the impact of the variable cost analyses. Manual labor costs in Providenciales, Turks and Caicos, BWI, the location of the Caicos Conch Farm, average $5.00 (US) per hour. In the calculations for cages the cost allocated for labor allows for one worker at a maximum of 40 weeks for the year. In areas where cheaper labor is available, an alternative rate of $2.50/hr has been calculated for comparison. This drops the total operating cost by approximately $4,000 (US) over the 19-month cycle. The sensitivity analysis not only helps define areas where costs changes may occur depending upon the particular circumstances of the grow-out farmer, but also indicates areas where improvements can be made in operating cost efficiency through either developing technology or through increases in scale which will lead to further cost reductions.

Although numerous stock/harvest scenarios can be generated to further optimize cash flows, maximize use of ponds, expand harvests (i.e. continuous), or to include other more site-specific options, the scenarios chosen included the basic criteria needed to identify viable, cost effective grow-out potentials. Based on current standing, only the production of CQs and IPs are profitable. The production of these products have different requirements in terms of time to harvest, quantity produced, and investment needed to achieve those results. Mixed sales scenarios take advantage of both products and profit more than just producing the individual product when relegated to the same space allocations. Raising OEs from grow-out produces a small savings for the effort, but requires onshore facilities. As expected, cages are more cost effective than ponds with lower operating costs and less capital investment required. Although the cages are considered in the "experimental" phase, the results of the initial studies are promising. Other options to explore include the production of 3 cm conch for the aquarium trade. Although beyond the scope of this study, market values for their maximum 3-month culture cycle show promising profit margins.

Table 2. Sensitivity analysis for queen conch grow-out based on a 20 pond or 20 cage scenario culturing CQ conch for market. 50,000 OE seed (6.5 cm) are stocked and raised for 19 months to harvest at 16 cm. In the pond scenario, the actual column reflects year 2000 costs for the Caicos Conch Farm and the expected column estimates 2001 costs with changes in feed and fuel made. In the cage scenario, the actual column reflects estimations from an ongoing cage study, where the expected column shows changes in survival, shipping, feed, and labor costs that may occur based on the locale of the grow-out farmer.

Items	Actual ($)	Changes	Expected ($)
Ponds			
Sales Revenue	100,000	Survival 100↔95%	95,000
Seed ($0.24/OE)	12,000	no change	12,000
Shipping ($0.50/lb)	1,666	no change	1,666
Feed ($0.46/lb)	13,182	127lbs/m ↔190lbs/m	19,721
Labor	30,767	no change	30,767
Fuel ($1.87/gal)	11,930	Reduced by 30%	8,351
Supplies	6,907	no change	6,907
Total Operating Costs	76,452		79,412
Revenues-Operating	23,548		15,588
Cages			
Sales Revenue	100,000	Survival 100↔95%	95,000
Seed ($0.24/OE)	12,000	no change	12,000
Shipping ($0.50/lb)	1,666	$0.50/lb ↔ $0.25/lb	833
Feed ($0.46/lb)	13,800	($0.46 ↔ $0.36)	10,800
Labor	8,050	($5.00/hr ↔$2.50/hr)	4,025
Fuel ($1.87/gal)	—	—	—
Supplies	3,139	no change	3,139
Total Operating Costs	38,655		30,797
Revenues-Operating	61,345		64,203

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Integrated Water Quality and Coral Reef Monitoring on Fringing Reefs of Tobago: Chemical and Ecological Evidence of Sewage-Driven Eutrophication in the Buccoo Reef Complex

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ABSTRACT

Land-based discharges of nutrients from deforestation, sewage and agricultural activities are a rapidly growing threat to Caribbean coral reefs and Marine Protected Areas (MPA's). To assess localized sewage problems in Tobago, we conducted an integrated water quality and coral reef monitoring program in the dry season between April and June, 2001. The study included a variety of fringing reef sites around Tobago, including the Buccoo Reef Complex (BRC) that was established as an MPA in 1973. The study involved:

i) measurement of water column dissolved inorganic nitrogen (DIN = ammonium plus nitrate plus nitrite), soluble reactive phosphorus (SRP), and chlorophyll-a (chl-a),
ii) digital video monitoring of benthic reef communities to quantify cover of hard corals, octocorals, macroalgae, turf algae, coralline algae, sponges, and
iii) determination of $\delta^{15}N$ ratios (= $^{15}N/^{14}N$) in benthic macroalgae at the reef sites to discriminate among natural versus anthropogenic nitrogen sources.

Low DIN:SRP ratios (< 5:1) throughout the study area indicated DIN rather than SRP-limitation of algal growth. DIN (~ 1 μM, mostly ammonium) and chl-a (up to 0.6 ug/l) within the BRC were high compared to more oligotrophic fringing reefs around Tobago and were indicative of eutrophication. Cumulative impacts of land-based nutrient enrichment in the BRC was also evidenced by relatively low cover of hermatypic (reef-forming) corals and high cover of macroalgae, turf algae, octocorals, and the zoanthid *Palythoa* that was physically overgrowing reef corals. Schools of mobile, herbivorous fishes (parrotfish, surgeonfish) were abundant in the BRC because of protection from reef fishing in this MPA. The $\delta^{15}N$ values of macroalgae in the BRC ranged from a high of +11.8 ‰ in Buccoo Bay near a sewage outfall to +5.3 ‰ at Coral Gardens on the outer reef, values within the range reported for macroalgae growing on sewage nitrogen. Elevated DIN and chl-a

concentrations combined with relatively high $\delta^{15}N$ values of macroalgae at other fringing reef sites off southwest Tobago were indicative of sewage pollution from upland urban centers and tourist resorts around Scarborough, Crown Point, and Mt. Irvine. The lowest DIN and chl-a concentrations and $\delta^{15}N$ values (± 2.5 ‰) of macroalgae of the entire study were at Black Jack Hole off Little Tobago Island, a site characteristic of oligotrophic, background nitrogen sources and a lower degree of sewage pollution.

KEY WORDS: Coral reef, eutrophication, nitrogen

INTRODUCTION

Tropical coastal ecosystems, and coral reefs in particular, are suffering worldwide from the impacts of land-based nutrient pollution and eutrophication of coastal waters (NRC 2000). Pollution from land-based sources is considered the single most important threat to the marine environment of the Caribbean and an impediment to sustainable use of its resources (UNEP 1994). Sources of nutrient pollution known to impact Caribbean reefs include poorly treated sewage and grey-water, domestic and commercial (tourism) outfalls, fertilizers, deforestation, and top soil loss (Lapointe et al. 1990, Lapointe and Thacker 2001, Likens, 2001). Throughout the Caribbean SIDS (Small Island Developing States) inappropriate or non-existent wastewater treatment represents a major source of land-based nutrient pollution to not only coral reefs, but also to adjacent seagrass and mangrove ecosystems as well (NRC 2000).

One example of this problem can be found on the small island (300 km^2) of Tobago, located approximately 29 km northeast of Trinidad in the southeastern Caribbean. Approximately 70% of Tobago's coastal waters (along its eastern and Caribbean coastlines) are characterized by reef formations, of which the Buccoo Reef Complex (BRC) is the largest and the only Marine Protected Area (MPA) in the Republic of Trinidad and Tobago. Other major coral reef sites around Tobago include reefs at Speyside, Goat Island, Little Tobago Island, and Man-of-War Bay on the northeast; Culloden Bay, Arnos Vale, Englishman's Bay, and Three Sister's on the north coast; and Flying Reef, Diver's Thirst, Diver's Dream, Ketchup Reef, Grouper Ground, Kariwak Reef, Mt. Irvine Reef, and Stone Haven bay on the southwest coast (Laydoo 1991). These reefs are important to Tobago's tourism industry. Glass bottom boat tours use some of the reefs for reef viewing, snorkeling, and reef walking. The number of SCUBA divers visiting Tobago has increased to ~ 40 % of the total tourism market and currently supports 21 dive shops on the island. Conch, lobster, and fish are taken regularly from many of the reefs to support local restaurants and subsistence fishing. Pot and spearfishing are not encouraged on or near reef areas.

The BRC represents a classic example of a tropical fringing coral reef ecosystem that has been expressing symptoms of eutrophication from wastewater discharges for several decades (IMA 1994). The BRC encompasses an area of ~ 7 km^2 and was

officially designated as a Marine Protected Area (MPA) in 1973. But, like most MPA's in the Caribbean, such designation has not protected these economically valuable coastal resources from water quality degradation. Most coastal dwellings (~80%) in the Buccoo Bay catchment area have septic tank or "soak-away" systems built in the carbonate-rich limestone that overlays the volcanic geology of Tobago. These sewage disposal systems provide little removal of nitrogen, which is highly mobile in carbonate-rich systems; the sewage liquor enters the water table and flows subsurface via groundwaters into downstream coastal waters (Lapointe et al. 1990, Costa et al. 2000, Lapointe and Thacker 2001). Inadequately, treated sewage (at best, secondary treatment only -- no nutrient removal) also enters Buccoo Bay and the Bon Accord Lagoon via several sewage treatment plants that service subdividions near Buccoo Village (Coral Gardens Estates) and Bon Accord. Sewage pollution in Buccoo Bay presents a significant risk to public health as indicated by consistently elevated concentrations of coliform bacteria and fecal streptococci (John 1996).

Although there has been a long history of both sewage pollution and research designed to assess its impact on the BRC, there remains little appreciation of the complex ecological consequences of elevated nutrients on the degradation of these biologically diverse coral reef communities. Consequently, no remedial actions have yet been implemented. Kenny (1976) provided one of the first qualitative studies of coral communities in the BRC but did not recognize a vital interrelationship between the inshore waters of Bon Accord Lagoon and the health of the outer coral reef communities; however, he noted that "care should be taken not to increase run-off from the adjacent land and to restrict the entry of pollutants". Laydoo and Heileman (1987) sampled effluents from sewage treatment plants servicing neighboring subdivisions that flow into coastal waters of the BRC. They detected deleterious effects from the sewage and recommended upgrading the treatment facilities on the Buccoo Reef watershed. In 1994, the Institute of Marine Affairs completed a management plan for the BRC (IMA 1994) that specifically recognized sewage impacts (i.e. fecal coliform contamination) to the inshore waters of Buccoo Bay but not chronic ecological impacts to the more offshore coral reef communities.

Like the BRC, fringing reefs around much of Tobago are receiving increasing nutrient loads from poorly or inadequately treated sewage effluents. Both large and small communities rely on "soak-aways" as on the BRC catchment. In some cases, attempts have been made to develop centralized collection and treatment systems for sewage. But, once again, the systems provide only secondary-level treatment at best (no nutrient removal) and are usually inadequate for the end-volume, resulting in BOD and nutrient-rich discharges into rivers or wetlands that eventually flow into coastal waters. To specifically assess the chemical and ecological impacts of sewage pollution in the BRC and other fringing reefs around Tobago, we initiated an integrated water quality and coral reef monitoring program in April 2001. The study involved measurement of ultra-low concentrations of water column dissolved inorganic nitrogen (DIN), soluble reactive phosphorus (SRP), and chlorophyll-a. Underwater video monitoring of benthic reef communities was used to quantify

cover of hard corals, octocorals, macroalgae, turf algae, coralline algae, and sponges. Finally, determination of stable nitrogen isotope ratios ($\delta^{15}N$) in benthic macroalgae was used to discriminate among natural (N-fixation) versus anthropogenic (e.g. sewage, fertilizers) nitrogen sources fueling coastal eutrophication.

MATERIALS AND METHODS

Reef Sampling and Rationale

We sampled a total of four reef sites for water quality and biotic cover in the BRC along an inshore to offshore gradient between April 5 and 12, 2001. The sites included: Princess Reef and Buccoo Point Reef in the inner BRC and Coral Gardens and Outer Reef in the offshore areas of the BRC. In addition, samples were collected at Walkabout Reef and Nylon Pool in the middle of the BRC for the water quality variables and at a sewage outfall in Buccoo Bay for $d^{15}N$ in benthic macroalgae. We predicted that the inshore sites at the BRC would show the strongest evidence of nutrient pollution and advanced eutrophication from land-based runoff. In addition, a variety of fringing reefs around Tobago's Caribbean and Atlantic coasts were sampled for biotic cover, water quality, and $d^{15}N$ in benthic macroalgae between June 5 and 8, 2001, which included: Mt. Irvine "Wall", the Maverick (a sunken ship-artificial reef), Diver's Dream, Diver's Thirst, Culloden, Arnos Vale, Englishman's Bay, Three Sisters and, off Little Tobago Island, Kelliston Drain and Black Jack Hole. We predicted that evidence of nutrient enrichment and eutrophication would be relatively minimal off Little Tobago Island that is the site furthest offshore and flushed with oceanic "blue water" waters of the Guyana Current. This is especially true during the dry season when we conducted this study as the plume of the Orinoco River does impact much of Tobago's coastal waters during the wet season (July through November). Alternatively, we predicted greater evidence of impacts from nutrient enrichment and eutrophication on the fringing reef sites more directly impacted by land-based runoff, which includes sites at Mt. Irvine, the Maverick, Diver's Dream and Diver's Thirst that are hydrographically downstream of Scarborough or other urbanized watersheds on the southwest coast of Tobago.

Quantification of Reef Biota

SCUBA divers used an underwater digital video camcorder (Sony TRV 900 in an Amphibico Navigator housing, 100 degree spherical lens) to record imagery along two replicate 50 m long belt transects at each reef site. Divers obtained the imagery by holding the camcorder perpendicular to the reef surface (0.5 m off bottom, 0.4 m^2/image area) and slowly swimming along the transects to obtain clear, steady images. A second close-up oblique video transect was also recorded to allow identification of algal taxa and to distinguish among the fine-scale (1-5 cm) changes

in biotic composition among these diverse and often multi-layered communities. The high resolution video images were anaylzed on a high resolution monitor using the random point-count method. This method provided a relatively unbiased estimate of the percent cover of hard corals, macroalgae (> 2 cm tall), algal turf (< 2 cm tall), coralline algae, sponges, and octocorals (Lapointe and Thacker 2002). Two independant scorers used the point-count method (with ten randomized dots superimposed over the video image) to score ten randomly selected images from each 50 m reef transect (200 point counts/reef site x 2 scorers = 400 total point counts per reef site).

Collection and Analysis of Seawater for DIN, SRP, and Chl-a

Divers used clean, one liter polyethylene Nalgene bottles to collect replicate (n = 4) seawater samples ~ 1 m off the bottom at the various reef sites. The water samples were held on ice in the dark in a cooler until return to shore where aliquots of the samples were filtered through a 0.45 µm GF/F filter and frozen. The samples were analyzed for DIN (= NH_4^+ plus NO_3^- plus NO_2^-) and SRP on a Bran and Luebbe TRAACS Analytical Console at Harbor Branch Oceanographic Institution's Environmental Laboratory in Ft. Pierce, FL. The methods for collection, handling, and processing of all nutrient samples followed a quality assurance/quality control protocol developed by HBOI's Environmental Lab. This plan prevented problems associated with sample contamination and excessive holding times. Salinity of the water samples was measured to ± 1.0 ‰ using a Bausch and Lomb refractometer. The GF/F glass fiber filters used for filtering the water samples were frozen and analyzed for chlorophyll-a (chl-a) as a measure of phytoplankton biomass. The filters were extracted for 30 minutes using 10 ml of dimethyl sulfoxide and then with an added 15 ml of 90% acetone at 5 °C overnight in the laboratory of Dr. Larry Brand, University of Miami, Miami, FL. The samples were measured fluorometrically before and after acidification for determination of chl-a and phaeopigment concentrations. Fluorescence measurements were made using a Turner Designs 10-000R fluorometer equipped with a infrared-sensitive photomultiplier and calibrated using pure chlorophyll a.

Collection and Analysis of Reef Macroalgae for $\delta^{15}N$

SCUBA divers collected samples of macroalgae from the various reef sites between April 10 and June 20, 2001 during the spring dry season. Water temperatures and depths at the reef sites were measured using Oceanic Datamax Pro Plus dive computers. Immediately following the collection, the macroalgae were sorted to species, cleaned of debris, and transferred to plastic zip-loc baggies in a cooler. Back on shore in the lab, the samples were identified, rinsed briefly in deionized water to further remove debris and then randomly sorted into two replicate composite samples per species (~ 3-6 plants per composite). The plants were placed in plastic drying dishes and dried in a lab oven at 65 °C for 48 hours. The dried macroalgae were ground to a fine powder using a mortar and pestle and stored in plastic vials until analysis. Samples of dried, powdered macroalgae were

analyzed for stable nitrogen isotope ratios with a Carlo-Erba N/A 1500 Elemental Analyzer and a VG Isomass mass spectrometer using Dumas combustion (by Isotope Services, Los Alamos, New Mexico). The standard used for stable nitrogen isotope analysis was N_2 in air. $\delta^{15}N$ values, expressed as ‰, were calculated as $[(R_{sample}/R_{standard}) - 1] \times 10^3$, with R equal to $^{15}N/^{14}N$.

RESULTS

Quantification of Reef Biota

The four reef sites in the BRC showed a distinct offshore trend in % cover of macroalgae and hard corals. The highest % cover values for macroalgae, up to 40 %, occurred at the inner BRC sites (Princess Reef, Buccoo Point Reef) where blooms of *Halimeda opuntia*, *Bryopsis* spp., and *Caulerpa* spp. occurred in April (Figure 1). Coral cover was low on these two sites, < 10 %, compared to the more offshore sites (Coral Gardens, Outer Reef) that coral cover ranging from 20 to 40 % and comprised of the genera *Acropora*, *Montastrea*, *Diploria*, and *Siderastrea* (Figure 1). Algal turf was a major component of these reef communities with values ranging from up to ~ 50 % cover. The zoanthid *Palythoa* was a significant component of these reef communities and ranged up to > 20 % cover at Buccoo Point Reef where it was observed to be physically overgrowing the brain coral *Diploria* (Figure 1). The fringing reef sites around Tobago had the highest % cover value for hard corals (i.e. Culloden, > 50 % cover), lower % cover of macroalgae (< 10 % cover), high cover of coralline algae (up to ~ 30 % cover), and high cover of algal turf (> 50 % cover, Figure 1).

Seawater DIN, SRP and Chl-a

DIN concentrations were relatively high in the BRC, averaging ~ 1 - 1.5 µM on the outer reef sites and 0.7 - 0.9 µM at the inner reef sites (Figure 2). In contrast, SRP concentrations did not vary among inner and outer reef sites and averaged ~ 0.20 µM throught the BRC (Figure 2). Chl-a values were highest at the two inshore reef sites (0.25 to 0.65 µg/l) and < 0.10 µg/l at the two offshore reef sites (Figure 2).

In general, DIN concentrations were relatively low at the fringing reef sites around Tobago, with a few notable exceptions (Figure 3). DIN was lowest at Black Jack Hole off Little Tobago Island (< 0.20 µM) and highest at Arnos Vale and Culloden (~ 1.0 µM, Figure 3). In general, DIN values increased from Englishman's Bay to Culloden along Tobago's Caribbean coast although values decreased at Mt. Irvine and the Maverick off southwest Tobago where high chl-a concentrations occurred (Figure 3). Like the BRC, there were no significant patterns in SRP among the reef sites with average values ranging from 0.20 - 0.30 µM (Figure 3). Chl-a values increased significantly from the low background values (~ 0.1 µg/l) at Kelliston Drain and Black Jack Hole off Little Tobago Island to higher values at

Englishman's Bay (~0.3 µg/l), Mt. Irvine (~0.6 µg/l), and the Maverick (~0.6 µg/l, Figure 3).

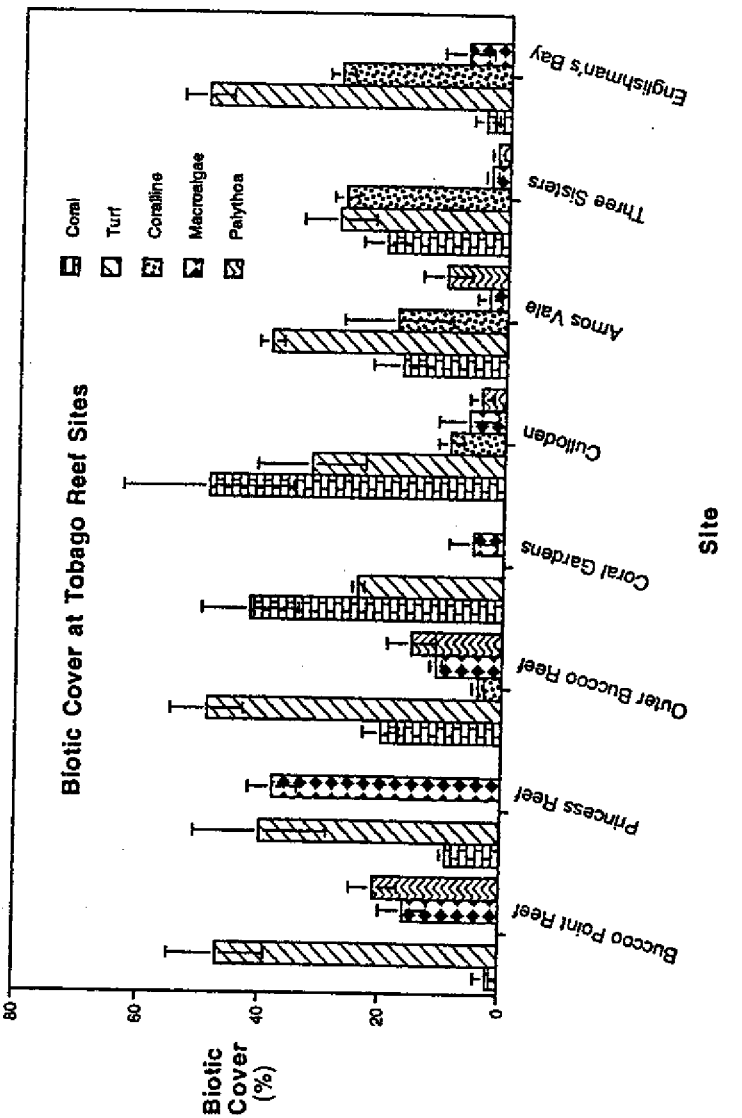


Figure 1. Biotic cover of four reef sites in the Buccoo Reef Complex (Buccoo Point Reef, Princess Reef, Outer Buccoo Reef, Coral Gardens) and four other reefs (Culloden, Arnos Vale, Three Sister's, Englishman's Bay) on Tobago's Caribbean coast. Values represent means ± 1 SD (n = 2 replicate 50 m transects; a total of 400 point counts per reef).

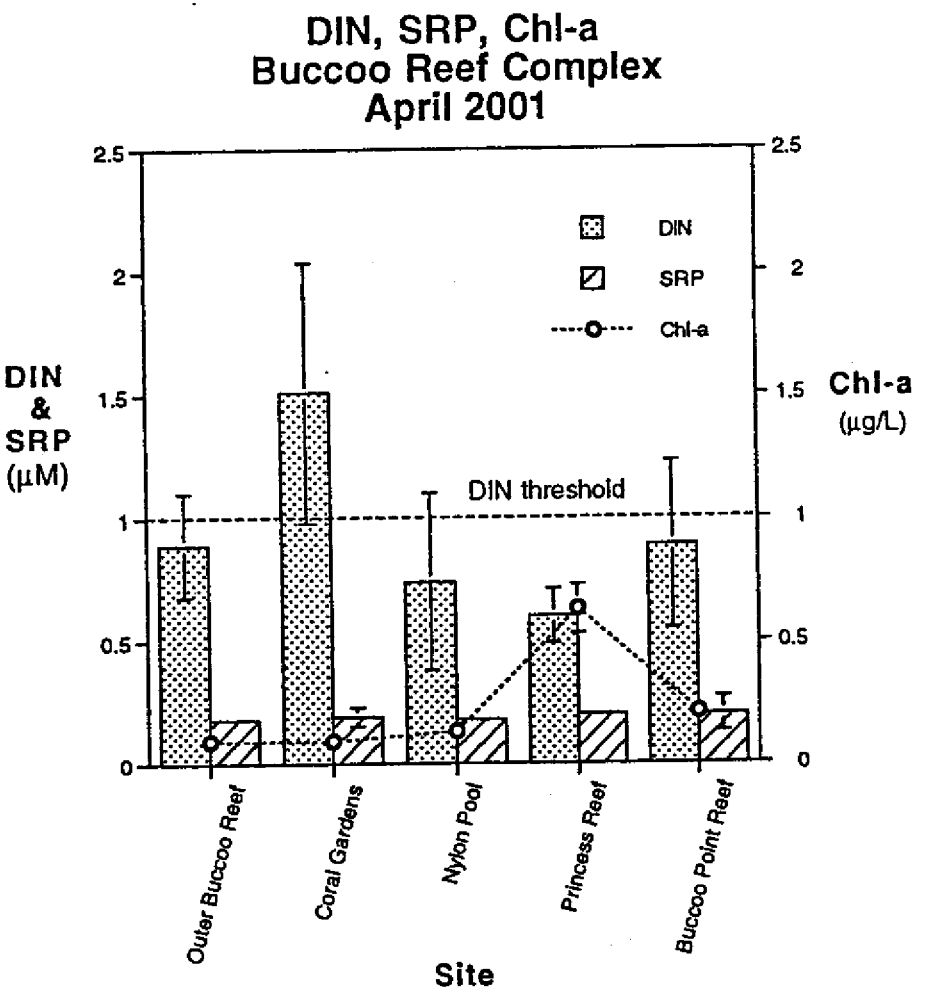


Figure 2. Water column dissolved inorganic nitrogen (DIN), soluble reactive phosphorus (SRP), and chlorophyll a (chl-a) concentrations at five sampling sites in the Buccoo Reef Complex. Values represent means ± 1 SD (n = 4).

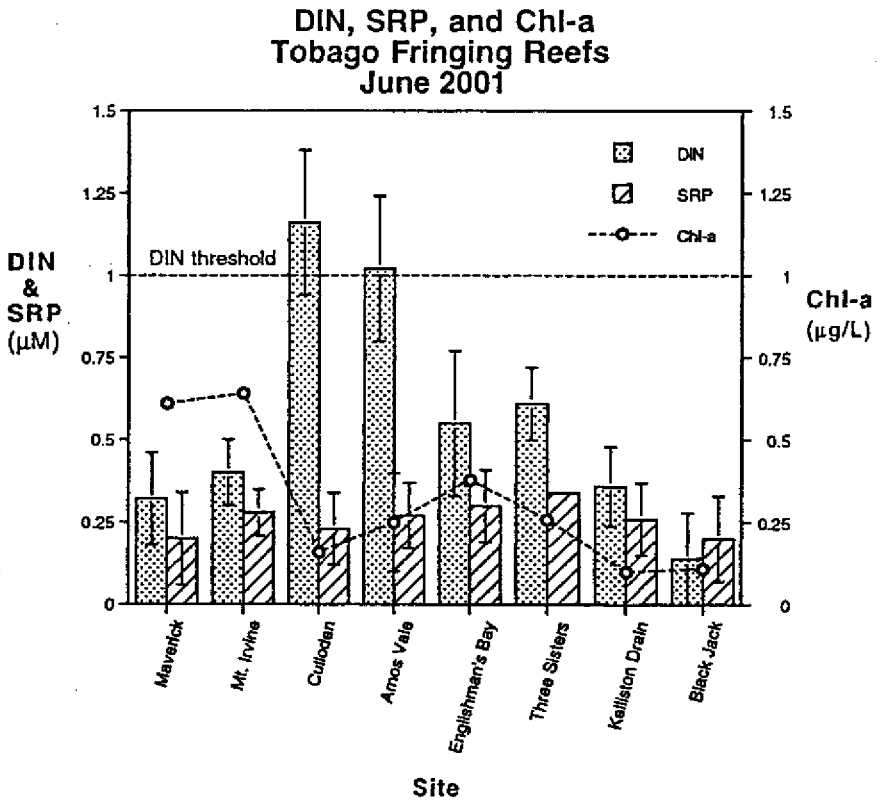


Figure 3. Water column dissolved inorganic nitrogen (DIN), soluble reactive phosphorus (SRP), and chlorophyll a (chl-a) concentrations at eight fringing reef sites around Tobago. Values represent means ± 1 SD (n = 4).

$\delta^{15}N$ of Reef Macroalgae

The mean $\delta^{15}N$ values of reef macroalgae on Tobago's reef ranged from a high value at the sewage outfall in Buccoo Bay to the lowest value at Black Jack Hole off Little Tobao Island (Figure 4). The $\delta^{15}N$ values of macroalgae in the BRC decreased with increasing distance from shore from a high of + 11.77 ‰ at the Buccoo Bay sewage outfall to + 6.98 ‰ at Princess Reef, + 6.42 ‰ at Buccoo Point Reef, + 6.22 ‰ at Walkabout Reef, + 6.24 ‰ at Outer Buccoo Reef, and + 5.30 ‰ at Coral Gardens (Figure 5). The average $\delta^{15}N$ value for macroalgae from the

Buccoo Bay sewage outfall was significantly (ANOVA, Fisher's PLSD test, $P < 0.0001$) higher than the average values for Princess Reef, Buccoo Point Reef, Walkabout Reef, Outer Buccoo Reef, Coral Gardens, and the other fringing reef sites around Tobago. In addition, the average $\delta^{15}N$ value of macroalgae from Princess Reef was significantly (ANOVA, Fisher's PLSD test, $P = 0.039$) higher than that of Coral Gardens (Figure 5).

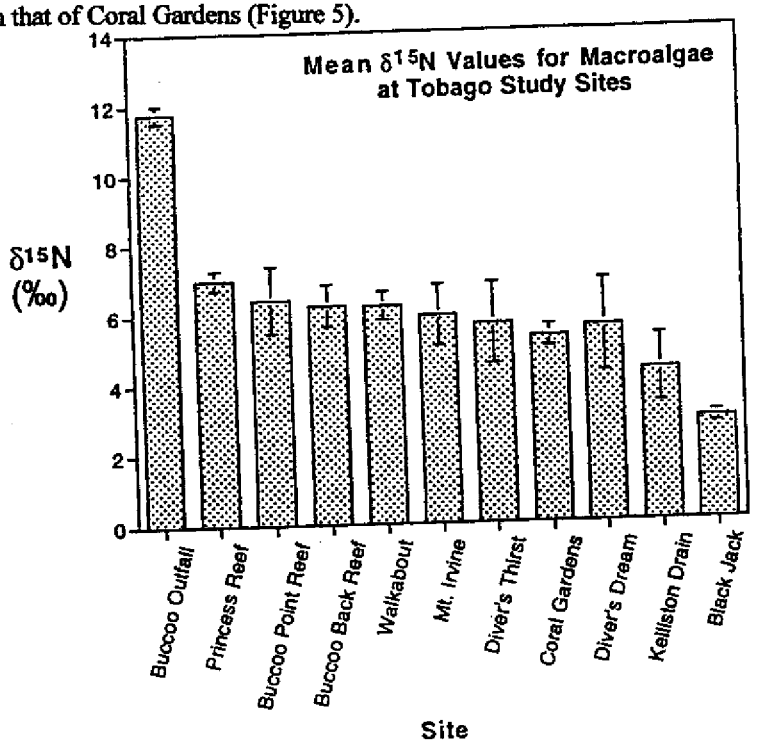


Figure 4. Mean $\delta^{15}N$ values for reef macroalgae from eleven reef sites, which includes six from the Buccoo Reef Complex (Buccoo Outfall, Princess Reef, Buccoo Point Reef, Walkabout Reef, Coral Gardens) and five other fringing reef sites around Tobago. Values represent means ± 1 SD ($n > 4$).

For the fringing reef sites around Tobago, the $\delta^{15}N$ values of macroalgae decreased from the highest value of + 5.93 ‰ at Mt. Irvine to + 5.66 ‰ at Diver's Thirst, + 4.58 ‰ at Diver's Dream, + 4.33 ‰ at Kelliston Drain and + 2.88 ‰ at Black Jack Hole (Figure 6). The average $\delta^{15}N$ value for macroalgae from Black Jack Hole was significantly (ANOVA, Fisher's PLSD test) lower than all other reef sites in the study, including Kelliston Drain ($P = 0.047$), Diver's Dream ($P = 0.037$), Diver's Thirst ($P = 0.0003$), Mt. Irvine ($P = 0.0003$), Coral Gardens ($P = 0.0083$), Outer Buccoo Reef ($P = 0.0002$), Walkabout Reef ($P < 0.0001$), Buccoo Point Reef ($P < 0.0001$), Princess Reef ($P < 0.0001$), and the Buccoo Bay outfall ($P < 0.0001$).

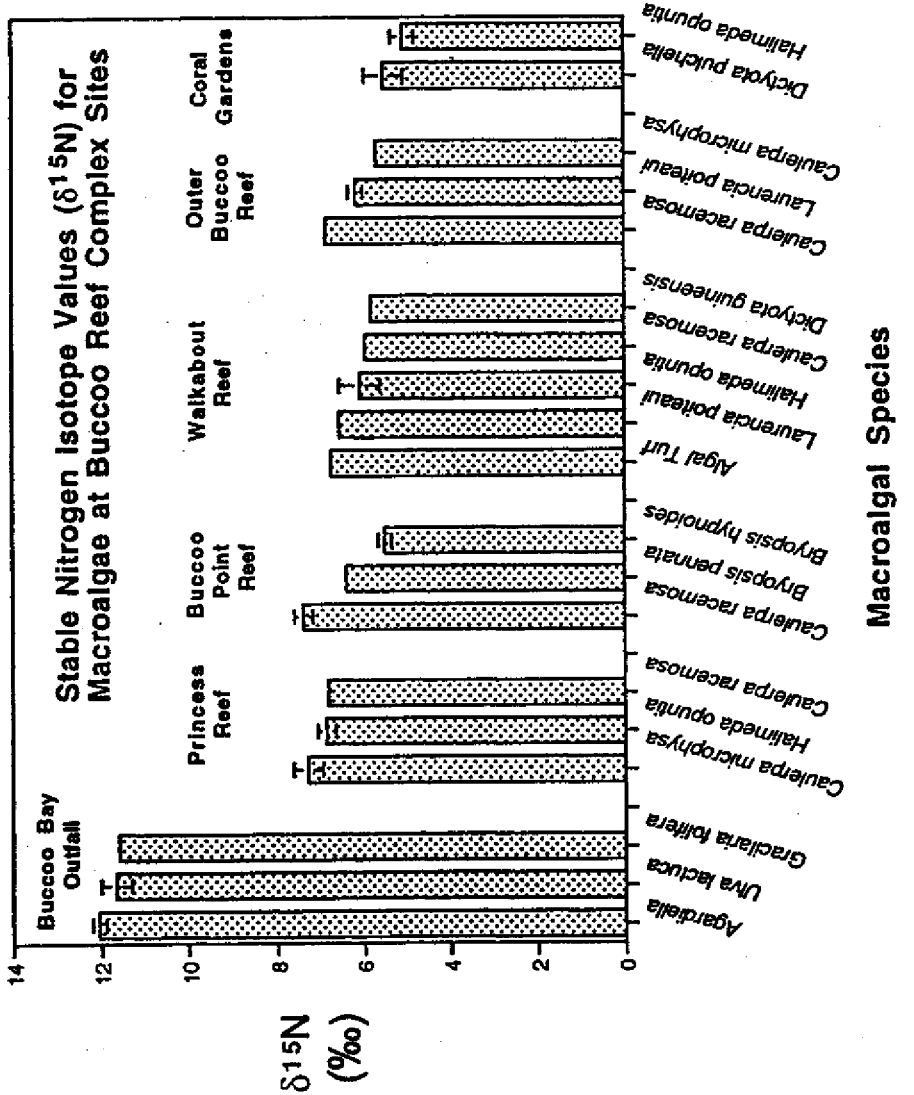


Figure 5. $\delta^{15}N$ values for reef macroalgae from six sites in the Buccoo Reef Complex (Buccoo Outfall, Princess Reef, Buccoo Point Reef, Walkabout Reef, Coral Gardens, Outer Buccoo Reef). Values represent means ± 1 SD (n = 2).

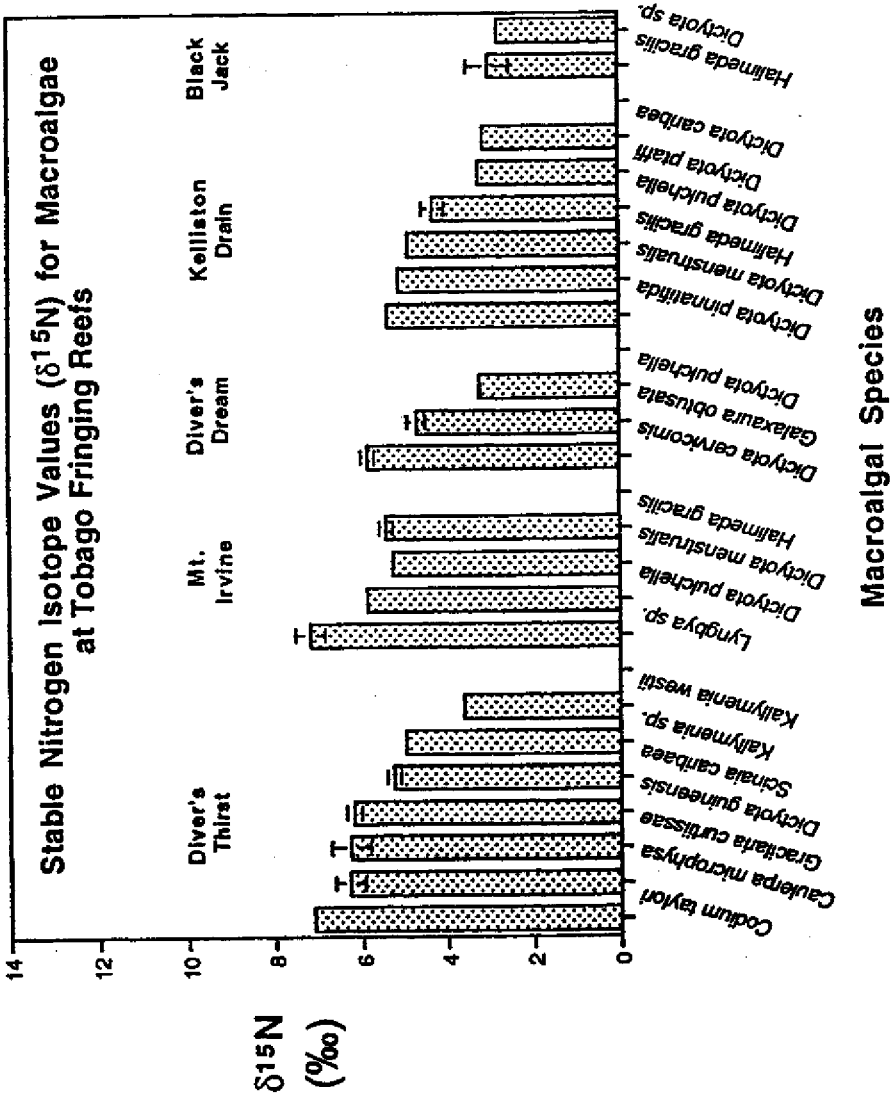


Figure 6. $\delta^{15}N$ values for reef macroalgae from five fringing reef sites around Tobago. Values represent means ± 1 SD (n = 2).

DISCUSSION

Our assessment of water quality and reef health on Tobago's fringing reefs is the first to document the primary role of land-based nitrogen runoff in fueling coastal

eutrophication processes on these fringing coral reefs. Previous studies in the Republic of Trinidad and Tobago have emphasized the role of land-based phosphorus pollution from industrial (Kumarsingh et al. 1998) and domestic (Kumarsingh et al. 1998) wastewaters. However, the relatively high background SRP concentrations throughout the study area (~ 0.20 μM), combined with low DIN:SRP ratios (< 5:1), clearly indicate nitrogen rather than phosphorus limitation of primary production (Lapointe 1999). Such high background SRP concentrations, low DIN:SRP ratios, and tendancy towards DIN-limitation are indicative of a siliciclastic geology and contrasts with carbonate-rich environments found in Jamaica, the Bahamas, and the Florida Keys where low SRP concentrations and high DIN:SRP ratios tend towards SRP-limitation (Lapointe et al. 1992). Hence, the natural volcanic geology of Tobago may predispose its coastal waters for nitrogen rather than phosphorus limitation.

The strong DIN-limitation was evident from the inverse relationship between DIN concentration and phytoplankton biomass in the BRC and on fringing reefs along Tobago's Caribbean coast. In both cases, maximum phytoplankton biomass (chl-a) correlated with decreased DIN concentrations (but not SRP). This pattern results from rapid uptake of DIN – the primary limiting nutrient– by phytoplankton "blooms" in coastal waters receiving land-based sewage pollution. These findings support previous observations in Kaneohe Bay, Hawaii (Laws and Redalje 1979) and the Florida Keys (Lapointe and Clark 1992) that chl-a provides a good "integrated" index of eutrophication in tropical and subtropical coastal waters. The generally low DIN concentrations on Tobago's fringing reefs (< 0.3 μM), especially off Little Tobago Island, not only limits phytoplankton biomass, but also the growth of macroalgae. Mean DIN concentrations > 0.5 μM are needed to support "blooms" of benthic macroalgae, such as those we observed on reef sites in the inner BRC. Classic "indicator species" of nutrient enrichment, including the macroalgae *Ulva*, *Halimeda*, *Bryopsis*, *Caulerpa*, and *Sargassum* were abundant on reefs in the BRC that had DIN concentrations > 0.5 μM. In contrast, macroalgae were less abundant on the fringing reefs around Tobago that had lower DIN concentrations.

The elevated $\delta^{15}N$ values of macroalgae in the BRC and other reefs around southwest Tobago are indicative of macroalgae growing in sewage polluted coastal waters. Several studies have shown that $\delta^{15}N$ values of macroalgae can be used to effectively discriminate among various natural and anthropogenic nitrogen sources. France et al. (1998) showed that 21 species of tropical macroalgae in coastal waters of southwestern Puerto Rico had a mean $\delta^{15}N$ of 0.3 ± 1.0 ‰, which is close to the atmospheric signature of 0 ‰ and indicative of nitrogen fixation as the source of nitrogen. For nitrogen derived from sewage, the macroalgae *Cladophora vagabunda*, *Gracilaria tikvahiae*, and *Enteromorpha sp.* from the Childs River estuary, which receives substantial N loading from septic tanks via submarine groundwater discharges, had elevated $\delta^{15}N$ values of 5.4, 7.6, and 8.4 ‰; even estuaries with relatively low rates of sewage N loading showed elevated $\delta^{15}N$ values in macroalgae (McClelland and Valiela 1998). Six species of macroalgae from Boston Harbor, which has been polluted by sewage for many decades, had a mean

$\delta^{15}N$ value of 6.5 ± 0.7 ‰ (France et al. 1998). In Negril, Jamaica, Lapointe and Thacker (2001) reported a $\delta^{15}N$ value of + 5.0 ‰ for human sewage from "soak-aways" and values of + 5.0 to + 6.5 ‰ for macroalgae on reefs adjacent to or downstream of sewage pollution. Based on this evidence, we suggest that the entirety of the BRC has been impacted by DIN derived from septic tank or "soak-away" sewage. Higher $\delta^{15}N$ values of +10.0 ‰ occur in secondarily-treated wastewater effluent (Lindau et al. 1989) and indeed, we observed similarly high values for macroalgae at the sewage treatment plant outfall in Buccoo Bay. Lower but elevated $\delta^{15}N$ values occurred in macroalgae at other reef sites in southwest Tobago, suggesting widespread sewage DIN enrichment on reefs downstream of urban and population centers. The lowest $\delta^{15}N$ values of + 2.5 ‰ for macroalgae at Black Jack Hole off Little Tobago Island were indicative of more oligotrophic and "natural" nitrogen sources, although these levels are still elevated above what would be expected for nitrogen-fixation alone (~ 0.5 ‰).

The loss of hard coral cover and replacement by macroalgal "blooms" on Jamaican coral reefs over the past two decades has been attributed simply to the "top-down" effects of overfishing (via fish traps) of herbivorous fish stocks (Hughes 1994). However, similar loss of hard corals and macroalgal blooms have occurred over the past two decades in the BRC, a MPA with abundant schools of parrotfish (including large adults), surgeonfish, and chubs. However, as described here, the BRC has also been polluted by land-based sewage inputs. The most sewage impacted inshore reef in the BRC (Princess Reef) not only had extensive macroalgal blooms (*Caulerpa, Halimeda*) but also had dense populations of reef urchins (*Echinometra viridis*). These observations point to "bottom-up" control (i.e. nutrients) of not only the macroalgal biomass, but the echinoid populations as well. Hunter and Price (1992) suggested that a "bottom-up template" is the most realistic approach for understanding trophic dynamics in ecosystems because plants have obvious primacy in food webs. We concur and suggest that sewage nitrogen subsidies over recent decades may have increased grazer populations (both echinoids and herbivorous fishes) in the BRC where growth is typically limited limited by dietary nitrogen (Lapointe 1999). Unfortunately, coral cover, biodiversity, and the economic value for tourism have all been reduced by sewage-driven eutrophication in the BRC despite abundant populations of grazers. These results support the conclusion of Agard and Gobin (2000) that the most important source of urban pollution in Trinidad and Tobago is domestic sewage, which appears to be impacting not only the BRC but also other fringing coral reefs "downstream" of Tobago's populated southwest coast.

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Advances in Hatchery and Growout Technology of Marine Finfish Candidate Species for Offshore Aquaculture in the Caribbean

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ABSTRACT

This paper describes advances in hatchery and growout technology of selected candidate species of marine finfish for offshore aquaculture in the Caribbean, Gulf of Mexico and the Southeastern US. Emphasis is given on relevant progress achieved with mutton snapper (*Lutjanus analis*), greater amberjack (*Seriola dumerili*) and cobia (*Rachycentrum canadum*), focusing on our own research and development program. The following topics are reviewed: broodstock management, including capture, transport, handling, sampling, prophylaxis, acclimation and quarantine; biological control of parasites; biosecurity; broodstock nutrition; and environmentally conditioned and hormone-induced spawning techniques; intensive and semi-intensive larval rearing using mesocosm systems with artificial substrates; proactive health management, specifically the use of probiotics to improve health and aquaculture performance of marine fish during early developmental stages; nursery techniques; and, studies conducted on growth, survival and feed conversion rates of mutton snapper raised in floating cages.

Site assessment criteria and environmental issues related to offshore fish aquaculture in net cages are addressed, as well as the legal framework and relevant regulatory issues. A project being developed by Snapperfarm and the University of Miami to demonstrate the technological, environmental, social and economic viability of offshore aquaculture in Puerto Rico is described. The project is scheduled to begin in 2002 with the deployment of two 3,000 m^3 SeaStation submersible cages and their subsequent stocking with mutton snapper and cobia fingerlings. The offshore growout demonstration project is the first and most important component of the "*Sustainable Offshore Aquafarm*", a conceptual idea that Snapperfarm and the University of Miami set out to establish in the region within the next few years. The Sustainable Offshore Aquafarm concept is also described in this paper.

Most countries throughout the Caribbean have appropriate offshore areas with

great potential for sustainable aquaculture development. Adequate utilization of available areas and infrastructure can lead to the development of unexploited resources with the potential of generating a large number of jobs and enormous social and economic benefits to the region. The main hurdle is the required establishment of an effective and integrated collaborative effort among private industry, local governments, academic and research institutions, non-government organizations, and stakeholders from influential social and professional sectors.

KEY WORDS: Offshore aquaculture, marine fish culture, sustainable aquaculture

INTRODUCTION

Aquaculture currently contributes approximately 30% of total world fisheries production and is increasing at an impressive annual growth rate of approximately 12%. Since 1984, marine aquaculture production around the world has increased by an average of nearly 12% per year. In contrast, world marine capture fishery production has remained stagnant since the late 1980s with landings in recent years increasing by only 0.6% per year (FAO 2001). Future projections of marine capture landings do not indicate significant increases in the near and mid term. As exemplified by the tuna ranching in Mediterranean countries, aquaculture development is entirely reshaping the fishery industry as well as fishery management strategies in many regions throughout the world. By 2030, aquaculture will be the dominant source for supplying fish to world markets, and less than half of the fish consumed worldwide are likely to originate in traditional capture fisheries (FAO 2001). The same report estimates that the role of capture fisheries in the economies of the wealthier countries will be further reduced as developing countries increase their share of production. Aquaculture will have expanded geographically, in terms of species cultured and technologies used. It is very unlikely that Asia will continue to dominate production to the extent that it did during the 1990s. Mariculture will account for a larger share of total production, particularly when offshore culture technology becomes viable (FAO 2001). High-value marine finfish landings are and will remain inadequate to meet worldwide demand. Imports into developed nations have risen dramatically within the past decade, and the prospects of replacing imported wild-caught fish with a farm-raised product are excellent.

Due to greater depths, stronger currents, and distance from shore, environmental impacts are considerably lower in the open ocean, suggesting that offshore cage systems are among the most environmentally sustainable methods for commercial marine fish culture (McVey 1997). Inevitably, commercial operations for raising high-value marine fish will be established within the next few years in the offshore areas of the Caribbean, southeastern United States, Gulf of Mexico, and Latin American countries (Benetti et al. 1999, McVey and Treece 1999). Most of these regions have suitable offshore areas with great potential for the development of this emerging industry. Adequate utilization of available areas and infrastructure can lead to the development of unexploited resources with the potential of

generating a large number of jobs and enormous social and economic benefits for those countries taking the aquaculture initiative.

Beginning in 2002, Snapperfarm, Inc. will implement an important project for the demonstration of the technological, environmental, social and economic viability of offshore aquaculture. The project will include the deployment of two 3,000 m^3 SeaStation submersible cages in Caribbean waters off of Puerto Rico followed by stocking of the cages with mutton snapper and cobia fingerlings that will be produced by the Aquaculture Center of the Florida Keys (ACFK). The Aquaculture Program of the University of Miami's Rosenstiel School of Marine and Atmospheric Science has been conducting the research and development in collaboration with both the ACFK and Snapperfarm, Inc. The projects are funded by the private sector with the assistance of NOAA's National Marine Aquaculture Initiative, Sea Grant, and PRIDCO (Puerto Rican Industrial and Development Corp.). The University of Puerto Rico is collaborating with the University of Miami for conducting environmental assessment and social and economic studies related to the project.

This paper reviews recent technological progress in marine finfish aquaculture at the hatchery and growout levels within the context of relevance to the Caribbean region. The levels of feasibility of native candidate species are also addressed, with emphasis on the use of environmentally friendly technology such as offshore cages. We emphasize the use of applied technology for the development of a commercially feasible and environmentally sustainable marine fish aquaculture industry in the Caribbean.

SPECIES

Emerging technologies for the artificial propagation of marine finfish species endemic to Caribbean and American countries have brought the establishment of marine fish aquaculture industry a step closer to reality. Considering recent technological advances and market demand, species with potential for commercial aquaculture development in offshore areas of Caribbean countries are the snappers (Lutjanidae, *Lutjanus spp*), dolphin fish or mahi mahi (Coryphaenidae, *Coryphaena hippurus*), jacks and pompanos (Carangidae, *Seriola spp, Caranx spp* and *Trachinotus spp*), tunas (Scombridae, Thunnus *spp*), cobia (*Rachycentrum canadum*), and groupers (Serranidae, *Epinephelus spp*). Red drum (*Sciaenops ocellatus*) has potential for offshore cage aquaculture and is indigenous to the Gulf of Mexico. However, it is not recommended to introduce this species anywhere outside of its distribution range, which does not include most Caribbean Islands. Only indigenous species should be considered for aquaculture development in these regions. Several projects dealing with the hatchery and growout stages of these species are in the early stages of development. It is foreseen that two to three of the listed species will be raised commercially within the next few years in the Gulf and Caribbean regions. Technological progress has been fast with a few species (e.g. mutton snapper, cobia, amberjacks), but slow with important species such as

groupers (Serranidae). Results of research and development conducted thus far indicate that mutton snapper, yellowtail amberjacks, cobia, and red drum exhibit the best potential for aquaculture development in the Caribbean and Gulf of Mexico within the next five years. Red drum is a traditional species whose aquaculture technology is available, but progress towards development of its commercial aquaculture in the Gulf has been slow due to questions regarding its market.

BREEDING PROGRAM

The development of a successful breeding program is the first and most important stage for the formation of a sustainable aquaculture industry in the Caribbean. The basis of every hatchery operation is the maintenance of a healthy group of sexually mature broodfish conditioned to spawn year-around using environmental cues such as photoperiod and water temperature. The consistent supply of a large number of high quality fertilized eggs can only be achieved through the implementation of a rigorous protocol aimed at reducing stress levels in the broodstock fish from the time of initial capture and acclimation to containment to final maturation. The techniques for the capture, transport, handling, sexing, sampling and acclimation of marine finfish have recently been described by Benetti and Alarcón (2000). Prophylaxis using chemotherapeutants, antibiotics, and quarantine are necessary before introducing fish into maturation facilities. Recent advances have led to improved transportation, handling, sampling and biological control of parasites through symbiosis. The effectiveness of clove bud oil as an anesthetic has been demonstrated for a number of species and can be an effective alternative to synthetic anesthetics. Some marine fish species have reacted negatively to other anesthetics such as MS-222 and 2-phenoxy-ethanol. Clove bud oil at dosages of 20 ppm has been used for anesthetizing *Lutjanus griseus*, *L. analis*, and *S. dumerili* and *Rachycentron canadum* with remarkable results. The use of cultured and wild-caught neon gobies, *Gobiosoma oceanops,* and wild-caught juvenile porkfish, *Anisotremus virginicus,* has proven to be an effective long-term means to control ectoparasites on mutton snapper, *Lutjanus analis*, greater amberjack, *Seriola dumerili*, and cobia, *Rachycentron canadum*, broodstock in recirculating systems.

Following quarantine and acclimation, broodstock fish are stocked in maturation tanks, where they are conditioned to spawn naturally through the manipulation of environmental parameters such as photoperiod and temperature cycle. Chillers and/or heat pumps and banks of fluorescent lighting are used for supplying required temperature and light cycles. Hormone-induced ovulation followed by voluntary spawning or manual stripping has also been widely used for several species that do not complete vitellogenesis and ovulation in captivity in response to environmental stimuli alone. In addition to traditional methods of inducing spawning with injections of HCG (Human Chorionic Gonadotropin) at 500 – 1000 IU/kg body weight, LHRH-a (Luteinizing Hormone Releasing Hormone analogue) at 50 - 100µg/kg and/or other natural and synthetic hormones, techniques

involving the implantation of synthetic copolymers and cholesterol pellets – which serve as inert matrices for LHRH-a and GnRH (gonadotropin releasing hormone) - in the muscle tissues of the target broodstock fish – have been widely used with various degrees of success, depending on the species. Specifically, either natural or induced spawning of males and mature females have been achieved in all species listed by intramuscular injections of HCG (500 -1,000 IU/kg body weight), and LHRH-a (50 - 100µg/kg) or GnRH-a intramuscular implants.

Captive mutton snapper broodstock have recently been conditioned to spawn voluntarily in maturation tanks at the Aquaculture Center of the Florida Keys on the sole basis of manipulating environmental cues such as varying the water temperature between 20 and 28 °C. This has been an unprecedented achievement. Mahimahi, amberjack, and red fish have also been consistently spawned without hormonal inducement in several hatcheries in the United States. In Japan, Australia and Ecuador, spawning of *S. quinqueradiata*, *S. lalandi* and *S. mazatlana* have been consistently achieved in captivity, and research is underway in the U.S. to spawn *S. dumerili*. Research with yellowfin tuna (*Thunnus albacares*) conducted at the Inter-American Tropical Tuna Commission Achotines Laboratory in Panama has resulted in daily voluntary spawns of high quality fertilized eggs with additional plans for establishing protocols for the larval rearing phase (Scholey et al. 2001). Induced and voluntary spawning of cobia have been achieved in Taiwan and the U.S. through research taking place at University of Texas in Texas, Southland Fisheries in South Carolina, and Virginia Institute of Marine Sciences in Virginia. Currently, the Aquaculture Center of the Florida Keys and the University of Miami are conducting intensive R&D work with cobia, aiming to develop a breeding program for controlled reproduction to make fingerling production available for stocking offshore cages beginning in 2002.

LARVAL HUSBANDRY

Intensive and semi-intensive (mesocosm) larval rearing techniques have been used to demonstrate the feasibility of fingerling production of several high-value marine finfish species. Spawns are collected by a surface skimmer installed in each maturation tank and are passed into an egg collector. Eggs are rinsed with sterilized salt water and stocked into incubator tanks where volume and fertility counts are obtained. A rinse with formaldehyde solution (10 ppm) is also used on newly hatched eggs to reduce bacterial levels. At 26 °C, eggs of tropical species generally hatch within 24 hours and the larvae begin feeding two days post hatching (DPH). Yolk-sac larvae are stocked at densities of up to 100 per liter in intensive systems, while semi-intensive larval rearing uses stocking densities of up to 20 larvae per liter. Larval feeds consist primarily of microalgae-fed rotifers, *Brachionus plicatilis and B. rotundiformis* (ss-strain), wild plankton (particularly copepods), *Artemia* nauplii and enriched metanauplii and subadults. Feed types are overlapped and the growth rate of a particular species determines the timing at which feed items are introduced at progressively larger sizes. Traditional live feeds can be supplemented with wild

zooplankton, including copepods of the genus *Acartia* and others, which are part of the larvae's natural diet in the wild and therefore ideal first food items. Live food production research is now focusing on the mass production of copepods in outdoor systems.

Probiotics and artificial substrates have been used in mesocosm systems bloomed with phytoplankton and zooplankton to improve larval rates of growth and development. Preliminary results of trials conducted with mutton snapper indicate that, while survival rates remain low, rates of growth and development of *L. analis* are faster in outdoor semi-intensive mesocosm systems than in intensive indoor systems. High mortalities are still observed during early developmental stages, especially at first feeding and metamorphosis and can sometimes be linked to poor broodstock nutrition. Weaning from live feeds onto artificial diets in species like snappers, amberjacks, grouper, and drums may take up to 40 days post hatching (DPH). Cannibalism during early stages does not constitute a problem in the case of mutton snapper, but it can be a constraint during larval rearing of pelagic species, especially after metamorphosis. Lower stocking densities, stronger water flow and aeration, and increased feeding frequency are some of the strategies used to alleviate this problem. Larval fish are highly susceptible to stress and will not tolerate handling prior to 30 DPH. Intensive larval culture methods have been successfully used to produce significant numbers of juvenile mutton snapper, although commercial feasibility of the operation has not yet been achieved.

Commercial-scale hatcheries exist for groupers and snappers in southeast Asia and in Japan, for red drum in the U.S., Taiwan and Israel, and for several temperate species in Taiwan, Japan, Australia and Japan. The aquaculture of *Seriola dumerili* and *S. mazatlana* are still in the research and development stage (Benetti 1997), but a survival rate of 9% from eggs to fingerlings of *S. quinqueradiata* has been reported in Nagasaki. In Australia, yellowtail kingfish (*S. lalandi*) offshore cage aquaculture is currently expanding to commercial scale with fingerlings produced in hatcheries. Tuna larval rearing is a new field emerging after the recent success with spawning of captive adult brood fish (Scholey et al. 2001). Cobia is considered to be a prime candidate for aquaculture in the southeastern United States, Gulf of Mexico, and Caribbean based on the combination of successful commercial development of this species in southeast Asia (Su et al. 2000) and recent research conducted in the US, in which larvae and fingerlings exhibited high survival rates and remarkable growth.

GROWOUT

Of the species considered in this review, only cobia in Taiwan, *Seriola spp* in Japan and Australia, yellowfin tuna in Mexico, red rum in several Asian countries and grouper in southeast Asia are being commercially grown in cages. The industry is quickly moving away from relying on wild caught juveniles to hatchery-produced fingerlings to stock growout cages. A remarkable cage culture industry based on hatchery-produced fingerlings has been developed in European countries,

particularly in Greece, with sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*) (Kissil et al. 2000a, 2000b). Currently, there is a major effort towards the development of offshore aquaculture in the southeast U.S., the Gulf of Mexico and the Caribbean (McVey and Treece 1999).

Preliminary data regarding the aquaculture performance of hatchery-reared high-value marine fish cultured in cages are only recently becoming available in this part of the world. In a growout trial recently conducted in the Florida Keys, growth, survival and feed conversion rates of mutton snapper raised in floating net cages have been assessed (Benetti et al. 2002). Results are summarized as follows: out of approximately 18,000 fingerlings produced at ACFK in 1999/2000, 10,500 juveniles were stocked in two circular high density extruded polyurethane (HDEP) floating net cages moored in a 7-acre saltwater lake in the Florida Keys. The dimensions of the cages used were 10m diameter x 7 m deep (600 m^3) and 7 m diameter x 7 m deep (300 m^3), and both were fitted with 1/2" mesh (stretched). Fish grew from an average weight of 12.25 g to over 300 g in nine months, indicating that the commercial size of 0. 5 kg (over 1 lb) can be achieved within a 1-year growout period (Figure 1). Estimated survival rate was over 70%. Stocking densities were 25 fish/m^3 (3.2 kg or 6.0 lb/m^3) and 5 fish/m^3 (0.72 kg or 1.4 lb/m^3). Fingerlings were fed a 2.5 - 5.0 mm marine grower (Moore-Clark) pellet containing 50% crude protein and 14% crude fat and a 1/4" pellet (AquaXcel, Burris) containing 53% crude protein and 10% crude fat. Estimated feed conversion ratio (FCR) was 1.4, ranging from 0.79 - 3.4. Results, described in detail by Benetti et al. (2002), confirm that *L. analis* has excellent potential for commercial aquaculture development in net cages in the U.S. and the Caribbean. These results corroborated an earlier work by Watanabe et al (1998), who raised this species in tanks with similar results.

When compared to other species, growth rates of pelagic species such as dolphin fish, cobia, tuna, and amberjack are significantly higher (Benetti 1997). Captive dolphin fish, *Coryphaena hippurus*, grew to almost 5 kg in weight and 76 cm in length from hatching in 9.5 months in Hawaii (Benetti et al. 1995). Cobia cage-culture production in Taiwan produced an estimated 1,500 tons in 1999, with reported growth rates of up to 6 kg after a one year growout period (Su et al. 2000). Red drum can tolerate a wide range of salinities as adults as well as during their early life history stages, therefore its commercial growout can be done in both ponds and cage systems, where favorable environmental conditions (water temperature 24 - 30 °C) allow for the production of 1 kg fish after a growout period of 8 - 12 months (Sandifer 1993).

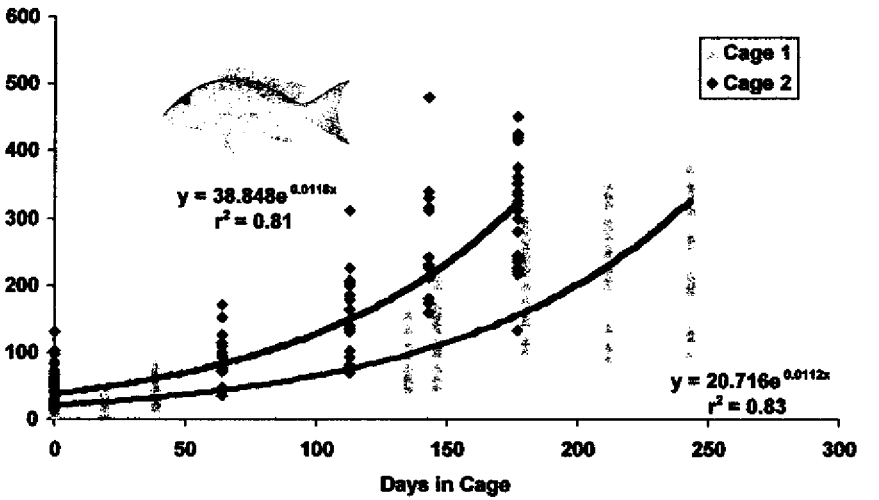


Figure 1. Growth rates of hatchery-reared mutton snapper, *Lutjanus analis*, reared in floating net cages. (Data from Benetti et al. 2002).

OVERVIEW OF OFFSHORE PROJECT DEVELOPMENT AND REGULATIONS

Beginning in June 1999, Snapperfarm, Inc. and RSMAS University of Miami joined efforts to develop a project to perfect and apply aquaculture technology of mutton snapper (*Lutjanus analis*) and other high value marine fish species using offshore cage systems. During the first stage of this project, an interdisciplinary site assessment and feasibility study were conducted to evaluate potential sites for project development in the Caribbean. Combining all relevant criteria, several potential sites were selected with many unsuitable sites eliminated on the basis of conflicting uses. The selected site covers 250,000 square meters in the Vieques sound, two nautical miles southwest of Culebra Island, Puerto Rico. The site is ideal for the deployment of two SeaStation 3000 submersible cage systems, and the water quality parameters are optimal for the growout of mutton snapper, among other species. Social, economical and educational issues were evaluated in great detail during site assessment. Snapperfarm and RSMAS have formed a partnership with the Culebra Fisherman Association, a cooperative of about 40 fishermen on the island of Culebra. Eighty percent of Snapperfarm's workforce will be comprised of

local fisherman and regular educational seminars will be held on the island so that the community may learn more about the emerging offshore cage culture industry.

Once the appropriate site was selected and a productive relationship was established with the local community, the Federal and Commonwealth Joint Permit Application (JPA) for Puerto Rico was submitted in September 2000. In December of the same year, a National Pollution Discharge Elimination System (NPDES) permit application was submitted to the U.S. Environmental Protection Agency. Due to the overwhelming support that the project received from governmental, academic, and public sectors in Puerto Rico, Snapperfarm and RSMAS anticipated a short permitting process. However, a number of extrinsic factors led to delays. The new government is currently supporting the project, the federal permit has been issued and Snapperfarm and RSMAS anticipate a short wait for the approval of the final permits. The following is a short summary and interpretation of existing policy, zoning and regulations in Puerto Rico, where the Snapperfarm offshore aquaculture operation is being established:

Policy

The Commonwealth of Puerto Rico has declared, in Title 5, Chapter 52 of the 1999 Laws of Puerto Rico, that "fishing and aquaculture shall be promoted as important activities for the economic development and nutrition of the Puerto Rican people." As such, systems are in place to assist with expansion of aquaculture into offshore waters (i.e., a coordinated single application procedure). The laws and regulations are conducive to aquaculture development, but companies that apply for a permit must endure a lengthy and complex procedure to ensure that all environmental aspects related to project development are in full compliance with the laws and regulations of the 13 agencies directly involved in the permitting process. The permit application must be reviewed and approved by all 13 agencies before a final permit can be granted. An underwater archeological survey is but one example of the large number of studies required. The Army Corps of Engineers (ACE), the United States Coast Guard (USCG) and the National Oceanographic and Atmospheric Administration (NOAA) are three of the main agencies involved in the process, along with the Department of Natural and Environmental Resources (DNER).

Zones

Puerto Rico has jurisdiction, subject to all applicable federal laws, for all coastal waters (including bays and inland waters) from the established low water mark out to 12 NM.

Regulations

All Puerto Rico commonwealth laws are subject to applicable U.S. federal laws (i.e., Puerto Rico can enforce stricter laws but can not ease or try to limit federal laws). The Department of Agriculture and the DNER each oversee different regulatory aspects of the aquaculture industry in Puerto Rico. However, the Fishing

and Aquaculture Industry Council (with a separate representative for mariculture) works as an interagency group to ensure that these industries thrive with the least amount of governmental interference. Leases are available for submerged lands and associated water columns. Regulations are strictly enforced, and the DNER treats every permit application with diligence.

The two SeaStation 3000 submersible cage systems will be deployed in 2002, when the Snapperfarm offshore aquaculture demonstration project is scheduled to officially begin. The two cages will be stocked with mutton snapper and cobia fingerlings produced at the Aquaculture Center of the Florida Keys. This project is the first and most important component of the Sustainable Aquafarm concept, which is briefly summarized in the following section.

THE "SUSTAINABLE OFFSHORE AQUAFARM"

The offshore growout demonstration project previously described is the first and most important component of the "*Sustainable Offshore Aquafarm*", a conceptual idea that Snapperfarm and the University of Miami set out to establish in Puerto Rico within the next few years. The main overall objective is to develop and implement technology for a new, environmentally responsible and commercially feasible industry that will generate scientific, technological, social, economic, and educational benefits.

The development of offshore sustainable aquaculture technology will require combined expertise in science and technology as well as in management, socioeconomic, environmental, and legal issues. In addition to the establishment of the cages and infrastructure, we propose to develop models for the prospective environmental impacts of EEZ-based aquaculture. Like any human activity, aquaculture in the EEZ waters of the US will have impacts on the ecology of ambient waters. Establishing benchmark conditions, modeling potential impacts on planktonic and benthic processes, and providing mechanisms to adapt aquaculture technology with the least environmental impact, will be the major objectives of this component. For example, environmental models based on energy budgets, mass balance, current velocity and direction, depth (bathymetry) and water quality parameters must be constructed to determine the amount of solids and nutrients being generated by the offshore growout systems (cages), to estimate the biomass of filter-feeder mollusks (e.g. oysters, mussels) and nutrient-stripper macroalgae (e.g. *Gracilaria*, *Ulva*) required to "clean up" the water downstream. These parameters can be determined using mass balance and differential equations. The carrying capacity of the area must be precisely determined to avoid the risks of eutrophication. The conceptual Sustainable Offshore Aquafarm can be summarized as follows:

The Offshore Aquafarm demonstration project will be completely submerged, as illustrated in Figure 2. This preserves the aesthetic aspects of the area. In compliance with USCG regulations, systems comprised of cages, rafts, lanterns, longlines and moorings will clear at least 25 ft (8 m) from the surface in order to

avoid impediments with navigation. The depth of the site (90 ft/30m) and steady current (0.5-1.5 knots) maintain water movement in a downstream direction, dispersing organic and inorganic pollution that could potentially be associated with aquaculture operations. No coral reefs are present in the area surrounding the Offshore Aquafarm. Rather, sparse patches of *Halimeda* - a macroalgae characteristic of oligotrophic environment- are found at the predominantly sandy bottom. The cages, to be stocked with hatchery-reared snapper, cobia or amberjack for growout, will inevitably generate a certain amount of nutrients and suspended solids, which will not dramatically affect the nutrient deprived, offshore environment due to its carrying (i.e., environmental) capacity. Downstream from the cages' site, the concept includes the deployment of rafts and longlines of filter feeder mollusks and banks of macroalgae that will utilize the inorganic nutrients being released by the system.

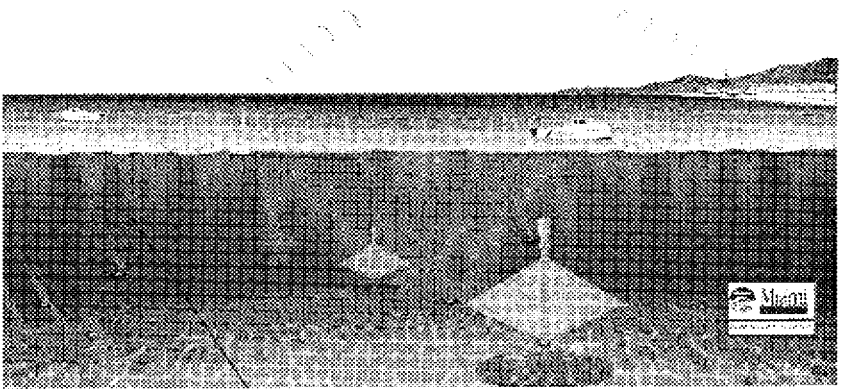


Figure 2. The Conceptual Offshore Aquafarm, currently being developed in Puerto Rico.

The submergible cages will also function as FADs (Fish Aggregating Devices). Since an estimated 50% of the hatchery-reared fish will be suitable for stock enhancement purposes, FADs will provide the ideal habitat for releasing fish. Additionally, the combination of FADs and hatchery-reared released fish will promote the enhancement of fish stocks in the area. The concept of Acoustic Ranching in Aquaculture (ARIA) will also be tested. To ensure long run autonomy

of the Offshore Aquafarm, a state of the art marine hatchery and school will be established in the Island of Vieques and/or Culebra. The marine hatchery and school are seen in the background of Figure 2. An educational program and curricula will be established for training of personnel at all levels, from high-school to technical and graduate level. Simultaneously, the marine hatchery will be producing larvae, post-larvae and juveniles of high-value marine fish and invertebrate species for aquaculture and stock enhancement.

The submersible cages being used, SeaStation, are state of the art, manufactured in the U.S. by Ocean Spar Technologies, NET Systems. To ensure long-term sustainability and to develop this concept properly, scientific research is required. For example, environmental models based on energy budgets, mass balance, current velocity and direction, depth (bathymetry), and water quality parameters must be constructed to determine the amount of solids and nutrients being generated by the fish cages to estimate the biomass of filter-feeder mollusks (oysters, mussels) and nutrient-stripper macroalgae (*Gracilaria, Ulva*) required to "clean up" the water downstream. These parameters can be determined using mass balance and differential equations. The environmental carrying capacity of the area must be precisely determined to avoid the risks of eutrophication. Since the cages deployed and their mooring systems will act as artificial reefs or FADs (Fish Aggregating Devices), the model should also incorporate data on fish and invertebrate assemblges surrounding the cages.

The Offshore Aquafarm will be autonomous and self-sustained. Automated feed hoppers loaded with environmentally friendly feeds will dispense automatically pre-calculated rations to ensure the highest assimilation and feed conversion rates with minimal organic and inorganic wastes. A key determinant in the success of major aquaculture operations is the ability to monitor water quality parameters such as temperature, salinity, oxygen, pH, suspended solids, as well as nutrients, in order to determine whether fish feeds are being dispensed at the optimum rate. We propose to accomplish this by installing autonomous monitoring devices with several sensors in the cage system. The Seakeepers monitoring device will allow for gathering and transmission of real time data via satellite to computerized systems in the control room at the hatchery. This will be a fundamental tool in assisting the development of improved management strategies for minimizing solid organic and inorganic wastes (feeds, feces and nutrients) as well as promoting optimal food conversion and growth rates. The International SeaKeepers Society, which owns a patent on this monitoring device, is a technological partner in the proposed offshore project.

Properly developed, this concept may enable the simultaneous development of aquaculture of high-value organisms that feed low in the food chain such as filter feeders and nutrient strippers in areas of the Caribbean which could otherwise not be utilized for any purpose because of the extremely low productivity. Mollusks and algae, for instance, can only be cultured in nutrient rich areas. Therefore, nutrients and solids being released by the fish cages will create a favorable environment for raising species of mollusks and algae that could, in turn, provide additional crops

while removing the organic and inorganic nutrients from the area. The University of Miami's Center for Sustainable Fisheries is supporting this initiative.

CONCLUSIONS

Advances in technology, suitable environmental characteristics, excellent candidate species, the need for diversification, and a growing market demand have brought the prospect of developing an environmentally sustainable and commercially viable marine fish aquaculture industry in the Caribbean and the Gulf of Mexico a step closer to reality. However, the development of reliable techniques for mass production of fingerlings of several marine finfish species through artificial propagation in hatcheries is necessary for the establishment of a sustainable offshore cage industry in the region. Research is currently focused on improving technology in the areas of broodstock nutrition, egg quality, live feeds, first feeding, larval nutrition, and bacterial contamination of live feeds, which are the main constraints for the development of the industry at the hatchery level. Progress has been fast with a few species (e.g. mutton snapper, cobia), but slow with important species such as groupers (Serranidae).

Growout technology is readily available. At the growout level, the main hurdle to overcome is the required establishment of an effective and integrated collaborative effort among the private industry, government agencies, non-government organizations, academic and research institutions, as well as stakeholders from different social and professional sectors. Both private and governmental sectors recognize that now is the perfect time for the development of high-value marine finfish aquaculture industry in this part of the world. Indeed, most countries throughout the Caribbean have appropriate offshore areas with great potential for the development of this emerging industry.

Adequate utilization of available areas and infrastructure can lead to the development of unexploited resources with the potential of generating a large number of jobs and enormous social and economic benefits to the region. However, extreme caution must be undertaken to ensure that the operations are properly planned and developed, primarily taking into account the environmental sustainability of the projects. Environmental assessment is an obvious requirement for all projects, and access to all data and information should be made readily available to environmental managers, decision-makers, and scientists. Based on real data collected prior to and during the operation, mass balance and carrying capacity modeling should allow for a high degree of environmental monitoring and control of offshore aquaculture operations in oligotrophic areas. Since the private sector is primarily profit driven, much of the regulatory and monitoring responsibility will rely on the government and academic sectors.

ACKNOWLEDGMENTS

This work was partially funded by the National Sea Grant College Program with support from the National Oceanic and Atmospheric Administration (NOAA), National Marine Aquaculture Initiative (NMAI), Office of Sea Grant, U.S. Department of Commerce, Grant No. Grant No.DOC/NOAA/NSG NA 06 RG – 0068 to the first author.

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Calico Scallop Culture In Bermuda: A Low Cost, Pilot Hatchery for the Tropics and Subtropics

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ABSTRACT

The potential for large scale aquaculture of the calico scallop, *Argopecten gibbus*, has been investigated in Bermuda since 1997. An initial broodstock of 100 mature individuals was collected from Cape Canaveral, Florida, and transferred to a quarantine system at the Bermuda Biological Station for Research Inc. (BBSR). Hatchery and nursery facilities at BBSR are housed in two 20' insulated fiberglass containers; an independent seawater system allows for the continuous supply of filtered seawater; a temperature control system for seawater further allows for broodstock conditioning and optimal larval rearing. Insulated 1,000 litre tanks are available for larval rearing; post-larval rearing is conducted in 450 L round tanks, and raceways. Using a 4,600 L larval tankage capacity 40,000 5 mm juveniles are generally produced during one spawn. The facilities are compact and efficient, and they may moreover be easily duplicated in any location. *A. gibbus* is a hermaphrodite species, spawning during the winter months. Larval culture for this species was developed, investigating optimal temperature and food ration. The length of larval life is 12 days, and approximately 30% pediveligers are obtained from Day 2 larvae. Settlement is performed either by the use of polyethylene mesh or on 150 µm sieves in the raceway; the former method allows for transfer at sea within 20 - 30 days of settlement, minimizing labour during the nursery phase. Juvenile scallops, 10 - 15 mm shell length, are thereafter grown in suspended cultures. Shell growth rate is rapid, averaging 5 - 7 mm/month, and survival rate from 15 mm to 65 mm shell height is high ranging between 70% and 90%. Reproductively mature and market size individuals are obtained 12months after fertilization. Market demand for fresh local seafood is high in Bermuda, and supply to selected restaurants has received positive feedback. Further assessment of the market demand is conducted at present. The techniques developed for calico scallop culture in subtropical waters are relatively simple and have yielded a high percentage of mature market size individuals; furthermore, the custom designed facilities have proved flexible in use and efficient. In brief, the technology for *A. gibbus* aquaculture may be easily transferred to other sub-tropical and tropical locations, providing a reliable supply of shellfish to tourist-oriented areas.

KEY WORDS: Calico scallop, hatchery, tropical

INTRODUCTION

The potential for large-scale aquaculture of the calico scallop, *Argopecten gibbus*, has been investigated in Bermuda since 1997. The main constraint to the development of the program was the lack of facilities and limited funding available for this purpose. Moreover, there was limited land available for the construction of a proper hatchery, and the approval for building permits is a lengthy process in Bermuda. In light of this, a low cost "temporary" hatchery was built in June 1999 utilizing three refrigerated "reefer" containers. This facility was designed and fitted for larval and post-larval rearing of bivalve species; the main goals were to develop techniques for large-scale production and to conduct experimental work towards optimizing culture techniques for all stages of scallop life cycle. Flexibility of usage was a fundamental part of this model hatchery. The calico scallop was selected as the culture candidate following preliminary investigations indicating a rapid growth rate from juvenile to market size, coupled with a high survival rate (Sarkis et al. unpublished). This paper describes the pilot hatchery concept, and provides a synopsis of calico scallop culture developed at the Bermuda Biological Station for Research Inc. (BBSR) resulting from two seasons' operation in this facility.

PILOT HATCHERY

Hatchery and nursery facilities are compactly arranged in two 20' insulated, air-conditioned, glass-fibre containers with an additional 12' container dedicated to algal culture. Culture facilities comprise:

i) An independent seawater system providing a continuous supply of filtered seawater,
ii) A temperature control system for seawater in support of broodstock conditioning and requirements for larval and juvenile rearing,
iii) 1,000 L insulated, polyethylene and 200 L conical, glass-fibre tanks for standard larval rearing in closed systems, and for experimental rearing in flow-through larvae culture systems,
iv) Flexible usage 450 L round tanks, and stacked raceways for setting pediveligers and growing spat. Raceways may be either connected together as a single open-flow or semi-recirculating system, or used independently of one another, or as holding tanks for a series of small, independent aquaria.

Seawater Supply

Seawater is pumped continuously at a flow of about 50 gallons per minute from 10' depth to a pumphouse, where it flows through a sand filter before supplying the hatchery / nursery and algal facilities. Seawater in excess of requirements bypasses the sand filter and is discharged back into the bay.

The facility was rapidly and inexpensively set-up by linking together two 20' insulated cargo containers. Internal walls are of glass-fibre, and the floors are ribbed aluminum, allowing for easy cleaning and drainage. A well-serviced and space-

efficient working area of approximately 300 square feet was developed following the installation of pipework for climate control, temperature controlled seawater, as well as freshwater and electrical supply. Independent, multi-stage filtration units providing water filtered to a minimum of 1 μm particle size are installed at key points within the hatchery to allow for flexibility of use.

Seawater temperature is controlled and supplied on demand. Pre-filtered water (to 1 μm) is heated to desired temperature in a semi-recirculating1,000 L insulated tank; within this tank are three, 3 kW titanium immersion heaters individually connected to digital temperature controllers. Heated water is distributed to the hatchery, mainly for larval rearing, by a small pump. The system is able to heat 1,250 L/hour through a temperature differential of 8°C.

Hatchery and Nursery Facilities

One of the interconnected containers forms the hatchery area, accommodating foursemi-square 1,000 L insulated tanks. These are used for conventional, closed system rearing of bivalve larvae. These tanks have proved very reliable in rearing scallop larvae, maintaining temperature within 1°C of the required for a 72 hour period. In addition, there are three 200 L conical tanks currently used for experimental work in flow-through larval rearing. A total tank volume of 4,600 L is available for larval rearing.

The nursery area, occupying the other linked container, has been designed for flexible use in setting procedures and for early nursery culture. Two 450 L circular tanks are available as either closed or open systems for setting larvae on mesh collectors. Two 6' x 2' x 0.5' deep flow-troughs are mounted on a side wall, one above the other, acting as raceways. They are connected to a sump tank of 220 litre capacity fitted with a small pump and 250 W heaters to deliver water to either or both troughs at the required temperature through water delivery pipework. This system is extremely versatile; each raceway can be used independently as an open, closed, or recirculating system. This allows for the setting of larvae on sieves, conducting experiments in a series of independent aquaria, or using both raceways as one larger system with a total capacity of 510 L for early nursery culture of spat.

Broodstock and Holding Tanks

Two air-lift driven, semi-recirculating tanks, each 120 L volume with a sub-sand filtration system, are supplied with coarsely filtered seawater and are utilised for broodstock conditioning. Seawater within each tank may be cooled using a titanium coil, 1/5th HP chiller unit to manipulate the spawning period. The chiller is matched in size with the capacity of the tanks to allow for cooling through a 5°C differential from ambient seawater temperatures.

Additional insulated, 400 L tanks with lids are located outside on a pad fitted with drainage. They are supplied with coarsely filtered, ambient temperature seawater, and are used as holding tanks for animals brought in from the field.

Algae

The independent algal culture container receives UV sterilized, 1 µm filtered seawater at ambient temperatures. Cultures of a variety of useful algae species range in volume from 500 ml flasks to 100 L tanks. They are maintained in a climate-controlled environment with 24 hour illumination, and are continuously supplied with a mixture of air and CO_2. The current maximum output of about 100 L per day is sufficient for the current operations of the hatchery / nursery facility.

SYNOPSIS OF CULTURE METHODOLOGY

Specifications for the hatchery were well known through previous experimental work conducted on scallop culture in Bermuda (Sarkis et al. unpublished). Furthermore, scallop culture is performed on a large-scale for several other species in Japan, Chile, France, Canada, among others (Aoyama 1989, Dao et al. 1993, Bourne et al. 1989, Disalvo et al. 1984)). However, the calico scallop, *Argopecten gibbus*, although an important fishery in Cape Canaveral, Florida, is not to our knowledge cultured on a large-scale or commercially anywhere in the world (Miller et al. 1981). Hence, investigations on food ration, temperature, and reproduction were conducted to develop techniques for juvenile production (Hohn et al. submitted). Further investigations were carried out for optimising transfer of juveniles to the field, and grow-out.

Spawning, Hatchery, and Nursery

Argopecten gibbus is an hermaphroditic species, with a well defined spawning period lasting from January to May in Bermuda. Reproduction, therefore, coincides with minimal water temperatures, and spawning is associated with a slight increase in ambient temperature above 18°C.

A broodstock of 20 animals is induced to spawn by thermal shock. Release of gametes generally occurs within 60 minutes of exposure to warm water at 25°C. Each female releases approximately 5.8 million eggs. The basic protocol for larval rearing follows that used for other bivalve species (Bourne et al. 1989). Larvae are reared in 1,000 L insulated tanks at an initial density of 10 larvae/ml, decreasing to 2 larvae/ml towards the end of larval life. Larval life is relatively short, ranging from 12 to 14 days at a rearing temperature of 24°C (Figure 1); at this time, pediveligers attain a shell length of 210 ± 15 µm (Sarkis and Helm 2001). Approximately 25 - 35% of Day 2 larvae survive to metamorphosis; this is comparable to development recorded for other species, ranging from 10 - 20 % in *Argopecten irradians* and up to 50% for *Placopecten magellanicus* (Couturier et al. 1996).

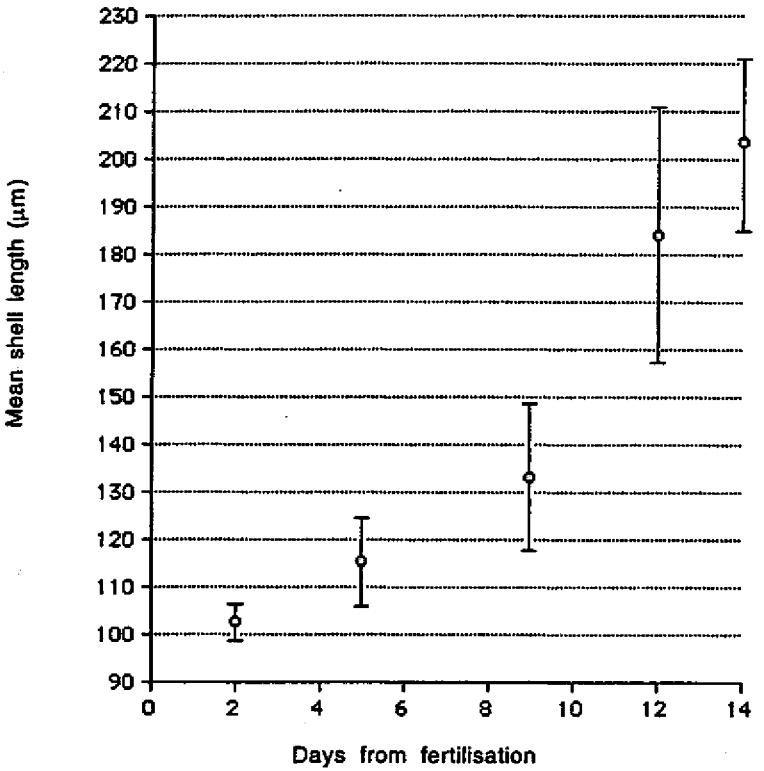


Figure 1. Mean shell length (± s.d.) for *Argopecten gibbus* larvae reared at BBSR in a typical production run. (n = 50)

Settlement:

Pediveligers are set following two different methodologies at BBSR:

i) The first is geared towards minimal labour requirement at the nursery stage, and is for all intensive purposes referred to as "remote set" technique. Circular 450 L tanks are packed with soaked bundles of lightweight, polyethylene mesh (cultch), and filled with 1µm filtered seawater; pediveligers are transferred to these setting tanks, at a density ranging from 2 - 4 larvae/ml. Metamorphosing scallops are allowed to settle on the provided cultch, and are maintained for a period of 20 - 30 days, reaching approximately 1 mm in size, before transfer to longlines in the field. For the first seven days the tanks are operated as closed systems, after which they are set as semi-recirculating systems with partial through-flow and air-lift driven recirculation. Upon transfer to the field, cultch is packed loosely in collector bags. Bags are thereafter suspended on longlines using Irish scallop trays.

ii) The second method is more conventional and optmizes survival rate to 2 - 3 mm prior to transfer to the field. Pediveligers are set in 150 µm mesh-

based sieves in the raceway, and reared for a period of 2 - 3 months. Although survival is considered to be better with this method, the required labor is greater, as is the quantity of algae produced daily. The growth and survival at 22°C of a batch of pediveligers set in four sieves in the raceway at an average density of 80,000 spat per sieve, is shown over a six-week period in Figure 2. Improved growth rate and survival can be expected through grading and reducing density as the spat grow.

With the installed 4,600 L larval tankage, four million pediveligers are produced on average from one spawning; the raceway system allows for the maintenance and growth of approximately 420,000 post-larvae < 500µm shell height. A total of 250,000 3 mm spat may currently be reared using existing facilities. The current constraint for increasing production is the larval and post-larval tankage capacity.

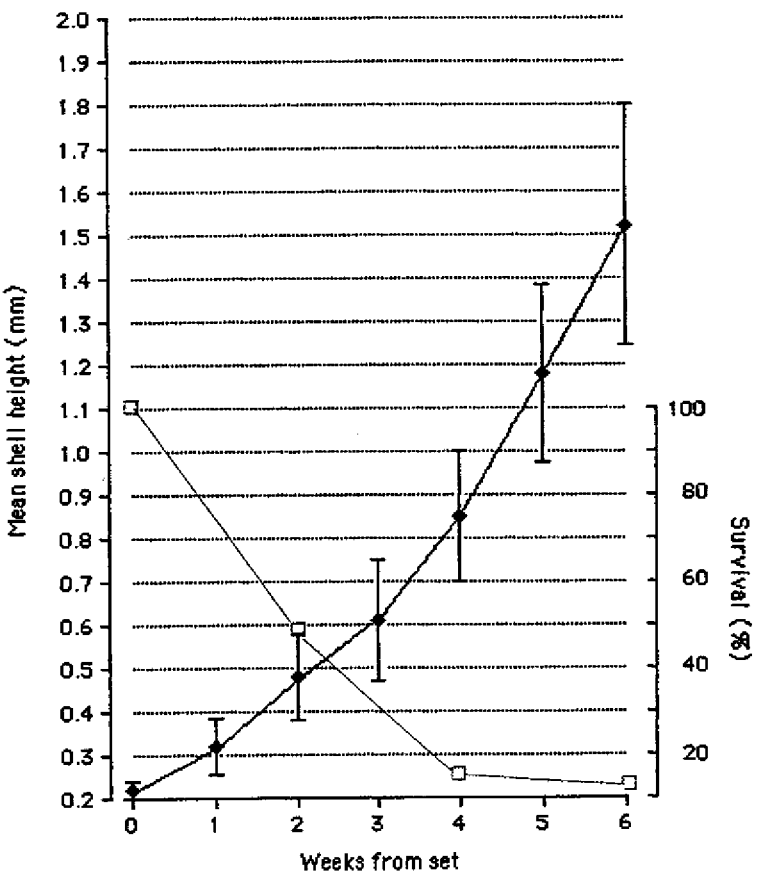


Figure 2. Shell growth (± s.d.) and survival rate of *Argopecten gibbus* post-larvae reared in a raceway system for a 6-week period following Day of set. (n = 50)

Growout

Spat transferred to the field following remote setting technique are left for a period of eight weeks on longlines. At this time, spat are picked from the cultch, measured and counted. Mean shell height at this time is 11.4 ± 1.4 mm. Survival rate over the eight-week period is difficult to assess, but 600 - 2500 spat are routinely picked from the mesh cultch within an individual collector bag. Juvenile scallops are thereafter distributed for growth to adult size. At present, 40,000 5 mm juveniles are generally produced during one culture cycle from a single spawning.

Grow-out is performed in Japanese pearl nets. Mesh size and density vary with scallop size such that 10 mm scallops are transferred to 3 mm nets at a density of 150 per net. Numbers are gradually reduced to 70 individuals/net in July, and to 40 individuals/net in September to allow for rapid growth. Shell height increases to 48.0 ± 2.7mm in seven months; and reaches a maximum of 58.3 ± 4.5mm for 21-month old scallops. Growth rate ranges from 5 - 9 mm/month. Maximum rates are associated with high sea surface temperatures (29.5°C) during July and August. Survival rate from 15 mm to the maximum size of about 65 mm shell height is good, ranging between 70% and 90%. Reproductively mature and market size individuals are obtained 12 months after fertilization. The life span of *Argopecten gibbus* in Bermuda is in the order of 24 to 30 months.

CONCLUSIONS

The techniques developed for calico scallop culture in sub-tropical waters are relatively simple and have proved capable of yielding a high percentage of mature, market-size individuals. In order to obtain a greater production with this system, the number of tanks only needs to be increased, but techniques remain the same. The custom-designed facilities are space-economic and have proved flexible in use as well as very cost-efficient. This basic technology can easily be duplicated in any location adjacent to a seawater source in other sub-tropical and tropical locations. In this way, a reliable supply of a potentially valuable shellfish species may be produced through low technology and environmentally friendly means. Alternatively, the concept lends itself as an effective experimental wet laboratory at modest cost compared with building in bricks and mortar.

Further information and photographs of the hatchery can be found at:

http://www.bbsr.edu/Studies_of_Bermuda_s_Air___Wat/aquaculture/aquaculture.html

ACKNOWLEDGEMENTS

This entire program was initiated with the enthusiastic help of Leroy Creswell and Peter Woodward, who supplied us with a first broodstock of calico scallops from Cape Canaveral. This work is also possible thanks to the fundraising efforts of BBSR, and to the generosity of individual and corporate donations from Bermuda.

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Probable Nursery Areas for Juvenile Groupers Along the Northern Coast of the Yucatan Peninsula, Mexico

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ABSTRACT

Groupers contribute with the maximum number of individuals and catch biomass of the entire Yucatan's fishfish production. Despite the importance of this resource, little information is available on the biology of grouper juveniles.

Through a five month survey in nine different sites along the coast, we captured 192 individuals, belonging to five species of juvenile's groupers. *E. morio* (5.5* cm), *M. bonaci* (38* cm), *M. microlepis* (7.1* cm), *E. striatus* (34* cm) and *E. adscensionis* (15.7*cm) (*minimum value for standard length). *E. morio* was the most abundant specie captured (N = 89), following *M. microlepis* (n = 84) and *M. bonaci* (n = 17), being July the month in which more individuals were captured (n = 89).

The potential nursery areas defined by this study match the four natural protected areas along the coast of Yucatan, even though when these areas were decreed, the marine environment was not taken into account, and there are no marine management plans for any of them. Therefore, this study is focused on the distribution of juveniles, potential nursery and recruitment areas, and habitat dependency along the Yucatan coastline.

KEY WORDS: Groupers, juveniles, nursery areas

INTRODUCTION

In Yucatan State, the catching of groupers was by 1995, the 91.5% of the entire national fishing production in Mexico and in 2000, 8.755 tons were captured in this State (INEGI, 2000). Based on the studies carry out by Colás- Marrufo, *et al.*, (1998) and Tuz- Sulub (1999), 17 different species of groupers could be identified at the Campeche Bank. From these species, the most important registered were the red grouper (*Epinephelus morio* 84% individuals), the black grouper (*Mycteroperca bonaci*, 12% individuals) and the gag (*Mycteroperca microlepis*, 2% individuals).

The shoreline of the state of Yucatan is approximate 342.47 km long, and represents different ecosystems such as coastal lagoons, estuaries, mangroves and an extensive continental platform (part of the Campeche Bank) limited 25 km inwards the Gulf of Mexico, where different bottom habitats can be found. This

biotic richness offers multiple possibilities for sustainable uses, such as fishing, which is the main economic activity of the state (Figure 1).

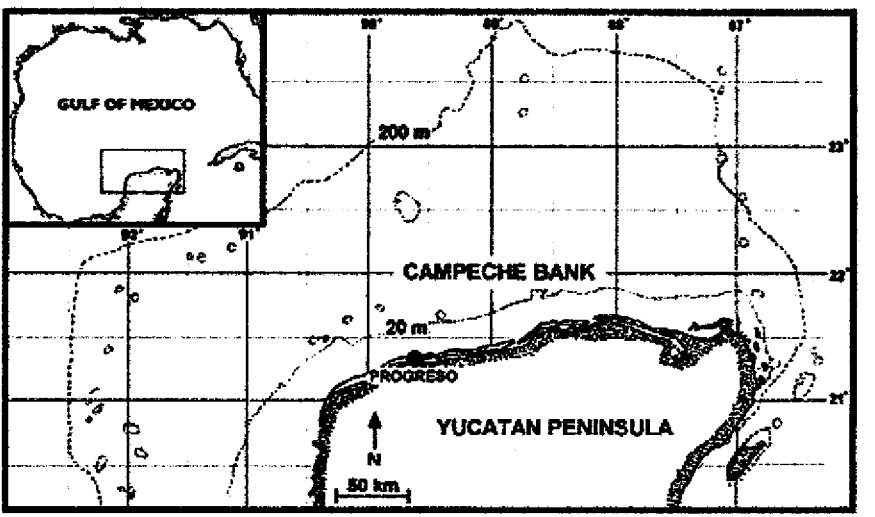


Figure 1. Map of the Yucatan Peninsula and the northern coast of Yucatan where the surveys were performed

In the state of Yucatan, and due to the bathymetric distribution known for groupers, juveniles live in shallow waters closer to the coast whereas adults select deeper habitats (Thompson and Munro 1978, Sluka and Sullivan 1996). The fishing activities for these populations are divided into technified and artisanal fishing fleets. The first fleet harvests mainly adults while the second one captures juveniles and sexually immature individuals (Sánchez- Salazar et al. 1999). Groupers are known to be hermaphrodite protogynous species (Moe 1969, Shapiro 1987, Sadovy and Shapiro 1987, Bullock and Smith 1991), but there are still some doubts whether some are monandric or diandric (Collins et al. 1987, Brulé et al. 1999, Renán et al., 2001).

The coastline of Yucatan has a dynamic and complex interrelationship between different natural, demographic and economical factors. These processes involve the exploitation and transformation of the whole natural system, which becomes the most important impacts to the topography's shoreline, its natural processes, and its biological resources (UNCED, *in*: INE 2000).

The Yucatan State has four Natural Protected Areas (272, 050 ha approximately) adjoined to the sea. Two of them are Natural Biosphere Reserves, Ría Lagartos, and Ría Celestún, and the other two are Natural State Reserves, Bocas

de Dzilam and El Palmar (INE 2000). Of the nine sites probed, six are found in these Protected Areas.

The main objective of this study is to determine the existence of potential nursery areas for groupers in order to established adequate management policies for this important fishery resource in four different Yucatan Natural Protected Areas. An additional objective is to determine, through histological samples of juvenile grouper gonads, whether these populations are diandric or monandric, at least for the captured species.

METHODS

Grouper juveniles were caught from June to November 2000 in shallow waters near shore (ranging from 1 to 10 m depth). These grouper juveniles were captured with standard hook, traps, a small trawl net, and spear gun fishing, depending on the type of bottom habitat existing in each site. Nine sites were chosen according their importance as fishing ports along the coast of Yucatan: El Cuyo, Ría Lagartos, San Felipe, Dzilam de Bravo, Progreso, Uaymitún-Telchac, Sisal, El Palmar and Celestún. These nine different sites (100 x 100 m) were surveyed for nine days each, in an extent up to 10 km from the shoreline using a small vessel belonging to the artisanal fleet (Figure 2). Data registered for each individual included grouper specie (Bullock and Smith 1991, Heemstra and Randall 1993, Humman 1994), collection date, location (using a GPS), fork (FL) and standard length (SL) (cm), total (TW) and gutted body weight (GW) (g), and gonads were removed for an histological study., The preserved gonads were embedded in paraffin, thin sectioned at 6 μm, and stained as suggested in Gabe (1968). Gonads were examined to determine sex and gonad development, according to the microscopic cellular characteristics established by Moe (1969) and Brulé and Déniel (1996). Gonads exhibiting male-like tissue were classified as male according to Sadovy and Colin (1995). When no distinguishable tissue was observed, individuals were classified as "unidentified".

Data recorded for each site was number of species found per site, number of individuals captured per site, number of individual for each grouper species. Frequency histograms were done for the number of individuals for each species found per month and for the standard length of number of individuals. To establish the relationship between the standard length and the presence of males or "unidentified" individuals, a linear regression was performed ($\alpha = 0.05\%$)(Scherrer 1984).

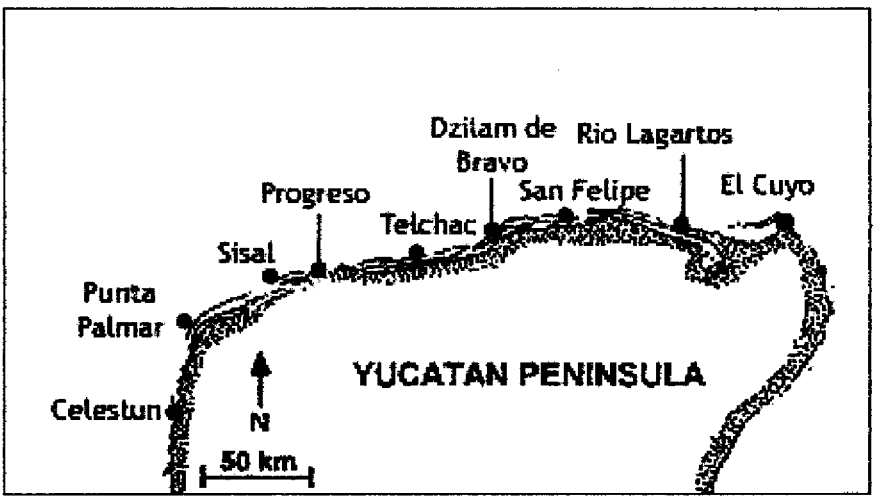


Figure 2. Nine sampling sites surveyed to identify probable nursery areas for grouper juveniles

RESULTS

A total of 192 grouper juveniles were caught and examined during this study. Five different species were captured: 89 individuals of *Epinephelus morio* (6.0–38 cm SL), 17 individuals of *Mycteroperca bonaci* (7.6–43 cm SL), 84 individuals of *Mycteroperca microlepis* (10.9 – 38.5 cm SL) and one individual of *Epinephelus striatus* (46.2 cm) and one of *Epinephelus adscensionis* (20.3 cm SL) (Figures 3 and 4).

Individuals were capture nearshore in the eastern part of the coast of Yucatan in El Cuyo, Ría Lagartos and San Felipe, in the central part in ports of Dzilam de Bravo, Uaymitún-Telchac, Progreso and Sisal, and in the western part in El Palmar and Celestún. From the nine explored sites the highest number of individuals were captured in El Cuyo (56 individuals), Dzilam de Bravo (52 individuals) and Ría Lagartos (21 individuals) (67% of the total number). Progreso (19 individuals), Uaymitún-Telchac (11 individuals), San Felipe (7 individuals), Celestún (2 individuals), El Palmar (12 individuals) and Sisal (12 individuals) (33% of the total) had more or less the same number of individuals caught (Figure 5).

In the six months survey, 26 individuals were captured in June, 74 were captured in July, 43 individuals were capture in August, 30 were capture in September, 7 were capture in October and 12 individuals were capture in November (Figure 6).

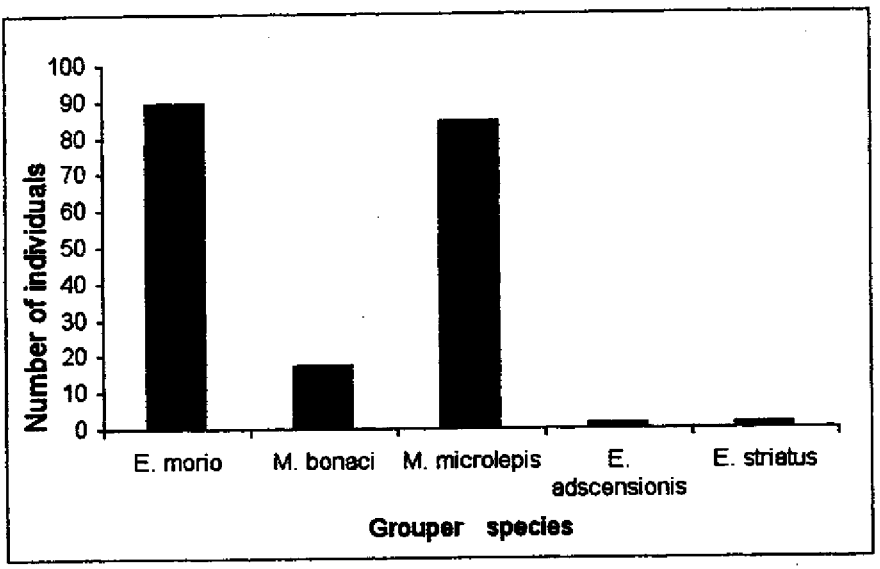


Figure 3. Grouper species caught in the northern coast of Yucatan through June to November 2000

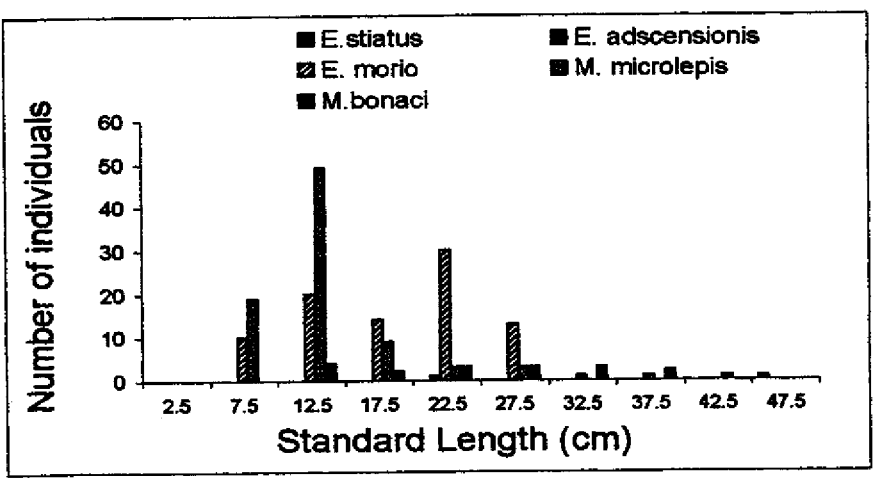


Figure 4. Size frequency distribution of five grouper species caught along the northern coast of Yucatan. The X-axis is the class distinction (cm).

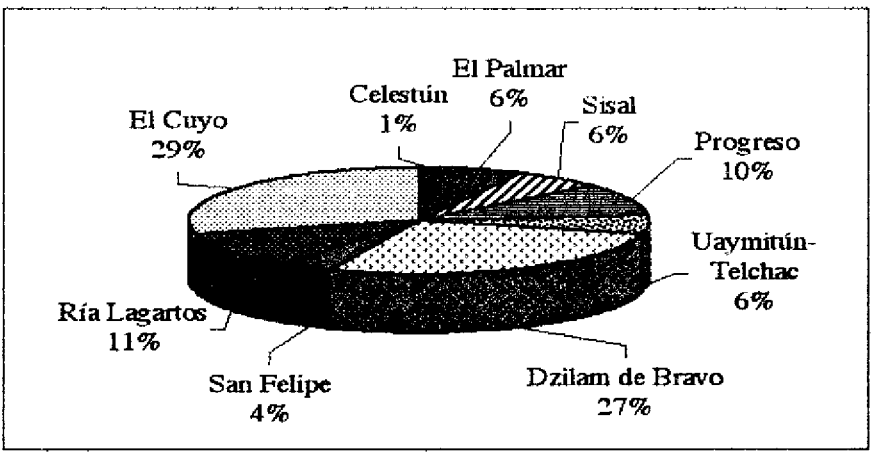


Figure 5. Percentage of captured grouper individuals per site along the northern coast of Yucatan

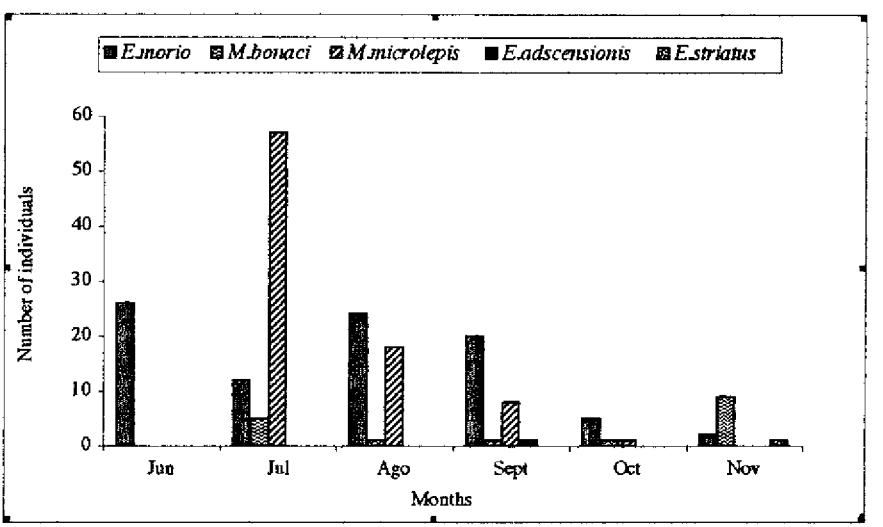


Figure 6. Number of individuals per species captured in each month from June to November 2000 along the northern coast of Yucatan

Different kinds of bottom habitats were recorded. El Cuyo, San Felipe and Dzilam de Bravo presented conspicuous seagrass beds, whereas Ría Lagartos, Progreso, Uaymitún-Telchac, Celestún, El Palmar and Sisal hard bottom habitats dominate. Some clear habitat specific associations were observed; *M. microlepis* upon sea grass beds (*Thalassia* spp. and *Gracillaria* spp.), and *E. morio, E. striatus, E. adscensionis* and *M. bonaci* with sandy-rocky bottoms with some ridges and crevices.

Species associated with hard bottom were caught using traps (4 individuals), hook line (43 individuals) and spear (71 individuals), this fishing technique the most effective one. In the case of *M. microlepis*, most of the specimens (74 individuals) were captured with a trawl net as they were found in seagrasses beds.

Through a histological analysis 68% of the captured individuals were females (n = 131), 8% were males (n = 15) and 24% (n = 46) were "unidentified" individuals (Table 1).

Table 1. Sex determination for each species caught along the Yucatan Peninsula from June to November 2000.

Species	Females	Males	"Unidentified"	Total individuals
E. morio	69	1	19	89
E. striatus	1			1
E. adscensionis	1			1
M. bonaci	10	3	4	17
M. microlepis	50	11	23	84

All females were immature individuals as they display gonias and/ or primary oocytes. All male specimens exhibited seminiferous tubules and spermatogenic cysts, in a "compact" gonad tissue without the presence of a lumen or lamellar wall were classified as immature males. "Unidentified" individuals showed no characteristic cellular development so it was decided to left them unclassified.

E. morio females sizes ranged from 7.5 cm to 38.0 cm (SL), the only male registered has a standard length of 26.7 cm, and "unidentified" individuals ranged from 6.0 - 24.3 cm (SL). *M. microlepis* sizes recorded for females, males, and "unidentified" individuals ranged from 7.6 - 43.0 cm, 9.5 - 20.2 cm and 9.5 - 20.5 cm (SL), respectively. For *M. bonaci* sizes ranged from 13.0 - 38.5 cm for females, 12.5 - 22.5 cm for males and 9.5 - 20.5 cm for "unidentified" individuals (SL). The sizes for individuals of *E. striatus* and *E. adscensionis* were 46.2 and 20.3, respectively.

The relationship between the standard length of each individual and the sex differentiation was statistically significant ($p = 0.048$; $\alpha = 0.05$) but its correlation between the variables was moderately week (sex = 0.06063 + 0.01077 x sizes; correlation coefficient = 0.145).

DISCUSSION

Grouper juveniles live in shallow waters near the coastline where they established to feed and protect themselves from predators (Jory and Iversen 1989). The individuals captured during this study were all juveniles as defined as an individual who has completed its metamorphosis, lives in a benthic habitat, but is sexually immature (King 1996, Kovác and Copp 1999).

The five species caught *E. morio, E. striatus, E. adscensionis, M. bonaci* and *M. microlepis* are considered "giant" groupers since they grow larger, reproduce at an older age when compared with other "dwarf" groupers (Sluka and Sullivan 1996), and settle in nearshore waters. Like most of the groupers in the present study, these five species display a bathymetric distribution where larger individuals live in open, wide and deeper waters, whereas juveniles tend to live in defined small areas in shallow waters living inside caves, ridges, and crevices (Johnson and Collins 1994).

In the nurseries areas groupers are dependant on their habitat for food, shelter and cleaning, but this dependency is probably more closely related to the need for shelter than for food (Sluka et al. 1994). The dependency for rocky bottoms by *E. morio, E. striatus, E. adscensionis* and *M. bonaci* and for seagrass beds by *M. microlepis* was observed, in accordance with Moe (1969), Thompson and Munro (1978), Ross and Moser (1995), García- Cagide and García (1996), and Shirripa and Legault (1997).

The most effective gear for rocky-bottom species such as *E. morio, E. striatus, E. adscensionis* and *M. bonaci* was the spear, while for *M. microlepis* the most effective one was the trawl net, since must of the individuals were captured in seagrasses beds.

Six of the surveyed sites match with four Yucatan's Natural Protected Areas (NPA's) adjoined to the coastline. El Cuyo, Ría Lagartos and San Felipe belong to the Biosphere Natural Reserve "Ría Lagartos", Dzilam de Bravo is part of the Natural State Reserve "Bocas de Dzilam", "El Palmar" is a Natural State Reserve and "Celestún" is another Natural Biosphere Reserve. All of these Protected Areas include the part of sea habitat (1 mile from the coastline), although when these Areas were decreed, the marine environment was not taken into account, and there are no management plans for them. If NPA's are to be used to protect a resource, the nursery areas for grouper populations, in this case, must been known in order to protect them from the effects of exploitation (Sadovy 1998).

All of the individuals captured during this study were determined to be sexually immature individuals. *E. morio, M. bonaci, M. microlepis*, and *E. adscensionis* are considered protogynous hermaphrodites displaying monandric populations (Mc Erlean and Smith 1964, Collins et al. 1987, Brulé et al. 1999, and Renán et al. 2001), because they only exhibit secondary males in the commercial captures. Nevertheless, the individuals analyzed in these studies are bigger than 15 cm (FL). For *E. striatus* Sadovy and Colin (1995) established as essentially gongochoristic with potential for sex change. The males determined trough the

histological study, display characteristics of primary males, and so we may considered this populations as probable diandric. However, an extensive study should be made, using more individuals, in order to conclude this. The "unidentified" individuals were found at different sizes, but there was no relationship between the length and the presence of these individuals.

Threats to juvenile grouper populations include nearshore habitat degradation and recruitment overfishing (Sluka et al. 1994). Therefore, it may be prudent to evaluate a habitat-based management strategy as a viable alternative to traditional fisheries measures, such as minimum size limits. In order to establish adequate management policies for the juvenile grouper populations in the northern coast of Yucatan, scientific research needs to continue. We propose a comprehensive investigation of these nursery areas found for groupers in at least an annual cycle, to determine their biology, habitat dependency, and populations sexuality.

AKNOWLEDGMENTS

We would like to express our gratitude to the Federación de Cooperativas de Pescadores de Oriente: Sociedad Cooperativa de Producción Pesquera (SCPP) El Cuyo, SCPP Ría Lagartos, SCPP San Felipe. Also to the Federación de Coopertivas de Pescadores de Centro- Poniente: SCPP Dzilam de Bravo, SCPP Sisal, SCPP La Pobre de Dios y SCPP Real de Celestún.

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Reproductive Biology of the Bonefish, *Albula vulpes*, at Los Roques Archipelago National Park, Venezuela

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ABSTRACT

The bonefish, *Albula vulpes*, is a common species in Los Roques Archipelago National Park and is considered an important recreational fish in this area. The purpose of this study is to describe the reproductive characteristic of *A. vulpes* (i.e., spawning season, length at sexual maturity) in Los Roques. A total of 440 specimens were collected from October 1999 to September 2000. Fish sizes ranged from 286 to 717 mm fork length (FL) and females were significantly larger than males (Mann Whitney U-test, $P < 0.001$). The smallest sexually mature female and male were 351 and 424 mm FL, respectively. The length at 50% sexual maturity was calculated in 456 mm FL for females and 467 mm FL for males. Spawning season extended from June to January and peaked from November to December.

KEY WORDS: Bonefish, reproduction, seasonality

Biología Reproductiva del macabí, *Albula vulpes*, en el Parque Nacional Archipiélago de Los Roques, Venezuela

El macabí, *Albula vulpes*, es una especie común en las aguas del Parque Nacional Archipiélago de Los Roques, y aunque carece de interés para el consumo humano, es de gran importancia para la pesca deportiva, por ser un excelente luchador. Con el fin de describir el desarrollo gonadal y estimar la época de mayor actividad reproductiva y la talla de madurez sexual, se colectaron 440 ejemplares de *A. vulpes*, desde Octubre de 1999 hasta Septiembre del 2000. Se calcularon los índices gonadosomáticos (IGS) de todos los individuos colectados y se examinaron histológicamente las gónadas de 120 ejemplares. Las talla de los individuos capturados oscilaron entre 28,6 y 71,7 cm de longitud de horquilla (LH), siendo las hembras significativamente más grandes que los machos (Prueba U Mann-Whitney, $P<0.001$). El macho maduro más pequeño midió 35,1 cm de LH y la hembra madura más pequeña midió 42,2 cm de LH. La talla a la que madura el 50% de la población fue 47.32 cm de LH para los machos y 45.19 cm para las hembras. La actividad gonadal de esta especie es estacional con un pico reproductivo prolongado desde Junio hasta Enero. El IGS promedio, tanto para machos como para hembras, fue mayor durante los meses de Octubre a Diciembre y menor durante Febrero-Abril. Se espera que los resultados obtenidos

ayuden a las autoridades responsables del manejo del parque y sus recursos pesqueros, en el establecimiento de un programa que garantice el aprovechamiento y protección de esta especie.

PALABRAS CLAVES: Macabí, *Albula vulpes*, biología reproductiva

INTRODUCTION

The bonefish, *Albula vulpes*, is found in the tropical western Atlantic and is a common species in Los Roques Archipelago National Park, Venezuela (Pulido 1983, Cervigón 1991). *Albula vulpes* supports important recreational fisheries in the Florida Keys, the Bahamas and other Caribbean islands (Mojica et al. 1995). Recently, this activity has been growing in Los Roques Archipelago National Park, where big schools of bonefish can be found in waters of less than one meter deep. Despite its recreational importance, there is no information about the biology of this species in Venezuela, except for brief comments made by Cervigón (1991). Contrarily, Mojica et al. (1995) studied its recruitment patterns in the Bahamas, while Crabtree et al. (1996, 1997) described its population and reproductive parameters in South Florida waters, respectively. Therefore, the aim of the present study is to contribute to the knowledge of the reproductive characteristics of this species in Los Roques Archipelago National Park, Venezuela.

METHODS

Study Site

Los Roques Archipelago National Park is a complex reef system located 155 Km to the north off the central coast of Venezuela (11°44'45'' to 11°58'36'' N and 66°57'27'' to 66°57'27'' W), comprising an area of 1250 km^2. Samplings were conducted in the shallow waters (< 2 meters) surrounding Dos Mosquises Sur island.

Sampling and Processing

A total of 440 specimens were collected from October 1999 to September 2000 (average: 35 ind/month), using a beach seine (2 cm mesh opening). All individuals were measured to the nearest millimeter of fork length (FL) and weighted to the nearest gram. The sex of all specimens was determined macroscopically. Their gonads were removed and weighted to the nearest 0.1 gram. Preserved gonads (10% buffered formalin) from 120 representative specimens were embedded in paraffin, sectioned (6 μm), and stained (hematoxylin and eosin).

Length at Sexual maturity

Length at 50% sexual maturity was estimated using the inflection point of a logistic function fitted to the percentage of sexually mature females and males and to their respective length. To avoid misclassifying regressed and immature fish, all the specimens collected in the postreproductive months (February - April) were excluded from this analysis (Crabtree et al. 1997). The length of the smallest sexually mature female and male were also recorded.

Reproductive Seasonality

The Gonadosomatic index (GSI, Htun-Han, 1978) was calculated for each gonad, according to the following equation

$$GSI = [\, GW / (TW - GW) \,] \times 100$$

Where, GW and TW represent gonad weight and total body weight (in grams), respectively. Monthly median GSI values were plotted for each sex to show changes in reproductive state throughout the year.

RESULTS

Of the 440 *A. vulpes* examined 255 were females (57.9%) and 185 (42.1%) males. The sex ratio of 1:1.38 was significantly different from the unity (X^2 = 11.184, $P < 0.001$). Females ranged from 286 to 717 mm FL (mean = 49.22 mm; s.d = 65.36; n = 255) and males from 334 to 600 mm FL (mean = 459.36; s.d = 35.15; n =185) (Figure 1). Length-frequency distributions of females and males were significantly different (Kolmogorov-Smirnov two-sample test, D = 0.0410, $P < 0.001$) and females were significantly larger than males (Mann Whitney U-test, $P < 0.001$).

Length at sexual maturity

The smallest sexually mature female and male were 351 and 424 mm FL, respectively. The length at 50% sexual maturity was estimated in 456 mm FL for females (95% confidence interval 446 – 466 mm) and 467 mm FL for males (95% confidence interval 454 - 479 mm) (Figure 2).

Reproductive season

Three oocyte stages were identified in female *Albula vulpes*: primary growth, cortical alveolar and vitellogenic (Figure 3). Females with vitellogenic oocytes were observed in most of the months except between March and May and were most abundant in October. This appears to agree with median GSI values, which suggest that *A. vulpes* spawning season extend from June to January, with a peak from November to December (Figure 4). However, evidences of imminent or recent spawning, such as fully hydrated oocytes and postovulatory follicles, were not observed.

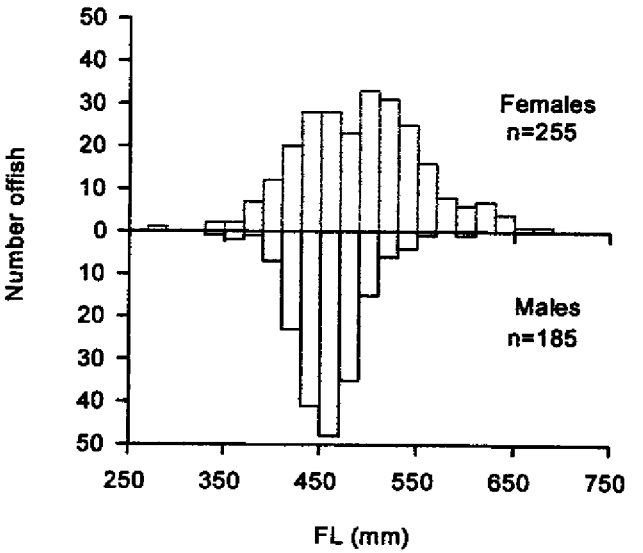


Figure 1. Length-frequency distributions of female and male bonefish, *Albula vulpes*, at Los Roques Archipelago National Park

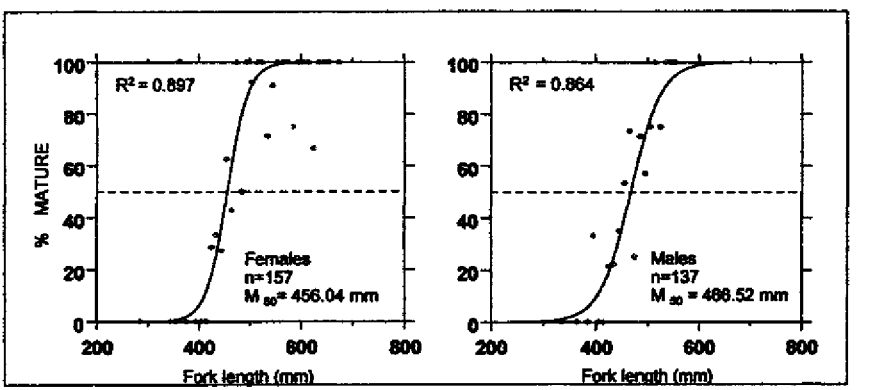


Figure 2. Length-maturity relations for females and males of the bonefish, *Albula vulpes*, sampled in Los Roques Archipelago National Park. Lengths plotted are the midpoints of 10 mm size classes. The red line represents the predicted relation from the logistic function: Y = 100 / (1+ex p(-a (X-b)). Parameter b in the equation is the inflection point and is the estimate of the length at which 50% of the individuals were sexually mature (M_{50}).

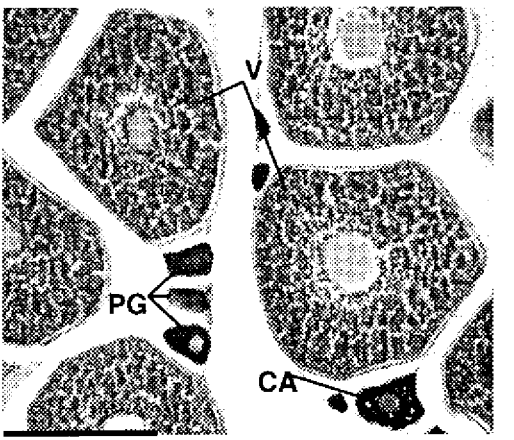


Figure 3. Histological section from an ovary of a 548 mm-FL *Albula vulpes*, sampled in Los Roques Archipelago National Park. Oocyte stages: primary growth (PG), cortical alveolar (CA) and vitellogenic (V). Scale bar = 400 microns.

DISCUSSION

There is a good level of agreement between present and Crabtree et al. (1996, 1997) studies. In both cases, the sex ratio was biased towards the females. The size ranges of the sampled populations in the two regions overlapped (228 to 700 and 290 to 700 mm FL for females and males in South Florida, respectively), with females being significantly larger than males.

Albula vulpes examined at Los Roques reached sexually maturity at a similar length than reported by Crabtree et al. (1997) in the Florida Keys (358 and 425 mm FL for females and males, respectively). However, females in the present study reached 50% maturity at a smaller size than reported by Crabtree et al. (1997) while the opposite result was observed for males.

The reproductive seasonal patterns were also similar for Los Roques, South Florida and Bahamas. Crabtree et al. (1997) reported that *A. vulpes* from South Florida runs sexually mature from November to June, while are reproductively inactive during a few months of the summer. Mojica et al. (1995), based on the presences of field-collected larvae, suggests that *A. vulpes* in the Bahamas may spawn continuously from mid October through early January and probably extends until May. The absence of females with fully hydrated oocytes and postovulatory follicles in our sample may indicate that bonefish does not spawn in shallow waters (< 2 m) as suggested by Crabtree et al. (1997).

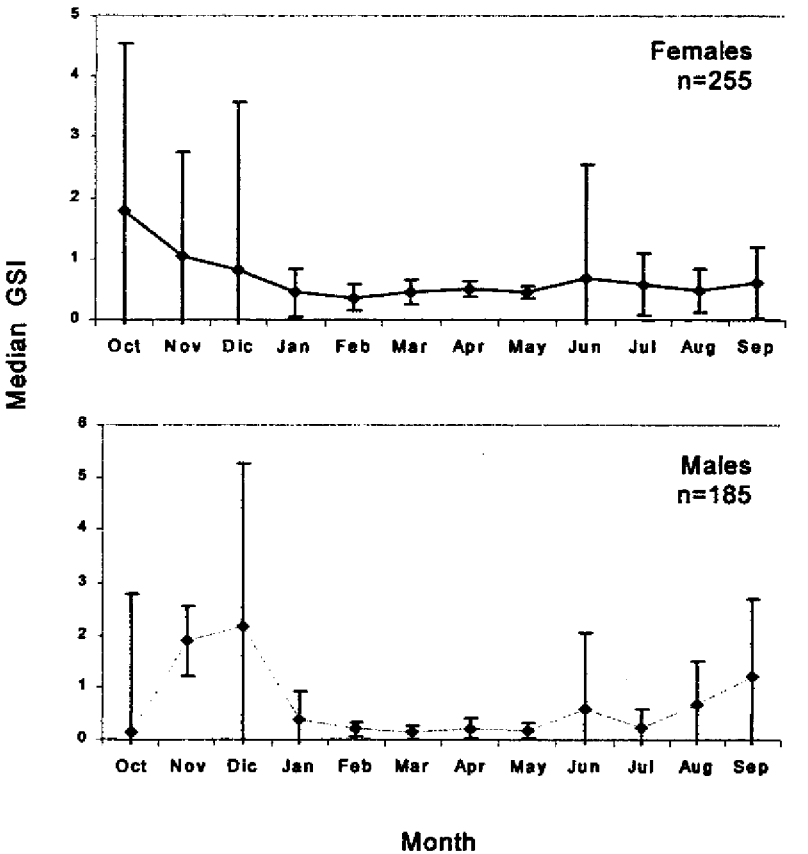


Figure 4. Monthly median gonadosomatic index (GSI) and interquartil ranges for females and males of the bonefish, *Albula vulpes*, sampled in Los Roques Archipelago National Park.

ACKNOWLEDGMENTS

Our sincere appreciation goes to Pablo Segundo Mata for his assistance in the field collection and to the "Fundación Científica Los Roques" for providing all the logistic facilities. To "Instituto Nacional de Parques (INPARQUES)" for giving us permission to survey in the area. We also thank Luis Gallardo and Maria Isabel Camejo for their cooperation with the histological processing.

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Current and Potential Yield per Recruit of Hogfish, *Lachnolaimus maximus*, in Florida

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ABSTRACT

Hogfish (*Lachnolaimus maximus*) is a valuable fishery species that lives on reefs of the Gulf of Mexico, Caribbean Sea, and Atlantic Ocean north to the Carolinas. In Florida, hogfish landings have been declining in recent years. Moreover, maximum size of hogfish landed in south Florida, where landings are greatest, is only half the maximum size of those landed in the eastern Gulf of Mexico. These trends in landings and fish size suggest continuing problems for the fishery. In this paper we explore some of the costs and benefits of increasing the minimum legal size at which hogfish can be captured in order to increase the yield per recruit of hogfish. We also comment on the potential additional benefit, in terms of increased recruitment, that could result from this management option.

KEY WORDS: Reef fish, age, growth, mortality, yield per recruit, hogfish

La doncella de pluma (*Lachnolaimus maximus*) es una especie pesquera valiosa que vive en los arrecifes del golfo de México, mar Caribe, y en el Océano Atlántico hasta las Carolinas. Los desembarques de doncella de pluma en la Florida han declinando en años recientes. Ademas, las tallas máximas en el sur de la Florida, en donde los desembarques son mayores, tienen solamente la mitad de la talla máxima del este del golfo de México. Estas tendencias en los desembarques y tamaños de los pescados sugieren que los problemas en esta pequería continuarán. En esta publicación exploramos algunos costos y beneficios del aumento a la talla legal mínima para incrementar el rendimiento-por-recluta de la doncella de pluma. También comentamos sobre el beneficio potencial adicional en términos de incremento en reclutamiento que podría resultar de esta opción en el manejo.

PALABRAS CLAVES: Doncella de pluma, rendimiento-por recluta

INTRODUCTION

Hogfish form harems in reef habitats of Florida, where they support a valuable commercial and recreational fishery. At Alligator Reef, in the Florida Keys, hogfish are common and conspicuous throughout the diel period at 25 - 30 m depths (Starck and Davis 1966, Stark 1968, Nybakken 1997). The diet of hogfish is dominated by invertebrates, and anglers use clams, squid, or small crabs as bait (McClane 1965,

Randall 1968). Hogfish are also targeted by divers with spears and often enter trap-fishing gear.

Hogfish are protogynous hermaphrodites (Davis 1976, Claro et al. 1989, McBride et al. 2001). Males have been observed to reach 9,915 g total body weight (824 mm fork length [FL] or 905 mm total length; McBride 2001). The Florida record weight for hogfish captured on hook and line is 8,863 g (19 lbs., 8 oz.). McBride (2001) modeled hogfish growth and found that the predicted maximum size of hogfish from the eastern Gulf of Mexico is twice that of hogfish from south Florida (939 versus 448 mm FL). The smaller maximum size of hogfish in south Florida compared to the eastern Gulf of Mexico may suggest higher levels of fishing mortality in south Florida. A minimum size limit of 305 mm FL (i.e., 12 inches FL) was implemented July 1, 1994, largely in response to observations of decreasing availability of large hogfish in the Keys (e.g., DeMaria 1996). The 12-inch size limit was based on data from Davis (1976), which showed that the smallest male that had completed sexual transformation was 295 mm (11.6 inches) FL. McBride (2001) reported, however, that the size at 50% sexual transformation was considerably larger: 389 mm (15.3 inches) FL. Because a single male controls a harem of as many as 15 females (Colin 1982), harvesting mature males could disrupt reproductive output for not only a specific male but also for the entire harem. Because sexual transformation appears to require a few months to complete and is most common during the non-spawning season, the harvest of mature males would at the very least require the females to disperse to other harems and could potentially disrupt the spawning activity of a harem for several months (McBride 2001). The exact effect that harvesting a male may have upon a harem's reproductive success depends on the social behaviors and stock-recruitment relationship of hogfish, neither of which have been described. However, sufficient data are available for assessing hogfish yield per recruit.

In this paper we first examine the status of the hogfish fishery, particularly in reference to the effect of the 1994 minimum-size regulation on hogfish landings in Florida. Age, growth, and mortality estimates were not available for hogfish when this minimum size limit was implemented. Here, we use recently available life-history information to examine hogfish yield per recruit and to predict the probable time lag between the passing of a new regulation and the time when the hogfish fishery can realize the full benefits of the regulation.

MATERIALS AND METHODS

Data about hogfish landed in the commercial fishery were taken from the Florida Fish and Wildlife Conservation Commission's Marine Fisheries Information System (MFIS). The MFIS contains data describing landings, effort, areas fished, ex-vessel value, and gear used during commercial fishing trips since 1986; we used edited data covering landings through August 2001 and unedited landings data through batch # 675. Hogfish sizes were characterized from the National Marine Fisheries Service's Trip Interview Program (NMFS, TIP) data. The TIP data

include lengths of hogfish landed by the commercial fisheries operating in various fishing locations and using various gears since 1991. Commercial landings data were grouped according to three fishing areas, depicted in Figure 1A: East (Atlantic Ocean and inshore waters north of Biscayne Bay), South (Biscayne Bay to Charlotte Harbor, including the Florida Keys), and West Florida (Gulf of Mexico and inshore waters north of Charlotte Harbor). All lengths were converted to fork lengths, if necessary, using the equations from McBride (2001):

$$FL = 8.48 + 1.184\ (SL) \qquad r^2 = 0.997 \quad (10 - 699\ mm\ SL;\ n = 1563),$$

$$FL = 12.35 + 0.8632\ (TL) \quad r^2 = 0.995 \quad (13 - 905\ mm\ TL;\ n = 1563),$$

where SL = standard length, FL = fork length, and TL = total length, measured in millimeters.

Recreational fishing data were taken from the NMFS Marine Recreational Fisheries Statistics Survey and included landings, effort, county of each interviewed angler's landings, gear used, and fish size. Regional estimates of recreational landings were calculated using post-stratification methods outlined in Gray et al. (1999). Recreational landings were estimated for six regions, depicted in Figure 1B: Northeast (Nassau – Flagler counties), Central East (Volusia to Martin counties), Southeast (Palm Beach-Dade counties), Southwest (Monroe-Pinellas counties), West (Pasco-Franklin counties), and Panhandle Florida (Gulf-Escambia counties).

We extracted von Bertalanffy growth parameters for use in this study from McBride (2001). The model is $FL = L_{inf}(1-e^{(-K[t-to])})$, where L_{inf} is the asymptotic length, K is the Brody growth coefficient (i.e., how fast fish size approaches L_{inf}), and t_o is the predicted age at which fish length is zero. Although McBride (2001) estimated different sets of growth parameters for fish from the south Florida and eastern Gulf of Mexico samples, we use only the eastern Gulf of Mexico growth equation ($r^2 = 0.84$) in this study, $FL = 939(1-e^{(-0.0741[t+2.01])})$. McBride (2001) concluded that the south Florida growth equation ($r^2 = 0.62$), $FL = 448(1-e^{(-0.231[t+1.02])})$ was based on a sample with an age structure that was truncated because of the high fishing mortality rate in that area. Therefore, we assume the eastern gulf parameter set represents the true growth potential of hogfish in both areas.

Yield-per-recruit analyses followed the method of Thompson and Bell (1934). Input data included average weight-at-age for ages 0 through 25 – predicted by using the growth model for eastern Gulf of Mexico hogfish (weight in grams = $9329(1-e^{-0.131(\text{age in years}+0.26)})^3$, $r^2 = 0.844$) – and a constant instantaneous natural mortality rate of 0.15/yr. The choice of natural mortality rate (M) was a compromise between the $M = 3/t_\lambda$ method (Gabriel et al. 1989) and the $M = 4.6/t_\lambda$ method (Royce 1972), where t_λ is the maximum observed age. The former implies a constant rate of natural mortality in which less than 5% of the cohort lives beyond t_λ, while the latter implies a constant rate of natural mortality in which less than 1% of the cohort lives beyond t_λ. When t_λ is 25 years, M = 0.12/yr and M=0.18/yr using the two methods. The instantaneous fishing mortality rates (F) used were extracted

from McBride (2001): 0.17/yr for south Florida and 0.06/yr for the eastern Gulf of Mexico. Yield per recruit was calculated using knife-edge recruitment at each age from 1 to 15 years. Current yield per recruit was estimated for each fishery by using as the age-at-recruitment the age at which hogfish reach the 50th percentile of the cumulative distribution of lengths of hogfish landed by each fishery. We defined optimum yield per recruit as the yield at the biological benchmark $F_{0.1}$, the fishing mortality rate at which the slope of a tangent to the yield response curve was one-tenth the slope of the yield curve at the origin (Gulland and Boerema 1973, Deriso 1987).

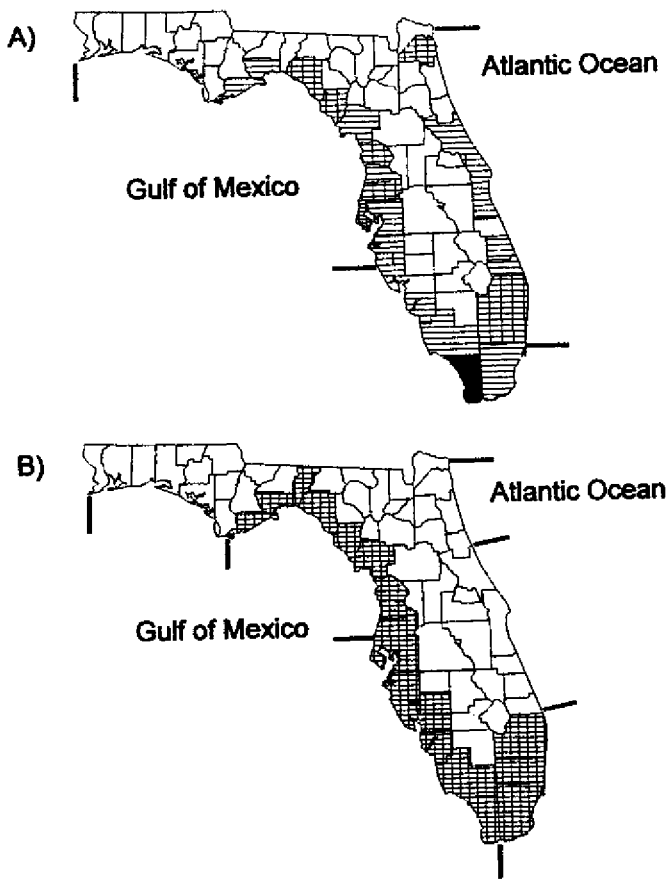


Figure 1. Geographic distribution of Florida's hogfish, *Lachnolaimus maximus*, landings in 2000. (A) Commercial landings are shown by county (marks delineate three regions): open (0-1,000 pounds), horizontal stripe (1,001-5,000 pounds), cross hatch (5,001-10,000 pounds), and solid (10,001-50,000 pounds). (B) Recreational landings are shown by region (marks delineate 6 regions): open (0-1,000 individuals), horizontal stripe (1,001-10,000 individuals; not evident here), and cross hatch (10,001-50,000 individuals).

RESULTS AND DISCUSSION

Description of the Commercial Fishery

Commercial fishing for hogfish was unregulated until 1994, when the State of Florida and the South Atlantic Fishery Management Council (SAFMC) enacted a 12-inch FL minimum size limit and restricted harvest to those who could demonstrate past participation in the reef fish fishery. These restrictions included a Restricted Species Endorsement issued by the Florida Fish and Wildlife Conservation Commission and a Reef Fish Permit issued by the National Marine Fisheries Service for the South Atlantic region. In 1999, the Gulf of Mexico Fishery Management Council (GMFMC) also adopted these regulations for fishermen operating in the Exclusive Economic Zone of the Gulf of Mexico.

Commercial landings of hogfish in Florida increased from 1987 to 1993 but declined from about 62,000 kg in 1993 to about 22,500 kg in 2000 (Table 1). The sudden change in trend for landings was coincident with the initial (i.e., 1994) implementation of hogfish fishing regulations and may have been due to the fact that a notable proportion of the catch, newly classified as undersized, was no longer being landed. The decline in landings also appears attributable to declining fishing effort in the past decade. Participation in the fishery, measured as the annual number of saltwater products license holders reporting hogfish landings, has dropped by more than 50%, from about 1,000 annually during 1987 - 1990 to fewer than 400 annually since 1998. Nearly all (99%) of these fishers reported landing less than 227 kg (500 pounds) of hogfish each year, so annual earnings from the sale of hogfish is small for most fishers.

The declining landings of hogfish since the mid-1990s has led to an overall decline in the value of the commercial fishery, even though the price per kg of hogfish has increased during this period (Table 1). The average ex-vessel price paid to fishers doubled from $2.25 per kg in 1987 to just over $4.50 per kg in 1996, and the price has remained at about $4.80 - 4.90 per kg since 1997. Nonetheless, because of the overall declines in landings, the total annual ex-vessel value of hogfish in Florida has fallen from $227,000 in 1993 to an average of $103,500 since 1998.

Most (67%) hogfish landed by commercial fishers during 1995 - 2000 were reported captured in waters adjacent to the southern tip of the Florida peninsula (Fig. 1A). Twenty-nine percent of landings were captured in the eastern Gulf of Mexico, along Florida's west coast, and only four percent were reported as caught in the Atlantic Ocean, along the east coast of Florida.

In Florida's commercial fishery, nearly all hogfish were landed by hook and line, by spear, or in traps. During 1995 - 2000, commercial fishers using these types of gear reported about 98% of the annual landings made each year in South Florida or in the eastern Gulf of Mexico. Of these types of gear, hook and line was used to capture more hogfish (19,769 pounds) on average during 1995 - 2000 than were traps (18,239 pounds) or spears (14,591 pounds). No single gear was responsible for >50% of the landings in any Florida region.

Table 1. Florida's annual hogfish, *Lachnolaimus maximus*, landings and value 1987-2000. Commercial landings are all reported ex-vessel sales. Recreational landings include the estimated weight and number of hogfish kept by anglers or reported released dead. See text for details and data sources.

A) Commercial landings

Year	Kg.	Lb.	$/Kg.	$/Lb.
1987	33,312	73,439	$2.25	$1.02
1988	34,412	75,865	$2.80	$1.27
1989	49,859	109,919	$2.87	$1.30
1990	52,713	116,211	$3.00	$1.36
1991	48,831	107,653	$3.20	$1.45
1992	53,270	117,438	$3.31	$1.50
1993	62,010	136,706	$3.66	$1.66
1994	42,393	93,460	$3.95	$1.79
1995	28,861	63,626	$4.50	$2.04
1996	27,396	60,397	$4.56	$2.07
1997	29,829	65,761	$4.83	$2.19
1998	21,297	46,950	$4.89	$2.22
1999	20,994	46,284	$4.81	$2.18
2000	22,490	49,582	$4.85	$2.20
Mean	37,691	83,092	$3.82	$1.73

B) Recreational landings

Year	Kg.	Lb.	Number
1987	244,591	539,222	253,676
1988	145,977	321,819	151,797
1989	78,968	174,092	104,856
1990	82,715	182,351	121,134
1991	193,557	426,713	179,094
1992	192,802	425,048	193,004
1993	150,606	332,024	218,539
1994	128,540	283,377	174,265
1995	153,153	337,638	128,701
1996	76,602	168,876	90,112
1997	106,066	233,832	92,176
1998	49,893	109,994	62,126
1999	81,579	179,847	91,033
2000	37,987	83,746	42,766
Mean	123,074	271,327	135,949

Description of the Recreational Fishery

Recreational fishing for hogfish was also unregulated until 1994, when the State of Florida and the SAFMC enacted a 12-inch FL minimum size limit and a 5-fish bag limit. As for the commercial regulations, the GMFMC did not adopt these regulations until 1999. Prior to the 1994 regulations, the number of hogfish landed annually varied between 105,000 and 254,000 but fell to a low of 43,000 in 2000 (Table 1). Landings, by weight, show a similar trend. These declines may partially be a result of the new size regulations and partially a result of declining angler effort (see below).

The recreational fishery for hogfish is centered in south Florida, but a significant portion of the landings is also made farther north in the eastern Gulf of Mexico (Figure 1B). During 1995-2000, 85% of the annual statewide landings were made in the Southeast and Southwest regions, especially in the Florida Keys, and 14% were landed in the West region, particularly in association with the Middle Ground reef area.

During 1995-2000, divers speared 71% of the hogfish and anglers hooked 29% of the hogfish, according to interviews with recreational fishers. The estimated number of recreational fishing trips on which fishers had caught or had tried to catch hogfish has declined dramatically since 1994, from a statewide average of about 98,000 trips during 1992 - 1994, to about 47,000 trips during 1997 - 1999, and to only 19,000 trips in 2000.

Hogfish Sizes

The smallest hogfish were generally caught in traps, larger hogfish were captured on hook and line, and the largest hogfish were caught with spears (Figure 2). The differences in the mean lengths of hogfish captured in these three gear types were more pronounced in the eastern Gulf of Mexico, varying by nearly four inches or 100 mm, than they were in south Florida. A two-way ANOVA showed that these differences – and specifically the interaction effect between harvest gear and area fished on fish size – were statistically significant ($P < 0.05$). The mean lengths of hogfish caught by using the three types of gear were very different in the eastern Gulf of Mexico (i.e., 11.2 inches [284 mm] FL for traps, 12.4 inches [315 mm] FL for hook and line, and 14.9 inches [378 mm] FL for spears). The sizes of hogfish landed with the three gear types in South Florida did not differ as much (i.e., 12.4 inches [315 mm] FL for traps, 13.1 inches [333 mm] FL for hook and line, and 13.9 inches [353 mm] FL for spears) as observed for the eastern Gulf of Mexico. Sizes of hogfish landed in Florida's Atlantic coast region were similar to sizes of those landed in south Florida, but too few measurements from the Atlantic regions were available for comparison.

The length at recruitment to each fishing gear type followed the same pattern as that of mean lengths: in the eastern Gulf of Mexico, 11.0 inches (279 mm) FL for traps, 11.5 inches (292 mm) FL for hook and line, and 14.0 inches (356 mm) FL for spears; in South Florida, 12.0 inches (305 mm) FL for traps, 13.5 inches (343 mm) FL for hook and line, and 14.0 inches (356 mm) FL for spears. These lengths

corresponded best to predicted lengths for age 3 (291 mm FL) and age 4 (337 mm FL) hogfish. For estimates of current yield per recruit (next subsection), both age 3 and age 4 were used as the age at knife-edge recruitment.

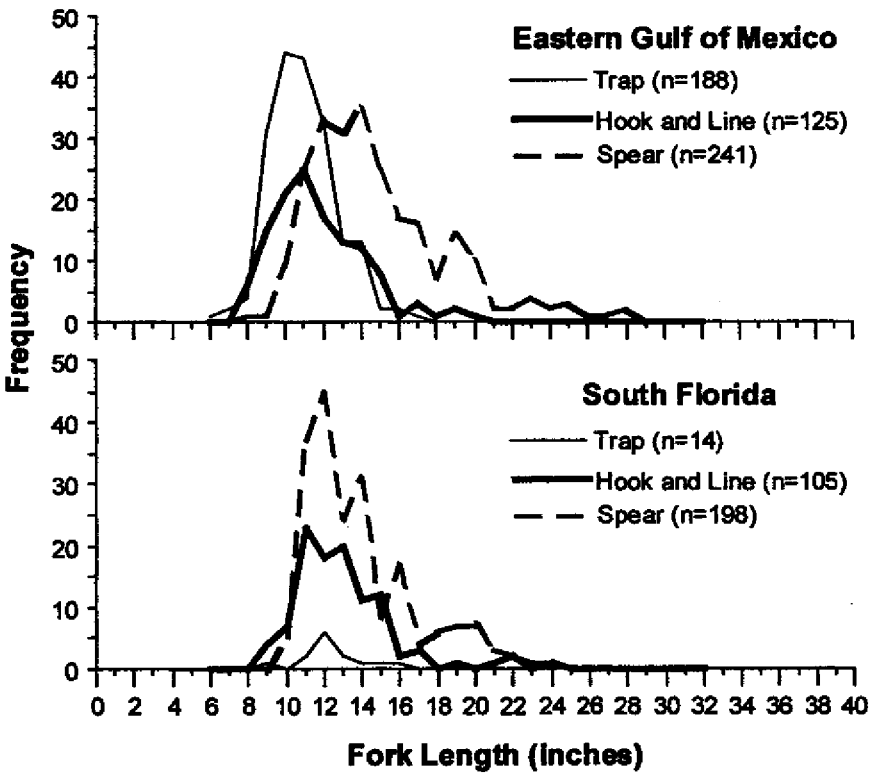


Figure 2. Size frequencies of hogfish, *Lachnolaimus maximus*, landed during 1995-2000 from the eastern Gulf of Mexico (Florida's west coast) and south Florida. Sizes are depicted separately by fishing gear type. Commercial and recreational landings are combined. (Number of fish = n).

We interpret these observed differences in sizes of landed hogfish to be largely the result of differences in the fishing regulations of each region, although larger hogfish may also exist in the eastern gulf because fishing mortality rates are lower there than in south Florida (McBride 2001). Most hogfish < 12 inches were from traps fished in the Gulf of Mexico, but it was not illegal to land these small hogfish from federal waters of the gulf until late 1999. Some of the hogfish < 12 inches caught on hook and line and spears in the Gulf of Mexico may also be from

federal waters. Hogfish landed in traps and hook and line in south Florida were larger, conforming more closely with the 1994 regulations of the State of Florida and SAFMC for those waters. All in all, it would appear that small (i.e., < 12 inches) hogfish were common in the landings during the latter half of the 1990s (Figure 3).

Since late 1999, the state and federal regulations governing the hogfish fishery have been the same; this consistency is expected to be of long-term benefit to the hogfish fishery. The trap fishery of the Gulf of Mexico is being phased out over the next several years, so the issue of release-related mortality is limited to anglers. No specific information on capture-release survival rates exists for hogfish, but studies on groupers (Serranidae) show that released fish have a high survival rate even when harvested from waters up to 44 m deep (Wilson and Burns 1996). Hogfish are known for remaining in the vicinity of diver activity, a behavior that makes this fish particularly vulnerable to spearfishing; however, spearfishers can see the fish before they shoot, so they should kill few undersized hogfish.

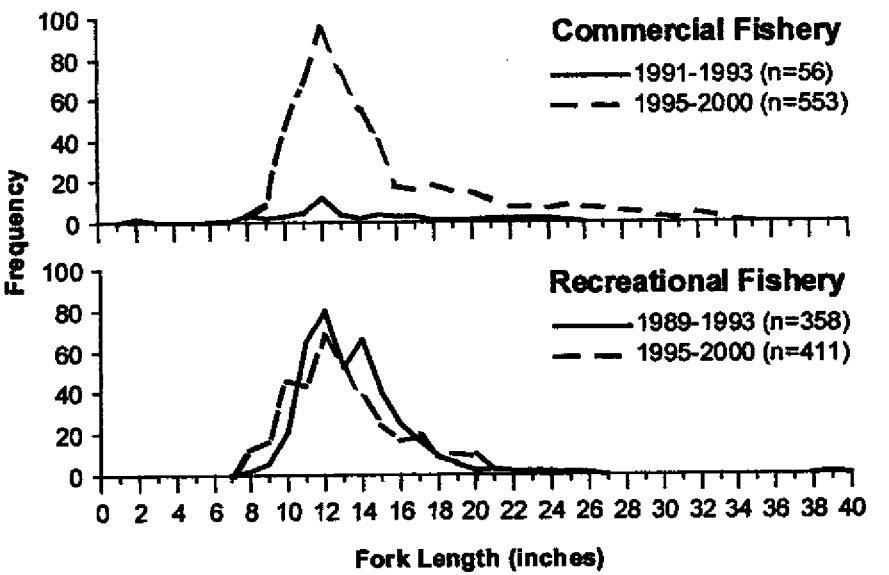


Figure 3. Size frequencies of Florida's hogfish, *Lachnolaimus maximus*, from commercial and recreational landings. Sizes are depicted before and after the 1994 regulations enacted by the State of Florida and the South Atlantic Fishery Management Council. Landings from all Florida regions and all fishing gear types are combined. (Number of fish = n).

Yield-per-recruit Analysis

Increasing the size limit can increase the fishery yield of hogfish in Florida, although the actual gains in yield are strongly dependent on the level of fishing. At optimum fishing mortalities ($F_{0.1}$), the greatest potential yield per recruit occurs when hogfish are recruited to the fishery at about 19 inches FL where $F_{0.1}$ is about 0.20/yr. If the current length at recruitment, modeled here as sizes corresponding to either age 3 or age 4, was changed to 19 inches FL then this would increase the optimal yield per recruit 20 - 33%, from 0.50 or 0.55 kg/recruit to 0.66 kg/recruit (Figure 4). However, current fishing mortality rates are 0.17 yr^{-1} in south Florida (McBride 2001), slightly less than the $F_{0.1}$ level at a 19-inch size-at-entry to the fishery. Therefore, a 19-inch FL minimum size limit in south Florida would increase the yield per recruit by only 9 - 20% above the current level. In the eastern Gulf of Mexico, where the current fishing mortality rate is even lower, 0.06/yr (McBride 2001), yield per recruit with a 19-inch FL minimum size limit would actually drop below the current level by 5 - 8%. If fishing mortality rates were maintained at present levels in both regions then the greatest yield per recruit could actually be achieved with 18-inch FL and 15-inch FL minimum size limits in south Florida and the eastern Gulf of Mexico, respectively (Figure 4). These would provide increases in yield per recruit of 11 - 23% in south Florida and 1 - 4% in the eastern Gulf of Mexico.

Increases in the minimum size limits may bring other benefits to the hogfish populations. For example, if such regulations delay the legal harvest of newly matured males, spawning success could improve as a result of increased harem stability. A 19-inch FL minimum size limit would increase the abundance of hogfish that are between 12 and 19 inches long. In south Florida, we would expect this change to result in more than a two-fold increase ($\exp^{5 yrs * F}$ where F = 0.17/yr) in the number of hogfish that reach a FL of 19 inches. The expected increase in the abundance of 19-inch hogfish in the eastern Gulf of Mexico is lower, 37%, than the expected increase in south Florida waters because current fishing mortality in the gulf is lower than it is in south Florida. This significant increase in the abundance of hogfish who reach 19 inches could, in theory, sustain or improve the reproductive output of a hogfish population if either the abundance or the size of males is related to the population's reproductive success. Sexual transformation appears to require a few months (McBride, 2001), and presumably, once a male is killed, the reproductive output of all the harem's females is zero, at least temporarily. Colin (1982) observed spawning behavior of hogfish but did not comment on how readily females move between harems or if male size affects the sex ratio or spawning frequency of a harem. Further behavioral observations should elucidate how long this problem persists and to what magnitude.

Increasing the minimum size at which hogfish may be captured may also help promote and maintain eco-tourism in the region. Larger hogfish are usually the sexually dimorphic males, which are often characterized as charismatic reef residents. Allowing hogfish to grow larger before they can be legally caught would result in more sightings of the males and of harem behavior and would eventually

provide more 'trophy' fish to be harvested by divers and anglers. Further discussion or research is needed to understand the social attitudes and cost-benefits of such regulatory options.

We have tried to outline some of the benefits that increasing the minimum size limit for hogfish might bring to the hogfish population and fishery. Changes in hogfish regulations would, however, adversely affect the fishers temporarily. Implementation of a new size regulation would be followed by a period of low legal catch rates before the average-sized hogfish could reach the new larger legal size. For example, hogfish in the Gulf of Mexico fishery measure about 12 inches at approximately age 3 and 19 inches at about age 8. Thus, it would take about 5 years for the size structure of hogfish to increase sufficiently in response to a 19-inch size minimum and for fishers to fully benefit from this specific regulatory option.

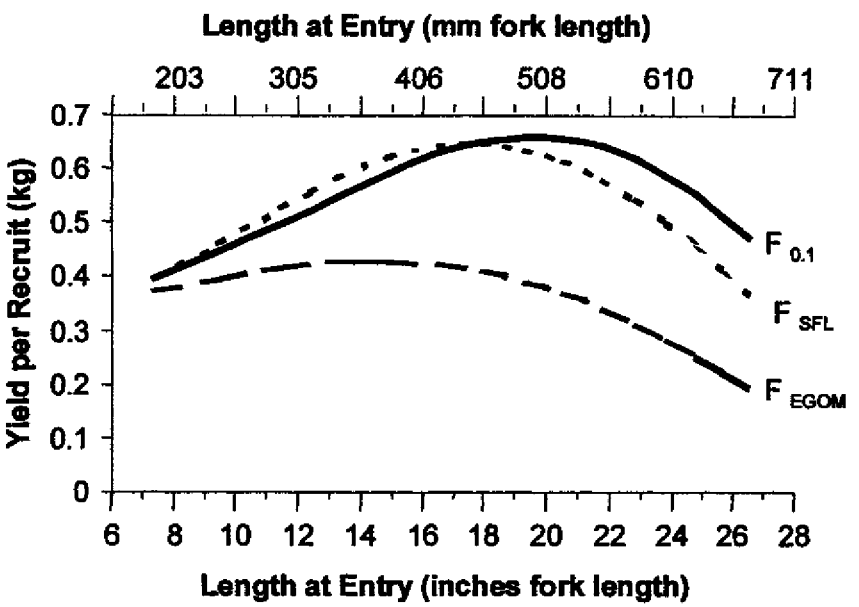


Figure 4. Estimated yield per recruit (kg) of hogfish, *Lachnolaimus maximus*, at various sizes-at-entry to the fishery (mm and inches) and fished at a benchmark mortality rates ($F_{0.1}$) and two observed mortality rates from McBride (2001): the current south Florida fishing mortality rate (F_{SFL}) and the current eastern Gulf of Mexico fishing mortality rate (F_{EGOM}).

CONCLUSIONS

Most hogfish landed in Florida before 2000 measured very close to the 12-inch (305 mm) FL size limit. Hogfish at this size are predicted to be age 3. But this species grows to 824 mm (32.4 inches) FL and reaches age 25. The observed maximum size is smaller in south Florida than in the eastern Gulf of Mexico, suggesting that growth overfishing is more severe in that region. This was confirmed by yield-per-recruit analyses. Increased yield should occur for hogfish caught in Florida, especially south Florida, if harvest was delayed until hogfish grew to larger sizes.

Maximum yield-per-recruit for hogfish would occur at a size larger than the current mean size at recruitment to the three main fisheries: trap, hook and line, and spear. Given an optimal fishing mortality ($F_{0.1}$), maximum yield per recruit is achieved at a mean size at recruitment of about 19 inches (483 mm) FL. There are other probable benefits associated with minimum size increases, including increased hogfish spawning success and the development of a trophy fishery. There would be short-term (about five years) costs to this size limit change because the number of legal-sized fish would be temporarily reduced.

ACKNOWLEDGMENTS

L. Bullock, K. DeMaria, M. Johnson, D. Murie, F. Stengard, and P. Thurman assisted in the hogfish life-history study. R. Ruiz-Carus translated the abstract. L. Barbieri helped improve the manuscript and J. Quinn, J. Leiby, and L. French provided editorial assistance. Funding for life history research was provided, in part, by a Marine Fisheries Initiative (MARFIN) Grant (No. NA87FF0422). We thank all of the above.

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Size and Age at Maturity of Female Red Snapper *Lutjanus campechanus* in the Northern Gulf of Mexico

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ABSTRACT

Red snapper, *Lutjanus campechanus*, support important recreational and commercial fisheries in the Gulf of Mexico (Gulf). Both fisheries have been intensely managed since the early 1990s after perceptions of overfishing in both sectors surfaced during the 1980s. Due to incomplete or missing life history data, particularly in regard to the species' reproductive behavior and output, certain assumptions have been made as regulations to promote the species' recovery have been designed. To provide information on the size and age of female red snapper at the onset of reproductive maturity, specimens from the Gulf off Alabama and Louisiana were examined for evidence of spawning activity during the spawning seasons of 1999, 2000, and 2001. The progression of oocyte maturation to vitellogenesis as observed in histological sections of ovarian tissues was used to define sexual maturity. The smallest red snapper having either hydrated oocytes or postovulatory follicles, definitive evidence of imminent or recent spawning, was 267 mm FL and was two years old. Female red snapper in Alabama reached maturation at a smaller size and younger age than those in Louisiana and growth rates did not differ between the regions.

KEY WORDS: Maturation, population demographics, red snapper

INTRODUCTION

The red snapper, *Lutjanus campechanus*, has supported important recreational and commercial fisheries in both the United States and Mexico for over a century. Both fisheries have been intensely managed in the U.S. since the early 1990s after perceptions of overfishing in both sectors surfaced during the 1980s. The Reef Fish Management Plan was developed in 1990 to provide for assessments of the status of the red snapper stock in the northern Gulf of Mexico (hereafter Gulf) and to adopt measures to rebuild the stock, ultimately to a sustainable yield. These recommendations are based principally upon the assumption that the red snapper population is one continuous or unit stock. However, data concerning stock structure (Camper et al. 1993, Chapman et al. 1995, Gold et al. 1997, Heist and

Gold 2000) are inconclusive and the unit stock hypothesis has yet to be tested. Despite management efforts, red snapper in the Gulf remain overfished (Goodyear 1995, Schirripa and Legault 1999).

The red snapper is a long-lived reef fish that can grow to be greater than 1000 mm TL and can live more than 50 years (Wilson and Nieland 2001). It is restricted to the Atlantic coast of the southeastern United States and the Gulf of Mexico (Rivas 1966). In the Gulf, adult red snapper are commonly found at depths ranging from 30 to 130 m (Fischer 1978). This gonochoristic species spawns multiple times during a prolonged season. Though many publications on red snapper exist, none addressing spawning and reproductive biology of the species in the wild have been published in the peer-reviewed literature. Studies presented in available publications differ in the spatial and temporal scales and in sampling protocols and methodologies (Table 1). Previous studies of more than one year have been restricted to a single state, while those studies incorporating larger regions only lasted a year. This study covers a greater region for a greater time period than any previous study.

Camber (1955), Moseley (1966), and Futch and Bruger (1976) all presented limited data on red snapper length- or age-at- maturity and the duration of the spawning season in the Gulf of Mexico. Length at maturity has been reported to be 320 mm FL (Camber 1955) and 190-300 mm SL (Mosely 1966). Wilson et al. (1994) presented preliminary estimates of maturation at 290 mm FL. Age at maturity has been reported as greater than 2 years old (Futch and Bruger 1976). Duration of spawning season has been reported differently among studies (Camber 1955, Mosely 1966, Bradly and Bryan 1975, Futch and Bruger 1976, Wilson et al. 1994, Collins et al. 1996). It has been described to occur for as long as seven months, lasting from May until January (Bradly and Bryan 1975), and as short as two months, lasting from July until September (Camber 1955); one study included April in the spawning season (Wilson et al. 1994).

Ovary analyses also vary among studies. While authors prior to 1976 (Camber 1955, Bradly and Bryan 1975, and Mosely 1966) used macro-assessment of gonad condition and maturation, later authors (Collins et al. 1996, Futch and Bruger 1976, and Wilson et al 1994) used histological techniques to determine distinct oocyte maturation. Histology is a more effective method for staging oocytes because it allows a detailed view of cross-sectioned and stained oocytes and thus, precise descriptions of oocyte maturation stages can be most clearly defined (West 1990). Despite this precision, problems still exist in the histology technique due to differences in terminology among authors, as well as subtle differences in oocyte maturation among species.

This research sought to gain a better understanding of red snapper population dynamics for optimum management. Our objectives were to provide data on age and size at reproductive maturity of red snapper in the northern Gulf of Mexico and to determine if differences exist east and west of the Mississippi River over a time span of three years.

Table 1. Results of this study and past studies pertaining to reproductive biology of red snapper.

Reference	Year of study	Location	female:male	length range	length/age at 50 % maturity	spawn season	peak spawn
Camber 1955	1955	Campeche Banks	1.1:1	250-800 mm FL	320mm FL	July-Sept	July-Aug
Moseley 1966	1964-65	NW Gulf	1:1.3	200-700 mm SL	190-300mm SL	June-mid-Sept	Aug
Bradley & Bryan 1975	1970-72	Texas	1:1	200-845 mm FL	255mm FL	May-January	June-July
Futch & Bruger 1976	1972-75	Clearwater, Florida	1.2:1	100-941 mm FL	2+ years	July-October	Aug-Sept
Wilson et al. 1994	1989-93	Louisiana	-----	340-850 mm FL	290mm FL	April-Sept	June-Aug
This Study	1999 – 2001	Alabama - Louisiana	------	239-916 mm FL	AL: 275mm FL/ 2 LA: 300mm FL/ 2	May-Sept	May-July

METHODS

During the recreational fishing season of 1999, 2000, and 2001 red snapper were sampled by hook and line from the Gulf of Mexico west of the Mississippi River off Louisiana waters, and east of the Mississippi River off Alabama (Figure 1). Between the months of May and October, a minimum of 600 individuals per region were targeted in 1999 and 2000 and 300 individuals per region were targeted in 2001. Minimum size (406 mm TL) of the recreational harvest was dependent upon federally controlled size limits. In addition to these targeted fish, a National Marine Fisheries Service permit allowed us to collect undersized red snapper. In this study only female individuals are considered.

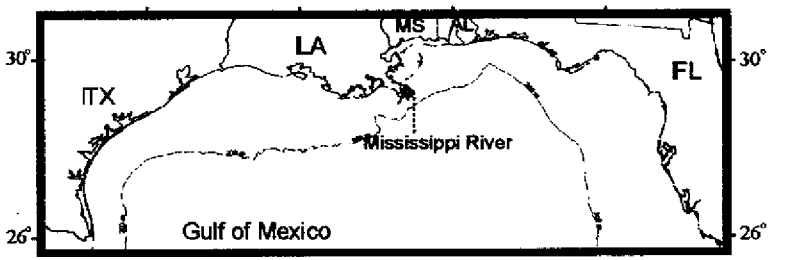


Figure 1. Red snapper were collected east of the Mississippi River off Alabama (AL) and west of the River off Louisiana (LA)

Fork length (FL) (to the nearest mm), and total (TW) and eviscerated weights (EW) (to the nearest 0.01 kg) were recorded for each fish sampled. Sagittal otoliths were removed as described by Beckman et al. (1990) and processed for age analysis following Cowan et al. (1995). Gonads were excised, placed in individually labeled plastic resealable bags, and transported on ice to the laboratory. After the gonads were weighed (nearest 0.1 g), the ovaries were stored in 10% formalin until further analysis.

We analyzed several reproductive characteristics of female red snapper to determine age and size at maturity. These characteristics include gonadosomatic indices (GSI), oocyte maturation stages, and duration of spawning season.

GSI was calculated as gonad weight as a function of body weight (Htun-Han 1978): GSI= (100) (gonad weight in g / ovary free body weight in g). A peak in the GSI suggests a peak in seasonal spawning.

Oocyte maturation stages were determined by histological analysis. The lobes of the ovaries are symmetrical (Collins et al. 1996); therefore, a subsample of formalin fixed ovarian tissue (30-50 g) was dissected from one randomly chosen region of the two lobes. Each subsample was embedded in Paraplast and sectioned to 3µm thickness. Sections were mounted on microscope slides, stained in Gill hematoxylin, and counterstained in eosin Y.

Oocytes were categorized into one of four oocyte stages by microscopic examination of the prepared histology slides at 40x and 100x magnification. The four stages of oocyte maturation described by Wallace and Selman (1981) are

primary growth (PG), cortical alveoli (CA), vitellogenic (V), and hydrated (H). Progression of oocyte maturation to vitellogenesis was used to define and identify mature females (Figure 2A) (Hunter and Goldberg 1980, Brown-Peterson et al. 1988, Nieland and Wilson 1993). Immature ovaries contained only PG and CA oocytes (Figure 2B).

Females were classified as mature by size and by age. Females were grouped into size classes of 25 mm and 50 mm FL and age classes. Differences in defined reproductive characteristics between regions were tested by chi-square analysis. The Benferroni technique was used to adjust for the possibility of a Type I error. A weighted log regression was used to determine if differences in growth rates existed between regions.

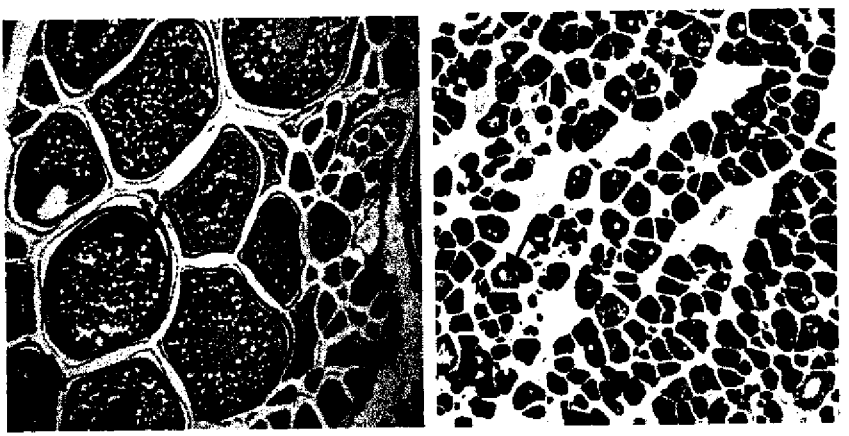


Figure 2. Image of mature (A) and immature (B) ovaries of red snapper. V indicates a vitellogenic oocyte. PG indicates a primary growth oocyte. CA indicates a cortical alveoli oocyte.

RESULTS

A total of 1681 female red snapper were collected from the northern Gulf: 1029 from Alabama and 653 from Louisiana. Alabama females ranged from 237-916 mm FL, Louisiana females ranged from 292-910 mm FL. Ages of Alabama and Louisiana females ranged from 1-34 years and 2-37 years, respectively. Age data from 2001 was not included in this analysis because fish collected in 2001 had not been aged as of this writing.

Gonadosomatic index indicated that spawning began in May and ended by September. The peak months of the spawning season appeared to be May, June, and July. Only individuals captured during June, July, and early August were considered in determining size- and age-at-maturity. Individuals captured in May were not

analyzed in order to insure 'truly immature', as opposed to apparent immaturity resulting from the beginning of the spawning season. A total sample size of 1,247 females was used for comparisons of length-at-maturity, and 864 for comparisons of age-at-maturity.

The smallest mature Alabama fish was 267 mm FL and the smallest with hydrated oocytes, indicative of imminent spawning, and POF, indicative of recent spawning, were 280 mm and 267 mm FL, respectively. The smallest mature Louisiana fish was 292 mm FL and the smallest with hydrated oocytes and POF were 304 and 324 mm FL, respectively. All of these fish were 2 years old.

Combined data showed that all fish greater than 590 mm FL, and all greater than age 5 years were mature, with one exception. A 720 mm FL, 7 year old captured off Alabama was immature. A comparison of the maturity schedules for each region indicated that fish captured east of the Mississippi River in Alabama reached 50% maturity at 275 mm FL and 2 years old and 100% maturity by 600 mm FL and 5 years old; fish captured to the west in Louisiana reached 50% maturity before 300 mm FL and 2 years old and 100% maturity by 600 mm FL and 6 years old (Figures 3 and 4). Compared to Alabama, Louisiana females progressed to maturity over size and age classes more slowly. Chi-square analyses indicated that Alabama size classes between 300 mm – 500 mm, and age classes between 3 – 5 years, had significantly more mature females than in Louisiana (Tables 2 and 3). Weighted linear regression on $\log_{10}$-transformed data of length at age indicated no significant differences between growth rates of these two regions (ANCOVA test for equal slopes, $p = 0.56$).

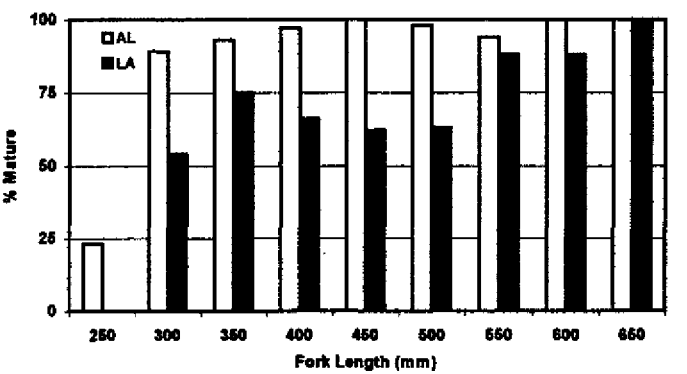


Figure 3. Percent of mature female red snapper by fork length (mm) for Alabama (AL) and Louisiana (AL)

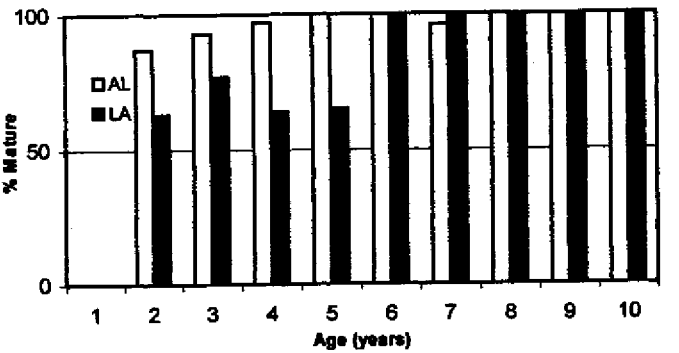


Figure 4. Percent of mature female red snapper by age) for Alabama (AL) and Louisiana (AL)

Table 2. Percent of mature females and sample size N by size class in 25 mm increments for Alabama and Louisiana. Size classes having significantly different proportions of mature females are indicated by (*).

Size Class	Alabama		Louisiana	
FL (mm)	% Mature	N	% Mature	N
250	0	7		
275	65	17		
300	92	38	67	9
325*	94	34	43	7
350*	94	31	70	20
375*	95	62	70	27
400*	97	65	70	27
425*	99	79	61	28
450*	100	78	69	54
475*	100	55	50	34
500*	96	46	67	24
525*	100	37	74	19
550	94	33	100	6
575	92	24	75	4
600	100	16	100	4
625	100	24	100	4
650	100	30	100	4

Table 3. Percent of mature females and sample size N by age classes for Alabama and Louisiana. Age classes having significantly different proportions of mature females between states are indicated by (*).

Age Class	Alabama		Louisiana	
years	% Mature	N	% Mature	N
1	0	8		
2*	87	55	63	16
3*	93	75	77	117
4*	97	200	65	99
5*	100	86	65	54
6	100	29	97	34
7	96	25	100	8

DISCUSSION

While our estimates of size- and age-at-50 %maturity do fall within the range of estimates of past studies (Camber 1955, Moseley 1966, Futch and Bruger 1976, and Wilson et al. 1994), only one other study has reported maturation schedule to 100% maturity and it was not similar to our results. Wilson et al. (1994) reported that females sampled from Louisiana reached 100% maturity by 420 mm FL.

Regional differences in red snapper age- and size-at-maturation could represent a real difference in population demographics of the red snapper east and west of the Mississippi River. Maturity schedules of a species generally are not static, and it is rare for all individuals in a fish stock to mature at the same age. However, a decline in age-at-maturity can be an indication of a stressed population and is often caused by compensatory responses to declining population size and/or by genetic selection (Trippel 1995).

Maturation schedules can change in response to fishing pressure, predator and prey abundance, stock composition, and other biotic and abiotic environmental factors (Wooton 1990). Zhao and McGovern (1997) identified changes through time in age- and length-at-maturity and in growth rate of vermilion snapper *Rhomboplites aurorubens* in the South Atlantic Bight; changes were probably due to gradual fishing pressure increases ultimately resulting in growth overfishing. A preliminary study indicated that, compared to fish sampled from the region five years earlier (Grimes and Huntsman 1980), vermilion snapper decreased in size and age at maturation; however, length at age for one and two year old fish changed little (Collins and Pinckney 1988). A temporal comparison of the stock in 1979-80 to 1985-87 also concluded that vermilion snapper declined in size- and age-at-maturity through time (Zhao and McGovern 1997) and that growth rate decreased through time (Zhao et al. 1997). Because growth rates decreased with time, the decrease in size at maturity probably is not part of a density-dependent compensatory response

to harvesting; more likely, it is a response to growth overfishing caused by the selective removal and incomplete replacement of faster-growing, later-maturing fish by harvesting (Zhao and McGovern 1997).

Jørgensen (1990) observed changes through time in age at maturity and growth rate of Arctic cod *Gadus morhua* to be a density-dependent compensatory response to harvesting. The cod population has been intensely exploited for the past 50 years and cod stocks have undergone severe population declines. Jørgensen determined that despite high fishing pressures, it is the age distribution and not the size distribution of the population that has changed. It is likely that in response to increased mortality, fish grow faster and mature at a younger age; implicitly, there is a minimum threshold for size-at-maturity (Jørgensen 1990). If this idea is correct, then declines in size and in age at maturity should not occur simultaneously.

In contrast, Reznick et al. (2001) presented a case in which populations of guppies experiencing high and low predation pressures had different population demographics. Guppies experiencing high predation rates had a smaller size and younger age at maturity and a faster growth rate than fish experiencing low predation pressure because higher levels of resource availability existed as an indirect consequence of high predation. The populations experienced different mortality, lived in different environments, and due to mortality and environmental differences, food availability differed. Guppies at sites of low-predation did not have a greater density per unit area but had more large, old fish and fewer small, young fish, and thus, a greater biomass.

Similarly, red snapper populations could vary by region due to a compensatory response. If mortality rates are different and/or if the environments in areas off Alabama and Louisiana coastlines differ, then population demographics could also differ. Greater fishing pressure off Alabama could decrease the density of fish per unit area, thereby decreasing intra-specific competition and allowing for an increase in resource availability. If red snapper in the Gulf have reached their maximum physiological growth potential, then the increased available energy in Alabama's system could be allocated to reproduction. This would allow fish to reproduce at a smaller size, and therefore, younger age in Alabama waters. However, there are no reliable estimates to compare mortality rates east and west of the Mississippi River.

Environmental differences could also exist between the regions. Both have a great number of artificial reefs which red snapper are known to inhabit. While Alabama's artificial reefs are predominantly small, low-vertical-relief structures, Louisiana's artificial reefs are predominantly oil and gas platforms. Compared to the smaller artificial reefs of Alabama, it is unknown as to whether platform reefs are more productive as habitat for red snapper. Regardless of these artificial reef structure differences, there is a vast amount of natural hard bottom off each the coastlines (Gore 1992) and differences in habitat are likely to be negligible.

Shifts in maturation schedule in red snapper may be attributable to genetic selection coincident with increased mortality (Roff 1992). Tagging studies have implied that red snapper movement may be sufficient to facilitate stock mixing in the

stock in the northern Gulf have not strongly supported genetic differences in the stock (Camper et al. 1993, Gold et al. 1997, Heist and Gold 2000, but see Chapman et al. 1995). However, these genetic tests would not indicate differences in a maturity genotype. A genotype for smaller size and younger age at maturity can be selected for in some species (Trippel 1995). Early maturing genotypes reproduce before being fully recruited to the fishery. Genotypes that mature at larger sizes or older ages are likely to be removed before reproduction. In contrast, fish that mature early may participate in one or more spawning seasons before being captured. The progeny for later maturing fish would be selected out of the population over time. Therefore, it may be that the late-maturing genotypes have been removed from the Alabama population due to high fishing pressure. This process would explain the lesser abundance of larger and older immature fish (if it is true that Alabama has fewer large and old individuals than Louisiana) in the Alabama region and would account for differences in size and age at maturity.

It is unclear what is causing differences in size- and age-at-maturity in regions east of the Mississippi River off Alabama and west of the River off Louisiana. It is evident that differences in population demographics exist between the two regions. This study is part of a larger effort to gain a better understanding of the red snapper population in the northern Gulf. Although a difference in mortality due to fishing is likely to be the cause of the differentiation in reproductive demographics that we observed, results of ongoing studies will bolster these preliminary results.

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Age Structure of Gag (*Mycteroperca microlepis*) in the Eastern Gulf of Mexico by Year, Fishing Mode, and Region

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ABSTRACT

Based on estimation of age structure from catches derived from the west Florida shelf, gag (*Mycteroperca microlepis*) stocks exhibit alternating strong and weak year classes. Four year classes (1985, 1989, 1993, 1996) were observed to exceed 40% of the total annual age structure by ages 4 - 6, the ages at full recruitment to the fishery. When sample locations were more precisely reported during 1998 - 1999, there was a slight trend towards older ages and increased ratio of males from the southwest Florida coast versus north of Tampa, the area where the fishery has historically been concentrated. The influence of gear on age-structure was quite apparent. In general, recreational hook-and-line gear captured the youngest fish, with increasing proportions of older ages occurring in commercial hook-and-line and long-line gears. Because of the catch patterns resulting from a strong 1993 year class, we suggest that gear selectivity by age is determined more by location and depths fished relative to the population distribution and less due to direct attributes of the gear, such as hook size or differences in fish behavior and susceptibility by size.

KEY WORDS: Age structure, gear selectivity, *Mycteroperca microlepis*

Estructura por Edades de la Cuna Aguají (*Mycteroperca microlepis*) en el Golfo de México Oriental por Modalidad de Pesca y Región

Se compararon muestras de cuna aguají procedentes de pesquerías comerciales y recreativas de los EE.UU. para identificar patrones espaciales y relacionados con el arte de pesca en la distribución por edades. Se encontró una tendencia hacia edades mayores y una mayor proporción de machos en la costa sudoeste de la Florida en comparación con el norte de Tampa, el área donde la pesquería se ha concentrado históricamente, indicando una posible diferencia geográfica en la estructura del stock. Los datos de capturas también indicaron que el stock adulto se centra alrededor de dos zonas de profundidad: en la plataforma intermedia y en la plataforma exterior, que corresponde a la presencia de paleo-arrecifes de la plataforma del oeste de la Florida que en su mayor parte no han sido mapados. La influencia del arte de pesca en la estructura por edades era bastante aparente. En

general, la pesca recreativa con caña y anzuelo capturó los peces más jóvenes, mientras que las pesquerías comerciales de caña y anzuelo y palangre mostraban proporciones crecientes de edades mayores. Pero la influencia en las edades también estaba correlacionada con las profundidades en las que pescan comúnmente las respectivas artes de pesca. Debido al patrón de capturas que muestra una clase anual fuerte, sugerimos que la selectividad del arte de pesca por edades viene determinada más por la localidad y profundidad en la que se pesca en relación a la distribución de la población y en menor medida debido a atributos directos del arte de pesca, como los tamaños de anzuelos utilizados comúnmente o diferencias en el comportamiento de los peces y susceptibilidad por tallas.

PALABRAS CLAVES: *Mycteroperca microlepis,* modalidad de pesca, cuna aguají

INTRODUCTION

The broad shelf of the west coast of Florida is a highly productive source of economically important reef fish. Nearly 95% of the groupers and over 50% of the snappers taken from the U.S. Gulf of Mexico are landed on the west coast of Florida. Of the grouper species, gag grouper (*Mycteroperca microlepis*) is one of the more economically important in the south Atlantic and Gulf of Mexico (Sadovy 1990). Gag comprise about 31% of the approximately 10 million lb shallow-water grouper quota for the Gulf of Mexico (GMFMC 1999).

However, gag are currently approaching an overfished condition in the Gulf of Mexico (GMFMC 1999, NMFS, 2000). A recent assessment of the gag fishery identified a particular need for age and growth information and annual age-structure data for future assessments (Schirripa and Legault 1997). Our goal was to characterize available age data in order to detect any patterns in year-class variation over time. Expanded sampling and increased reporting of capture locations and gears used in 1998 and 1999 allowed us to examine differences in age structure by gear type and region; north versus south of 28 degrees (approximately the latitude of Tampa, Florida).

METHODS

To examine interannual patterns of age structure, an age data base was developed from otolith samples from National Marine Fisheries Service and state of Florida sampling programs (state/federal cooperative Trip Interview Program, Beaufort NMFS Headboat Program and Panama City NMFS Charter Boat Survey). Age frequencies from 1991 through 1994 were taken from Johnson and Koenig (in press) and were primarily based on hook-and-line caught fish from the commercial and recreational headboat and charter boat fisheries. Unpublished age data from Allyn Johnson (retired, NMFS Panama City Laboratory) were also available for years 1995 and 1996 from similar sources targeting catches from the northeast Gulf of Mexico. During December 1997 through 1999, we were able to obtain otolith

samples across a better defined geographic gradient. Adult gag were sampled by NMFS and state port agents in cooperation with a MARFIN study (through Florida State University) of gag reproduction along a geographic gradient. Port agents recorded lengths, weights, gear used, and endeavored to determine the depth and location of capture to the nearest minute of latitude/longitude from interviews with fishermen. Often, however, only approximate locations were given. After 1997, collections differed from previous years in that many gag were being sampled from the west Florida shelf south of Tampa and more otolith samples were being taken from commercial long-liners.

We generally followed earlier aging methods used in northeastern Gulf studies (Johnson et al. 1993, Johnson and Koenig, in press) and determined the ages of gag from whole otoliths following the original interpretation in McErlean (1963). Older gag (greater than about eight annuli present) are difficult to age using whole otoliths and these otoliths were sectioned. We followed the processing method of Cowan et al. (1995). Whole and sectioned otoliths were assigned an age based on the count of annuli (opaque zones observed with reflected light) and the degree of marginal edge completion. Annulus counts were advanced a year in age after January 1st if their edge-type was a nearly complete translucent zone. After June 30, when opaque zone formation is underway or complete for gag in the Gulf of Mexico (Hood and Schlieder 1992, Johnson and Koenig, in press), all fish were assigned an age equal to the annulus count by convention. By this traditional method, an annual age cohort is based on a calender year rather than estimated time since spawning (Jearld 1983).

RESULTS AND DISCUSSION

Gag can be aged at relatively low cost as agreement between ages determined from whole and sectioned otoliths is high (Johnson and Koenig, in press) and most age determinations can be made reliably from whole otoliths. By 2000, two readers (GRF and NME) each had aged in excess of 1000 gag otoliths, and so by gaining moderate experience, could make independent estimates of age for comparison. The resulting measure of precision, average percent error (APE; Beamish and Fournier 1981), was 2.8 for the year-2000 age samples. This is a lower value than that determined during recent red snapper aging efforts (APE ranging 5.2 - 8, Allman et al. 2002) and less than the threshold (APE= 5) recommended for production aging (Morison et al. 1998). As aging precision is high, "readability" of the gag otoliths is relatively good.

The gag sample sizes for age frequency varied from about 300 to 800 fish each year (with the exception of 1997). Although these are not large data sets for understanding age structure, the lengths of the aged gag correspond to the lengths reported in a recent stock assessment. For example, in 1996, a dominant mode of small-sized gag, just reaching the minimum legal size limit, 508 mm (20"), was observed in the handline and powerline fishing gears (Schirripa and Legault 1997) and was detected among the aged gag as well (500 - 600 mm TL, Figure 1).

Generally during the 1990s, the sizes sampled reflect the 508 mm (20") legal size limit and often the annual modes are between 600-800 mm TL (25-30 inches) for the hook-and-line gear (Schirripa and Legault 1997, Figure 1). Since the U.S. gag fishery in the Gulf of Mexico is almost exclusively confined to the west Florida shelf and that the sizes of the aged gag match the length distributions reported in the last assessment, gives us some confidence to infer age structure from the fishery with the sample sizes of otoliths available to us.

Gag appear to be fully recruiting to the commercial fishery by age-4 or 5 and dominant year classes were observed to exceed 40% of the annual age structure at this age during some years (Figure 2). Specifically, dominant year classes were those apparent for at least 3 - 4 years and include the 1985, 1989, 1993 and 1996 year classes based on the available age data (Figure 2). An apparently strong 1993 year class, detectable as age-3 fish entering the fishery in 1996, provides an explanation of the notable 500 mm (20") size mode reported in a previous assessment (Schirripa and Legault 1997). Based on a juvenile survey, the 1993 year class was predicted to be a particularly strong year class (Koenig and Coleman 1999, Johnson and Koenig in Press) and appears to be the dominant year class harvested from 1996 through 1999 (Figure 2).

The pattern of strong and weak year classes detectable among the adult age structure monitored over time supports earlier findings of highly variable annual recruitment from juvenile surveys (Koenig and Coleman 1999, Johnson and Koenig, in press). Two previous age studies; one in the south Atlantic (Harris and Collins 2000) and one in the Gulf (Johnson et al. 1993) also detected changes in age-structure from age data sets collected at two intervals over 10 years apart. In both studies, the age-structure changes were hypothesized to be a result of changes in levels of fishing. Our results indicate that a likely explanation for change in adult age-structure is recruitment variation.

When we examined the age data for years with more complete gear information (1998 - 2000), there were apparent differences in the age structure by gear. Recreational-caught gag were the youngest each year with dominant modes at age-4 (1998 and 2000) and age-3 (1999) (Figure 3). Commercial hook-and-line gear and long-line gear showed dominant modes at age 5 (1998) and age 6 (1999) still tracking the strong 1993 year class. But long-line gear was tending to harvest older individuals with age-class frequencies not dropping below 1% until age 15 or 16 (Figure 3). On the west Florida shelf, bottom long-lining for reef fish is allowed to a depth as shallow as 20 fathoms. Since commercial hook-and-line and long line fisheries broadly overlap depth zones from the mid to outer shelf, the similarity in age structure between the two commercial fishing gears may not be surprising, particularly if a strong year class is present at the depths where the two gears overlap (e.g., 1998 and 1999). However, by 2000, the previously dominant 1993 year class was only apparent as 7-year olds in the long-line fishery while the younger 1996 year class was appearing to dominate in the commercial and recreational hook-and-line fishery. The patterns clearly seem to reflect the fishing gauntlet across depth, that is - youngest ages taken in the recreational sector, followed by

commercial hook-and-line and finally commercial long-line sectors. These findings support earlier studies showing larger and older gag tend to be sampled from deeper water depths (Manooch and Haimovici 1978, Hood and Schlieder 1992).

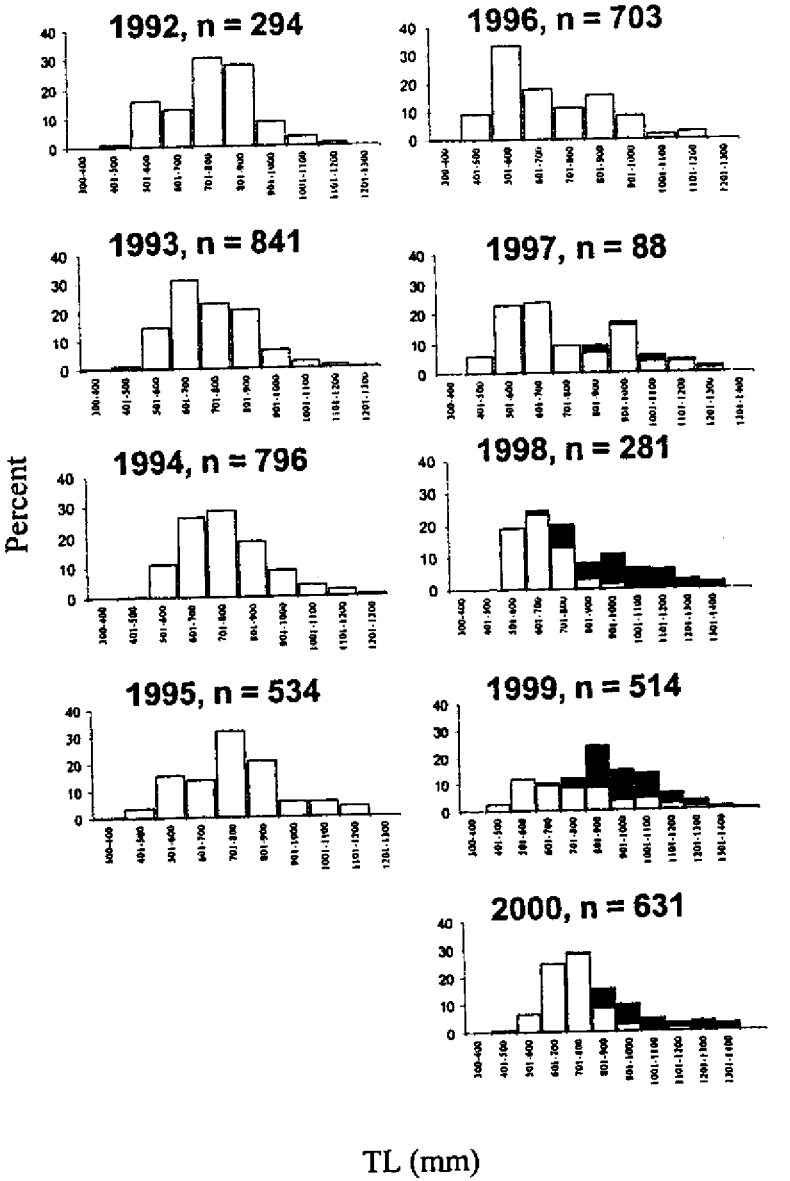


Figure 1. Size distribution of gag sampled for age. Hook-and-line data represented by open bars and long-line data are represented by black bars.

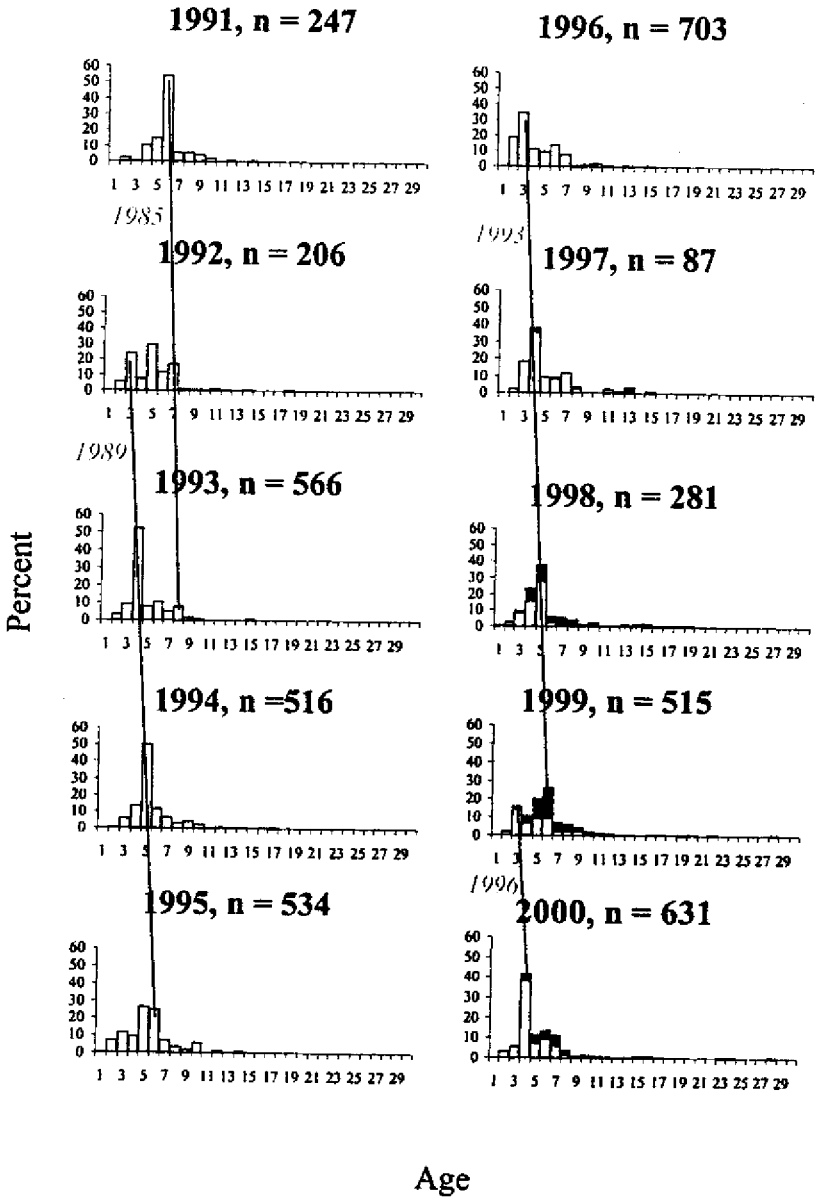


Figure 2. Gag age distribution. Hook and line data represented by open bars and long-line data are represented by black bars. Dominant year classes (1985, 1989, 1993, and 1996) are denoted by lines. 1991-1994 data from Johnson and Koenig (in Press).

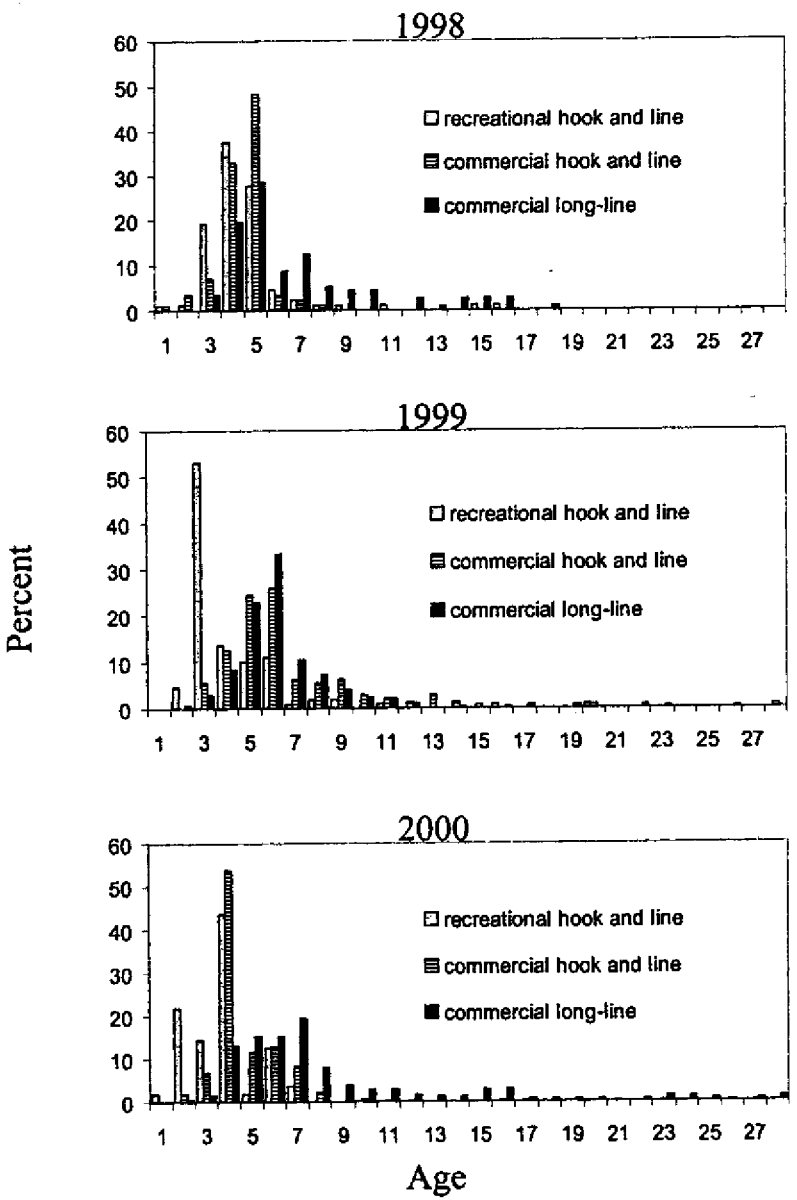


Figure 3. Age distribution by principal fishing modes for years 1998-2000. Age frequencies for each gear within each year were scaled to 100% for comparison.

We also wished to examine regional differences, and particularly compare an area where the fishery has been recently active (north of Tampa; Schirripa and Legault 1997) to an area where gag landings are much smaller (south of Tampa), possibly reflecting a geographic difference in the fishing effort experienced by the stock. From December 1997 through December 1999, gag were sampled by port agents returning otoliths, lengths, weights, and in most cases, gonads and information about gear, position and depth of capture in cooperation with a MARFIN study (Fitzhugh et al. 2000). For most of the gag sampled, we were provided enough information to distinguish catches from north and south of Tampa (about 28 degrees N latitude). This differs from previous Gulf of Mexico gag research where gag samples were taken from the mid to outer continental shelf north of Tampa (see Hood and Schlieder 1992, Coleman et al. 1996 and Collins et al. 1998), the general location where the fishery was known to primarily exist (Schirripa and Legault 1997). To our knowledge, these data represent the first substantial effort in sampling adult gag so far south (to the Tortugas) along the west Florida shelf.

Gag captured by hook-and-line (commercial and recreational) north of Tampa showed a notably skewed size distribution with a mode at 600-700 mm TL and with individuals ranging to greater than 1300 mm TL (Figure 4). Of the 256 gag, 215 were identified to sex with 4.65% being male. More larger gag were captured by hook-and-line gear south of Tampa with much higher frequencies of gag from size-classes greater than 900 mm TL (Figure 4). Of the 218 gag from this category, 125 were identified to sex, of which 14 % were male. Long-line gag sampled south of Tampa were generally larger than hook-and-line fish with a mode at 800-900 mm TL (Figure 4). This category represents the largest sample with 409 gag, of which, 231 were identified to sex and 17% were male. Only seven gag were sampled from long line catches north of Tampa and are not shown.

We compared age structure north and south of Tampa for commercial hook-and-line gag. Subdividing the data resulted in a much reduced sample size but some trends may be robust. Age structure between regions was similar but more older gag were evident from the southern hook-and-line catch (Figure 5). In 1998, most fish sampled in the north were age-4 and age-5 in contrast to a more evenly distributed age structure from samples taken south of Tampa. For both regions, the progression of year classes was notable as age-4 and age-5 fish dominated in 1998 and age-5 and age-6 fish dominated the age structure in 1999 (Figure 5).

By observing the alternating pattern of strong and weaker year classes progressing through the various fisheries, and by observing the pattern of catch from gears which tend to harvest at different depths, a hypothesis can be derived for gear selectivity. The largest factor affecting selectivity appears to be gag age and size differences occurring at depth and locality where a gear is fished, and to lesser degrees age/size differences in behavior, gear susceptibility or gear effects (hook size, etc.). An example which highlights the size/age-by-locality effect is the domination of 3-year olds in the commercial hook-and-line catch occurring only once within the decade. In 1996, the 3-year olds (1993 year class), independently

observed to be a large year class via a juvenile survey, recruited to mid-shelf depths and frustrated many fishermen due to the high number of undersized discards (Fable 1996, Johnson et al. 1997). To clarify these age/size patterns, future research should focus on increased sampling for age and compare geographic differences between age-structure for long-line gear and similar components of the recreational fishery (e.g., private, head boat and charter) related to regional differences in fishing effort.

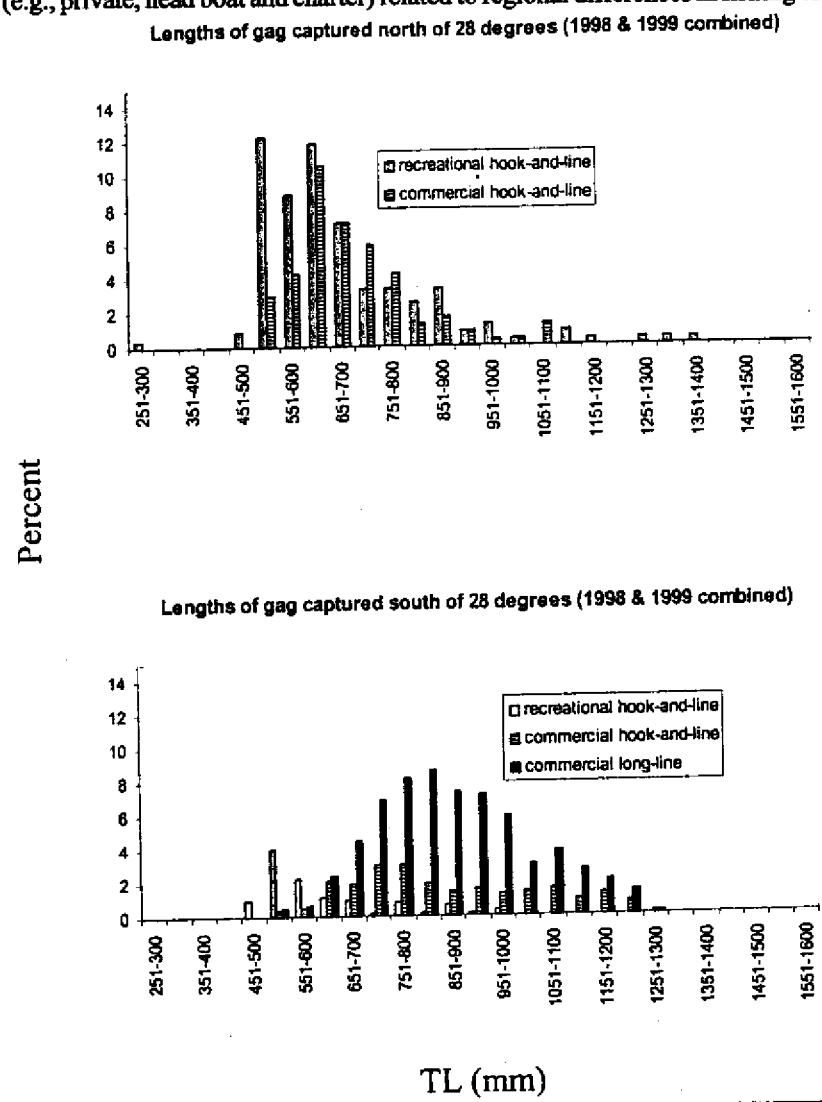


Figure 4. Length distributions of gag sampled for age by gear type, north and south of Tampa (28 degrees N. latitude) expressed as percent of total samples available for each region.

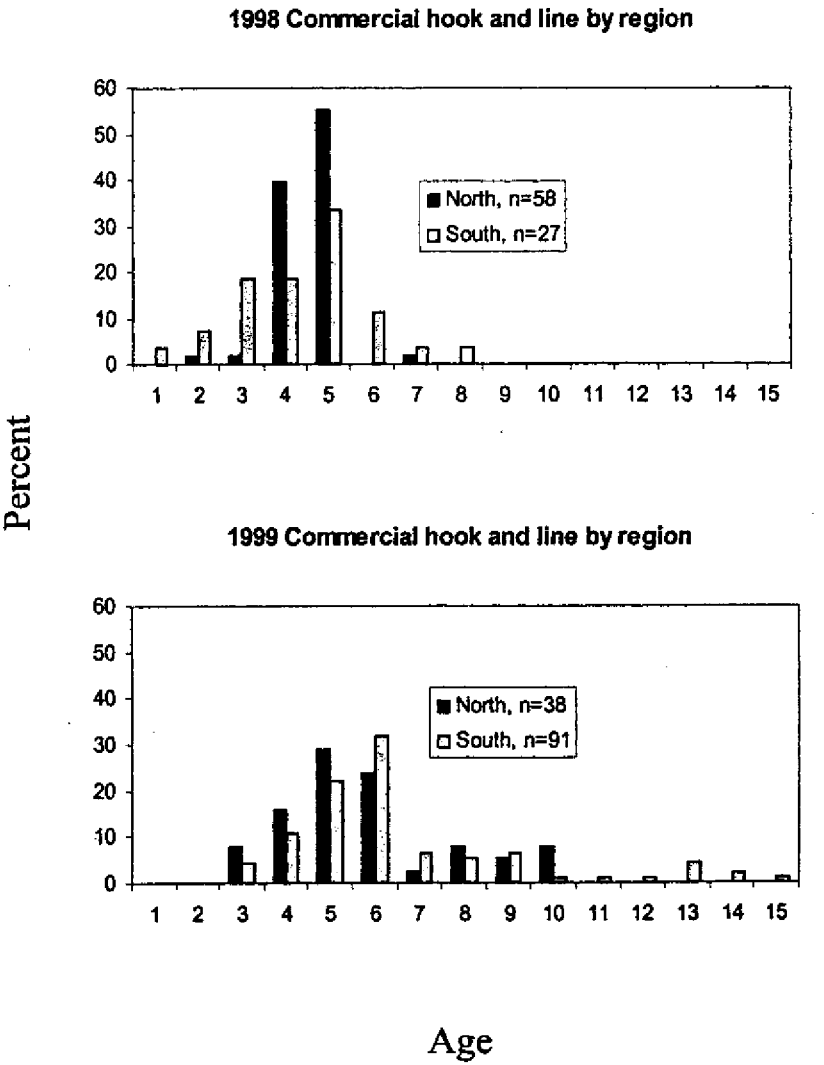


Figure 5. Age distribution of gag captured by commercial hook and line from locations north and south of Tampa (28 degrees N. latitude) for 1998 (top panel) and 1999 (bottom panel).

ACKNOWLEDGMENTS

This work was accomplished because of several port sampling programs including the Trip Interview Program (TIP), Beaufort NMFS Headboat Survey, Florida Department of Environmental Protection and the Marine Recreational Fisheries Statistical Program. Several port agents went beyond the call of duty to obtain samples and data and include David Bartee, Lew Bullock, Debbie Fable, Greg Fairclough, Lisa Hallock, Tom Herbert, Rene Labadens, Ed Little, Rene Roman, Bill Walling, and June Weeks. This research was supported in part by the U.S. Department of Commerce Marine Fisheries Initiative Program (MARFIN)

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Diferencias entre Modelos Geoestadísticos Aplicados en el Análisis de la Distribución Espacio-temporal de Especies Biológicas

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RESUMEN

Se comparan mediante kriging ordinario, universal y bayesiano los modelos de distribución espacial del número de especies bentónicas obtenidos en una zona sometida a tensiones ecológicas (Puerto CALICA, Quintan Roo. México) entre mayo de 1996 y junio de 1999. Estos modelos fueron evaluados considerando su capacidad como descriptores de la estructura espacial de los datos, como estimadores de valores e interpoladores, observando diferencias mínimas de predicción y estimación. En la interpolación, los kriging ordinario y universal consideran todos los datos muestrales, mientras que el bayesiano ignora valores extremos eliminando algunos de los datos de los muestreos. El kriging universal presentó las mejores características con el tipo de datos analizados; no obstante, las diferencias con el Kriging ordinario fueron mínimas. En la variación espacial se presentó una tendencia a la disminución del número de especies bentónicas durante el período de análisis.

PALABRAS CLAVES: Modelos geostadisticos, especies bentónicas

INTRODUCCIÓN

El desarrollo de la técnica del kriging bayesiano (BK) ha incrementado el uso de la geoestadística en trabajos ecológicos, en especial después de los trabajos de Kitanidis (1986, 1997), Omre (1987) y Omre y Halvorsen (1989). Este incremento ha dado origen a evaluaciones comparativas con otros tipos de kriging, destacándose los trabajos de Quai (1997) y Krivoruchko (2001). No obstante, no se han realizado evaluaciones de distribuciones espaciales de especies biológicas con el BK.

En el presente trabajo se analizan de manera comparativa las distribuciones y variaciones espacio-temporales de especies bentónicas obtenidas con BK, kriging ordinario (OK) y kriging universal (UK) en una área bajo tensiones ecológicas (el área aledaña a Puerto CALICA, Estado de Quintana Roo, México). En la determinación del mejor estimador de la distribución espacial de las especies bentónicas, se consideraron, además de los parámetros de validación geoestadística, las observaciones in situ de la distribución espacial de especies bentónicas reportadas para el Caribe mexicano.

MATERIALES Y MÉTODOS

Puerto CALICA se localiza a 8.7 km de la ciudad de Playa del Carmen junto al Centro Turístico de Xcaret al norte del Estado de Quintana Roo, México, (Figura 1). El trabajo de campo se realizó dentro del programa de monitoreo ambiental que realiza el Centro de Investigación y Estudios Avanzados del IPN Unidad Mérida, desde mayo de 1996 a la fecha, los datos usados para este ensayo comprenden desde su inicio a junio de 1999.

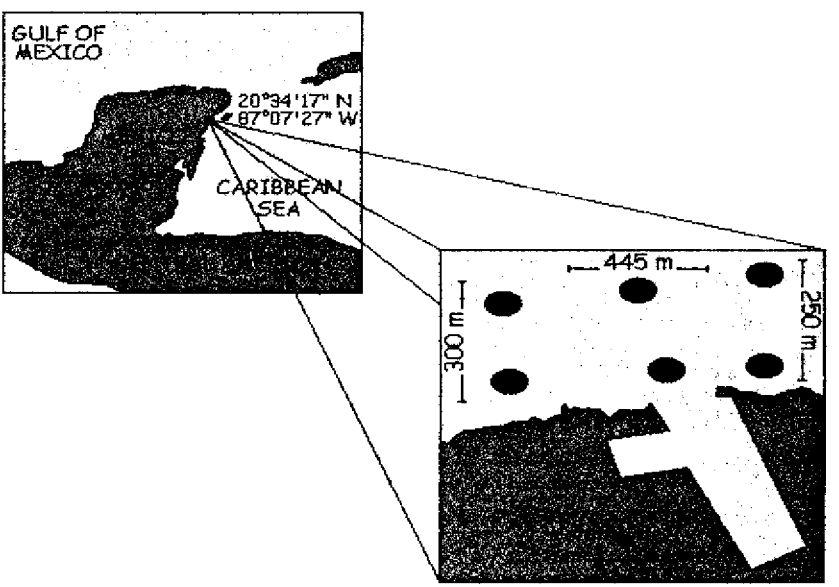


Figura 1. Localización y mapa de la región de estudio

En la obtención de datos se utilizó la técnica de fototransecto (Ohlhorst et al. 1987), en cada transecto se utilizaron 18 fotografías, cada una representa una área de 1904 cm^2 (56 x 34 cm) del fondo marino y un área de 3.427 m^2 por cada transecto. El área de estudio se dividió en seis zonas de muestreo con dos fototransectos por zona, los cuales se geoposicionaron (GPS Magellan) para asegurar una ubicación espacial constante.

Cada fotografía fue digitalizada para determinar el número y tipo de especies bentónicas (Torruco y González 1994) y se ubicó espacialmente definiendo un sistema de coordenadas XY. Mediante el número de especies se definió el valor Z para la obtención de un sistema XYZ necesario en la interpolación, el cual se escaló reportando los resultados en número de especies bentónicas por metro cuadrado.

Análisis Geoestadístico

El OK se seleccionó por considerar variaciones locales de la media de los valores en estudio, limitando el dominio de estacionalidad a la vecindad local, en lugar de considerar a la media como constante en toda el área de estudio (como lo supone el kriging simple), lo cual se apega al comportamiento espacial de especies biológicas con distribución en parches. El UK se seleccionó por considerar que la media local varia suavemente en cada vecindad local, comportamiento que presentan distribuciones espaciales de especies con distribución continua en un hábitat.

Las características de la estructura de intercorrelación espacial de la variable aleatoria para los tres tipos de kriging, fueron determinadas por la función de semivariograma (Materon 1963) expresada como:

$$\gamma(h) = \frac{1}{2|N(h)|} \sum_{N(h)} (Z_i - Z_j)^2$$

Donde:

N(h) = Número total de parejas en las que la distancia euclidiana i – j = h

½N(h)½ = Número de pares distintos en N(h)

Z_i y Z_j = Valores del parámetro en las localidades espaciales i y j

h = Distancia específica

Los algoritmos para determinar el estimador Z* en cada kriging son los siguientes:

Kriging Ordinario

El estimador Z^*_{OK} fue determinado mediante (Verdoy , 2001):

$$Z^*_{OK}(u_O) = \sum_{\alpha=1}^{n(u_O)} \lambda_\alpha^{OK}(u_o) Z(u_\alpha)$$

Condicionado a que:

$$\sum_{\alpha=1}^{n(u_O)} \lambda_\alpha^{OK}(u_O) = 1$$

El sistema de ecuaciones de OK fue determinado por: $n(u_o) + 1$ ecuaciones lineales, $n(u_o)$ pesos l_a^{OK} y el parámetro de Lagrange $L_{ok}(U_o)$ considerado para la determinación de los pesos:

$$\left\{ \begin{array}{l} \sum_{\beta=1}^{n(u_o)} \lambda_\beta^{OK}(u_o) C_R(u_\alpha - u_\beta) + L_{OK}(u_o) = C_R(u_\alpha - u_\beta) \quad \alpha, \beta = 1, \ldots n(u_o) \\ \sum_{\beta=1}^{n(u_o)} \lambda_\beta^{OK}(u_o) = 1 \end{array} \right\}$$

Kriging Universal

El estimador Z^*_{UK} fue definido como una combinación lineal de las $n(u_o)$ variables $Z(u_o)$ y determinado por:

$$Z^*_{UK}(u_o) = \sum_{\alpha=1}^{n(u_o)} \lambda_\alpha^{UK}(u_o) Z(u_\alpha)$$

$$\sum_{\alpha=1}^{n(u_o)} \lambda_\alpha^{UK}(u_o) f_k(u_\alpha) = f_k(u_o) \qquad k = 0, \ldots, K$$

El sistema de ecuaciones a resolver fue:

$$\begin{cases} \sum_{\beta=1}^{N(u_0)} \lambda_\beta^{UK}(u_0) C_R(u_\alpha - u_\beta) + \sum_{k=0}^{K} L_k^{UK}(u_0) f_k(u_0) = C_R(u_\alpha - u_\beta) \quad \alpha,\beta = 1 \ldots N(u_0) \\ \sum_{\beta=1}^{N(u_0)} \lambda_\beta^{UK}(u_0) = 1 \\ \sum_{\beta=1}^{N(u_0)} \lambda_\beta^{UK}(u_0) f_k(u_\beta) = f_k(u_0) \quad k = 0 \ldots K \end{cases}$$

Kriging Bayesiano

El estimador utilizado en el kriging bayesiano se basa en el predictor de mínimos cuadrados, el cual minimiza el error cuadrático medio de la predicción y está definido por (Ribeiro y Diggle, 2001) :

$$Z_0^* = E[Z_0 \mid Z]$$

En la determinación del predictor dentro de los lineamientos bayesianos se consideró un modelo simple definido por:

$$Z(u) = X\beta + \sigma T(u)$$

Para conocer el valor medio se consideró al parámetro b desconocido, por lo que se contó con la función de covarianza, bajo una matriz de la forma $V(\sigma_*^2, f_*) = \sigma_*^2 R(\varphi_*)$, denominada $\sigma_*^2 R$.

La distribución de probabilidad conjunta para (Z, Z_0) está dada por:

$$\left(Z, Z_0 \mid \beta, \sigma_*^2, \phi_*\right) \sim N\left(\begin{bmatrix} X \\ X_0 \end{bmatrix} \beta; \sigma_*^2 \begin{bmatrix} R_z & r \\ r' & R_0 \end{bmatrix}\right)$$

Las correspondientes distribuciones marginal y condicional están dadas por:

$$\left(Z \mid \beta, \sigma_*^2, \phi_*\right) \sim N\left(X\beta; \sigma_*^2 R_z\right)$$

$$\left(Z \mid \beta, \sigma_*^2, \phi_*\right) \sim N\left(X_0\beta + r' R_z^{-1}(z - X\beta); \sigma_*^2\left(R_0 - r' R_z^{-1} r\right)\right)$$

Se consideraron dos diferentes tipos de distribución a priori del parámetro b para determinar la distribución a posteriori de los parámetros del modelo: La distribución conjugada y la uniforme.

Distribución conjugada: Se asumió que la distribución a priori del parámetro media b era Gaussiana de la forma:

$$\left(\beta \mid \sigma_*^2, \phi_*\right) \sim N\left(m_\beta; \sigma_*^2 V_\beta\right)$$

El valor esperado y la varianza de la distribución predictiva tienen la forma:

$$E\left[Z_0 \mid Z\right] = \left(X_0 - r' R_z^{-1} X\right)\left(V_\beta^{-1} + X' R_z^{-1} X\right)^{-1} V_\beta^{-1} m_\beta + \left[r' R_z^{-1} + \left(X_0 - r' R_z^{-1} X\right)\left(V_\beta^{-1} + X' R_z^{-1} X\right)^{-1} X' R_z^{-1}\right] z$$

y

$$Var\left[Z_0 \mid Z\right] = \sigma_*^2 [R_0 - r' R_z^{-1} r + \left(X_0 - r' R_z^{-1} X\right) \left(V_\beta^{-1} + X' R_z^{-1} X\right)^{-1} \left(X_0 - r' R_z^{-1} X\right)]$$

Distribución uniforme: Se asumió que la distribución a priori del parámetro media b era de la forma $p(\beta)\ \alpha\ 1$, y que la distribución a posteriori era:

$$\left(\beta \mid Z, \sigma_*^2, \phi_*\right) \sim N\left(\left(X R_z^{-1} X\right)^{-1} X R_z^{-1} z, \sigma_*^2 \left(X R_z^{-1} X\right)^{-1}\right) \sim N\left(\hat{\beta}, \sigma_*^2 V_{\hat{\beta}}\right)$$

El valor esperado y la varianza de la distribución predictiva para una distribución uniforme a priori puede obtenerse a partir del valor esperado y la varianza de la distribución conjugada con $V_b^{-1} \circ 0$, tomando la forma:

$$E\left[Z_0 \mid Z\right] = \left(X_0 - r' R_z^{-1} X\right)\hat{\beta} + r' R_z^{-1} z$$

y

$$Var\left[Z_0 \mid Z\right] = \sigma_*^2 \left[R_0 - r' R_z^{-1} r + \left(X_0 - r' R_z^{-1} X\right)\left(X' R_z^{-1} X\right)^{-1}\left(X_0 - r' R_z^{-1} X\right)'\right]$$

La distribución *a posteriori* para el parámetro *b* conocido puede obtenerse a partir del valor esperado y la varianza de la distribución conjugada con las siguientes consideraciones:

Transformación de datos

Para garantizar la gaussianidad de los datos, se utilizó la transformación Box-Cox sugerida por Christensen y coautores (2001), en la que se considera que los valores observados de *Z* en las localizaciones *X* son una realización de: $Z(x_1)$, $Z(x_2)$, . . . , $Z(x_n)$, en la cual $\{Z(x) \hat{o} x \hat{I} I\}$, $I \acute{I} R^2$, siendo este el campo aleatorio de interés. La transformación Box-Cox es indexada por *l* y se determinó mediante:

$$g\lambda(Z) = \begin{cases} \left(Z^{\lambda} - 1\right) / \lambda & si \ \lambda \neq 0, \\ \log\left(Z\right) & si \ \lambda = 0. \end{cases}$$

Particularmente para $l \, ^3 \, 0$ consideramos que:

$$Z(x) = \begin{cases} g\lambda^{-1}\left(S(x)\right) & si \ S(x) \in g\lambda\left(0 ; \infty\right) \\ 0 & otherwise \end{cases}$$

Donde $\{S(x) \hat{o} x \hat{I} I\}$ = un campo aleatorio gaussiano con media $m(x) = d(x)^T b$ y covarianza $Cov[S(x), S(x')] = C(x,x')$, $d(x)^T$ = vector de covarianzas asociadas con la localidad *X* y *b* = vector de parámetros de regresión.

Validación de los Modelos

En la validación de los modelos obtenidos se utilizó la técnica de validación cruzada, la cual determina si los errores del kriging son sistemáticos o compatibles con la varianza de estimación. La técnica es un proceso iterativo en el que se elimina un dato real para posteriormente estimarlo a partir del resto de los datos, cada uno de los datos reales y estimados se comparan mediante regresión lineal para determinar el nivel de error.

Los modelos de las tres modalidades de kriging obtenidos en cada uno de los dos muestreos, se conformaron en un sistema de información geográfica para su comparación. Los modelos kriging se compararon entre si en cada uno de los muestreos, mediante sobreposición se obtuvo la diferencia de la distribución espacial intermuestral, esta diferencia se comparó entre las modalidades del kriging.

El análisis geoestadístico se realizó utilizando los siguientes softwares: En el análisis de semivariograma GS$^+$ Geostatistics 3.2 (Gamma Desing Software 1998); en la obtención y validación de los kriging S-Plus 2000 (MathSoft, Inc. 2000a) con los módulos S+spatilStats (MathSoft, Inc. 2000b) para los krigings ordinario y universal, y GeoS en el kriging bayesiano (Ribeiro y Diggle,1999); la edición de los modelos con SURFFER 7.0 (Golden Software Inc. 1999).

En la determinación del modelo óptimo se consideraron los valores de validación geoestadística (los parámetros del semivariograma y de la validación cruzada), las observaciones *in situ* sobre la distribución espacial de las especies y la conformación espacial de las especies que se han reportado en el Caribe Mexicano. La zona de estudio es un área entre barreras arrecifales, por lo que tiene especies de escleratíneos y gorgonáceos que no conforman un arrecife desarrollado, la distribución de especies presentó un gradiente de aumento en el número de especies con la profundidad hasta los 15 m, las algas fue el grupo dominante con una distribución uniforme, los gorgonáceos y las esponjas tienen una distribución dispersa en toda el área y los escleratíneos se distribuyeron en pequeños parches dispersos (Jordan 1979, 1992, Chavez 1996, Torruco y González 1996).

RESULTADOS Y DISCUSIÓN

Los modelos para OK y UK se obtuvieron con los datos sin transformar, en el BK los datos fueron transformados, por lo que se volvió a aplicar el análisis de semivariograma a los datos transformados; así mismo, se compararon los parámetros del semivariograma en el OK y UK con los del BK.

Los parámetros del semivariograma en los modelos kriging se presentan en la Tabla 1. Los valores de nugget, relación nugget-sill (NSR) y proporción de estructura espacial (PSS); indican que los datos obtenidos en los muestreos son representativos de las variaciones espaciales del número de especies bentónicas y que es el componente espacial el que explica la variación muestral. En junio de 1999, se observó una mayor NSR y una menor PSS, lo que indica que en este muestreo hay factores que influyen en la dinámica de la comunidad bentónica que no están siendo reflejados en el componente espacial.

Tabla 1. El análisis de Semivariogram del número de especies bénticas durante may/96 y june/99 para diversas clases kriging, todos los modelos del variogram son anisotropic (90°) y exponenciales a excepción del kriging bayesian de june/99 que es esférico. NSR = relación Nugget-Sill, PSS = Proportion de la estructura espacial, R^2 = coeficiente de la regression, RSS = reducion de la suma de los cuadrados.

	Ordinary & Universal Kriging		Bayesian Kriging	
	May/96	June/99	May/96	June/99
Nugget	0.010	18.400	0.001	0.631
Sill	82.867	131.539	2.813	5.523
NSR	0.012	13.99	0.035	11.42
Range	1512.300	3147	1398	3080
PSS	1	0.860	1	0.886
R^2	0.663	0.800	0.661	0.636
RSS	9256	10953	8.954	23.79

Los valores del coeficiente de regresión para los modelos BK fueron menores en ambos muestreos en especial en junio/99, mientras que los residuales fueron marcadamente menores en ambos muestreos. Al aalizar los coeficientes de regresión y sus residuales, consideramos que los modelos de BK tienen un menor ajuste al variograma de los datos, aunque este ajuste es más confiable.

El análisis de validación cruzada (Tabla 2) reportó una alta confiabilidad en las predicciones de los modelos y un bajo error predictivo en los modelos de los tres tipos de kriging. El menor error de predicción para ambos muestreos se observó en los modelos de BK, mientras que en ambos muestreos el mayor error se presentó en OK. Los modelos de distribución espacial del número de especies bentónicas para los tres tipos de kriging, con su gráfico de error asociado, se presentan en la Figura 2. En mayo de 1996 se registró un máximo de 30 especies por metro cuadrado y un mínimo de 10, en Junio de 1999 se registró un máximo de 24 especies por metro cuadrado y un mínimo de cero.

Los modelos obtenidos en los tres tipos de kigring presentan el mismo patrón general de distribución espacial durante los dos muestreos, siendo muy semejantes los modelos de OK y UK en ambos muestreos, se diferenciaron solo en la amplitud de algunos de sus parches. La diferencia espacial entre modelos se observa en la Figura 3.

Tabla 2. Validación cruzada del modelo kriging. RC = el coeficiente de la regresión, SE = error estándar, SN = número de especies.

	Ordinary Kriging		Universal Kriging		Bayesian Kriging	
	May/96	June/99	May/96	June/99	May/96	June/99
RC	1.004	1.007	0.999	1.003	1.027	0.999
SE	0.019	0.043	0.018	0.027	0.021	0.001
Y Intercept	-0.046	-0.058	0.009	-0.039	-0.411	0.010
SE	1.372	2.724	1.044	1.783	0.553	0.091
Prediction SN	11 - 36	0 – 25	11 - 36	0 – 25	11 - 36	0 – 25

En mayo de 1996 el patrón general de distribución espacial del número de especies registró un parche central con orientación perpendicular a la línea de costa, a partir del cual se inició un incremento en el número de especies, observándose la mayor concentración por metro cuadrado en el extremo noroeste próximo a la línea de costa. Los modelos de OK y UK presentaron la máxima similitud entre modelos (88.56%), con el mismo rango de especies (de 10 a 30), así como con el mismo número de parches (11) e igual clase de parches. Los gráficos de error asociado de OK y UK presentaron alta similitud, con un rango de ± 4 especies por metro cuadrado, un parche central de error cero, una subvaloración del número de especies en la zona más alejada de la costa y una sobre valoración en la parte cercana a la costa.

La diferencia en mayo de 1996 entre el modelo BK y los otros modelos, se caracterizó por considerar un rango menor de especies (10 – 18), por lo que muchas observaciones que se registraron en los muestreos, no se ven reflejadas en el modelo BK. La similitud de BK con OK fue del 84.61% y con UK fue del 79.46%, su gráfico de distribución de errores asociados presentó una orientación perpendicular a la línea de costa, con un parche central (error de –1) y parches a su costado con error cero, en el extremo suroeste se observa un pequeño parche de error 1.

En junio de 1999, el patrón general de distribución espacial del número de especies, registró un gradiente de aumento en el número de especies por metro cuadrado, del extremo noroeste próximo a la línea de costa al extremo sureste distante a la línea de costa. La similitud entre modelos en este muestreo es marcadamente menor que en mayo de 1996, la mayor similitud se registró entre OK y UK con el 63.18% y la menor entre BK y UK con el 48.72%, en tanto que la similitud entre OK y BK fue del 50.44%.

Al igual que en mayo del 1996, los modelos de OK y UK presentaron pequeñas variaciones en el tamaño de los parches, el patrón general registró el mismo rango de especies por metro cuadrado (0 – 24), el mismo número de parches y de tipos de clases de parches. Sus gráficos de error asociado presentaron un patrón de distribución de error semejante, con un rango de –4 a 4, siendo el parche con error cero el parche principal. Ambos modelos sobre valoran el número de especies en la zona central del área de estudio (parte profunda del canal de navegación a Puerto CALICA) y lo subvaloran en la parte norte.

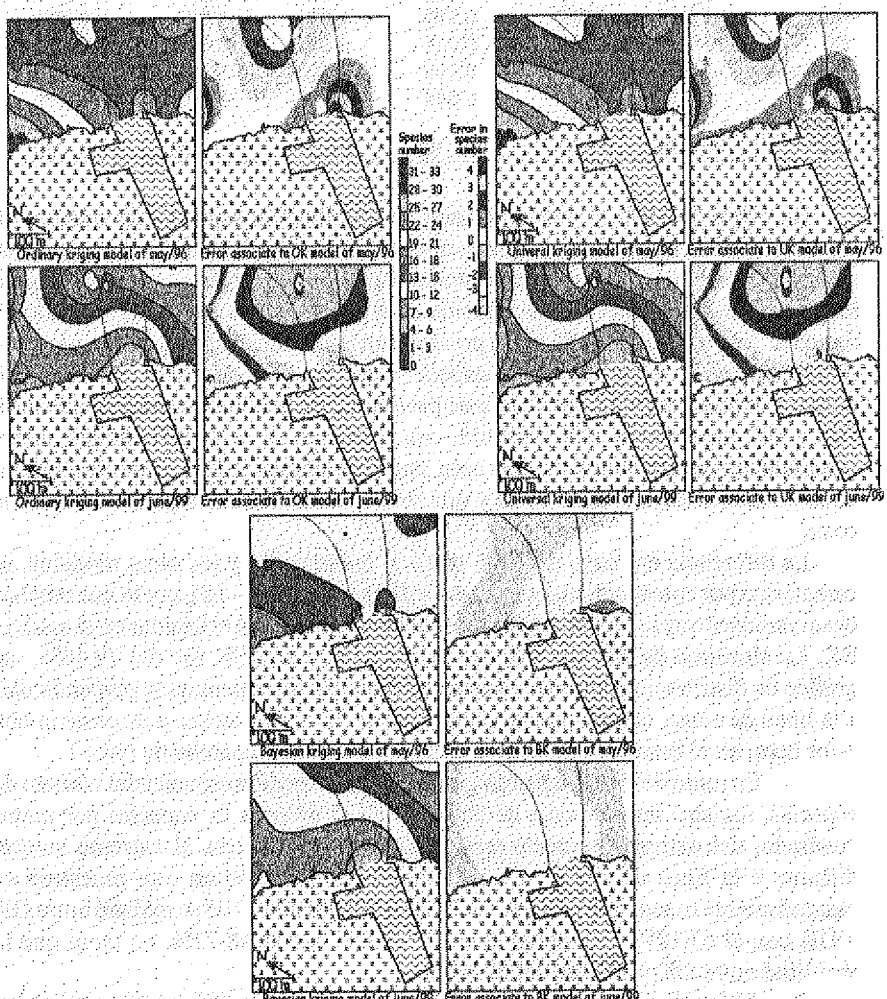


Figura 2. Modelos de Kriging y el error asociado durante may/1996 y june/1999.

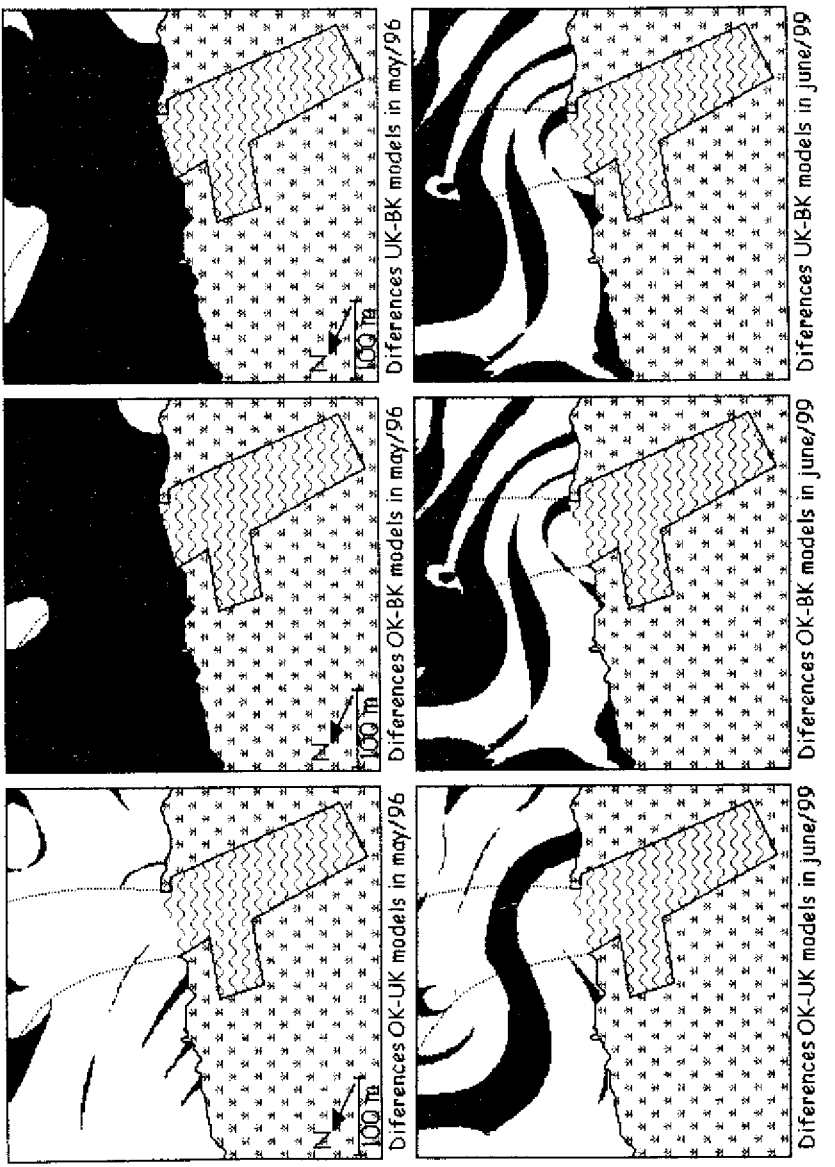


Figura 3. Las diferencias entre los modelos kriging durante may/1996 y june/1999.

El modelo de BK mostró el mismo patrón general de distribución del número de especies, pero al igual que en mayo de 1999, el rango de especies que se consideró fue más reducido (10 – 18), por lo que nuevamente los valores extremos (de 0 - 9 y de 19 - 24 especies por metro cuadrado) registrados en los muestreos no se ven reflejados en el modelo. El grafico de error asociado reportó error cero en la mayor parte del área con zonas de subvaloración al costado del canal de navegación.

Las variaciones de los modelos de la distribución espacial del número de especies en el tiempo, se observan en la Figura 4 y sus valores se presentan en la Tabla 3.

Tabla 3. El porcentaje de variación del número de especies por unidad de área para cada modelo kriging entre may/96 y june/99.

	Ordinary Kriging	Universal Kriging	Bayesian Kriging
Decrease	54.56	55.39	39.65
Unchanged	19.84	18.10	29.97
Increase	25.59	25.50	30.37
Total Variation	80.15	80.89	60.02

La variación entre los muestreos presentó el mismo patrón general de distribución en los tres krigings, con un parche sin variación que cruza el área de estudio del extremo suroeste al noreste, al norte disminuyeron el número de especies y al sur se incrementaron, la máxima variación correspondió a zonas con disminución en el número de especies y la menor variación, al área sin cambio.

Las diferencias entre las variaciones en el tiempo de los tres modelos de kriging fueron causadas por el área que no tuvo variación, siendo menor la diferencia entre los modelos OK y UK y mayor entre BK y UK.

CONCLUSIONES

Los modelos obtenidos por los tres tipos de kriging presentaron una alta confiabilidad como descriptores de la estructura espacial de los datos, comportándose igual en ambos muestreos. Los parámetro obtenidos indican que los modelos OK y UK fueron más descriptivos que BK, pero BK fue más confiable.

Como estimador de datos, los tres modelos son óptimos, teniendo diferencias marginales entre si. En relación a los errores de predicción, el modelo BK tuvo el menor error y el OK el más alto.

Las interpolaciones en los modelos OK y UK presentaron poca diferencia y es representativa de todos los valores registrados en el muestreo, BK difiere notablemente de los otros dos modelos, siendo mayor sus diferencia con OK. La interpolación de BK fue muy limitada y no representó todos los datos obtenidos en los muestreos, tendiendo a ignorar los valores extremos.

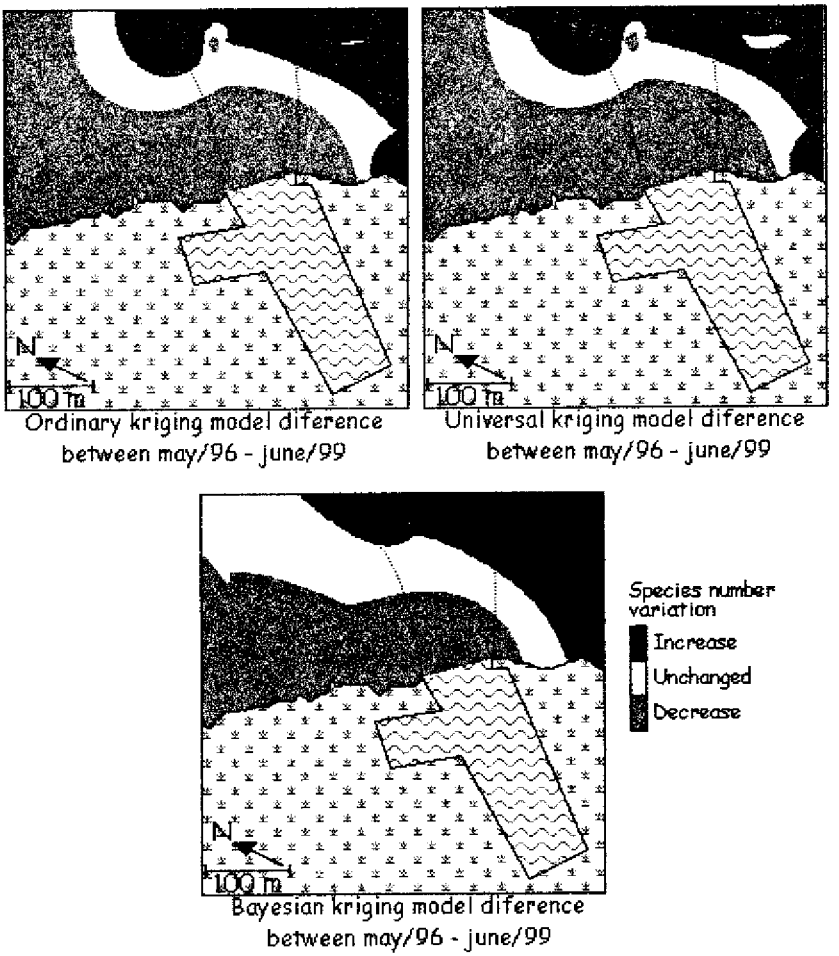


Figura 4. Variación espacial temporal del número de especies bénticas para cada modelo kriging

Considerando sus características como descriptor de la estructura espacial de los datos y su capacidad como estimador e interpolador, el UK fue el modelo que mejor representó el comportamiento espacial de los datos muestrales.

En relación a la variación espacial del número de especies bentónicas en el tiempo, con los tres modelos se concluye que en el área hay una notoria disminución en el número de especies por metro cuadrado, en especial en la zona norte próxima a la línea de costa, lo que puede reflejar el efecto del canal de navegación y de las corrientes dominantes en la zona.

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Scaling Our Understanding of Habitat Selection by Coral Reef Fishery Species

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ABSTRACT

Our ability to quantify habitat use by a managed species improves our capabilities to discern the species' biological needs, predict effects of environmental changes, test hypotheses concerning ecological relationships, or support protection of key habitats. The white grunt, *Haemulon plumieri*, is an important component of commercial, recreational and artisanal fisheries in the Caribbean and Gulf of Mexico. Broad scale surveys for white grunt in southwestern Puerto Rico, identified biotic and abiotic characteristics of coral reefs and reef associated habitats reflective of size-specific habitat requirements, producing a qualitative picture of habitat selections. Subsequent side scan sonar, transect sampling, and GIS mapping of the same area defined the full extent of positive and negative associations for the white grunt as well as other species. Comparisons of the qualitative and quantitative methods can define future directions for evaluating habitat use by coral reef species and selecting appropriate scales for ecological experimentation.

RESUMEN

Nuestra habilidad de cuantificar el uso de hábitat de una especie controlada mejora nuestra habilidad de percibir los requerimientos biológicos de la especie, pronosticar los efectos de los cambios del hábitat, justificar la protección de zonas clave, o probar hipótesis de procesos ecológicos. El roncador (*Haemulon plumieri*) es un componente de importancia comercial, de forma recreativa y artesanal de la pesquería del Caribe y el Golfo de Méjico. Estudios a grande escala del roncador, *H. plumieri*, en el sureste de Puerto Rico, identifican características bióticas y abióticas de los arrecifes de corales y hábitats asociados con los arrecifes que reflejan los requerimientos de hábitats de un tamaño concreto, produciendo una idea cualitativa de la selección de hábitats. Con el uso del sonar, muestras de transectos, y mapas de GIS de la misma zona, definieron la extensión de asociaciones positivas y negativas para el roncador y otras especies. Las comparaciones de métodos cuantitativos y cualitativos pueden definir la dirección futura de evaluación de hábitat que las especies de arrecifes usan y la selección de escalas apropiadas para la experimentación ecológica.

KEY WORDS: *Haemulon*, marine habitats, coral reefs, marine reserves

INTRODUCTION

Coral reef organisms exist in environments that are spatially structured from global to local scales. At the largest scale, coral reefs exist where environmental conditions are appropriate for the diverse communities of interacting organisms that produce and maintain reef structures. Locally, physiographic zonation (a shift in species, assemblages, or communities in response to changes in physical properties of the environment) was one of the early focuses of ecologists in their investigations of coral reefs (Hiatt and Strasburg 1960) and has been documented in the heterogeneous distributions of stony corals (Done 1982, Glynn 1976), reef fishes (Williams 1982, Williams and Hatcher 1983, McGehee 1994), and soft corals (Dinesen 1983).

The effects of habitat heterogeneity or patchiness on reef fish distributions depend largely on the species' life history traits and may occur at settlement or after. Some strongly site-attached species (e.g., some blenniids) are restricted to particular zones of the reef throughout their entire life cycle (Clarke 1996) while many other reef fishes (e.g., acanthurids, jacks, and grunts) have home ranges that encompass different reef zones and/or adjacent habitats (Ehrlich 1975, Ogden 1977, Sale 1980). A number of reef species, utilize a succession of habitats as their resource needs change ontogenetically (Lirman 1994, Eggleston 1995, Appeldoorn et al. 1997, Lindeman 1997, Nagelkerken et al. 2000).

The effects of habitat distribution on fish abundances and distributions are of practical importance for fishery managers, particularly in tropical reef fisheries. Conventional fishery management methods are data intensive; in most tropical settings the infrastructure for data collection is lacking (Pauly 1979). Fishery management can be augmented through enhanced conservation of essential fish habitat (EFH) and the establishment of marine reserves (Roberts and Polunin 1991, Bohnsack 1996, 1998). EFH is defined in the Magnuson-Stevens Fishery Conservation and Management Act (1996) as *those waters and substrate necessary to fish for feeding breeding, spawning and growth to maturity* (16 U.S.C. §§1801 *et seq*). Under US federal fishery management regulations, EFH must be described and identified for all managed species; and, fishery management councils and the National Marine Fisheries Service must conserve EFH. Marine reserves (no-take zones) can effectively increase abundance and size of heavily fished species in tropical settings (Roberts and Polunin 1993, Russ and Alcala 1996). They are, in theory, simple to develop and enforce. The effectiveness of management, as evidenced by changes in population or community structures, can be monitored non-destructively using an appropriate permutation of the various visual census methods available (PDT 1990, Bohnsack 1996, Appeldoorn 1998). Knowledge of habitat use and dependence can contribute to the design and placement of effective marine reserves (Appeldoorn et al.1997, Recksiek and Appeldoorn 1998, Chiappone

and Sullivan Sealey 2000) and is necessary to meet the EFH mandates of US federal fishery regulations..

This paper compares three complementary approaches for assessing habitat use by reef fishery species. The first used broad scale surveys of nearshore habitats to locate common haemulid habitats and identify characteristics that distinguish juvenile white grunt habitats from those of other species. The second used a stratified transect sampling procedure and *in situ* habitat mapping to document use of habitats by all species. The third used systematic benthic mapping and habitat characterization produced by side scan sonar. The objective in comparing the approaches is to delineate the range of information and advantage of each approach and suggests ways they complement one another in assessing habitat use by fish.

METHODS

Site Description

This research was conducted offshore of La Parguera on the southwest coast of Puerto Rico. The coastal waters of La Parguera support artisanal and recreational fisheries that catch resident and transient reef fish, conch, and spiny lobster from coral reefs and reef-associated habitats. The coastline surrounding La Parguera is, or was historically, lined with mangroves and is protected by a series of coral reef platforms (Figure 1).

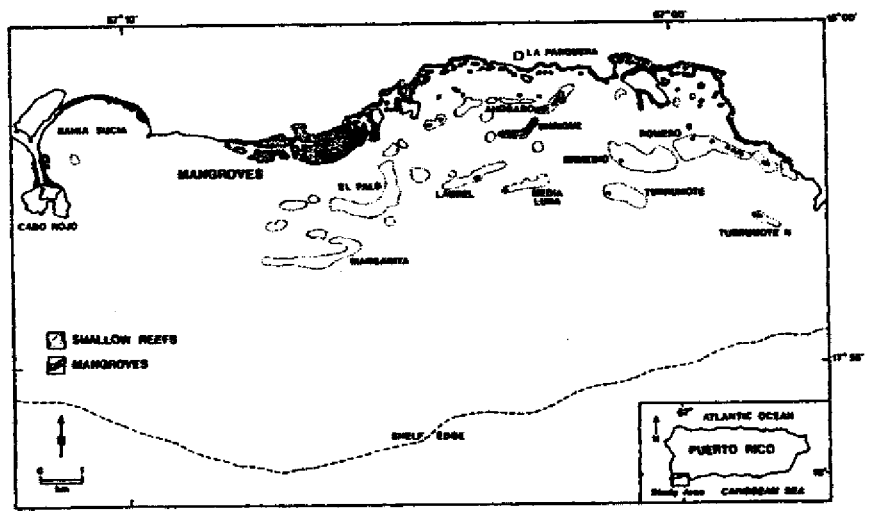


Figure 1. Study area: La Parguera coral reef ecosystem showing mangrove-lined shoreline and series of reef lines extending offshore.

An inner platform of intermittent emergent or near emergent reefs borders and parallels the shoreline. Several reef crests have been colonized by red mangroves (*Rhizophora mangle*) providing additional fish habitat in the prop roots. Backreef areas are typically sand bottom with mixed seagrasses and small patch reefs, soft coral fields, and/or isolated hard corals. A second, mid-shelf line of reefs, about 1 km offshore, and the outer-shelf reefs, about 3 km offshore (e.g., Media Luna and Turrumote), both have a mix of habitats similar to the inner reef line. A fourth line of submerged reefs occurs at the edge of the insular shelf, up to 8 km offshore. These shelf-edge reefs rise to a depth of approximately 15 - 20 m below the surface, mainly with typical spur and groove configuration. Since they are not emergent, they do not offer the same sheltering effects as the three inshore reef lines. Deeper areas (~20 - 40 m) between the shelf-edge, outer, and inner reefs offer additional habitats (e.g., algal flats, deep patch reefs) not found in the shallower strata.

Habitat Surveys

Single-taxa search — The taxa-based approach focused on assessing habitat use by the white grunt, *Haemulon plumieri* and other sympatric haemulid species (Hill 2001). The goal was to locate schooling sites and identify habitat characteristics, specific to particular species or size classes of grunts, that would reliably predict haemulid schooling sites. Shallow water habitats off La Parguera were surveyed from 1993 to 1996. Sites from Cayo Romero (east of La Parguera) to Isla Margarita (the westernmost reef platform off La Parguera) were surveyed (Figure 1) while snorkeling or SCUBA diving. The surveys encompassed lengthy swims searching all habitats, including seagrass beds, sand areas, and mangrove prop roots and circumnavigating coral reefs. Surveys were conducted opportunistically across all four reef lines. Locations and physical characteristics (i.e., depth, location, and type) of schooling sites, total numbers in schools of haemulids, species composition, and estimates of range and mean size were recorded on underwater paper or slates. More detailed methods and results are presented by Hill (2001).

Cross-shelf Habitat Matrix (Stratified Habitat-Faunal Sampling) — Local knowledge, including information gathered during the single-taxa searches, was used to develop a matrix, based on distance from shore, depth, wind and wave energy, and habitat types, to organize habitat-species associations. The cross-shelf habitat (CSH) classification system, based on the principles of Lindeman (1997) but modified to fit the local conditions, was reported in Appeldoorn et al (2001b). The shelf was divided into three primary physiographic regimes (Inner Shelf, Intermediate Shelf and Outer Shelf) and each regime was partitioned into geomorphic zones (e.g., Windward Shallow, Channel Axis, etc.) (Figure 2). Twenty habitat types were identified within four categories, using the terminology of Lindeman (1997): 1) trees, 2) grasses & algae, 3) sediments, and 4) hardbottom & invertebrates. The habitat types were cross-referenced to the geomorphic zones, forming a matrix for graphic depiction, data organization and analysis.

Representative physiographic zones were selected for replicate sampling. Transects (24 x 4 m) were marked by a measuring tape and contiguous 1 m^2 quadrats were mapped *in situ*. Maps identified dominant habitat type (from the CSH list) of each quadrat and structural features. Mapping was followed by visual census of selected fish species, chosen for their fishery or ecological importance. These fish data were spatially defined by points (single fish), polygons (fish schools), or lines (roaming species). All mapping and census data were transferred to a geographical information system (GIS) for data management and analysis. The GIS provides for spatial analysis of habitats and faunal assemblages. More detailed methods are contained in Recksiek et al. (2001) and Appeldoorn et al. (2001b).

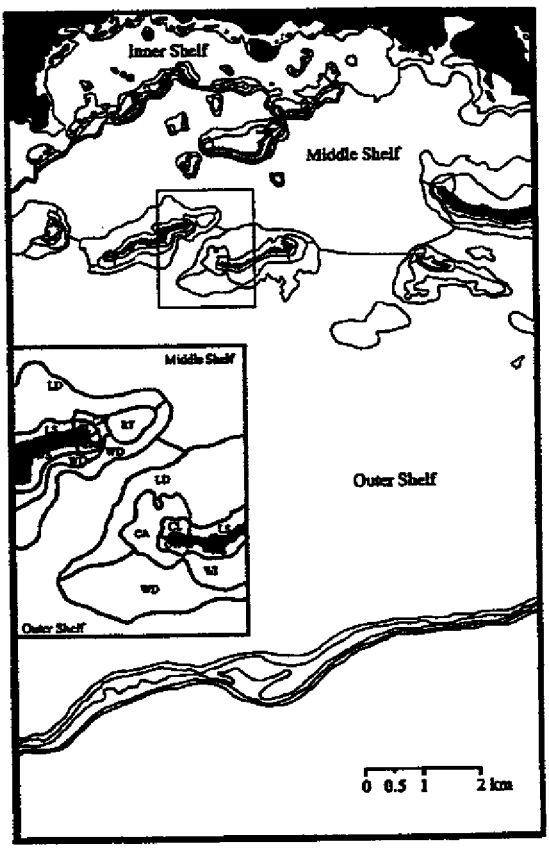


Figure 2. Cross-shelf Habitat (CSH) Matrix Space Example. Physiographic regimes (e.g., Middle Shelf, Outer Shelf) are defined by cross-shelf position, e.g., distance from shore. Geomorphic zones (e.g., LD = Leeward Deep; CA = Channel Axis) combine geomorphic structure, depth, position relative to wind and wave energies, and other morphological differences. Habitats, as sampled, are defined within geomorphic zones (modified from Appeldoorn et al. 2001b)

Benthic Mapping and Systematic Sampling — A 22-ft. fiberglass boat with a bow cabin was used to deploy the Side Scan Sonar (SSS) and navigation system (Details of the SSS equipment set-up can be found in Appeldoorn et al. 2001a). A 300-kHz transducer (fish) was towed 3-5 m off the bottom over a 100-m wide swath. Connections between a differentially-corrected Geographic Positioning System (GPS) and the SSS image acquisition software provided geo-referencing for the SSS images as they were collected. All data were recorded to hard disk.

In post-processing image analysis, filters were used to improve the quality of single images (Appeldoorn et al. 2001a). Single images were merged to form large mosaics using GIS software. Generated mosaics were visually interpreted based on variations in the sonar echo return signals; and, polygons, with similar echo return texture, were defined. Polygons were then related to habitat types based on interpreter experience and groundtruthing information. Groundtruthing, using divers or a tethered black and white underwater video camera, was used to check the accuracy of the interpretation and to revise the delineation of the different polygons on the mosaic. Ground truthing by divers was particularly important to get a general perception of habitat areas. Mosaics joined into GIS maps provide a well organized means to extrapolate transect, point counts, or gear sampling across the mapped area.

RESULTS AND DISCUSSION

Studies have shown that in spite of a broad appearance of overlap in general habitat use (e.g., seagrass bed, type of reef) there is a great deal of specificity demonstrated by the distributions of coral reef fishes (Sweatman 1983, Shulman 1985, Booth 1992, Buchheim and Hixon 1992, Eggleston 1995, Appeldoorn et al. 1997, Hill 2001). While each of the three methods described here offers a different framework for sampling and different levels of qualitative to quantitative investigation, the methods are complementary and can lead to the same observations. The interpretations or analyses of the findings however are quite different.

Single-taxa Search

Using the single-taxa search approach, schools of grunts were found throughout the La Parguera reef ecosystem in almost all habitat types (Hill 2001). The only habitat types consistently lacking in grunts were muddy bay bottom areas, such as Bahia Fosforescente and other mangrove-lined bays, where no grunts were found. Eight species of haemulids were found (*Haemulon aurolineatum, H. carbonarium, H. chrysargyreum, H. flavolineatum, H. macrostomum, H. parra, H. plumieri, H. sciurus*). Generally schools were mixed, containing more than one haemulid species; although, usually one species was numerically dominant. In many cases, species with similar appearances (e.g., goat fish or juvenile snappers) were mixed into the grunt schools. Schools were generally well matched in appearance and size of individuals. Dominance in the schools could generally be linked to different habitat

types or characteristics.

A number of spatial patterns were observed. For example, schools of juvenile grunts, while prevalent on the intermediate and outer reefs, are essentially lacking on the outermost, shelf-edge reefs. On these deeper offshore reefs, adults of several haemulid species (e.g., white, French, bluestriped, Spanish) can be found, mostly as solitary individuals; although, white grunts are sometimes in pairs or small groups. Adult white, French, and bluestriped grunts are also common on the deeper forereefs of the mid-shelf and inner-shelf reefs in areas with high relief. On the submerged mid-shelf and inner reef lines (e.g., Ahogado), white grunt adults are frequently seen at the top of the forereef, but upon approach, they flee down the reef face to the base of the reef (Hill 2001).

The distribution of white grunts and sympatric species around the inner shelf reef of San Cristobál illustrates differences in species' distributions. Subadult and adult white, French and bluestriped grunts are frequently found on the forereef of San Cristobál. Schools of medium sized juveniles can also be found, typically located at the ends of the forereef near the channels running along each end of the reef. In the backreef, a sand lagoon with scattered hard and soft coral colonies is the dominant habitat. Dense *Acropora cervicornis* thickets mark the northern boundary of the lagoon and a medium to high relief reef line drops into a deeper sand channel on the southern side separating the lagoon from an adjacent reef. Within the lagoon, small coral colonies are scattered; these structures are frequently populated with small-sized juvenile grunts. They are typically dominated by French grunts with fewer white grunts (Figure 3). Within the *A. cervicornis* thickets, schools of larger juveniles, dominated by white grunts are found. In the deeper sand channel colonies of *A. cervicornis* are common; but, these colonies typically support schools of small-sized tomtates mixed with French grunts. Although these habitats might all be called "*A. cervicornis* in sand," the differences in depth (lagoon vs channel) and branch density or water flow (single colonies vs thickets) seem to be reflected in their use by different species and different size classes. The differences in the size frequency distributions are consistent through time and can be seen across the La Parguera coral reef ecosystem in similar habitats.

CSH/Stratified Transect Approach

At this time 67 transects have been completed, distributed in 7 geomorphic zones and 18 different habitat types. A total of 13,582 individuals and 40 taxa (36 identified to species) belonging to 10 families were censussed (Recksiek, et al. 2001). Three taxa comprised 65% of the total fish abundance among all cross-shelf habitats combined: striped parrotfish, French grunt and redtail/yellowtail parrotfish (the later two grouped as indistinguishable). Seven haemulid species were identified. *H. aurolineatum*, recorded during the single-taxa searches, has not been encountered during the transect surveys. Size estimates (Total Length) ranged from one (1) cm to thirty (30) cm covering the range from early juveniles to adults. The French grunt (*H. flavolineatum*) size class distributions and densities are plotted in a subset of cross-shelf habitats for comparison with other sampling methods (Figure 4).

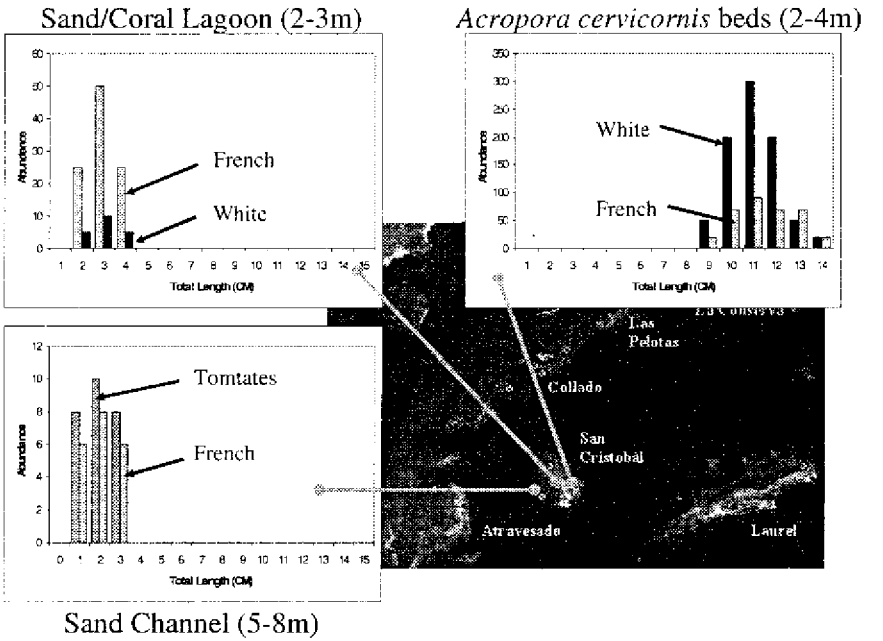


Figure 3. Grunt schools recorded at San Cristobál reef: in the main part of the sand lagoon (Sand/Coral Lagoon), in the *A. cervicornis* thickets on the north of the lagoon (*Acropora cervicornis* beds), and in the *A. cervicornis* colonies found in the channel to the south of the lagoon (Sand Channel). Species dominance and size frequencies vary with depth, position in lagoon, and density of coral colonies.

Using this stratified sampling system, it can be demonstrated that species' densities within habitat types vary according to cross-shelf position (Recksiek et al. 2001) and that densities of different life stages vary according to structural habitat types (Figure 4). Early juvenile French grunt were recorded in seagrass and mangrove habitats in three different strata: Intermediate Shelf-Leeward Shallow, Inner Shelf-Leeward Shallow, and Inner Shelf-Windward Inshore. However, mid-sized juveniles and adults were virtually absent from seagrass habitats and noticeably rarer in mangroves. The exception being higher densities of medium sized juveniles in Inner Shelf-Leeward Shallow mangrove habitats (Figure 4b). Adults were found only in shallow coral reef habitats in the Inner Shelf-Windward Intermediate and Inner Shelf-Windward Shallow strata (Figure 4c). Such findings lend correlative support to previous studies indicating ontogenetic migrations and habitat shifts in tropical grunts documented by Appeldoorn et al. (1997) and Brothers and MacFarland (1981).

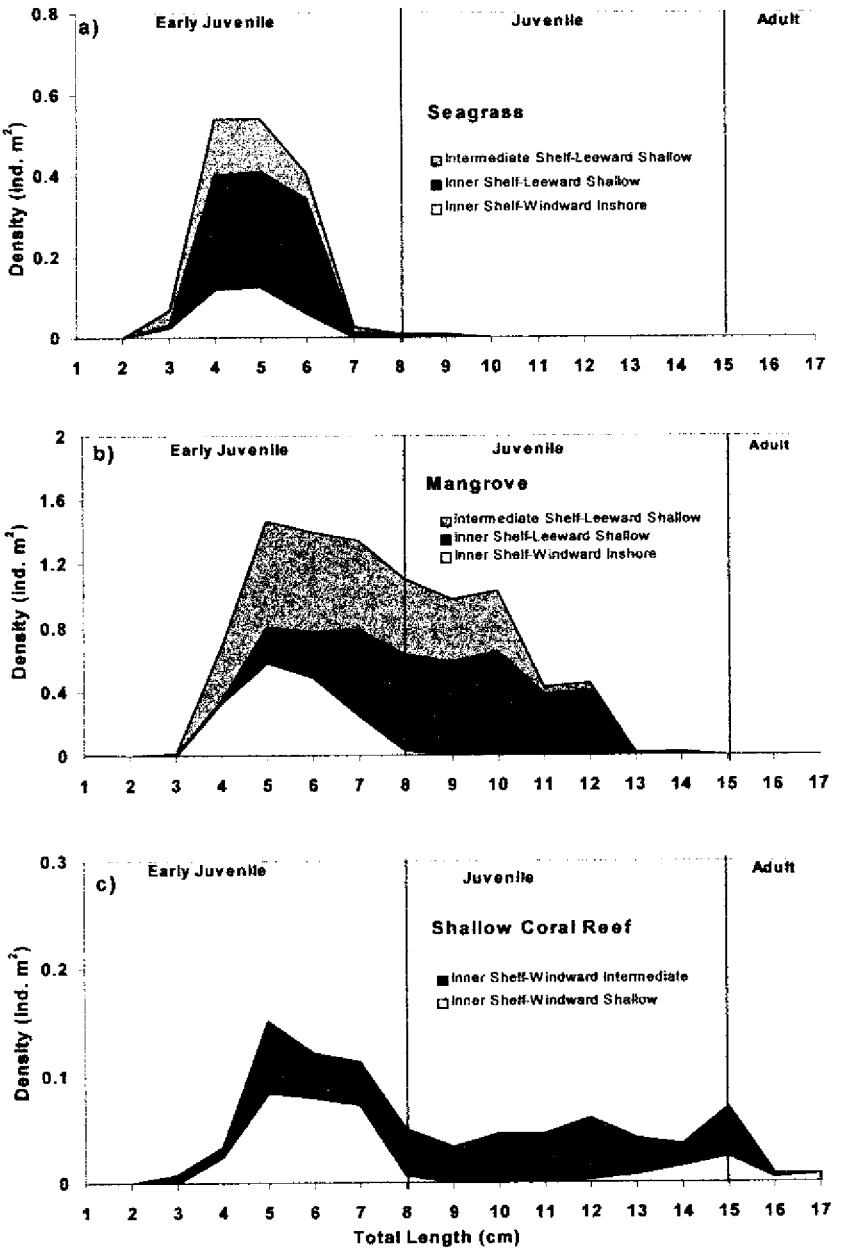


Figure 4. Size distributions of French grunts sampled by CSH-stratified mapped transect method. Habitats located in different cross-shelf strata (defined by physiographic regimes-geomorphic zones) are shown. Differences among habitats and within habitats among strata are evident.

Stratified sampling, based on the CSH matrix, using mapped transects of defined areas allows additional analysis and extrapolations not justified with the single-taxa search and other more qualitative sampling methods. Species diversity measures can be calculated for multiscalar levels (Murphy, MS thesis manuscript), as can habitat diversity measures (Appeldoorn et al. 2001b). Both measures provide ecological information about the system and provide insights into the validity of CSH matrix groupings. Mapped transects and species densities permit fine-scale analysis of habitat-species relationships and more reliable extrapolations to estimate total population sizes within the defined system. All fish species and habitat data is being analyzed for associations, primarily using multidimensional scaling analysis (Murphy manuscript). Future plans include analysis of habitat features for associations of species with particular aspects of the habitats and additional tests of the validity of the habitat matrices and classifications.

SSS Benthic Mapping

The entire area of La Parguera, approximately 442 Nm of SSS transect lines, has been surveyed. The mosaics, 19 in all, are in final processing. Habitat types have been differentiated based on the strength of signal return which varies according to benthic characteristics. Habitat types, including reef platforms, patch reefs, isolated coral heads, mixed coral-gorgonian areas, sandy bottoms, seagrass beds, and algal bottoms, have been mapped and quantified (Appeldoorn et al. 2001a). Reflection sensitivities and resolutions as fine as 10 cm provide sufficient detail to distinguish different densities of algae, ripple marks in sandy bottoms, and fine from coarse sediments. A number of uncharted patch reefs with interesting characteristics, i.e., algal halos, have been located in zones that were previously believed to be soft sand or mud bottoms covered with algae. The identification of unknown habitats and features will allow modification and improvement of the CSH matrix and enable more accurate stratification of sampling effort. A number of sampling efforts are underway that make use of the detailed SSS benthic mapping. Sampling of fish species on previously unknown patch reefs are being compared with similar areas of continuous reef habitat (Prada, PhD dissertation manuscript). The SSS mapping is being used as the basis for spatially-based trophic modeling, focused sampling of species that move diurnally between habitats, and to analyze the spatial distribution of fishing traps. Future studies will find the SSS habitat mapping invaluable for sampling design. A complete mapping of habitats will also allow confident extrapolation from site-specific samples to system-wide estimations of fish populations and length-frequency distributions.

CONCLUSIONS

The single-taxa search method is simple and inexpensive but it is time-consuming and requires intuitive interpretation of field data. It requires accurate understanding of spatial differences in habitats (leeward vs windward vs channel) and relies on assumptions regarding the important characteristics of habitats. In

many cases, its findings of correlations between species and locations or habitats should be considered hypotheses rather than conclusions until they have been tested. Extensive field notes, often recording characteristics and findings that may, at the time, seem of secondary importance, are critical to the ability to reinterpret samples if future conflicts arise.

The CSH-based stratified sampling with *in situ* mapping provides a more organized framework for sampling habitats and fish. It provides a more robust sampling of habitat features and characteristics to link with fish distributions. Density estimates are more reliable for interpretation of habitat importance than abundance or presence/absence data. The data can be analyzed by a number of statistical tests, providing greater support for hypothesized ecological associations. It samples the complete suite of species encountered so analysis of data provides more information needed by fishery managers. The method requires some prior knowledge of the ecosystem and accurate interpretation of the influence of cross shelf position and geomorphology. It requires slightly more advanced technologies (GPS, GIS) and is more time consuming than the single-taxa search method for covering the same areas.

The SSS benthic mapping is presented here as a demonstration of a more complete but more complex method for gathering species-habitat association data. It provides a clearly quantitative means to identify sampling strata and a well-defined framework for gathering, analyzing, interpreting, and extrapolating data. It is more expensive and time-consuming than the other two techniques presented here but it has also pointed out some gaps in our knowledge of habitats in the Parguera system (previously unidentified patch reefs).

While these three sampling methods have been presented as alternatives, it has also been stressed that in this case they were used sequentially, in complementary fashion. The single-taxa search was a means to develop familiarity with the entire ecosystem, quickly learn of habitat types used by different species and life stages, and capture data on species and habitat distributions. This information went into the development of the CSH matrix for La Parguera. The CSH-based transects and mapping of habitat features in fish sampling transects allowed more accurate interpretation of linkages between habitats/habitat features and densities of different fish species and life stages, generating hypotheses for future testing. The SSS benthic mapping provided additional insight into unknown habitats that can be used to correct the CSH matrix and reassess the findings from some benthic sampling. It forms the most complete framework for further ecological sampling. Any of these techniques can be used to document habitat use by managed species, contributing to the data necessary to describe and identify EFH and to identify areas appropriate for marine reserve designations. The choice of methods for future research depends on the goals of the research and on the resources available.

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Preliminary Results from a Study of Reproduction in the Vermilion Snapper (Lutjanidae: *Rhomboplites aurorubens*) from the Eastern U. S. Gulf of Mexico, 1991-2001

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ABSTRACT

Analysis of vermilion snapper (Lutjanidae: *Rhomboplites aurorubens*) spawning and fecundity from the U.S. Gulf of Mexico provided accurate length-specific estimates of fecundity (batch fecundity, frequency of spawning, and annual fecundity) for mature vermilion snapper in order to enhance stock assessment of this species. Fisheries-dependent sampling began off Panama City in northwest Florida (FL) in the northeastern Gulf of Mexico in 1991 and continues with greatly expanded sampling-coverage from off southwest FL to south Texas. Our main fisheries independent sampling began in 2000 and continues with day/night hook and line fishing as a necessity to determine length at first spawning, time of oocyte-hydration, spawning time, and location/depth/temperature of spawning. Maximum oocyte diameter, gonadosomatic index and histology indicate that vermilion snapper mainly spawn from April through September. We found at least 10 probable-spawning sites off west Florida in depths of 30 to 114 m. The smallest female with hydrated oocytes found thus far is 159 mm total length (TL). Most vermilion snapper spawned at approximately 2230 hours: most (90%) hydrated oocytes occurred from 1300 to 2230, with none occurring between 2230 and 0905. Most (91%) new postovulatory follicles occurred from 2230 to 0815, with none occurring between 0815 and 1320. Batch fecundity estimates for 1993 - 1994 ranged from 27,000 to 415,000 for 44 fish from 215 to 375 mm TL, for 2000 were 15,032 to 88,471 for 59 fish from 189 to 288 mm TL, and for 2001 were 7,385 to 377,226 for 20 fish from 159 to 510 mm TL. Average frequency of spawning for 2000 was 93 using the hydrated oocyte method. Average spawning periodicity for 2000 was 1.6 days. Annual fecundity estimates ranged from 1.4 to 8.2 million for 2000 (n = 59) and from 0.7 to 35 million including a few smaller and larger females for 2001 (n = 20), if the same spawning frequency estimate is used for both years.

KEY WORDS: Fecundity, snapper, spawning

RESUMEN

Nosotros estamos estudiando *Rhomboplites aurorubens* (Lutjanidae), el desove y la fecundidad en el Golfo de México de los Estados Unidos. Nuestro objetivo principal es proporcionar estimaciones longitud-específicas exactas de la fecundidad (fecundidad del tratamiento por lotes, frequencia de desove y fecundidad anual) para todas las talles de *R. aurorubens* del Golfo de México para avanzar la evaluacion de poblaciones de esta especie. El muestreo de pescas-dependiente comienzó de la costa de Panama City en Florida (FL) noroeste, en el noreste del Golfo de México en 1991 y continúa con la expansión del muestreo de el sudoeste de Florida al sur de Tejas. Nuestro muestreo principal de pescas independiente comienzó en 2000 y continúa para la pesca con gancho y sedal de día/noche para determinar largo a desove primero, tiempo de huevos hidración, tiempo de desove y posición/profundidad/temperatura de desove. El diámetro máximo del oocyte, el índice gonadosomatic y la histología indican que desove de *R. aurorubens* en el Golfo de México es de abril a septiembre. Encontramos al menos diez sitios probable para desove en la costa de Florida oeste en profundidades de 30 a 114 m. La hembra más pequeña con huevos hidratados encontrados hasta esta tiempo eran 159 mm largo total (TL). La mayoría de *R. aurorubens* desove a aproximadamente 2230 horas; la mayoría (90%) de los huevos hidratos occurrieron entre 1300 y 2230, con nadie ocurriendo entre 2230 y 0905. La mayoría (91%) de los folículos después de ovulación nuevos ocurrieron entre 2230 y 0815, con nadie occuriendo entre 0815 y 1320. Las estimaciones de la fecundidad del tratamiento por lotes para 1993-1994 extendido entre 27,000 y 415,000 para 44 peces de 215 a 375 mm TL; para 2000 fueron de 15,032 a 88,471 para 59 peces de 189 a 288 mm TL; y para 2001 fueron de 7,385 a 377,226 para peces de 159 a 510 mm TL. La frecuencia media de desove en 2000 fue 93 usando el metodo de los huevos hidratados. La desove periodicidad media de desove para 2000 fue 1.6 días. Las estimaciones anuales de fecundidad fluctuaron de 1.4 a 8.2 milliones para 2000 (n = 59) y de 0.7 a 35 milliones para algunas hembras mas pequenas y algunas hembras mas largas de 2001 (n = 20), si la misma frequencia de desove es usado en ambos anos.

INTRODUCTION

The vermilion snapper (Lutjanidae: *Rhomboplites aurorubens*) is a relatively small fish that is important to both recreational and commercial fisheries in many areas along the U.S. southern Atlantic and Gulf of Mexico coasts. Compared to two other larger and more popular Gulf of Mexico species (the red snapper, *Lutjanus campechanus*, and gag, *Mycteroperca microlepis*), the vermilion snapper is usually considered a valuable alternative species due to its normal abundance, catchability, and taste.

The most recent stock assessment of vermilion snapper in the Gulf of Mexico suggests that the species is overfished (Porch and Cass-Calay 2001). A recent study by Hood and Johnson (1999) provided information on age, growth and reproduction including the first published batch fecundity estimates for this species from the Gulf

of Mexico, and they also found that it was probably overfished. A similar study was published on vermilion snapper from the U. S. coast off South Carolina by Cuellar et al. (1996) who made the first published estimates of spawning frequency (35 spawns per year) as well as the first batch fecundity estimates from this area.

Research on reproductive biology of reef fishes is important to assessing stocks, testing management tools, and evaluating habitat. Spawning potential ratios (SPRs) require age-specific fecundity estimates to determine if stocks are overfished. Reproduction studies also help to gauge the success of marine reserves as a management tool. Reef fishes are usually aggregate spawners and little is presently known about the structure and function of those aggregations. The identification of spawning sites also helps to delineate essential fish habitat.

Extensive sampling and study of both age/growth and reproduction from the northern Gulf of Mexico was requested by NMFS. We had previously studied red snapper reproduction and published our results on histology and fecundity estimates from the northeastern, northcentral and northwestern Gulf of Mexico (Collins et al. 1996, and Collins et al. 2001). Samples of snappers from the north-central and northwestern Gulf of Mexico were more difficult to obtain and required the assistance of Gulf samplers from the NMFS Beaufort, NC, Headboat Survey Program.

Our objectives for the reproduction study were threefold:

i) To acquire female vermilion snapper of all possible sizes to be used for estimating fecundity;

ii) To determine spawning period/time-of-day, in order to be able to ensure the best fecundity samples from batch fecundity and spawning frequency estimates, and

iii) To identify vermilion snapper spawning sites using histology and catch location data.

METHODS

Our methods were similar to those in Collins et al. (1999), except that fishery independent field sampling was more intensive during 2000 and 2001. During 2001 we specifically targeted larger (> 300 mm total length, TL) vermilion snapper off Panama City, although we sampled smaller fish that were also caught on our fishery independent trips. We also targeted larger fish from west of Panama City during 2000 and 2001. Large vermilion snapper gonads and otoliths were sampled mainly from recreational headboats out of northwest Florida (FL), Alabama (AL), Louisiana (LA), and Texas (TX). Headboats and charterboats from Panama City, FL, were also sampled. Fishery-independent samples came from NMFS scientific surveys off Panama City, FL, and from research cruises mainly in the eastern Gulf of Mexico.

For each fish sampled in the field, fork length (FL) and TL were first measured to the nearest mm, and total wet weight was usually recorded to the nearest 0.01 kg. Gonads were then removed, placed dry in plastic bags and kept on ice until

processed. A sagittal otolith was also removed from each fish. Samplers from remote areas shipped otoliths and gonads on ice to our lab in Panama City by overnight mail.

In the laboratory, gonad samples on ice were processed as soon as possible. Excess tissue was removed and a small sample of each gonad (ovaries and testes) was examined at 250x to determine preliminary sex and stage of gonad maturation (1-immature/resting; 2-early developing; 3-late developing; 4-ready to spawn or spawning; 5-recently spawned or spawned-out; (West 1990)). The diameter of the largest oocyte (maximum oocyte diameter, MAXOD) found in the small sample was also recorded for each female. We previously ran a two-way analysis of variance that showed that hydrated oocytes were homogeneously distributed in hydrated ovaries. If no oocytes were visible under a microscope and the gonad was not round in cross-section, then the sex was male; male Stages 1-3 were judged from gonad thickness and Stage 4 males had milt when cut. All gonads were then weighed to the nearest 0.1 g before selected samples were placed in 10% buffered formaldehyde solution (formalin, mixed according to Hunter, 1985) inside a sealed plastic bag.

A gonadosomatic index (GSI = 100 X gonad weight/ total weight - gonad weight), the MAXOD, and preliminary gonad stages were used to generally delineate the spawning season, as well as to compare to the final staging from histology. Only female GSIs will be reported in this paper. After at least two weeks in formalin, tissue samples were used for standard histological slides (Fitzhugh et al. 1993) which were then examined at our laboratory in order to record the final sex, gonad-maturation stage, presence of postovulatory follicles (POFs), presence of atresia and quality of preservation. Histological-stages for females were determined by the most-advanced stage of oocyte development found in each fish: 1-primary growth; 2-cortical alveolar; 3-vitellogenic; 4- migratory nucleus; 5- hydrated; 6-at least 50% atretic. Histological-stages for males were: 1-inactive; 2-active, with many secondary spermatocytes; 3-developing, with some spermatids in ducts; 4-ripe, with large pools of spermatozoa in ducts.

Batch fecundity and spawning frequency were estimated using the hydrated oocyte method of Hunter et al. (1985) and Hunter and Macewicz (1985), respectively. Only histological Stage 5 females were used for batch fecundity estimates. We used the length of the smallest hydrated female as a benchmark for selecting fish included in the spawning frequency estimate: only histological Stage 5 females were counted as spawning. Reference to stages from here on refer to histological stage. Batch fecundity was regressed on TL using linear and non-linear models to identify which model best explained the variation in batch fecundity. The spawning frequency estimate was the estimated number of spawns per year by each female and was calculated as: duration of spawning season in days/100% of females/percent of females hydrated.

Possible spawning sites were identified as those locations where at least one female with hydrated oocytes or new POFs was found. Locating these sites required catch-coordinates from fishers.

RESULTS

We sampled a total of 3,234 vermilion snapper (159 - 587 mm TL) between Key West, FL, and Port Aransas, TX, from February 1991 through September 2001. The majority of gonad samples (98.8%) came from the west coast of Florida (Figure 1). Most samples (94.2%) were collected during 1991 - 1994 (60.2%) and 2000-2001 (33.9%). Although commercial and recreational catches were sampled in all years, most samples came from these fisheries during 1991 - 1994. Almost all fishery independent sampling occurred during 2000 and 2001.

Randomly sampled fish were 58.5% female. Sex ratio varied widely at different sampling locations. On one fishery independent sampling trip during August 2001, the first 15 fish caught were males. Typically, however, catches were at least slightly dominated by females.

The spawning season for vermilion snapper from FL to TX in this study was April through September or October, according to GSI (Figure 2, with low GSIs for November and December not shown), MAXOD and histological gonad-stages. Ovaries with hydrated oocytes were usually found from mid-April through mid-September. Results are shown graphically from 2000 and 2001 only, since data from earlier years were very similar to those and we were able to collect more important catch data with gonads from the last two sampling years. Nearly all nighttime sampling was done during 2000 - 2001 along with extensive daytime sampling, both as part of our fishery independent sampling. Data on time of catch was valuable since GSI, MAXOD and histological stage could change appreciably during the few hours before and after spawning. Samples taken right before spawning occurred were the best indicator of gonad-maturation, spawning and fecundity.

At least ten probable-spawning sites were identified from many fully hydrated oocytes in vermilion snapper caught at known fishing locations (Figure 1). Most of these sites were within 40 miles offshore of Panama City in 30 to 60 m where our intensive fishery-independent sampling occurred in 2000 and 2001 (Figure 1). Our 1996 at-sea sampling on commercial boats identified a probable spawning location at a depth of 85 m southwest of Panama City (Figure 1). Headboat dockside-sampling in 2001 found two Stage 5 females caught at a site 60 m deep located 80 miles northwest of St. Petersburg, and commercial fish house sampling in Key West also found a "running-ripe" female (our Stage 5 with fully hydrated oocytes) for which a fishermen provided a catch-location west of the Dry Tortugas (Figure 1). A 2001 at-sea sampling trip on a commercial boat found several fully hydrated females west of Ft. Myers in 114 m at a "spring" (Figure 1). Headboat samplers from just west of Panama City, FL, to AL, LA and TX also found a few large female vermilion snapper that were early hydrated and close to spawning, but apparently the catches were made before spawning was about to occur because oocyte hydration was never full in those fish (most headboat trips occur during daytime hours and many vermilion snapper are caught during the morning hours).

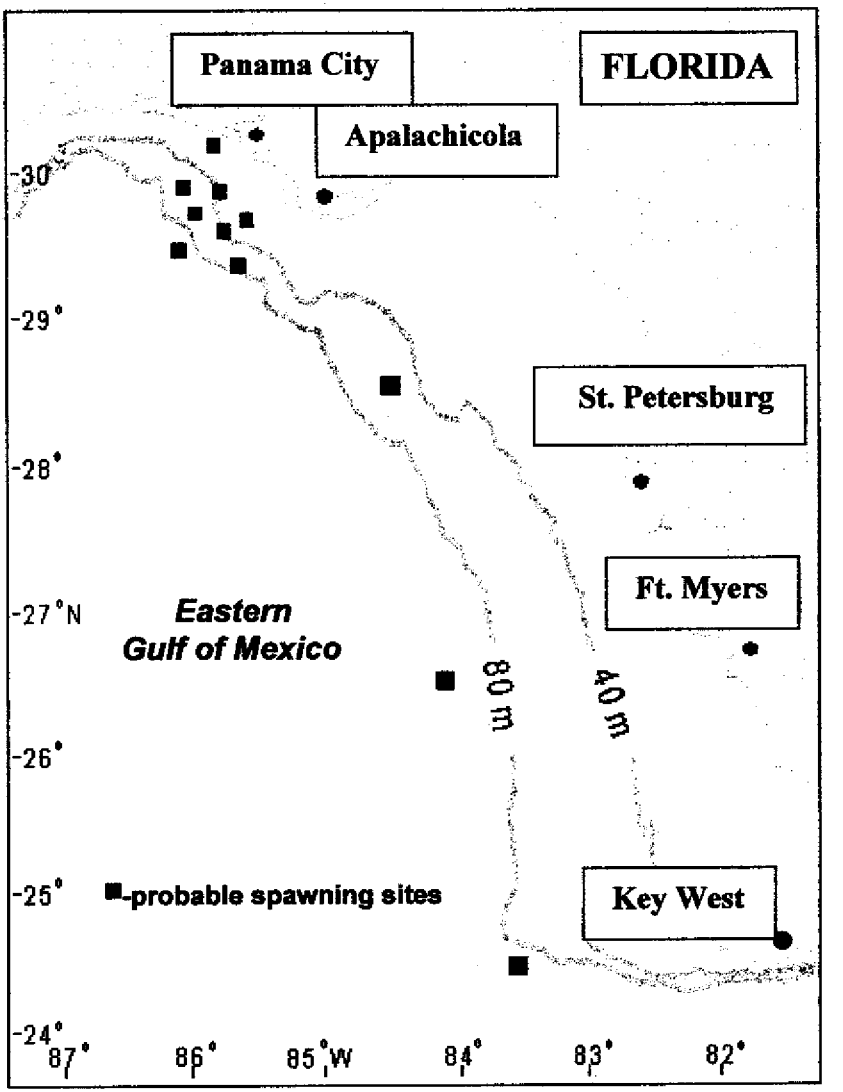


Figure 1. Vermilion snapper sampling area with probable spawning sites.

The smallest females that we sampled (153 and 159 mm TL) were Stage 4 (with migratory nuclei) and Stage 5 (hydrated), respectively. We found very few non-spawning fish during April through September. A scarcity of extremely low GSIs during the spawning season also suggests that gonad maturation and spawning occur in small fish (Figure 2).

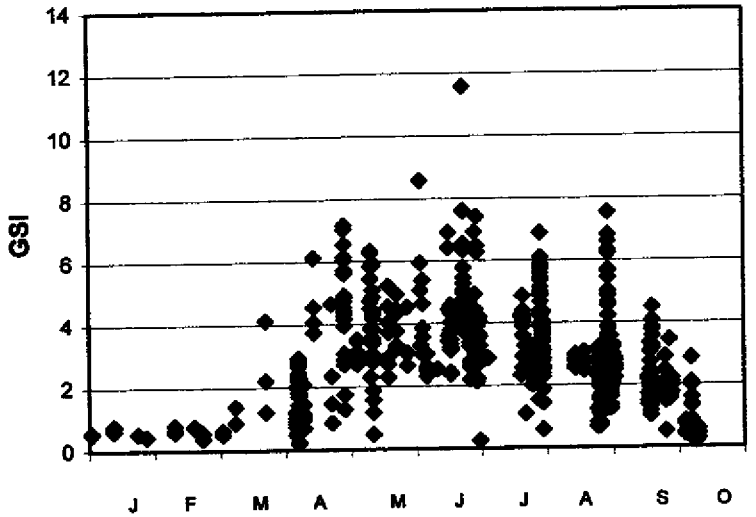


Figure 2. Gonadosomatic index of all female vermillion snapper during 2000 - 2001 (N = 572).

Spawning occurred at approximately 2230 hours according to ovarian histology during our intensive fishery independent sampling off Panama City in 2000 and 2001 (Figure 3). In both years, early hydration occurred as early as 0905, but late hydration did not begin until about 1300 or 1330 hours. During 2000, 25% of females were early-hydrated from 0905 to 1300 and all late hydrated ovaries occurred from 1300 to 2300; no females were early or late hydrated between 2300 and 0905. At the time that fully hydrated oocytes disappeared in the sampled females, some new POFs appeared to mark the time of spawning given above. A decrease in gonad weight and MAXOD was also noted for similar-sized spawning females between 2200 and 2300. During 2001, fully hydrated oocytes appeared from 1330 to 2240 and new POFs appeared from 2200 to 0130; two "running ripe" females that spewed large eggs on the deck of the headboat during sampling and contained both fully hydrated oocytes and new POFs (when viewed back at the laboratory) were collected at 2200 and 2210.

Batch fecundity was estimated as 7,385 to 407,570 from all females (n = 123) that contained intact ovaries with fully hydrated oocytes and no new POFs (Figure 4). Total length proved to be an effective predictor, with this model explaining almost 67% of the variation in batch fecundity (Figure 4). Dates of catch on these fish ranged from late April to early September during the four different years. Total length ranged from 159 to 510 mm TL. Depth and time of catch was 30 to 114 m and 1300 to 2240 hours, respectively (n = 79).

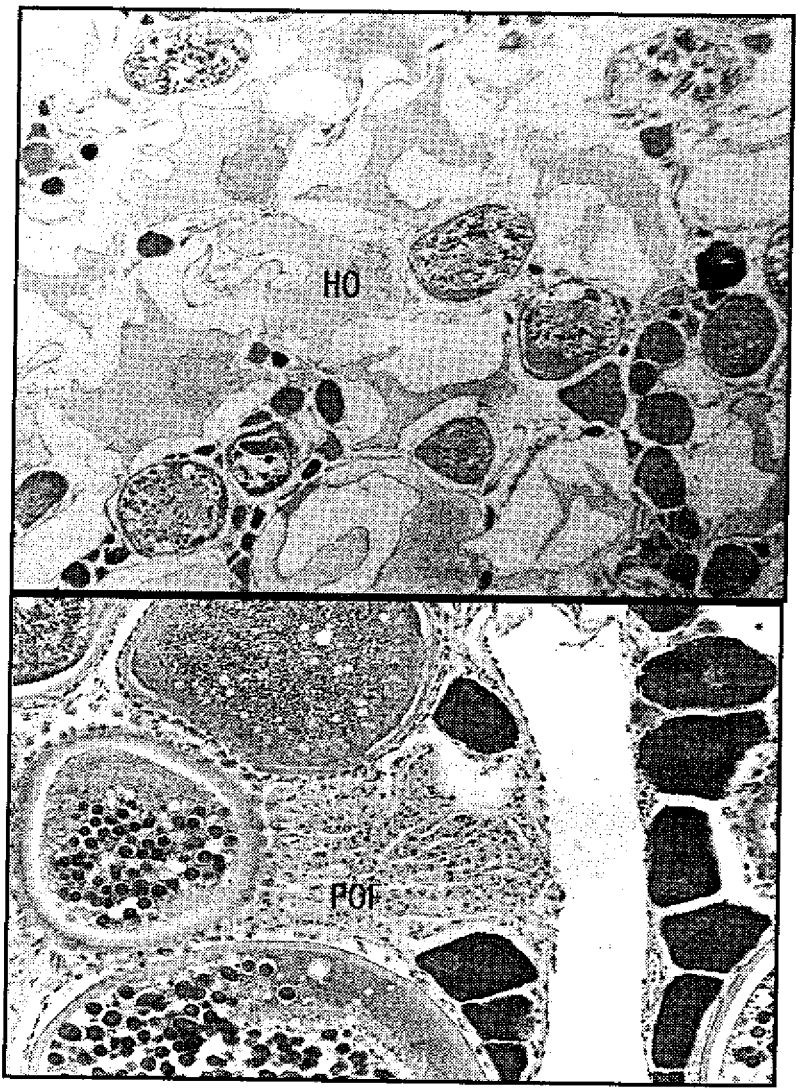


Figure 3. Photomicrographs of histological sections of typical vermillion snapper ovaries collected on June 27, 2000, from one location 10 miles south of Panama City, Florida. The top photo is from a 245 mm total length (TL) female collected between 19:340 and 21:00 hours: shown are fully hydrated oocytes (HO) indicating that the fish was ready to spawn. The bottom photo is from a 244 mm TL female colllected between 23:15 and 23:45 hours: shown is a relatively new postovulatory follicle (POF) indicating that the fish just spawned.

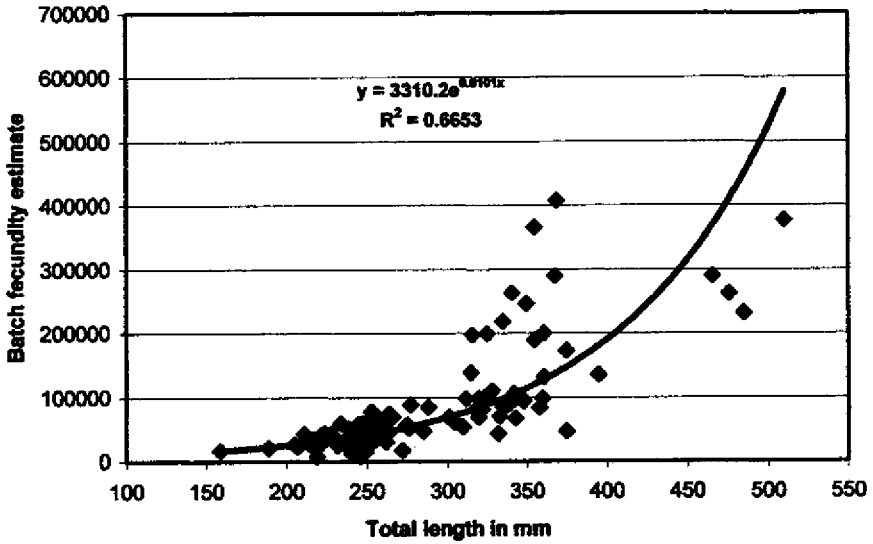


Figure 4. 1993 - 1994 and 2000 - 2001 vermilion snapper batch fecundity regressed on total length (N = 123)

A spawning frequency of 93 was estimated from females collected during 2000 and 2001 off Panama City between the day of first and last occurrence of Stage 5 ovaries in each year. We examined a total of 426 histological slides during these two spawning periods (n = 228 (with fish all < 300 mm TL) for 2000 and n = 198 (with 152 fish < 300 mm TL and 46 fish > 299 mm TL) for 2001). The percentage of females with fully hydrated oocytes between the hours of 1300 (or 1330) and 2230 was used as the best indicator of the percentage of females spawning per day in both years.

Only fishery-independent catches off Panama City were used for 2000 and 2001 spawning frequency estimates. During 2000, hydrated females were found between mid-April and mid-September (=150 days); we sampled 127 females between 1300 and 2230 hours and 63.8% of them were hydrated, giving an average spawning periodicity of 1.6 days (between spawns for each female) and a spawning frequency estimate of 150 (=length of the spawning season in days)/1.6 = 93. During 2001 for fish <300 mm TL, hydrated females were found between early May and late August (=107 days); we sampled 75 females between 1330 and 1700 (and unfortunately only one more female by 2230) and 32.0% of them were hydrated, giving an average spawning periodicity of 3.1 days and a spawning frequency of 107/3.1=35. During 2001 for fish >299 mm TL, hydrated females were found between mid-June and late August (=70 days); we sampled 16 females between 1330 and 2230 and 62.5% of them were hydrated, giving an average spawning periodicity of 1.6 days and a spawning frequency of 70/1.6=44. However, the latter two estimates for 2001 suffered from the fact that we were not able to sufficiently sample the late afternoon

and early evening hours for small fish, or find large fish until June or get good sampling trips in during September; therefore, we believe that it is better to use the same 150 day spawning period for all sizes of female vermilion snapper during 2000 and 2001.

Annual fecundity estimates ranged from 1.4 to 8.2 million for 2000 (n = 59) and from 0.7 to 35 million for some smaller and some larger females for 2001 (n = 20), if the same spawning frequency estimate is used for both years.

DISCUSSION

Our results on sex ratio, spawning months, spawning-time-of-day, and batch fecundity for smaller fish generally agree with recently published estimates for vermilion snapper, but Cuellar et al. 1996 estimated spawning frequency off South Carolina as 35. Our estimate of 93 was larger than theirs possibly due to differences in: areas sampled (Gulf of Mexico versus Atlantic Ocean), our longer sampling period (at least two years versus 13 months for Cuellar et al. 1996), time of sampling (day and night versus daytime), and slightly different methods of estimating spawning frequency. We chose the simplest spawning frequency estimation method using hydrated oocytes because it was too difficult for us to properly preserve gonads at sea in order to ensure that new POFs could always be separated from old POFs in histological slides. Also, ours is not the first seemingly high estimate of spawning frequency for a snapper: Davis and West (1993) found that *Lutjanus vittus* spawn 22 times per month for seven months each year in Australian waters.

Vermilion snapper in the Gulf of Mexico certainly warrant further study. The large vermilion snapper (n = 22 females) caught during June 2001 by a commercial boat off Fort Myers, FL, (Figure 1) were especially interesting. The four largest specimens (466, 476, 485, and 510 mm TL) used in estimating batch fecundity (Figure 4) were collected at this site, which was a 114 m deep "freshwater-spring" (personal communication, Capt. Eric Schmidt and Lisa Hallock, June - August 2001). These fish's reproductive parameters should probably be considered separately from fish in other areas because only the largest females were spawning at this site. All of the smallest females (313 - 424 mm TL; n = 8) from this site had Stage 2 ovaries which were most unusual in our samples from off Panama City: we found very few non-spawning vermilion snapper of any size during the spawning season. All other larger "spring" females (470 - 555 mm TL; n = 14) were Stage 4 and 5. Vermilion snapper from this site may essentially be unfished, or possibly the effects of the "spring" environment are directly or indirectly responsible for this occurrence of large non-spawning females.

ACKNOWLEDGMENTS

Doug DeVries and Gary Fitzhugh of NMFS Panama City assisted with sampling design and field sampling. Robert Allman, Linda Lombardi-Carlson, and Nancy Evou of NMFS Panama City provided age data, much needed data management, and

design and field sampling. Robert Allman, Linda Lombardi-Carlson, and Nancy Evou of NMFS Panama City provided age data, much needed data management, and data entry, respectively. Most of our 1991 - 1994 commercial samples came courtesy of Captain Sigurd Smeby of Panama City, Florida. Owner-Captain Jim Crowell, and Captain Keith Golden, of the "Jubilee" in Panama City allowed us to sample on their headboat during 2001. Captain Eric Schmidt of Fort Myers, FL, allowed us to obtain samples on his commercial boat at sea. Lisa Hallock of the Florida Marine Research Institute (FMRI) in Port Charlotte, FL, sampled commercial and recreational boats in port and at sea. Lewis Bullock and Scott Deitche of the FMRI in St. Petersburg also provided samples from commercial and recreational boats, respectively. We thank the NMFS Beaufort, NC, Headboat Survey Team led by Charles Manooch and Robert Dixon for providing large specimens from the Gulf of Mexico in 2000 and 2001. The following members of the Headboat Survey Team also deserve special mention: David Bartee, Scott Deitche (also of FMRI), Amy Mach, and Tami Eymard. Renee Roman and Greg Fairclough of NMFS St. Petersburg, FL, also provided samples for this study, as did Edward Little of NMFS in Key West. NMFS Panama City Volunteers Hope Lyon, Bob Hadley, and Dan Harris made oocyte counts for batch fecundity estimates. Rosalie Shaffer of NMFS Panama City assisted with our Spanish-abstract. Scott Baker, now with Louisiana State University, sampled some commercial trips at sea.

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Condition of Reef Fish on Jamaica's North Coast Signals Late Stages of Overexploitation

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ABSTRACT

Jamaica's commercial fishery has long shown signs of overexploitation expressed as reduced CPUE and the disappearance of large-sized fish. Heavy fishing pressure often results in reduced abundance, a change in size structure, and shifts in community structure. We assessed the reefs along ≈305 km of Jamaica's northern shelf and performed visual fish censuses at sixty sites according to the AGRRA protocol. Jamaica's fish community was characterized relative to AGRRA results from other Caribbean regions. Although variable, densities of most fish species were only slightly lower in Jamaica than other regions. Fish size was consistently small along the north coast. Total lengths of commercially valuable fishes (Serranidae, Lutjanidae, Haemulidae; n = 1,191) ranged from 5 - 10 cm smaller in Jamaica than other regions we sampled. As valuable species become increasingly scarce due to overfishing, lower trophic levels (e.g., herbivorous scarids and acanthurids) are targeted by the fishing community. Herbivores play an important role in maintaining coral reefs by keeping macroalgae from becoming competitively dominant. An inadequate abundance of herbivores on Jamaica's reefs has resulted in a shift from a coral-dominated to an algal-dominated community structure. Scaridae and Acanthuridae are smaller (by 4 - 15 cm and 5 - 8 cm, respectively) on Jamaica's reefs than conspecifics from other regions. Mean total length for all scarid species was 12 cm (n = 6158) and acanthurid species averaged 10 cm total length (n = 1950). Terminal phase scarids were not commonly encountered and large individuals (> 30 cm) of any fish species were rarely sited during our assessment. The fish population of Jamaica's north coast may be undergoing a late stage of exploitation, displaying signs of recruitment overfishing and indications of reduced genetic variation for size. Lower potential for reproductive output associated with

small-sized individuals puts Jamaica's fish population at risk and the potential loss of herbivorous fishes threatens the recovery and sustainability of Jamaica's reefs.

KEY WORDS: Jamaica, coral reef fishery, AGRRA

INTRODUCTION

Jamaica, the third largest island of the Caribbean Sea, is centrally located (18°N, 77°W) and lies at the center of coral diversity in the Atlantic system (Wells and Lang 1973). Coral reefs fringing much of Jamaica's northern coast and occurring less frequently along the southern coast (Figure 1), serve as a foundation for Jamaica's inshore fishery. The declining condition of this fishery has been well documented in recent decades (Hughes 1994, Munro 1983) and evidence exists that Jamaica's fishery resources have been in decline for over a century (Jackson 1997). Jamaica's inshore fishery has undergone changes typical of an overexploited fishery, characterized by declining catch rates, reduction in mean fish size, and a change in species composition of landings (Aiken and Haughton 1987, Munro 1983). Pauly et al. (1998) illustrated that fisheries worldwide, are more frequently targeting organisms in lower trophic levels than was common three decades ago. In Jamaica, this is evidenced as landings are decreasingly composed of valuable species, such as snappers (Lutjanidae) and groupers (Serranidae), and replaced by fishes once considered "trash" species, such as surgeonfishes (Acanthuridae) and parrotfishes (Scaridae) (Aiken and Haughton 1987, Munro 1983).

Reduced herbivory has been implicated as a major contributory factor to macroalgal overgrowth of Jamaica's coral reefs. The 1983 Caribbean-wide mass mortality of the herbivorous, long-spined black sea urchin, *Diadema antillarum* (Hughes et al. 1987) coupled with the destructive forces of Hurricane Allen (1980), resulted in a significant reduction in live coral cover and a shift from a coral-dominated to an algal-dominated community (Hughes 1994, Hughes et al. 1987, Woodley et al. 1998). The inability of *Diadema* to recover and the continuous exploitation of herbivorous scarids and acanthurids from Jamaica's reefs, have prevented recovery of, and threaten the continued existence of, Jamaica's coral reefs.

In this investigation, we sought to ascertain the relative condition of reef fishes of Jamaica's north coast in terms of species composition, size structure and abundance, in order to identify trends of decline associated with characteristics of the coral and algae community. In an effort to uncover factors associated with intense fishing activity in Jamaica, we compared results from our Jamaica assessment to regions that had previously been surveyed using the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol. These include the windward Netherlands Antilles (*i.e.* the reefs of St. Maarten, Saba, Saba Bank, and St. Eustatius); Andros Island, Bahamas; and the Tobago Cays, St. Vincent-Grenadines. Since 1987, Saba's fringing reefs and associated fish have been protected from fishing activity and are regulated by the Saba National Marine Park. Likewise, fish from St. Eustatius' reefs

have been protected from fishing in the form of a marine park since 1997. Saba Bank, although regulated at the time of the survey in 1999, has experienced heavy fishing pressure from foreign fishing fleets in recent decades (Klomp and Kooistra In review). Similarly, The Tobago Cays of St. Vincent-Grenadines has suffered from intense local fishing pressure (Deschamps et al. In review).

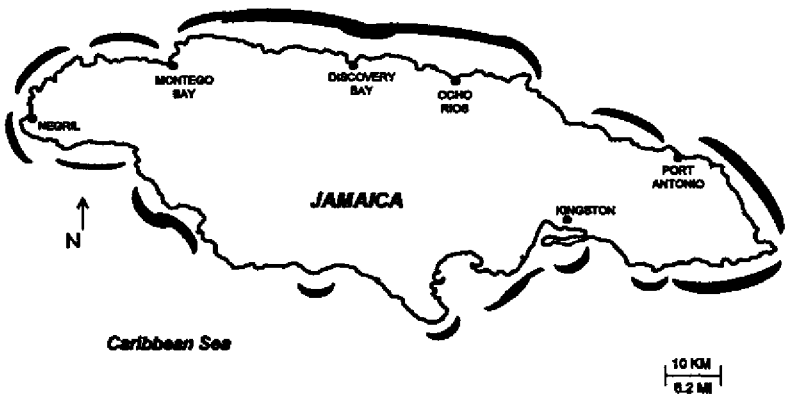


Figure 1. Approximate location of Jamaica's coral reefs (Wells 1988)

METHODS

During August 2000, a 7-day training workshop on the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol was held in Jamaica at the Discovery Bay Marine Laboratory. Twenty persons, including individuals representing Jamaica's Natural Resources Conservation Authority (NRCA), the University of West Indies, and officials from the Negril and Montego Bay Marie Parks, gathered for classroom instruction and field exercises designed to teach assessment techniques and standardization procedures. Following the workshop, participants were assembled into assessment teams and spent two weeks applying the AGRRA technique to Jamaica's northern coast.

Site selection was made using a combination of color aerial photos (scale 1:5000, 1991), a coastal zone habitat atlas (Norrman *et al.* 1997), nautical charts, and knowledgeable local individuals. Sixty sites, eleven shallow (< 5.0 m) and forty-nine deeper (> 5.0 m), were assessed along 305 km (190 miles) of coastline (Figure 2).

The AGRRA protocol (Kramer, P.R. In review) was used to visually assess and quantify condition of corals, algae and fish populations. Stony coral was characterized utilizing line transects (10 m), percent coverage of algae was estimated using quadrats (25 x 25 cm), and belt transects (30 m) were used to estimate fish size and density. We modified the AGRRA protocol to include all colonies ≥ 10 cm in maximum diameter to ensure adequate samples sizes. Additionally, counts of serranids (groupers) were restricted to *Epinephelus and Mycteroperca*; and scarids

(parrotfishes) and haemulids (grunts) less than 5 cm in length were not tallied. Fish biomass was estimated using length-weight relationships established from prior studies; and for species where prior data was not available, length-weight relationships from similar species were used (Marks and Klomp In review).

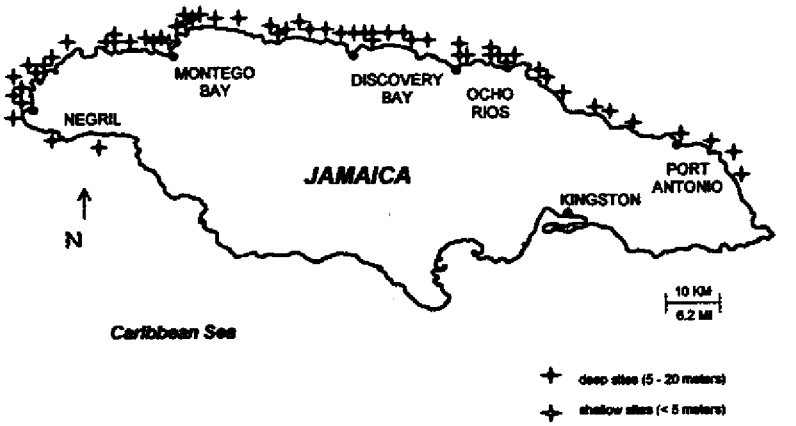


Figure 2. Location of sampling sites

In total, we assessed corals along 398 transects, algae within 1734 quadrats, and fish size and density for 10,448 individuals along 600 belt transects. Additionally, roving diver censuses of fish were performed at each site to estimate overall species richness. Along each coral transect, vertical relief was measured at 2 meter increments to indicate benthic rugosity and *D. antillarum* were counted to estimate overall density. Macroalgal index values (*i.e.* % macroalgae cover ´ mean macroalgal height) were determined as a proxy for macroalgae biomass.

We evaluated factors affecting Jamaica's reef fishes in terms of fish size, density and biomass, and provide a comparison to other Caribbean regions where AGRRA surveys have been carried out. These regions included Andros Island, Bahamas; Tobago Cays, St. Vincent-Grenadines; and the windward Netherlands Antilles (*i.e.* St. Maarten, Saba, Saba Bank, and St. Eustatius). The Kruskal-Wallis (non-parametric ANOVA) was used to determine differences in fish sizes and densities between Jamaica and other regions of the Caribbean. The Tukey HSD for unequal N was used as a multiple comparison test.

Data was analyzed using a linear regression analysis to detect geographic spatial trends in fish density and total length. Likewise, linear regressions were performed to investigate correlation between fish parameters (*i.e.* fish biomass, density and species richness) and reef parameters (*i.e.* benthic rugosity and percent live coral cover).

RESULTS

Based on roving diver surveys, a total of 135 fish species were documented among all sites. Fish abundance (Table 1; Figure 3) was dominated by grazing herbivorous species from the Scaridae (17 individuals/100 m^2) and Acanthuridae (5 individuals/100 m^2) families, and by the yellowtail damselfish, *Microspathodon chrysurus* (2 individuals/100 m^2). Fishes with commercial value from the Haemulidae, Serranidae, and Lutjanidae families were present in low densities (0.2 – 2.2 individuals/100 m^2). Abundance estimates from other families were recorded in very low densities (< 0.3 individuals/100 m^2; Figure 3). Although there was much variability, Jamaica's fish densities (Table 1) were not significantly less than those from other regions (Figure 4). Biomass estimates for Jamaica's fishes followed a pattern similar to total length (Figure 3; Table 1), with scarids accounting for the majority (53%; 670 grams/100 m^2) of fish biomass within the eight fish families we surveyed. Total biomass of these eight fish families was more than seven times less than total biomass for the same eight families of the windward Netherlands Antilles (Figure 5). In general, scarids, and to a lesser degree, acanthurids, decreased in density from western to eastern sites (Figure 6). Densities of herbivorous fishes were greater at sites along the western coast (Figure 7) than the mean density calculated for herbivorous fishes in Jamaica (> 30 individuals/m^2).

Mean total length was low for many of the fish species we documented (Table 1). In many cases, fish from Jamaica were significantly smaller than conspecifics from other regions (Figure 8), with the greatest disparity occurring between fish of Jamaica's northern coast and those from the more protected fisheries of the windward Netherlands Antilles. Fish size was consistently low along Jamaica's north coast, and except for *Scarus taeniopterus*, did not exhibit a trend in decreasing size from west to east or vice-versa (linear regression analysis for *S. taeniopterus*: $p = 0.04$; $r^2 = 0.07$). There were no significant correlations detected between benthic rugosity of the reef architecture and fish parameters of biomass, density, or species richness. Likewise, there was not a significant relationship detected between fish densities and live coral cover (Table 2). Species richness, however, displayed a slight, positive correlation with percent live coral cover ($p = 0.01$; $r^2 = 0.10$).

Relative abundance of macroalgae was high (mean index value = 150; Figure 7) at most sites along Jamaica's north coast compared to sites in the Tobago Cays (mean index value = 50) and the windward Netherlands Antilles (mean index value = 10). *Diadema* were present in mean densities of 11 individuals/10 m^2 in the shallow zones and 4 individuals/10 m^2 at the deeper sites. Distributions, however, were patchy and reached densities near 40 individuals/10 m^2 east of Ocho Rios (Figure 7).

Table 1. Mean densities (± 1 SE) and total length (± 1 SE) of key fish species along Jamaica's northern coast.

Species		n	Density Ind./100 m²	Mean Total Length (cm)
Scientific Name	**Common Name**			
Acanthurus coeruleus	blue tang	824	2.3 ± 1.8	8.8 ± 3.0
Acanthurus bahianus	ocean surgeon	838	2.5 ±2.0	10.9 ± 3.3
Sparisoma viride	stoplight parrotfish	607	1.7 ± 1.2	13.1 ± 2.8
Scarus croicensis	striped parrotfish	2492	6.9 ± 5.9	11.7 ± 1.8
Sparisome eurofrenatum	redband parrotfish	1717	4.8 ± 2.7	13.1 ± 1.6
Scarus teeniopterus	princess parrotfish	558	0.6 ± 0.6	12.4 ± 2.8
Microspathodon chrysurus	yellowtail damselfish	731	1.9 ± 1.7	12.5 ± 2.5
Epinephelus cruentatus	graysby	194	0.8 ± 0.9	14.8 ± 1.9
Haemulon Flavolineatum	french grunt	584	2.3 ± 4.4	15.1 ± 3.5
Haemulon chrysargyreum	smallmouth grunt	67	1.0 ± 1.6	13.5 ± 4.6
Ocyurus chrysurus	yellowtail snapper	11	0.4 ± 0.4	16.8 ±8.1
Epinephelus fulvus	coney	131	0.6 ± 0.6	12.6 ± 3.9
Caranx ruber	bar jack	204	1.1 ± 1.1	14.7 ± 4.1

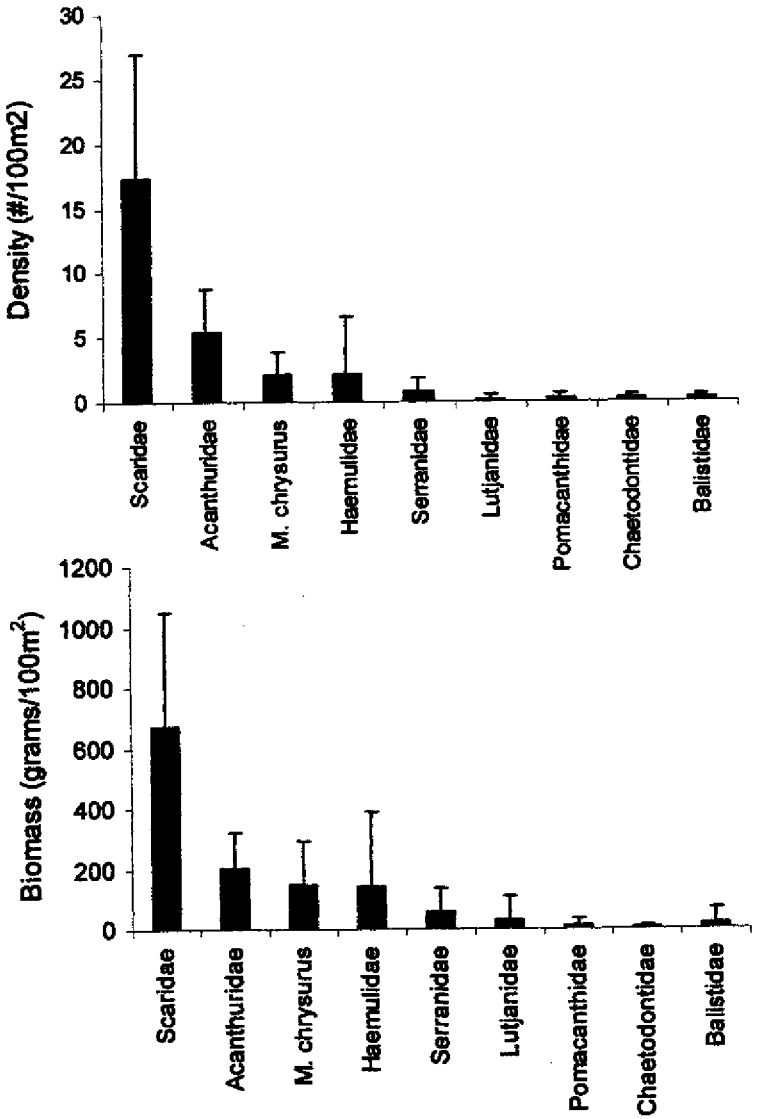


Figure 3. Density and biomass of key fish taxa. Error bars represent ± 1 SE.

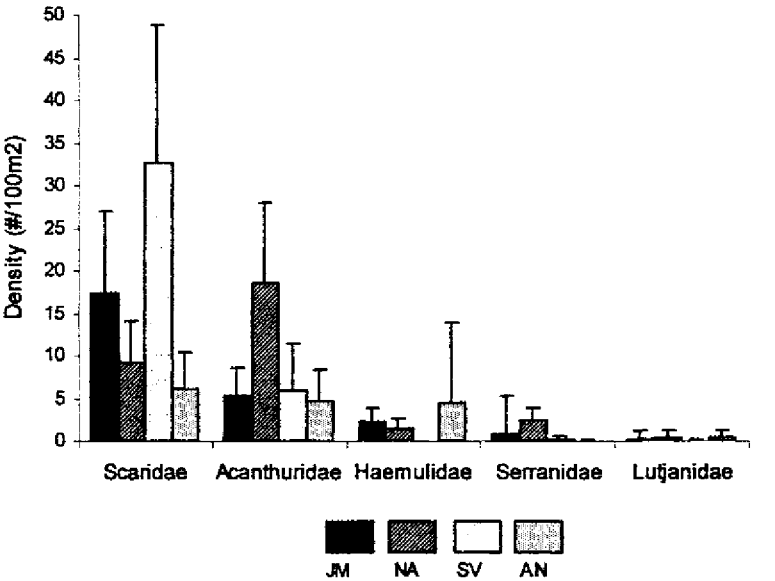


Figure 4. Fish densities (± 1 SE) of five major fish families from Jamaica (JM), windward Netherlands Antilles (NA), Tobago Cays, St. Vincent/Grenadines (SV), and Andros Island, Bahamas (AN).

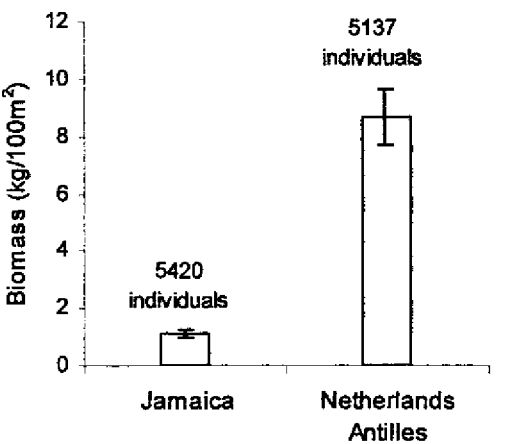


Figure 5. Biomass (± 1SE) of the eight fish families surveyed (Acanthuridae, Balistidae, Chaetodontidae, Haemulidae, Lutjanicae, Pomacanthidae, Scaridae, Serranidae) compared between the windward Netherlands Antilles (1999) and Jamaica (2000).

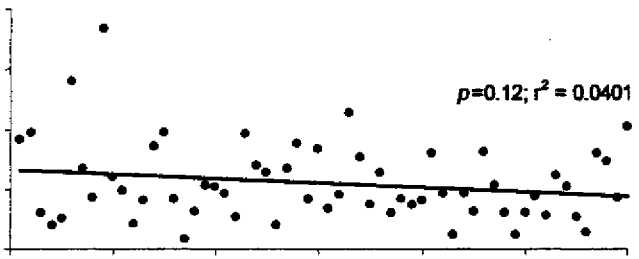


Figure 6. Density of fish from Scaridae and Acanthuridae families at each of the sixty sampling sites. Linear regression results suggest a significant trend for densities to decrease from western to eastern sites.

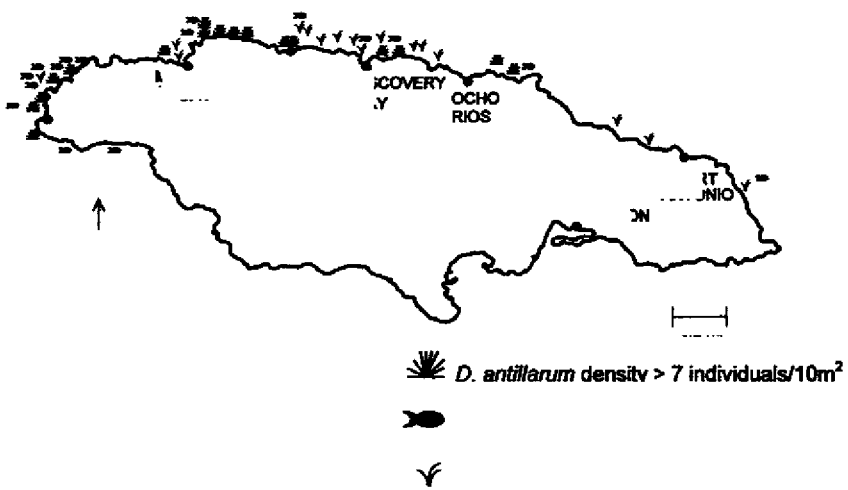


Figure 7. Location of sites where the fleshy macroalgae index, herbivorous fish densities, and *Diadema* densities exceed mean values by more than thirty percent.

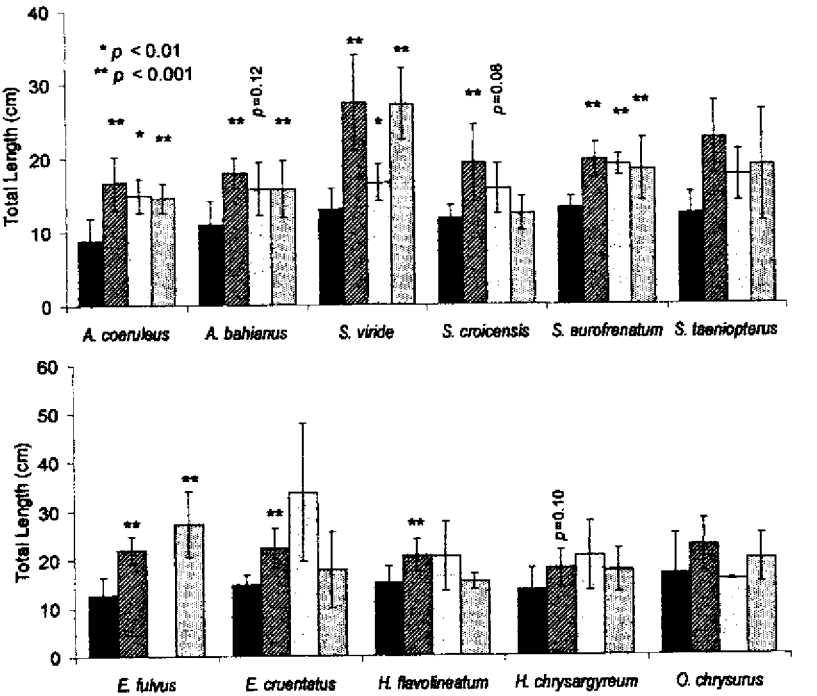


Figure 8. Fish size of key herbivorous and predacious species (total length ± 1 SE) from Jamaica (JM), windward Netherlands Antilles (NA), Tobago Cays, St. Vincent/Grenadines (SV), and Andros Island, Bahamas (AN). Asterisks indicate level of significant difference.

Table 2. Summary of correlation statistics between fish and reef attributes

Fish Attribute	Reef Attribute	Regression Equation	*p*	r^2
Biomass	Structural complexity	y = -0.0042x + 38.249	0.306	0.018
Density	Structural complexity	y = 0.089x + 30.110	0.628	0.004
Species richness	Structural complexity	y = 0.2716x + 28.537	0.742	0.002
Density	Live coral cover	y = 0.2067x + 26.77	0.513	0.007
Species richness	Live coral cover	y = 0.1682x + 13.479	0.014	0.099

DISCUSSION

Jamaica's fishery has been in a state of decline for decades. This decline is exhibited by decreased CPUE and reduction in mean fish size (Munro 1983). These are common effects of intense overfishing where fishing pressure selects for the largest individuals (Alcala and Russ 1989, Jennings and Polunin 1996, PDT 1990). Fish density on Jamaica's north coast did not differ significantly from other Caribbean regions assessed (Figure 4). However, the nature of variability in fish density obscures our ability to make statistically meaningful judgments when comparing fish abundance among regions. Fish biomass, on the other hand, which is a function of density and individual size, was strikingly lower on Jamaica's north coast than that of the more protected reefs of the windward Netherlands Antilles (Figure 5). The disparity in biomass between these two regions reflects the relatively small size of Jamaica's reef fish.

While small average size of fish recorded in Jamaica may simply be a reflection of the size composition after fishers have selectively removed larger individuals, a continuous size-selective mode of exploitation can result in populations that are genetically limited to produce small individuals. Bergh and Getz (1989) demonstrate that populations that are initially genetically homogeneous for traits such as those that govern body size lose genetic diversity as genotypes for large body size are selectively removed by intense fishing. As large individuals are continuously removed, the smaller individuals are the ones left to breed, and their genetic contribution will determine the characteristics of future generations. To the extent that body size is heritable, these selectively exploited fish populations are likely to exhibit small body size (Nelson and Soule 1987). This was demonstrated by a reduction in individual size after decades of intense, size-selective fishing pressure on groundfish populations (*i.e.* Atlantic cod *Gadus morhua*, haddock *Melanogrammus aeglefinus*, and pollock *Pollachius virens*) in the northwest Atlantic led to the collapse of the groundfish fishery in the late 1980s (Trippel 1995). Similarly, Ricker (1981) concluded that a genetic component was responsible for a decrease in individual fish size in Pacific pink salmon (*Oncorhynchus gorbuscha*) after a few generations of fish were subjected to harvesting gear that selected for larger individuals. Our assessment confirms the condition of low mean fish size in Jamaica's fishes and establishes the spatial extent of this phenomenon along Jamaica's north coast. Recognizing that conspecifics from other regions in the Caribbean are attaining significantly greater size, suggests that Jamaica's fishes may be under genetic influence for small size

The small size of Jamaica's fishes raises concern about the capacity of present stocks to replenish populations. Since fecundity in fish is a function of fish size (Charnov 1993, Polunin and Roberts 1993, Sadovy 1996), larger individuals have greater potential to contribute to larval supply. This has been demonstrated in red snapper (*Lutjanus campechanus*) where a single large (61 cm) individual is estimated to produce the same number of eggs as 212 smaller (42 cm) individuals (PDT 1990). Likewise, Pinhorn (1984) reports that a 100 cm Atlantic cod (*G. morhua*) produces more than eight times the eggs spawned by a 50 cm fish. Hence,

diminished fish size with a concomitant decrease of larval production could have strong implications for the potential recovery of Jamaica's exploited fisheries. Indeed, a recent study (1996-2000) carried out by Watson and Munro (in press) provides evidence that larval production near Discovery Bay is compromising stocks. They report that young recruits and juveniles of high-valued commercial species (*i.e.* snappers, grunts, and jacks) were nearly absent from the fish community. In contrast, the abundance of recruits and juveniles was relatively high for species whose larvae have extended pelagic stages (*eg.* Acanthuridae) and for species that mature before recruitment to the fishery (*eg. S. iserti (croicensis), Sparisoma aurofrenatum).* The results from our assessment concur with their findings, suggesting relatively higher densities for acanthurids (4.0 individuals/100meter^2) and scarids (*S. iserti (croicensis)* = 10 individuals/100meter^2 and *S. aurofrenatum* = 4 individuals/100meter^2) near Discovery Bay. Additionally, our assessment suggests that densities of high-valued species (*i.e.* snappers, grunt, jacks) were consistently low along the north coast and, within the vicinity of Discovery Bay, were absent from our survey transects entirely. Thus, our results support Watson and Munro's conclusion that recruitment overfishing has nearly eliminated some of Jamaica's fish stocks.

An additional concern associated with small-sized fish is that they have relatively higher metabolic rates, a condition that leaves them more susceptible to environmental toxins (Miller 1996). Many pollutants which are known to occur in Jamaica's coastal waters and which have been detected in the aquatic fauna (Mansingh et al. 1997, 2000, Robinson and Mansingh 1999) are recognized as having endocrine disrupting properties which can adversely affect development and reproductive processes. This situation could have a confounding impact on reproductive potential for fishes whose fecundity is compromised by small size.

A characteristic of the Scaridae population which was notably apparent from casual observation, but for which we present no data, was the paucity of terminal phase male scarids. By virtue of their relatively larger size, these individuals would be the first individuals targeted in the fishery. A similar situation has been reported for the rainbow wrasse (*Coris julis*) in the Mediterranean. *C. julis* is a protogynous hermaphrodite of which the terminal phase male is disproportionately targeted, resulting in decreased size, density, and proportion of terminal phase males within the *C. julis* population (Harmelin et al. 1995). According to the size-advantage model for explaining sex change (Ghiselin 1969, Warner 1988), the largest female in the community (assuming it has reached a genetically determined size threshold) should change sex to fill the vacancy of a terminal phase male. The condition we observed, that of scarcity of terminal phase males, would suggest that either fish are being exploited as quickly as sex change can occur, or that females are not reaching the prerequisite threshold size to change sex. Shapiro (1988) provides evidence for an alternative hypothesis to explain the initiation of sex change. He suggests that sex change in protogynous hermaphrodites is regulated by a disinhibitory mechanism whereby females must initially be inhibited from undergoing sex change by the presence of a terminal phase male, before she is disinhibited by the absence of a

terminal phase male. In reference to Jamaica's parrotfish populations, this would suggest that the lack of terminal phase males will perpetuate the condition, so that terminal phase males will also be missing from subsequent generations. It should also be noted that low densities of terminal phase males might be normal in some situations. Warner and Swearer (1991) suggest that individuals of bluehead wrasse, *Thalassoma bifasciatum*, may change sex as a response to a ratio of terminal to initial phase individuals, and that the threshold of this ratio is variable amongst locations. Regardless of the underlying sociobiological explanation, the apparent low abundance of terminal phase males raises questions regarding sperm limitation and the implications for subsequent population growth and structure (Yund 2000).

Grazing herbivores play an important role as primary consumers of benthic algae on Caribbean reefs. In the absence of *D. antillarum*, scarids and acanthurids have become the major herbivores on Jamaica's reefs. Their position at the lower trophic level coupled with the low abundance of predatory fishes, may explain the disproportionate composition of fish biomass allocated to herbivorous fish taxa (*i.e.* Scaridae, Acanthuridae, *M. chrysurus*). The reduced abundance of scarids and acanthurids as a result of overfishing, in addition to the diminished abundance of *D. antillarum*, has not permitted the process of herbivory to substantially control the abundance of algae on Jamaica's reefs. However, we documented *Diadema* at several sites along the coast indicating that there has been some recovery since the 1983 die-off (Figure 8). Of particular interest are stretches of coast where distribution was consistently higher, (*eg.* east of Montego Bay). Our data supports the assertion made by Edmunds and Carpenter (2001) that *Diadema* densities have increased, at least in isolated patches, since the 1983 event.

The positive correlation we detected between live coral cover and species richness, though statistically significant ($p = 0.01$), suggests that only about 10 percent of the variation in species richness is accounted for by the variation of live coral cover. Architectural structure on reefs, regardless of it's living condition, provides fish habitat (Grigg 1994). Since we did not find a correlation between fish species richness and benthic rugosity of the reef, we cannot assume that the correlation between live coral and species richness is attributable to additional fish habitat provided by the coral structure itself. Furthermore, only a small fraction of the fishes we sampled are obligate coral feeders (*e.g.* Chaetondontidae < 1.0% of fish composition), suggesting that greater species richness was not a direct result of additional foraging opportunity associated with the coral's living condition. Fishing activity, indicated by the presence of fish traps, was widely observed along Jamaica's coast during our assessment. However, there were tracts where concentration of activity was relatively elevated. It is feasible that the slight correlation we detected between live coral cover and species richness reflects the physical damage to corals associated with areas of greater fishing activity. However, we did not collect data on levels of fish activity, so further investigation would be necessary to support this conclusion.

ACKNOWLEDGEMENTS

Funding for the training workshop and assessment was provided by the U.S. Agency for International Development and Jamaica Natural Resources Conservation Authority and was administered by the Ocean Research and Education Foundation.

Many individuals participated in the arduous field assessments of coral reefs on which this report is based. Judith Lang led one of the teams and was a constant source of advice and encouragement. George Warner and Peter Gayle from the University of the West Indies and Discovery Bay Marine Laboratory were extremely helpful with the logistics of fieldwork and the training workshop. The commitment of team members to long days of diving and careful data collecting was essential to the success of the assessments. Participants included Courtney Black, Nikki Bramwell, Elizabeth Fisher, Tatum Fisher, Peter Gayle, Hector Guzman, Andrea Lanigan, Nicole Macpherson, Marjo Vierros, George Warner, Peter Wilson-Kelly, and Taylor Carlisle. Ground transportation and support was provided by Lloyd Linton and Anthony Downes. Mr. (Evon) Brown captained the boat and demonstrated the utmost patience during the weeks of the workshop and assessment.

Additionally, we would like to thank Robert Ginsburg for initiating this project and for his constant support. Also, we thank Doug Shapiro for sharing insight on the condition of hermaphroditic fishes.

Agencies and businesses in Jamaica graciously provided services and support for the field work. Special thanks go to Air Jamaica, Montego Bay Marine Park, Negril Area Environmental Protection Trust, Negril Coral Reef Preservation Society, Triff's Inn in Port Antonio, Goldeneye in Oracabessa, Half Moon Golf, Tennis and Beach Club in Rose Hall, Sandals Dunn's River in Ocho Rios, Rockhouse Hotel in Negril, Lady G'Diver in Port Antonio, North Coast Marine Sports in Rose Hall, Wyndham Rose Hall Dive Center in Montego Bay, Holiday Inn Sunspree Resort in Rosehall, FDR Pebbles Resort Scuba Center in Trelawny, Port Antonio Marina in Port Antonio, Negril Scuba Centre in Negril, and Drumville Cove Resort Dive Center in Negril. Additional support was generously provided by American Airlines.

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Distribution and Abundance of Fishes Associated with *Sargassum* Mats in the NW Gulf of Mexico

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ABSTRACT

Distribution and abundance of fishes associated with *Sargassum* mats in the NW Gulf of Mexico were examined off northern (Galveston) and southern (Port Aransas) Texas from May - August, 2000. A total of 37 species (17 families) was identified from larval purse seine collections. Individuals from seven species composed over 97% of the catch: planehead filefish (*Monacanthus hispidus*), blue runner (*Caranx crysos*), gray triggerfish (*Balistes capriscus*), chain pipefish (*Syngnathus louisianae*), sergeant major (*Abudefduf saxatilis*), sargassum fish (*Histrio histrio*), and greater amberjack (*Seriola dumerili*). Temporal patterns were observed for several taxa; *M. hispidus, S. louisianae*, and *H. histrio* were more abundant in early summer (May - June), while *C. crysos* and *A. saxatilis* were more prominent late in the season (July - August). Abundance of dominant taxa was higher in northern waters and both abundance and diversity increased as a function of distance from shore.

KEY WORDS: Gulf of Mexico, habitat use, *Sargassum*

RESUMEN

La distribución y la abundancia de pescados asociados a las esteras de *Sargassum* en el Golfo de NW de Méjico fueron examinadas de Tejas norteño (Galveston) y meridional (Port Aransas) de Mayo - Agosto, 2000. Un total de 36 especies (17 familias) fue identificado de colecciones larval de la jábega del monedero. Los individuos a partir de siete especies compusieron 97% del retén: filefish del planehead (*Monacanthus hispidus*), corredor azul (*Caranx crysos*), triggerfish gris (*Balistes capriscus*), pipefish de cadena (*Syngnathus louisianae*), comandante del sargento (*Abudefduf saxatilis*), pescados del sargassum (*Histrio histrio*), y mayor amberjack (*Seriola dumerili*). Los modelos temporales fueron observados para varios taxa; *M. hispidus*, *S. louisianae*, y *H. histrio* estaban considerablemente más abundante en el comienzo del verano (Mayo - Junio), mientras que *C. crysos* y *A. saxatilis* estaban considerablemente más abundante tarde en la estación (Julio - Agosto). La abundancia de taxa dominantes era más alta en aguas norteñas y abundancia y diversidad creciente en función de distancia de la orilla.

PALABRAS CLAVES: *Sargassum*, distribución y la abundancia de pescados

INTRODUCTION

Due to the complexity this habitat affords, *Sargassum* is of particular interest to scientists and fishery managers. Studies in the western Atlantic (Dooley 1972, Settle 1993), Japan (Edgar and Aoki, 1993), Australia (Kingsford and Choat 1985), central Pacific (Gooding and Magnuson 1967), and eastern Gulf of Mexico (Bortone et al. 1977) indicate that many fishes utilize *Sargassum*. These mats appear to enhance early life survival of pelagic fishes by reducing predation-mediated mortality (Kingsford 1995). In addition, the structural complexity acts to enhance growth by providing ample prey resources for juveniles (Hunter and Mitchell 1967, Gorelova and Fedoryako 1986, Edgar and Aoki 1993). As a result, survivorship of individuals associated with these mats may increase and therefore recruitment success may be linked to *Sargassum* (Kingsford and Choat 1985). In response, National Marine Fisheries Service (NMFS) has recently designated *Sargassum* as Essential Fish Habitat (EFH) for several coastal migratory species (NOAA 1996). Nevertheless, studies assessing the value of *Sargassum* as habitat are limited, particularly in the NW Gulf of Mexico where large floating mats are predominant surface features on the continental shelf.

The aim of this study was to evaluate the role of *Sargassum* as essential nursery habitat of fishes in the NW Gulf of Mexico. Patterns of habitat use were examined to determine the function and dynamics of the *Sargassum* complex. Specifically, patterns of abundance and assemblage diversity were assessed at two levels. Inshore versus offshore comparisons were analyzed for small-scale spatial patterns, while upper and lower regions of the northwestern Gulf were investigated for large-scale differences. In addition, seasonal changes in abundance were examined to evaluate temporal stability, and to identify important periods of recruitment to the *Sargassum* complex.

MATERIALS AND METHODS

Sampling Design

The present study was conducted in coastal and offshore waters of the NW Gulf of Mexico. All samples were obtained within the following boundaries: north (29° 0.782' N, 94° 43.32' W), south (27° 37.55' N, 96° 35.84' W), east (28° 58.52' N, 93° 55.19' W), and west (27° 46.81' N, 96° 45.05' W). Offshore waters (15 - 70 nautical miles) in Galveston, Texas and Port Aransas, Texas were designated as the offshore north and offshore south regions, respectively. Regions are separated by approximately 200 miles, and oceanographic differences between the two include currents, winds, bottom topography and nutrient concentrations (Smith 1980a, Sahl et al. 1993). In addition, an inshore north zone (< 15 nm) off Galveston, TX was sampled and compared to the offshore north zone (> 15 nm) (which is the offshore north region). This inshore north zone is heavily influenced by physical and biological processes occurring within the Galveston Bay estuary, such as advection

of riverine and bay discharges, while the offshore north zone is governed more by continental shelf processes, such as upwelling (Temple et al. 1977, Smith 1980b).

Sargassum spp. and associated fauna were sampled from May through August 2000. Replicate samples (3 - 5) were collected monthly from both the offshore north and offshore south regions. In addition, monthly samples were taken within the inshore north zone. All mats were haphazardly chosen and samples were taken from 0800 to 1500 h using a larval purse seine (20 m long, 3.3 m deep, 1000 μm mesh). The purse seine was deployed as the boat encircled the chosen mat and once completely around the mat the net was pursed. Next, *Sargassum* was discarded, and fishes were funneled into the cod end, collected, and frozen upon dry ice. Mat characteristics (e.g. size, density) and GPS locations were recorded at each sample location. Environmental parameters measured included depth, sea surface temperature, salinity, dissolved oxygen, and water clarity. Fishes were sorted and identified to species in the laboratory and standard length measurements were taken to the nearest 0.1 mm.

Data Analysis

Relative abundance of fishes was expressed as catch per unit effort (CPUE), representing the number of fishes caught per larval purse seine sample. Seven species comprised most of the overall catch and statistical analyses were limited to these taxa. CPUE data were log (x+1) transformed to minimize heteroscedasticity. Effects of location and date on CPUE estimates of each species were examined using a two-way analysis of variance (ANOVA). Two-way ANOVAs were also used to examine differences for several other dependent variables; these include environmental conditions, sizes, and diversity estimates. Regional August comparisons were not performed due to a lack of samples in the south region (Port Aransas). Tukey's honestly significant difference (HSD) test was used to determine *a posteriori* differences ($\alpha = 0.05$) among means. The assumption of homogeneity of variances was examined using Levene's test and residual examination. Normality was examined using a probability plot of residuals versus expected values. Sizes of all seven species were compared; however, only four species sizes were statistically analyzed between the offshore north and offshore south regions due to a low number of individuals in the south region. Patterns of diversity were investigated using Shannon diversity (H') and evenness (J') indices (Zar, 1984). Diversity measures were estimated using the following equations:

$$H' = \frac{n \log n - \sum fi \log fi}{n}$$

where n is the total number of individuals and fi is the number of individuals for each species.

$$J' = H'/\log S$$

where S is the total number of species. Data analysis was carried out using SYSTAT 8.0 (SPSS 1998).

RESULTS

Environmental Conditions

Seasonal variation in temperature, salinity, and dissolved oxygen was pronounced (Table 1). Temperature and salinity values were low early in the season (May and June), ranging from 26.8°C to 30.5°C and 29‰ to 38‰, respectively. Both parameters increased in July and August, ranging from 28.9°C to 30.9°C and 36‰ to 38.5‰, respectively. In contrast, dissolved oxygen content was higher early in the season, ranging from 6.7 mg/L to 8.2 mg/L, then decreasing from 4.8 mg/L to 7.2 mg/L late in the season. Environmental differences also existed between the inshore and offshore zones of Galveston (Table 1). Significantly higher temperature, salinity, and depth were observed in the offshore zone, while the inshore zone exhibited significantly higher dissolved oxygen content. Visibility was also greater in the offshore zone, but no statistical comparison was performed due to several missing values. A significant zone x season interaction occurred for salinity, indicating the magnitude of differences was variable over time between the inshore and offshore zones. Regional environmental comparisons exhibited similar trends (Table 1). Offshore south (Port Aransas) had significantly higher dissolved oxygen content, in addition to significantly lower temperatures than offshore north (Galveston). A significant region x season interaction occurred for dissolved oxygen. Additionally, both depth and visibility were greater in the offshore south region, but several missing values precluded statistical testing.

Catch Composition

A total of 10,518 individuals representing 36 species from 17 families was collected over the sampling season (Table 2). Dominant taxa included carangids (jacks), monacanthids (filefishes), balistids (triggerfishes), and syngnathids (pipefishes). Individuals from seven species comprised 97.2% of the total catch: *Monacanthus hispidus* (planehead filefish) 44.0%, *Caranx crysos* (blue runner) 17.4%, *Balistes capriscus* (gray triggerfish) 15.3%, *Syngnathus louisianae* (chain pipefish) 10.4%, *Abudefduf saxatilis* (sergeant major) 5.3%, *Histrio histrio* (sargassum fish) 3.5%, and *Seriola dumerili* (greater amberjack) 1.5%.

Overall catch efficiency was highly variable ranging from 1 to 3,201 individuals per seine, with an average CPUE of 276.6(± 100.8). Relative abundance of all seven abundant species varied among months, and CPUE values peaked early in the season. CPUE values ranged from 47 to 3,191 fishes per purse seine in May, while

averaging 632.0(± 374.1). Average CPUE values greatly decreased in June to 130.4(± 55.1), increased in July to 217.5(±158.3), and decreased to the lowest average CPUE values in August at 118.3(± 34.6).

Table 1. Environmental conditions from May-August of 2000. Average (± 1 SE) temperature (°C), salinity (‰), dissolved oxygen (mg/L), depth (m), and visibility (m). * indicates $P \leq 0.05$ and ns indicates $P > 0.05$.

	Temperature	Salinity	Dissolved oxygen	Depth	Visibility
Season					
May	27.8(0.29) *	32.1(1.02) *	7.6(0.14) *		
June	28.6(0.24)	35.2(0.70)	7.2(0.10)		
July	29.9(0.18)	37.4(0.21)	5.8(0.24)		
August	30.2(0.10)	37.0(1.00)	5.5(0.07)		
Zone					
Inshore	28.8(0.19) *	33.6(0.89) *	6.9(0.31) *	17.1(0.19) *	5.3(0.37)
Offshore	29.9(0.24)	36.1(0.51)	6.0(0.27)	24.9(2.64)	12.6(1.41)
Region					
North	29.9(0.24) *	36.1(0.51) ns	6.0(0.27) *	24.9(2.64)	12.6(1.41)
South	28.5(0.27)	37.4(0.32)	6.9(0.13)	36.7(3.15)	19.8(0.61)

Size Distribution

Large variability in size distributions existed within *Sargassum* mats and most species present were in the larval or juvenile stage (Table 3). The majority of *M. hispidus*, *A. saxatilis*, and *C. crysos* were less than 25 mm; 75%, 95%, and 62%, respectively. *Histrio histrio* and *B. capriscus* were abundant at larger sizes, as 75% of *H. histrio* ranged between 20 - 50 mm and 95% of *B. capriscus* ranged between 35 - 65 mm. *Syngnathus louisianae* and *S. dumerili* were prominent over a wide size spectrum, ranging from 52 - 209 mm and 32 - 210 mm, respectively.

Five of the seven abundant species (*C. crysos*, *B. capriscus*, *S. louisianae*, *H. histrio*, and *S. dumerili*) were small early in the season, significantly increasing in size from May to June (Tukey HSD, $P < 0.05$). Smallest sizes of *M. hispidus*, *C. crysos*, and *A. saxatilis* were present in July, while sizes of *B. capriscus*, *S. louisianae*, and *H. histrio* were smallest in August. Three of the seven abundant species were significantly larger in the inshore zone: *M. hispidus* ($F_{1,4420} = 89.78$, $P < 0.001$), *C. crysos* ($F_{1,1553} = 372.65$, $P < 0.001$), and *A. saxatilis* ($F_{1,430} = 20.38$, $P < 0.001$) (Table 3). Significant zone x season interactions occurred for all species, indicating the magnitude of differences in size between zones was variable over time. Of the four species statistically analyzed for regional differences, *M. hispidus* ($F_{1,1340} = 79.82$, $P < 0.001$), *C. crysos* ($F_{1,1604} = 52.81$, $P < 0.001$), and *A. saxatilis* ($F_{1,366} = 17.09$, $P < 0.001$) were significantly larger in the offshore south region. In contrast,

B. capriscus ($F_{1,1438} = 13.81, P < 0.001$) was significantly larger in the offshore north region (Table 3). *Monacanthus hispidus* and *A. saxatilis* had a significant region x season effect with a trend of both species having a pronounced size difference in July and a minimal difference in June.

Table 2. Number of fishes collected within *Sargassum* mats by family and species from May-August, 2000.

Family	Species	Total numbers
Antennariidae	*Histrio histrio*	368
Balistidae	*Balistes capriscus*	1604
	Canthidermis maculata	3
Carangidae	*Caranx crysos*	1827
	Seriola dumerili	154
	Decapterus punctatus	24
	Seriola rivoliana	17
	Caranx bartholomaei	11
	Seriola fasciata	5
	Elagatis bipinnulata	5
	Caranx hippos	1
Clupeidae	*Harengula jaguana*	23
	Sardinella aurita	1
Coryphaenidae	*Coryphaena hippurus*	1
Diodontidae	*Diodon holocanthus*	1
Engraulidae	*Anchoa hepsetus*	24
Haemulidae	*Conodon nobilis*	2
Kyphosidae	*Kyphosus sectatrix*	7
	Kyphosus incisor	7
Lobotidae	*Lobotes surinamensis*	16
Monacanthidae	*Monacanthus hispidus*	4621
	Aluterus scriptus	35
	Aluterus heudeloti	21
	Cantherhines pullus	19
	Monacanthus setifer	16
	Aluterus monoceros	2
Mugilidae	*Mugil curema*	2
Nomeidae	*Psenes cyanophrys*	14
	Psenes pellucidus	1
Pomacentridae	*Abudefduf saxatilis*	555
Priacanthidae	*Pristigenys alta*	1
Syngnathidae	*Syngnathus louisianae*	1096
	Syngnathus pelagicus	25
	Hippocampus erectus	1
	Syngnathus scovelli	1
Tetraodontidae	*Sphoeroides parvus*	7
TOTAL		10,518

Table 3. Size comparison (standard length) of the seven abundant species (±1 SE). * denotes significant difference in size between respective zones or regions.

Species	Min.	Max.	Mean Size	Inshore zone	Offshore zone	North region	South region
Monacanthus hispidus (n = 4621)	7.8	71.8	21.9 (±0.1)	32.5 (±0.4)*	20.5 (±0.1)*	20.4 (±65.6)*	29.1 (±0.8)*
Caranx crysos (n = 1827)	12.3	134.5	34.1 (±0.6)	93.5 (±6.3)*	32.5 (±0.6)*	29.7 (±0.6)*	48.4 (±3.3)*
Balistes capriscus (n =1604)	13.2	105.8	59.8 (±0.4)	65.2 (±2.2)	60.1 (±0.5)	61.5 (±0.5)*	58.6 (±0.7)*
Syngnathus louisianae (n = 1096)	52.2	209.0	99.7 (±0.8)	75.9 (±1.7)	103.2 (±0.9)	103.3 (±0.9)	135.0 (±74.0)
Abudefduf saxatilis (n = 555)	9.5	38.0	15.8 (±0.2)	20.1 (±0.8)*	14.9 (±0.2)*	13.8 (±0.2)*	17.6 (±0.5)*
Histrio histrio (n = 368)	12.0	91.8	36.5 (±0.8)	41.4 (±1.7)	34.8 (±0.8)	35.0 (±0.8)	30.5 (±4.8)
Seriola dumerili (n = 154)	32.4	210.3	120.2 (±4.0)	106.3 (±5.3)*	123.1 (±4.7)*	123.4 (±4.7)	115.1 (±50.0)

Spatial and Temporal Patterns of Abundance

CPUE of all seven abundant species in the offshore north zone greatly exceeded those of the inshore north zone (Table 4). Average CPUE of the seven species in the offshore zone ranged from 2 - 87 times higher than the inshore zone. Significant zone effects were observed for *M. hispidus*, *C. crysos*, *B. capriscus*, and *S. louisianae* (Table 4). In addition, *M. hispidus*, *S. louisianae*, *H. histrio* and *S. dumerili* showed a significant seasonal effect as abundance was higher early in the season (Tukey HSD, $P < 0.05$) (Figure 1). A significant zone x season interaction was observed for *S. louisianae*, as a large difference in May indicated the magnitude of the differences between zones varied over time.

Similar trends were observed regionally, as CPUE of the seven abundant species was higher in the offshore north region than the offshore south region. Average CPUE were 1.5-300 times higher in the north region (Table 5). Significant regional effects occurred for *M. hispidus*, *S. louisianae*, *H. histrio*, and *S. dumerili* (Table 5). Additionally, a significant seasonal effect was observed for *S. louisianae* and *H. histrio*; both were significantly more abundant early in the season (Tukey HSD, $P<0.05$) (Fig. 1). *Syngnathus louisianae* and *H. histrio* exhibited a significant region x season effect. The large difference in May suggests that CPUE between regions was not consistent over time.

Table 4. Two-factor ANOVA comparison of the average relative abundance (# per purse seine) (±1 SE) of the seven abundant species in the inshore and offshore zones.

Species	Inshore	Offshore	F ratio	P value
Monacanthus hispidus	29.6 (16.5)	289.0 (164.6)	11.32	0.003
Caranx crysos	1.4 (0.6)	121.4 (92.8)	5.70	0.027
Balistes capriscus	3.6 (1.1)	78.3 (25.8)	19.44	<0.001
Syngnathus louisianae	10.3 (6.1)	67.9 (42.3)	13.46	0.002
Abudefduf saxatilis	2.2 (0.8)	29.1 (15.2)	4.21	0.054
Histrio histrio	7.0 (3.7)	18.6 (11.1)	3.41	0.080
Seriola dumerili	1.9 (0.7)	9.0 (5.0)	3.50	0.076

Diversity Measurements

Species richness (S), diversity (H'), and evenness (J') were variable among locations and seasons. S and H' were higher in the offshore north zone, while J' was higher in the inshore north zone (Table 6). A two-way ANOVA indicated S ($F_{1,20} = 33.33$, $P < 0.001$) and J' ($F_{1,20} = 7.06$, $P = 0.015$) were significantly different between zones. Regional comparisons indicated significantly higher S ($F_{1,15} = 5.55$, $P = 0.033$) and H' ($F_{1,15} = 4.95$, $P = 0.042$) in the offshore north region (Table 6). Despite the change in composition, S remained constant throughout the sampling season. In addition, later months (July and August) exhibited significantly higher H' and J' than those of earlier months (May and June) (Tukey HSD, $P < 0.05$).

Table 5. Two-factor ANOVA comparison of the average relative abundance (# per purse seine) (±1 SE) of the seven abundant species in the north and south regions.

Species	North	South	F ratio	P value
Monacanthus hispidus	364.6 (205.2)	16.0 (7.2)	10.10	0.006
Caranx crysos	136.7 (118.8)	10.8 (4.1)	0.74	0.404
Balistes capriscus	89.6 (32.3)	45.8 (12.0)	0.19	0.671
Syngnathus louisianae	85.9 (53.0)	0.2 (0.1)	44.35	<0.001
Abudefduf saxatilis	28.7 (19.3)	11.7 (3.1)	0.02	0.895
Histrio histrio	23.2 (13.9)	0.9 (0.4)	13.65	0.002
Seriola dumerili	11.4 (6.2)	0.2 (0.1)	6.63	0.021

DISCUSSION

Abundance of juvenile fishes collected in association with *Sargassum* suggests these mats serve as pelagic nursery habitat. Based upon size-at-collection, over 95% of the fishes were in their early life stage; 72% were under 50 mm (SL) and the average size of all fishes combined was 40 mm. These results are consistent with other studies investigating the fauna associated with pelagic algae (Fine 1970, Kingsford and Choat 1985). Bortone et al. (1977) found the average size of fishes associated with *Sargassum* in the eastern Gulf was less than 25 mm, while Kingsford (1992) observed an average size less than 20 mm in NE New Zealand. The association of these small fishes to pelagic *Sargassum* is likely attributed to the structure and food supply this habitat affords. Druce and Kingsford (1995) found drift objects (i.e. algae and FADs) influenced the distribution of larval and juvenile fishes in surface waters when compared to open water habitats. Additionally, detached macrophytes have been suggested to serve as nursery areas for juvenile fishes as it provides prey resources and protection from predators (Lenanton et al. 1982, Lenanton and Caputi 1989). Again, gear selectivity may influence the size range collected in this study; nevertheless, the abundance of juveniles associated with *Sargassum* suggests this habitat may be important for early life survival.

Patterns of habitat use also appeared related to the timing and location of spawning. Variability in size frequencies throughout the sampling period suggests that protracted spring and summer spawning events occurred for several species. Additionally, three of the seven abundant species (*M. hispidus*, *C. crysos*, *A. saxatilis*) were significantly smaller in offshore waters. These results suggest the small sizes collected within the offshore zone are likely related to their proximity to spawning grounds. These findings are consistent with the season and location of reproduction for *M. hispidus* (Berry and Vogele 1961), *C. crysos* (Leak 1981, Shaw and Drullinger 1990), and *A. saxatilis* (Shaw 1955), as extended spring and summer spawning events are common in offshore areas for all three taxa. Conversely, *Syngnathus louisianae* is known to spawn inshore, often in close proximity to seagrass beds (Diaz-Ruiz et al. 2000). Our results are consistent with these findings, as *S. louisianae* was smaller within the inshore zone.

Table 6. Average species richness (S), Shannon diversity (H') and evenness (J') indices for all samples. August was removed from regional comparison due to a lack of samples in the south region. * indicates $P \leq 0.05$ and ^{ns} indicates $P > 0.05$.

		S	H'	J'	Total # of species	Total # of individuals
Season	May	7.5 ^{ns}	0.442 *	0.520 *	19	5091
	June	7.6	0.447	0.551	26	1529
	July	7.8	0.603	0.716	35	3393
	August	8.8	0.599	0.654	14	505
Zone	Inshore	5.4 *	0.523 ^{ns}	0.729 *	20	862
	Offshore	10.5	0.574	0.586	37	8756
Region	North	10.7 *	0.572 *	0.584 ^{ns}	36	8291
	South	7.2	0.457	0.515	21	900

Spatial patterns indicated that the abundance of fishes associated with pelagic *Sargassum* varies as a function of distance from shore. The seven abundant species associated with *Sargassum* in the offshore zone was much greater than in the inshore zone. Bortone et al. (1977) found similar trends in fish abundance for several species, including *M. hispidus*, *B. capriscus*, and *S. dumerili*, as distance increased from shore. Since physiochemical conditions differed between zones, physiological tolerances may contribute to the observed patterns. Average salinity values differed between zones by 2.5‰, with a range from 29‰ to 37‰ in the inshore zone and 33‰ to 38.5‰ in the offshore zone. In addition, differences in both temperature and dissolved oxygen content differed between zones by as much as 2.2°C and 2.5 mg/L in certain months, respectively. Boehlert and Mundy (1994) found temperature and salinity were likely factors responsible for onshore-offshore distribution patterns of tuna larvae. Additionally, Raynie and Shaw (1994) found ichthyoplankton assemblages from offshore to estuarine areas were attributed to different life-history strategies and temperature regimes. The combination of environmental conditions and life history patterns are likely to influence the observed spatial differences; however, other factors such as season, life-history strategies, and differential resource exploitation may also be important.

On a larger scale, patterns of habitat use were observed between the offshore north and south regions along the Texas Gulf coast. The seven abundant species in this study were far more abundant in the north region. Qualitative measurements of *Sargassum* biomass indicated less pelagic habitat was available in the north region throughout our sampling. Therefore, species may have been concentrated beneath the limited available habitat in the north region and dispersed in the south region, where much more *Sargassum* was present. Physiochemical factors may also contribute to this pattern as Sahl et al. (1993) found that temperature, salinity, oxygen, and nutrients (nitrate, phosphate, silicate) differed markedly between offshore areas of Galveston and Port Aransas. Results from this study indicated significantly higher temperatures and lower salinity and dissolved oxygen content were associated with the north region. The difference in shelf currents, freshwater discharges, and upwelling at the shelf edge may further contribute to both physical and biological differences between the two regions (Smith 1980b, Cochrane and Kell 1986). Previous studies investigating pelagic fish assemblages have shown their distribution and abundance are influenced by environmental and hydrological conditions (Rey 1996, White 1997). Consequently, the numerical dominance in the north region may result from a combination of biological, physical, and chemical conditions.

ACKNOWLEDGEMENTS

We thank the Aquarium at Moody Gardens for providing funding for this project. We would also like to thank Josh Harper, Mike Lowe, Top Hatt fishing charters and the Marine Biology Department at Texas A&M University at Galveston for the field assistance.

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Management of Spotted Seatrout in Mississippi: Effects of Changing the Minimum Size Limit

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ABSTRACT

Spotted seatrout, *Cynoscion nebulosus*, is the most targeted sport fish in Mississippi coastal waters. The growing popularity of spotted seatrout angling on the Mississippi Gulf coast and the subsequent increases in fishing pressure require managers to maintain appropriate size and bag limits if this important fishery is to be sustained. Although the number of anglers on the Mississippi coast has increased each year since 1994, data from fishery-independent monitoring and from the Marine Recreational Fishery Statistics Survey (MRFSS) show that population size, age structure, and length frequency distribution of spotted seatrout in Mississippi all display a positive, upward shift. Because catch-per-unit-effort (CPUE) data show that daily bag limits probably have little impact on this particular fishery, it is suggested that the minimum size limit is the determining factor in managing the fishery. A comparison of two groups of data illustrate the importance of applying appropriate management restrictions to a fishery in order to sustain a viable population. These groups of data are from the 1990s when the fishery was under what was essentially a 12-inch minimum size limit and later under a 14-inch minimum size limit.

KEY WORDS: *Cynoscion nebulosus*, fishery management, minimum size limit

INTRODUCTION

Spotted seatrout (*Cynoscion nebulosus*), a member of the family Sciaenidae (drums), is a relatively abundant finfish occurring in the Gulf of Mexico (Gulf) from the west coast of Florida to Texas (Tabb 1966, Mercer 1984). Spotted seatrout is an important recreational fishery species in the Gulf, and in Mississippi it is the most highly sought coastal sport fish (Deegan 1990). The growing popularity of angling for spotted seatrout in Mississippi and the subsequent increases in fishing pressure along the Mississippi Gulf coast necessitate fishery managers to continually assess this population to insure it remains at a sustainable level.

Tagging studies in Mississippi have shown that spotted seatrout is generally a non-migratory species (Hendon et al. in review). Fish tagged during this study seldom traveled distances greater than ten nautical miles and movement to the adjacent states of Louisiana and Alabama was rare (< 1% of recaptured fish). Similar tagging studies in Louisiana (Adkins et al. 1979), Florida (Iverson and Tabb

1962) and Texas (Bowling 1996) also report limited geographic movement for this species. Because of this limited movement, effective management of this fishery can be best accomplished on an individual state level.

Throughout the 1990s, Mississippi regulated its spotted seatrout fishery through minimum size limits (MSL) and daily bag limits (DBL). From 1992 through 1995, a 14 inch total length (TL) MSL and a 25 fish DBL were in effect, but a provision which allowed for five fish between 12 and 14 inches TL to be retained was also included. In late 1995, the allowance for the retention of five fish between 12- and 14-inches TL was removed, and the DBL was lowered to ten fish. Shortly thereafter, in March 1996, the DBL was increased to 15 fish with the MSL of 14-inches TL kept in place. These limits have remained through 2001. The purpose of this paper is to evaluate the general effectiveness of two management strategies applied to Mississippi's spotted seatrout fishery during the 1990s and to determine the effects of the two established MSLs on population dynamics of this species in Mississippi coastal waters.

MATERIALS AND METHODS

Abundance and length data for spotted seatrout surveyed/collected in Mississippi from 1992 to 1999 were obtained from the Marine Recreational Fishery Statistics Survey (MRFSS) and from the Gulf Coast Research Laboratory's research project "Studies of Spotted Seatrout in Mississippi Coastal Waters", hereafter referred to as GCRL. All hydrology and age data were obtained from the GCRL project, as described in Warren et al. (2001). These hydrology and biological data were compiled from collections taken as part of a fishery-independent monitoring program, in which spotted seatrout were collected on a monthly basis from ten established stations along the Mississippi coast with a 750-foot long by 6-foot deep gill net (Warren et al. 2001). Each net consisted of five 150-foot panels of 2.0 to 4.0 inches stretched mesh (0.5 inch increments). The MRFSS data are fishery-dependent and were obtained from dock-side interviews with anglers and surveys of their catch.

Because management regulations are not the only variables affecting fish populations, fluctuations in hydrological conditions were evaluated for 1993 to 1999 to determine if any of these parameters may have influenced Mississippi's spotted seatrout population. Mean surface water temperature (°C), salinity (‰), and dissolved oxygen (mg/L) measurements were compared between 1993 through 1994 (12-inch MSL) and 1996 through 1999 (14-inch MSL) to determine if any significant differences existed which may have impacted Mississippi's spotted seatrout population. Comparisons were made with the Kruskal-Wallis non-parametric statistic, and tests were considered significant at the $p < 0.05$ level.

Data were divided into two groups based on periods when different management restrictions were implemented for the spotted seatrout recreational fishery in Mississippi (Table I). Abundance, length and age data will hereafter be referred to based on which group (12-MSL or 14-MSL) they fall within. Note that

in graphical representations of abundance data the white bars depict the year in which regulations were changed and were removed from the analyses.

Table I. Table of management strategies applied to the recreational spotted seatrout fishery in Mississippi from 1992 to present. MSL = minimum size limit; DBL = daily bag limit; Undersize = number of fish between 12- and 14-inches TL allowed to legally be retained by anglers.

Group	Date/Period	MSL	DBL	Undersize
12-MSL	May 1992 to Nov 1995	14-in TL	25	5
14-MSL	Dec 1995 to Feb 1996	14-in TL	10	0
14-MSL	Mar 1996 to present	14-in TL	15	0

RESULTS

Although Mississippi's recreational fishery for spotted seatrout is regulated by both a MSL and a DBL, harvest numbers from MRFSS indicate that the DBL had minimal influence on the overall management success of the fishery in recent years (Figure 1). From 1996 to 2000, 90% of the intercepted angler trips in Mississippi yielded a harvest of ten fish or fewer, and almost 73% yielded a harvest of five fish or fewer. Less than 6% of the angler trips during this time period reached (or exceeded) the DBL of 15 spotted seatrout. Based upon the high percentage of angler trips that yielded five or fewer fish, it is assumed for purposes of this manuscript that the possession allowance of five fish between 12- and 14-inches TL from 1992 to 1995 equated to operating under a 12-inch MSL for most Mississippi anglers during this time period. Under this assumption, we have labeled fish taken when the fishery was under this allowance of undersize fish as "12-MSL", while "14-MSL" are those fish collected under a 14-inch MSL with no undersize allowance.

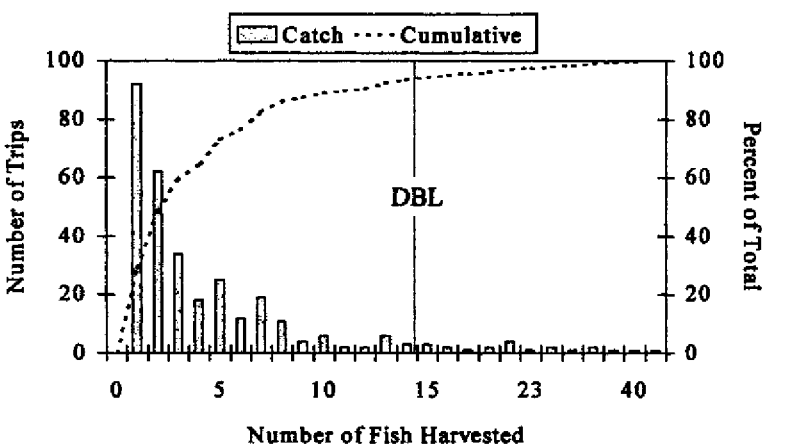


Figure 1. Number of angler trips that harvested increasing numbers of spotted seatrout in Mississippi (source: MRFSS).

Environmental Variations

Of the three hydrological conditions compared, both surface water salinity and dissolved oxygen differed between the two groups of data (Table 2), while tests of surface water temperature revealed no significant difference. Salinity was statistically higher for the 14-MSL period than for the 12-MSL, while dissolved oxygen was statistically higher for the 12-MSL period.

Table 2. Statistical values for comparisons of hydrological data of the Mississippi Sound for 12-MSL and 14-MSL, Kruskal-Wallis test considered significant at $p < 0.05$.

Parameter	p-Value	12-MSL $\bar{x}_{rank}$	12-MSL Actual $\bar{x}$	14-MSL $\bar{x}_{rank}$	14-MSL Actual $\bar{x}$
Salinity (‰)	0.000	156.1	8.45	200.9	11.50
Temp (°C)	0.310	221.7	22.78	208.8	21.98
D. O. (mg/L)	0.005	236.8	7.53	201.4	6.97

Trends in Abundance

Both MRFSS and GCRL data show an increase in spotted seatrout abundance in Mississippi beginning in 1996, immediately after the 14-MSL was implemented. MRFSS harvest data illustrate a gradual upward shift in the numbers of spotted seatrout landed in Mississippi, from an eight-year low in 1994 to a peak in harvest in 1999 (Figure 2). Under the 12-MSL, abundances averaged 204,707 fish harvested per year, the lowest average harvest for any two years in the MRFSS data for the time period evaluated. Numbers harvested for the 14-MSL averaged 329,524 fish per year, representing more than a 60% increase in fish landed in Mississippi. Although low sample size prevents statistical comparison of these data, the trend of increasing abundance from the 12-MSL period to the 14-MSL period indicates that Mississippi's recreational spotted seatrout fishery benefitted from the increase in MSL.

The GCRL fishery-independent data mirror the trend of continuous increasing abundance of spotted seatrout following the 14-inch MSL, with the exception of 1999 which represents a slight decline relative to 1998 (Figure 3). Average annual abundance for the 12-MSL period was 272 fish collected per year, nearly a third less than the average of 361 for the 14-MSL. For the years evaluated in this study, the MRFSS and GCRL data follow an almost identical trend for spotted seatrout abundance in Mississippi, albeit on a much different scale. As with the MRFSS numbers, these fishery-independent data illustrate a greater number of fish associated with the 14-MSL than with the 12-MSL, suggesting a larger population.

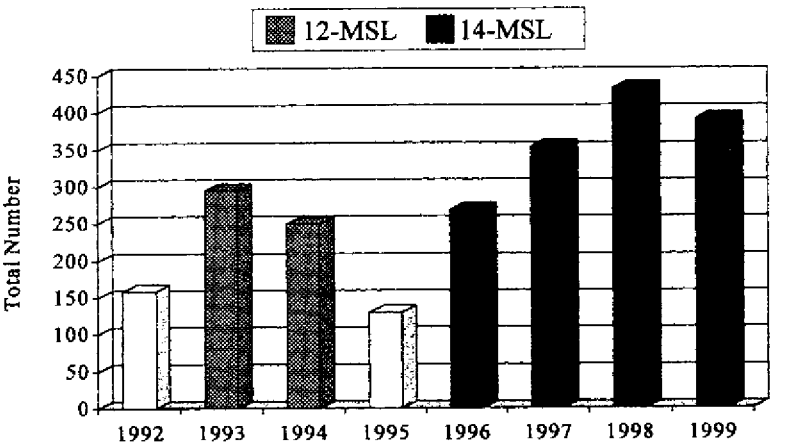


Figure 2. Annual harvest of spotted seatrout in Mississippi (source: MRFSS). White bars represent years not included in analyses because of MSL changes.

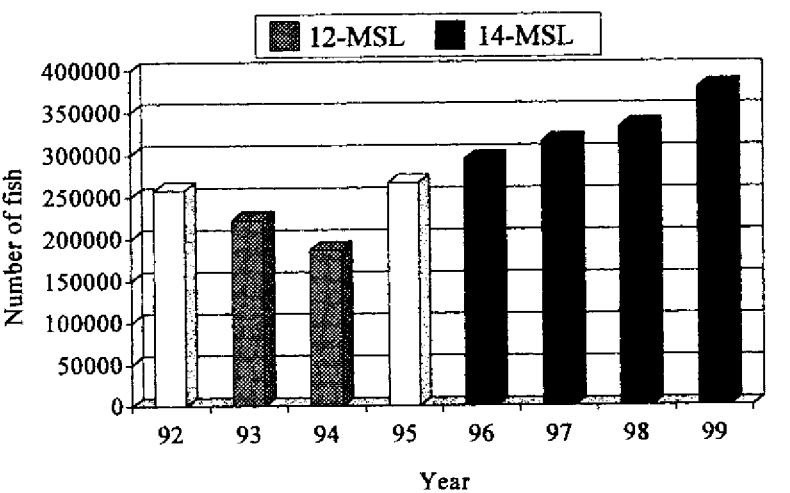


Figure 3. Annual abundance of spotted seatrout in Mississippi (source: GCRL).

Trends in Numbers at Length

With the increase in the MSL, the modal length for fish sampled in the recreational fishery (MRFSS) shifted up from 13-inches under the 12-MSL to 14-inches under the 14-MSL (Figure 4). Not only did the modal size shift upward, but the average number of relatively large fish harvested (14- to 16-inch TL) more than doubled from the 12-MSL period ($\bar{x}_{(14\text{-}16)}$ = 18,304) to the 14-MSL period ($\bar{x}_{(14\text{-}16)}$ = 42,554). Mean numbers from the GCRL data did not display the upward shift in modal length that the MRFSS data exhibited (Figure 5), although numbers at length increased from the 12-MSL to the 14-MSL for each length interval (one inch). The lack of a modal shift in the GCRL data would be expected since fish collected in this program were not subject to the MSL restriction.

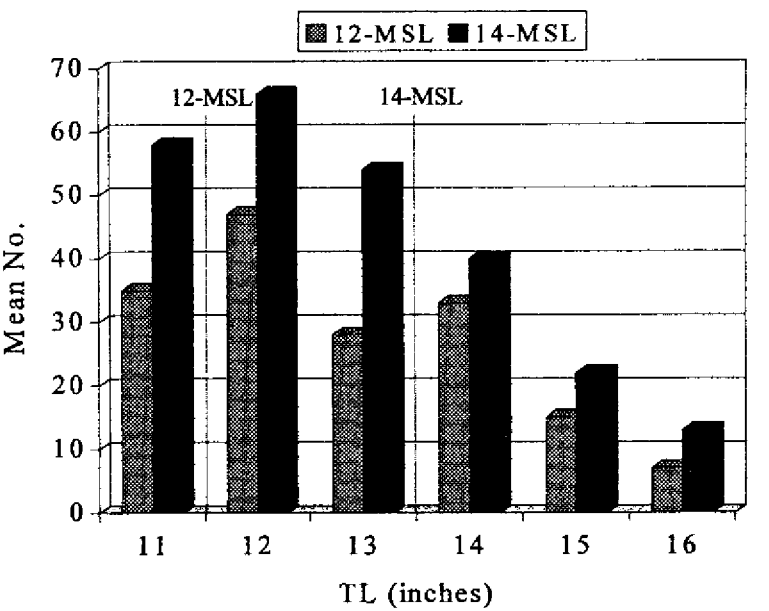


Figure 4. Mean numbers at length for spotted seatrout landed in Mississippi (source: MRFSS).

The purpose of the GCRL monitoring program was to attempt to provide an accurate sample of the state's adult/sub-adult spotted seatrout population. Fish are generally subject to capture by the independent sampling gear at approximately nine inches TL and longer. An increase in the numbers of fish in each size interval, with the exception of the MRFSS data for 12- and 13-inch fish under the 12-MSL, was observed after the establishment of the 14-MSL, and both groups of data illustrate higher abundances of larger fish in Mississippi's population of spotted seatrout.

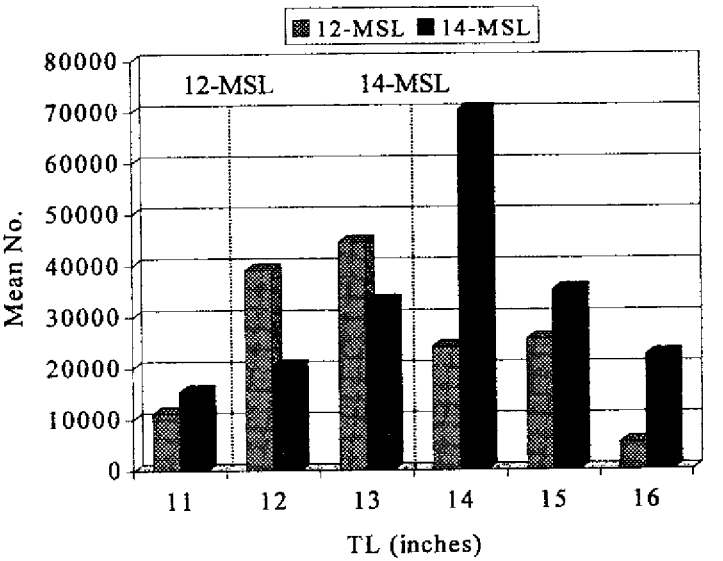


Figure 5. Mean numbers at length of spotted seatrout in Mississippi (source: GCRL).

Trends in Numbers at Age (GCRL Data)

As with length data, numbers at age of spotted seatrout also rose substantially with the implementation of the 14-MSL (Figure 6). In particular, mean abundance of age-1 fish rose from 132 fish under the 12-MSL to 230 fish under the 14-MSL (74% increase), while mean abundance of age-3 fish more than doubled from 15 to 34 fish, respectively. Total numbers of age-1 fish per year is used as an "annual index of recruitment" into the fishery, and these data also show the general trend of increasing abundance from the 12-MSL to the 14-MSL (Figure 7). These data are of particular interest to fishery managers as they provide an insight into the general "health" of the population, and the increases observed under the 14-MSL suggest a population of increasing numbers.

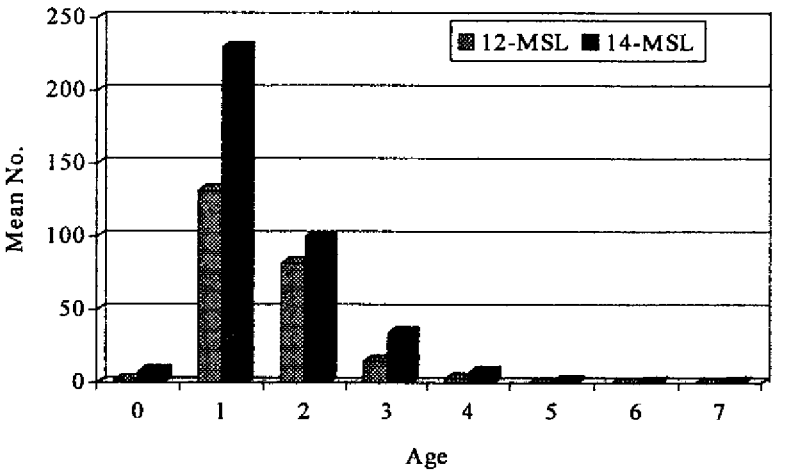


Figure 6. Age structure of spotted seatrout in Mississippi (source: GCRL).

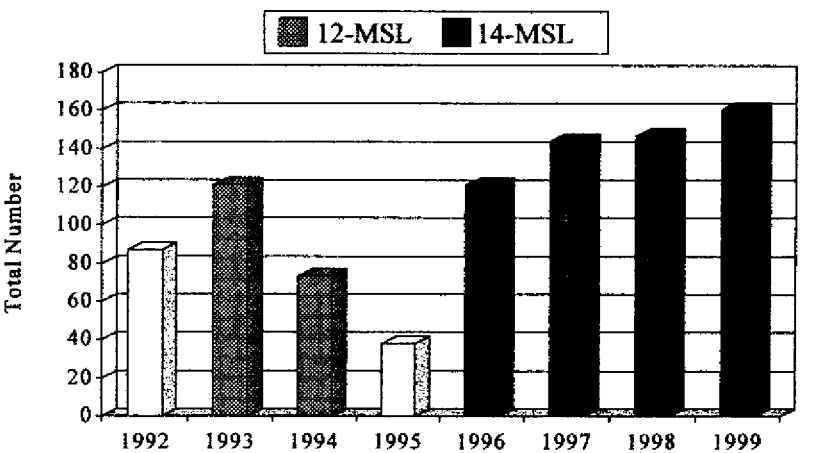


Figure 7. Annual abundance of age-1 spotted seatrout in Mississippi (source: GCRL).

DISCUSSION

Two management tools, the minimum size limit and daily bag limit, have been used by Mississippi fishery managers to regulate the state's important spotted seatrout fishery. Based on catch-per-unit-effort data, the DBL seems to have been of little significance in recent regulation of this fishery. Therefore, an assessment of effective management methods for Mississippi spotted seatrout was obtained by evaluating population dynamics when the fishery was under essentially a 12-inch MSL versus a 14-inch MSL.

In an attempt to remove environmental variation from this assessment, comparisons of surface water temperature, dissolved oxygen and salinity were made between the two management periods evaluated. Water temperature did not differ between the two groups of data, but differences in dissolved oxygen and salinity were detected. Dissolved oxygen levels were statistically higher for the 12-MSL period, and it is unlikely that the lower levels observed for the 14-MSL period would result in increasing numbers of fish. The salinity observed for the 14-MSL period averaged three parts per thousand higher than that for the 12-MSL, however mean salinity since 1993 remained fairly consistent until 1999 when average salinity in the Mississippi Sound increased almost five parts per thousand due to unusually dry summer conditions (Figure 8). Because numbers of spotted seatrout collected in the GCRL program showed a decline in 1999 during this period of higher salinity (Fig.ure 3), it can be surmised that the higher salinity for the 14-MSL period likely had little effect on increasing numbers of fish.

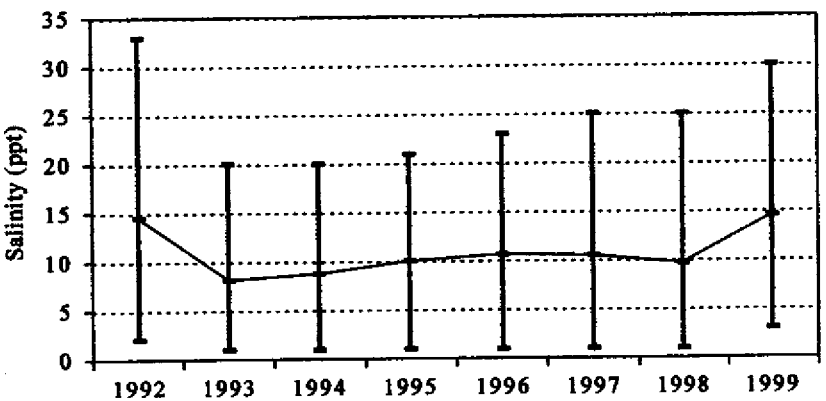


Figure 8. Mean annual salinity (‰) of the Mississippi Sound (source: GCRL). Vertical bars represent range of values observed.

Data from both fishery-dependent and fishery-independent sources illustrate the importance of maintaining an appropriate MSL to effectively manage an exploited fishery. Increasing the MSL on spotted seatrout in Mississippi from essentially 12-inches to 14-inches resulted in not only more fish in the population but also larger fish in the population. Consequently, anglers harvested not only a greater number of spotted seatrout from 1996 to 1999 but also a greater number of larger fish. In addition, based on the number of age-1 fish collected annually, the increase in the MSL equated to an overall larger population and fishery, even in the midst of escalating fishing pressure (based on annual license sales) and increases in spotted seatrout landings along the Mississippi coast.

The observed population trends after the increase in the MSL can probably be attributed in part to the subsequent increase in spawning stock biomass in the population. GCRL data suggest that spawning characteristics of this species are probably the governing component in the increase in population size relative to the higher MSL. Management of a fishery should attempt to allow sufficient numbers of fish within a population to have the opportunity to spawn. For spotted seatrout in Mississippi, this suggests that at least a 14-inch MSL be maintained (Figure 9). Samples to date illustrate that 100% of fish at or above 14-inches TL had evidence of spawning based on post-ovulatory follicles (POF) or final oocyte maturation stage (FOM), while only 43% of 12-inch fish and 66% of 13-inch fish displayed such characteristics (Warren et al., 2001). By allowing more fish under 14-inches to spawn before recruitment into the fishery, the overall potential for egg production in the population is greatly increased, thus enhancing successive year classes. Batch fecundity is broadly defined as the number of eggs spawned per female during one spawning event. Batch fecundity generally increases with fish size, as is the case with spotted seatrout. GCRL data indicate that batch fecundity for female spotted seatrout in Mississippi waters averages around 66,000 eggs per spawning event for 12-inch fish and 99,000 eggs for 13-inch fish, while fish between 14- and 16-inches average well over 101,000 eggs per spawn (Warren et al. 2001). Because spotted seatrout spawn multiple times per year, a single female at any of these sizes is capable of releasing over half a million eggs in any given year.

Future year class success for spotted seatrout is based on numbers surviving to maturity and successfully spawning. Spawning production is further mediated by spawning output by size. Nearly half (48%) of all fish sampled in the GCRL monitoring program measured between 11.0- and 13.9-inches TL. Batch fecundity is somewhat low for this size range when compared to those ≥ 14-inches, as less than two-thirds of fish ≤ 13.9-inches TL are capable of spawning (Brown-Peterson and Warren 2001). However, the lower output per fish in the 11- to 13-inch size range is offset by the higher numbers of fish within this range. The GCRL fishery-independent data provide an index of relative abundance for each length interval that is considered representative of Mississippi's spotted seatrout population. Assuming equal spawning frequency among the 12- to 16-inch size intervals, an index of mean egg production per spawning batch for each size interval can be estimated with the following equation:

$$\text{Index of } \bar{x} \text{ Egg Production Per Batch}_{\text{size interval x}} = [(\bar{x} \text{ eggs per batch}_{\text{size interval x}})*(\bar{x} \text{ abundance}_{\text{size interval x}})] * [\% \text{ mature}_{\text{size interval x}}]$$

A proportional comparison of the products of this equation shows the almost equal contribution of the pooled 12- and 13-inch fish (46% of total eggs produced) and the pooled 14- to 16-inch fish (54%) to the overall egg production of the 12- to 16-inch spotted seatrout in Mississippi. This size range of fish constitutes over 70% of the mature fish in the population, based on GCRL population data. Under the 12-MSL, the 12- and 13-inch fish constituted the majority of the recreational catch in Mississippi (Figure 4), whereas they are prohibited from being removed from the population under the 14-MSL.

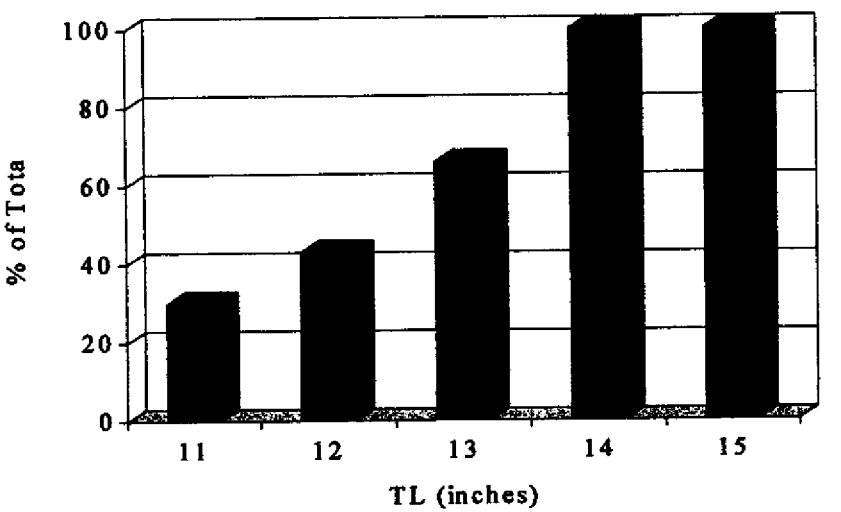


Figure 9. Percentage of Mississippi spotted seatrout with evidence of spawning (source: GCRL).

The 14-MSL has been in place for Mississippi's spotted seatrout fishery for almost five years. During this time, almost one-third of the fish sampled in the recreational fishery were not of legal minimum size (Figure 4). Increased enforcement of management regulations and enhanced compliance would further benefit the fishery by reducing the numbers of fish within these important size classes which are illegally removed from the population. While it is probably not realistic to totally eliminate the retention of undersize fish in a recreational fishery, effective management cannot be achieved without appropriate enforcement.

In 1997, regulations governing Mississippi's commercial fishery for spotted seatrout were revised to require that all gill and trammel (entangling) nets be constructed of a biodegradable material. Because nets made of such material were

not readily available, there was a gradual shift in the commercial fishery from entanglement nets as the primary harvest gear to hook and line, which theoretically allows undersize fish to be released alive. Although Mississippi's commercial fishery for spotted seatrout has historically constituted only around 8% of the statewide catch, gains in the state's spotted seatrout population size since 1997 may be attributable in part to the gradual decline in the use of entanglement gear.

In conclusion, proper management of a fishery should be based on sound, scientific information. When properly formulated, effective management measures such as minimum size limits can maintain and even improve an exploited fishery population, even in the face of increasing fishing pressure. Although the daily bag limit did not appear to be a major determinant in managing Mississippi's recreational spotted seatrout fishery over the past ten years, many fisheries rely on this tool, and it can be effective. For Mississippi's spotted seatrout fishery, increasing the minimum size limit from 12-inches TL to 14-inches resulted in a larger population, as evident by the increase in the total numbers of fish, the average size of fish and the numbers per size interval. The additional egg production resulting from the 12- and 13-inch fish which are now retained in the population is likely the primary reason for the increase in spotted seatrout numbers in Mississippi.

ACKNOWLEDGMENTS

We thank the Mississippi Department of Marine Resources, particularly Michael Buchanan and William "Corky" Perret, and the U. S. Fish and Wildlife Service, Sport Fish Restoration Program for their continued funding of the spotted seatrout research conducted at the GCRL. The instructive review comments provided by Jim Franks of the GCRL and by Michael Buchanan and Corky Perret were greatly appreciated. We are also grateful to Lisa Hendon of the GCRL for her contributions to this research.

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An Economic and Social Assessment of the Flying fish (pelagic) Fishery of Tobago, Trinidad and Tobago

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ABSTRACT

The oceanic pelagic fishery has historically been the most important commercial fishery of national importance in Trinidad and Tobago. The flying fish fishery accounts for about 70-90% of the total weight of pelagic landings at beaches on the leeward side of Tobago (Pandohee 1996). Fishing effort is seasonal from November of one year to July of the next year. The flying fish fleet consisted of about 75 pirogues and one iceboat between 1988 - 1991. It employed approximately 125 fishermen. Fishing practices involved the use gillnets, small dip-nets and the occasional hook-and-line method. The latter was used to obtain fresh bait needed in the capture of larger pelagics. Landings for the 1990/91 fishing season were estimated at about 359 mt, with an ex-vessel value of at least TT$395,000, and a retail value in excess of TT$790,000. Catches were landed at five locations where they were transported by jeeps and "pick-up vans" to the three processing plants on the island at the time. Approximately 75-80% of the processed flying fish continues to be exported. The major portion goes to Barbados and other Caribbean islands. In 1991, one processor secured an order of 40 mt whole flying fish to Japan. Management strategies pertaining to this fishery focus on defining the limits of foreign fishing effort. In January 1991 Trinidad and Tobago and Barbados signed a fishing agreement, which included provisions for Barbadian flying fish vessels to operate off Tobago (Samlalsingh et al. 1992). The pelagic fleet originally consisted of open wooden (bumboats) sailing boats of about 12ft in length, propelled by oars. Following extensive damage to the fishing fleet by hurricane Flora in 1963, and supported by the provision of credit facilities and subsidies by the government, the fleet was largely replaced by motorized vessels (as per records of the Department of Marine Resources and Fisheries, THA).

All coastal communities around the island depend greatly on the fishing fleet and their activities for daily fish sustenance. This has given rise to small (processing) cottage industries, which contribute to supplementing household income. One cottage industry can at times produce, as much as, 90-108lbs of processed flying fish on a daily basis. With the national unemployment rate at 21%, many young men upon completing their secondary school education choose to go into fishing as a career. Only a small percent operate full-time. The majority work for a relative or for some other investor on a regular or part-time basis. Retirees purchased vessels

and hire crew to work, thereby adding to the investment in a growing industry. Training toward obtaining the launch captains and engineers license is an on-going activity. The principal Trainer is a member of the staff of the Department of Marine Resources and Fisheries. The Maritime Services Division conducts examinations twice yearly.

Continued poaching of our country's fishing resources by neighboring countries and some international fishing fleets is of concern, especially with respect to sustainability of the biomass and its ability to support Trinidad and Tobago's need for fish in years to come. Recognizing the need for effective surveillance and management of the fishery resource under each country's jurisdiction, the FAO/UN Code of Responsible Fisheries, Rome 1995, was produced. Article 7, Section 7.1.7 of the document reads: "States should establish, within their respective competencies and capacities, effective mechanisms for fisheries monitoring, surveillance, control and enforcement to ensure compliance with conservation and management measures, as well as those adopted by sub-regional or regional organizations or arrangements". Article 7, Section 7.1.8 reads: "States should take measures to prevent or eliminate excess fishing capacity and should ensure that levels of fishing effort are commensurate with sustainable use of fishery resources as a means of ensuring the effectiveness of conservation and management measures". Against this background the Government of Trinidad and Tobago, in conjunction with the Tobago House of Assembly may initiate discussion with neighboring states re the issue of bilateral fishing agreements.

KEY WORDS: Flying fish, fisheries assessment, socio-economics, Trinidad and Tobago

INTRODUCTION

The fishery resources of Trinidad and Tobago have been put under severe fishing pressure, due mainly to poaching by foreign fleets. Tobago's flying fish and associated ocean pelagic resources are constantly poached between the months of November of one year to June of the following year by neighboring states. Some regional countries are convinced that Tobago is the land of "never ending" flying fish resource. This cannot be taken for granted unless comprehensive assessments of the biomass are done over time and using all the available scientific approaches at our disposal.

The flying fish ("drift") fishery of Tobago prior to the 1960s was very important for the supply of baitfish. This bait was used in the trolling fishery to catch the larger oceanic pelagics associated with the flying fish, such as tuna (*Thunnus albacares*), dolphin fish (*Coryphaena hippurus*), and wahoo (*Acanthocybium solandri*). The flying fish fishery is now of great importance to Trinidad and Tobago as well as the wider Caribbean. Tobagonians learned the important techniques required to catch and de-bone the flying fish from Barbadian fishermen as early as 1962 (R. Morsehead, pers. comm.). Flying fish landings for the period 1979 to 1982

were recorded at 860,833lbs (Table 1), with an ex-vessel value of TT$430,416.50 and a retail value in excess of TT$860,833. Landings of larger pelagics were recorded at 40,741lbs, with a retail value of TT$164,975. Most of the catch was marketed locally through a vessel collector system.

Table 1. Estimated landings of flying fish: 1979 to 1999 Fishing Seasons. Empty cells represent a year with no record. (There is no data for the period 1983-1987).

Season	Flying fish (kgs)	Total Landings (kgs)	% Total Landings
1979	7,251.9	-	-
1980	226,551.4	237,725.9	95.3
1981	65,556.82	70,911.82	92.4
1982	91,927.73	93,916.82	97.9
1983 - 1987	-	-	-
1988	165,868	224,787	73.8
1989	159,104	201,703	78.9
1990	305,104	379,441	80.6
1991	292,711	373,336	78.4
1992	415,484	480,443	86.5
1993	506,750	559,353	90.6
1994	616,742	717,904	85.9
1995	199,198	-	-
1996	240,724	-	-
1997	192,668	-	-
1998	216,214	-	-
1999	177,447	-	-

Pandohee, 1993; Pandohee, 1994; Mohammed, 1996; Fisheries Beach Landings (raw data), GORTT & Actual landings 95 – 99, DMR&F, THA.

Fisheries exports contributed about 3% of the gross domestic product (GDP) in 1999. One processing plant purchased approximately 403,438lbs of whole flying fish during the 1998/1999 fishing season. This plant contributed 995,029 fillets in exports to the gross domestic food production (GDFP), which had a value of approximately TT$1,293,537.00. In addition to employing fifty-five (55) persons, the plant also contributed 331,676 fillets to national food security that year.

THE FLYING FISH FISHERY OF TRINIDAD AND TOBAGO, AND ITS HISTORICAL EVOLUTION

Historical

Coastal fishing has been undertaken in Trinidad and Tobago waters for centuries. Fishermen traditionally used wooden boats called 'bumboats' rigged with cloth or canvass sail and two wooden oars for propulsion. One or two fishermen on board utilized a few fishing techniques. They sail their vessel with two lines towing at the stern, or they do banking while at anchor or engage in drift banking for demersals. Fishermen had problems with the eggs of the flying fish (*Hirundicthys affinis*) entangling their lines as they came to spawn. The fish were also attracted to the light from the lamps while fishermen fished at nights. This encouraged the

catching of this resource by scooping them out of the sea with baskets made from roseau bamboo. This fish was initially offered for sale in the whole, since the deboning technology was not yet available and utilized. Due to its bony nature, consumers did not readily accept flying fish though it was considered very tasty. Fishermen realized poor sales when the whole fish was offered to customers.

It was not until the early 1960s, that a Tobago processor/businessman (Morsehead per. comm.) contracted some fishermen from Barbados to teach the skill of de-boning the flying fish to his employees. This skill was quickly learned and transferred to many other persons (mainly women) throughout the various fishing communities in Tobago. This generated much needed employment in the processing sector and increased the exploitation of the flying fish resource.

As the years progressed, fishermen began increasing the sizes of their boats. Instead of 'corking' their wooden vessels with cotton twine between the spaces of the board and using tar inside and out to make the vessel waterproof, the use of fiberglass matting became the material of choice. In 1963, Tobago's fishing fleet suffered extensive damages from hurricane "Flora". The government offered subsidies, as well as credit facilities through the Agricultural Development Bank (ADB) and private commercial institutions to the fishermen. These facilities were utilized to replace the old sailing-type vessels with motorized ones- a transition from wooden 'bumboats' to fiberglass pirogues. These new vessels ranged from 22 - 24 feet in length. Today however, vessel sizes range from 22 - 40 ft and are propelled by outboard gas engines ranging from 15 - 100 hp, as well as inboard diesel engines ranging from 125 to 335 hp (Table 2). Vessels now have bait wells and larger storage holds to carry more fish and ice over a longer period. All open multi-gear pirogues are called day boats, while the larger, hooded, multi-gear vessels are referred to as multipurpose boats, iceboats, or overnight vessels. The gradual increase in landings in the pelagic fishery was realized with the introduction of iceboats. Most countries in the Eastern Caribbean are presently expanding, or intend to expand, their oceanic pelagic fishing fleets, primarily by increasing fishing fleet size but also by changing boat type (Hunte 1995). Thus, the fisheries are moving from "small-scale artisanal" towards "large-scale commercial" operations, with considerably more capital being invested in the fleets today than in the past. Large-scale commercial fisheries catch more fish, but they do so at a price. Compared with small-scale artisanal fisheries, they employ far fewer fishermen, the capital cost of each job on a fishing vessel is far greater, considerably more fuel is consumed overall, and typically fewer fish are harvested per ton of fuel consumed.

The fishing trade is fast losing its stigma as being a 'poor man's' job, or one for dropouts of the education system, where it is chosen as a last resort after they cannot find 'white collared' jobs. Over the last five (5) years, many young men upon leaving school go directly into fishing as a career.

Table 2. Propulsion System (Engines)

Engine Type	Horse Power													
	40	45	48	55	60	65	72	75	100	130	200	225	335	Total
Yamaha*	-	-	10	31	2	-	-	6	-	-	-	-	-	49
Mariner*	2	-	-	7	2	-	-	-	-	-	-	-	-	11
Johnson*	-	-	-	-	-	2	-	-	-	-	-	-	-	2
Evinrude*	-	2	-	2	-	-	-	-	-	-	-	-	-	4
Ford+	-	-	-	-	-	-	2	-	-	-	-	-	-	2
Detroit+	-	-	-	-	-	-	-	-	-	-	-	1	1	2
John Deere+	-	-	-	-	-	-	-	-	-	1	-	-	-	1
Volvo Penta+		-	-	-	-	-	-	-	-	-	1	-	-	1
Total	2	2	10	40	4	2	2	6	0	1	1	1	1	72

*Gasoline Outboard Engine; +Diesel Inboard Engine

Some of the following reasons were given as to why they chose fishing as their sole means of livelihood;

i) They have experience as part of being a crewmember on fishing trips,
ii) They grew up on the beachfront and in a fishing community,
iii) Family members have vessels engaged in fishing,
iv) They see it as something worthwhile, which gives them independence,
v) They have the ability to earn a living and have some financial security, and
vi) They have a real career choice.

Technological

Advances in technology in the flying fish industry in Tobago from the early beginnings in the 1960s have been gradual. Today, there are four (4) major and three (3) minor fish processing plants in the Southwest that process the flying fish. Fish processed from these plants are sold locally, nationally, regionally, and internationally. Many small cottage-type industries exist and they contribute significantly to the Gross Domestic Product. All processed fish are consumed locally from these cottage-type industries.

The vessels initially used ranged from 8 to12 feet in length and had one ended or double ended bows. These fishermen were mainly subsistence fishers who had other means of income to support their families. Children assisted their parents (and the activity of 'lend hand' became very popular) in the mending of nets, hauling nets, mounting lines and nets, and repairing boats.

The Department of Marine Resources and Fisheries in collaboration with Caribbean Fisheries Training and Development Institute (CFTDI) embarked on an island-wide extension service and training programme to train interested persons and fisherfolk in the capture, processing, storage, and marketing of the flying fish. This was facilitated by the re-institution of the collection of catch and effort statistics in Trinidad and Tobago under the Eastern Caribbean Flying fish Project and funded by International Research Centre of Canada (IDRC) of Canada. Today, the government of Trinidad and Tobago, in collaboration with the Japanese government/JICA, continues to train fisherfolk in fishing technology, fish handling and processing, engine repairs and maintenance, and marine fisheries resources management.

Socio-Economics

Flying fish were previously taken as a by-catch and contributed greatly to the discards of the fishery because there was little knowledge on how to use the resource. This changed over time and now flying fish constitute a very valuable commercial resource. Although small in body size, the flying fish constitutes the highest fishery product by volume and weight when landed. Households near or within the fishing communities depend largely on the flying fish trade for their livelihood. Some persons possessing the skill of de-boning the flying fish can be seen at landing sites receiving a few pounds of fish after assisting with offloading or cleaning the vessel. Both women and men get into the fray to de-bone flying fish at

the landing sites with fishing centres, for a fee, and encourage the increased consumption of flying fish. An untold number of fishers are engaged in this practice, and contribute significantly to the labor force, and subsequently the reduction in the unemployment rate on the island.

In the 1970s the local fishing industry underwent rapid expansion due to increased investment from both private and government sectors. The construction of a dry goods and cold storage complex in the southwest area of Tobago resulted in further development of the processing industry. Over the years processors used this facility for the storage of whole and processed fish. Presently, all processors have acquired their own in-house cold storage facilities due to high storage costs and the frequent failure of the private plant.

The boat building and repair industry in Tobago is almost nonexistent. Only one boat building and repair shop exists in the northwestern end of the island. Many fishers are now able to repair their own vessels because of frequent training sessions facilitated by the government and private entities. In Trinidad numerous boat building and repair shops exist. These also facilitate fishermen from Tobago who may need their services.

The private, commercial, and public lending agencies, such as credit unions and the ADB, continue to invest in the fishing industry in providing loans for boats and engines. The fisheries department provides extension services (e.g. boat, engine, and fishermen registration) and facilitates the incentives that are offered by government for commercial fishing such as the waiver of Value Added Tax (V.A.T) and gas rebates. The provision of ten (10) fishing centres around the island gives support to the industry. These contain lockers for the storage of engines and other gear and tackling. Water and electricity are also provided at no cost to the fishermen, and all operational costs are borne by the State. Some fishing centres have cleaners, and at times other times cleaning supplies are procured for the fishermen to keep the fishing centres in a clean and sanitary condition.

THE FISHING FLEET

Structure and Size of Fishing Fleet

Tobago's flying fish fishermen practice towing one to two lines either at the stern of the vessel or on two bamboo poles on the port and starboard side as the vessel travels to the fishing ground. On reaching the fishing grounds (5 – 30 miles from shore), and from any point along the western or northwestern (Caribbean Sea) side of the island monofilament nets between 4 - 7 meters long and about 2 - 2.5 meters deep are deployed. The nets are secured on the port side of the vessels. Fish attraction devices (FADS) are also deployed with these nets and about 6 - 8 nylon lines, each about 30 - 60 meters long are also used with one hook each. The drift and trolling fishery is pursued by about 228 fishermen from approximately 126

pirogues and [1]ice-boats (6 - 12 m in length), most of which are powered by either out board gas engines (2 x 30 - 75 hp) or diesel inboard (75 - 335 hp) engines (larger vessels). The typical crew consists of one to two fishermen for the pirogues and two to three for the ice-boats. The pirogues (day boats) fish for a period of one day. The larger multipurpose vessels fish for three days, with a two-day rest period. Fishing activity begins from as early as 6 a.m. to as late as 9 p.m. the same day (10 - 15 hours) for the day boats, and to some 72 hours later for iceboats.

The flying fish season runs from as early as November of one year until late July of the following year, while the trolling season begins as soon as the flying fish season ends (July to November). It is mainly concentrated in the southwestern part of the island and includes fishermen from the ports at Buccoo Point, Mt Irvine, Pigeon Point and Scarborough. Fishermen between Castara and Charlotteville fish from the head of the island to Sisters Rock from January to December, and fishermen from Speyside, Roxborough, Studley Park fish between Little Tobago and Bacolet Point from January to December. Some fish potting is done within the two seasons during the year. Multi-gear fishing is practiced throughout.

Fishermen secure loans from the local Agricultural Development Bank (ADB) at interest rates ranging from 15% to 17% per annum, as well as, from commercial banks at rates of 15 to 19%. A fisherman needs to procure at least 30% of his finance before he can secure the rest in loan funds from the lending institution. The loan repayment period ranges from 5 - 7years for boats and 1 - 3 years for engines. Each client requiring a loan is treated on an individual basis and the lending rate increases as the risk increases.

There is a share system in effect for catch distribution between the boat owner and crew. The following is applicable to the Southwest Tobago:

i) 50%-50% - (catch divided into two, between the boat and crew; or 50% for boat and the other 50% divided among owner, captain and crew)
ii) 60%-40% - (catch divided into two, 60% for owner/boat and the other 40% among the crew)

There are several fisher-folk organizations on the island. These include:

i) Castara Fishermen's Association
ii) Parlatuvier Fishermen's Association
iii) Tobago Marketing Cooperative Society
iv) Tobago Fishing Coop. Soc. Ltd
v) Tobago Fishermen Federation
vi) Studley Park Fishermen's Association
vii) South West Tobago Fishermen's Association
viii) Roxborough Fishermen's Association
ix) Bloody Bay Fishermen's Association

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[1] Iceboats are large multi- purpose vessels that can stay out at sea for long periods (2 days or more).

x) Blackrock/Plymouth Fishermen's Association
xi) All Tobago Fisherfolk Association (ATFA – The umbrella body for all fisherfolk organizations).

Other Notable Socio-cultural Information

i) The Tobago Fishing Cooperative Society Ltd., in Charlotteville is the only one that operates a gas station and tackle shop, a mini-mart, and process a small percentage of fish.
ii) Primary education and primary health facilities are easily available to all throughout the island. There are five health centres, ten primary schools, five secondary schools, one UWIDITE campus, a technical school and a community college in southwestern Tobago.
iii) Housing communities set up by the National Housing Authority and private investors exist throughout the island. These facilities are accessible to all those who wish to acquire land or property. In the Southwest five of such communities exists (Bon Accord, Mt Pleasant, Buccoo, Old Grange, Signal Hill and Friendsfield).

DISTRIBUTION AND MARKETING OF FLYING FISH

Upon arrival at the landing site, the flying fish from the ice-boats are put into sturdy plastic (80 - 100lbs) baskets then offloaded into large plastic bins on the processors' truck, where they are iced before being transported to the processing plants. Some day boat fishermen who have their own private vehicle usually make arrangements to deliver their catch to the plant, while the catch from other fishermen are picked up by the processor. The processor buys the catch at wholesale prices and pays the fishermen at an agreed time.

Some flying fish and associated large pelagics are offered for sale to the public at the landing sites. Some fishermen will have a sales-person at the site to conduct retail sale, while other fishermen do the sales themselves. Some hawkers (fish vendors) with vehicles buy large pelagics at a higher wholesale price than the processors. These vendors will truck the fish around through the villages for sale at retail prices. Fish taken to processing plants is processed, packaged and sold to local supermarkets, as well as, exported to Trinidad, other Caribbean countries, Canada, Europe, the United States, and Asia.

INSTITUTIONAL, POLICY AND MANAGEMENT ASPECTS

Open-access fishing has been common practice in Trinidad and Tobago's waters for decades. It has been rumored that the waters around Tobago have enormous quantities of fish to supply its people for decades. It has been said, "we have a billion dollar industry just waiting to be tapped". There have been many requests from various international companies wanting to fish or to set up processing plants in Trinidad and Tobago. The government through its fisheries division (Trinidad)

and department (Tobago) and the proactive fishing communities have seen the need to conserve and preserve their fisheries resources by looking at the best management options. Policies are being devised toward management of the archipelagic waters within the unitary state with specific reference to management the policies regarding the flying fish resources within the territorial waters and the 200 mile exclusive economic zone of Tobago.

In 1991 the government of Trinidad and Tobago entered into a bilateral fishing agreement with the government of Barbados to fish for flying fish and other large pelagics in the waters around Tobago. This fishing agreement ended, and since then no other agreement has been established. Government must, and should move to get the proper tools to ensure effective surveillance of its territorial sea, update fisheries legislation, and provide the basic infrastructure (landing facilities and fishing centers) for fishermen to carry out their daily operations in the various fishing communities.

CAPITAL INVESTMENT, INCOME AND EXPENDITURE IN THE CAPTURE SECTOR

The Department of Marine Resources and Fisheries collects catch and effort data from 25% of the landing sites around Tobago. Not all of the landings however, are recorded because of severe personnel shortage and time constraints. Interviews with fisherfolk confirmed information on fuel, ice, food and maintenance costs. Catch value was calculated using figures from the Fisheries Division that has been monitoring market prices since 1979.

Most of the boat owners interviewed had no insurance coverage but supplied data on the loan structures from the commercial banks and the Agricultural Development Bank (ADB). These loan structures were confirmed with the Agricultural Development Bank.

Capital Investments

The current cost of a fully equipped day-boat is approximately TT$72,000.00 while a typical iceboat (including gear and equipment) built in Trinidad and Tobago costs around TT$400,000.00. As shown in Table 3, a bank loan at the ADB for up to 70% of the boat value may be obtained for a fishing boat, at an annual interest rate of 16% for all vessels (the related information is shown in Table 3). For loans that are repaid evenly over the 5 years on a typical day boat, the annual repayment cost to the principal would be TT$10,080. Annual interest cost at 16% would be TT$8,064.00 for the first year devaluing to TT$1,612.80 in the fifth year.

The loan requirements for an ice-boat are shown in Table 3. The annual repayment cost to the principal would be TT$40,000. Annual interest cost at 16% would be TT$44,800 for the first year, depreciating to TT$6,400 in the seventh year.

For the typical [2]iceboat, insurance is TT$8,000.00 per year. The life of a fishing vessel is taken as approximately 15 years for a typical day-boat and 25 years for a typical iceboat. Depreciation costs for the vessel and the cost of the engines for both fishing vessels are shown in Table 3.

Table 3. Summary of estimated average costs (TT$) of a typical day-boat and a typical iceboat in the Tobago pelagic fishing fleet.

Cost	Day-Boat	Ice-Boat
Capital: average total	72,000	400,000
Loan:		
Maximum loan (% value)	70	70
Maximum loan ($ value)	50,400	280,000
Max. Repayment time (yrs)	5	7
Interest rate (%)	16	16
Average annual repayment	10,080	40,000
Insurance: annual premium	-	8,000
Depreciation: annual	400	2,304
Hull and engine (annual)		4,000
-		
Gear (annual)	3,500	6,000
Expenditure/Operational:		
Fuel/Oil (per trip)	400	500
Fuel (annual)	80,000	32,000
Ice (per trip)	-	2,900
Ice (annual)	-	17,400
Food (per trip)	50	600
Food (annual)	10,000	32,400
Fishers ID Renewal	10	30

[1]Day- boats rarely carry ice. In the pat five years, the Department of Marine Resources and Fisheries has made a concerted effort to educate the fishers on the importance of icing the fish caught

[2]Only 1 boat owner interviewed confirmed that he possessed insurance. Most ice-boats owners in Tobago have no insurance coverage. Insurance for day boats (pirogues) is done in Trinidad.

Expenditure/Operating Costs

All the maintenance costs and expenditure are shown in Table 3. Food supplies for each crewmember is minimal for day-boats, being TT$50.00 per trip. The annual cost of crew supplies is therefore TT$10,000. Food supplies for the three-man iceboat crew is TT$600.00 per trip. The annual cost of food supplies is therefore TT$32,400.

Landings and Income

Catch rates vary annually, reflecting variation in fish abundance due to market forces at the time, sea conditions in the year and weather conditions from time to time. However, from interviews with the fishermen the average catch of flying fish per trip is approximately 2,000lbs and large pelagics 150lbs for a typical day-boat. The average annual catch of flying fish per vessel is 400,000lbs and large pelagics at 30,000lbs for a typical day-boat. This gives a catch per metric ton of fuel consumed of 117.6 MT of flying fish and 8.8 MT of large pelagics for the day-boats. The catch of flying fish from a typical iceboat per trip averages 3,700lbs and large pelagics at 1,244lbs. The average annual catch of flying fish is 236,800lbs and 79,616lbs of large pelagics per iceboat. This gives a catch per metric ton of fuel consumed of 15.6 MT of flying fish and 5.2 MT of large pelagics per iceboat. This means that the former is considerably more favorable at present because of the greater number of trips per unit; as such day-boats are more productive and more efficient than ice-boats in terms of catch per unit effort and not necessary in terms of unit of fuel consumed. Analysis of costs and benefits for an average flying fish unit is given in Table 4.

OVERALL EVALUATION OF TOBAGO'S FISHING INDUSTRY

Fishing is an important though relatively under developed industry in Tobago. It is by far the main economic support for many coastal communities around the island. Records from the Department of Marine Resources and Fisheries, Division of Agriculture, Marine Affairs and the Environment show that there are twenty-two (22) major landing beaches, ten (10) with fish landing centres. There are onethousand and thirty-nine (1,039) registered fishermen operating six hundred and ninety-four (694) fishing boats (including ten (10) multipurpose fishing vessels). They harvest some nineteen (19) species of fish and shellfish utilizing eleven (11) different fishing methods from the marine environment around Tobago. The estimated total catch recorded from 1996 was 182,706kg (182.71 metric tonnes). A large proportion of the fish caught off the waters of Tobago is processed and marketed locally, regionally and internationally by some ten (10) fish processing plants on the island.

Table 4. Analysis of Costs and Benefits for an Average Flying Fish Unit with Depreciation Standardized (EC$)

Country	Tobago *	
Vessel Type	Dayboat	Iceboat
Total value of Investment:		
Boat	12,711	127,110
Engine	16,948	21,185
Gear	847	21,185
Total	30,506	169,480
Income:		
Flying Fish	338,960	200,664
Other Species	88,977	236,133
Total	427,937	436,797
%ff	79	46
Expenditure:		
Fuel	33,896	13,558
Oil		
Ice	0	78,639
Food	4,237	16,270
Market Fees	0	0
License	4	13
Crew shares	192,572	196,559
Vessel Insurance*	0	565
Social Insurance	0	0
*Maintenance & Repairs:		
Boat*	1,130	5,084
Engine*	0	1,525
Gear	1,483	2,542
Total	2,613	9,152
Other Costs	0	0
Total Costs/Expenses	233,322	314,756
Gross Cash Flow	194,615	122,042
Depreciation:		
Boat*	847	8,474
Engine*	5,649	4,237
Gear	424	7,062
Total	6,920	19,773
Interest Charges*	1,224	10,204
Net Cash Flow	186,470	92,066
Return on Investment (%)	611	54
(Net Cash Flow/Total Investment)		

Tobago: 2/3 (8 months/12months) of the costs (for dayboats ONLY, and NOT iceboats) are attributed to the flying fish and large pelagic

The fishing activity in Tobago is mainly artesional and seasonal. The main species caught include: flying fish, albacore, anchovy, barracuda, bonito, cavalli, dolphin fish, grouper, silver snapper, jacks, kingfish, lobster, marlin, chub, salmon, shark, ocean guard, tuna, wahoo and red snapper. The snappers and groupers though fished all-year by some fishermen are caught mainly during the period June to December. The flying fish (the main specie targeted) and other species associated with this fishery: Dolphin fish, albacore, yellowfin tuna, sail fish, shark, and marlin are mainly caught during the period November to July. It is estimated that the flying fish fishery accounts for some 75% of Tobago's fishing industry. This is also reflected in the similar figure seen in the ADB's entire loan portfolio in Tobago (75%), as well as, the overall percentage of all agro-products exported from this island (80%). Flying fish is important to Tobago, and there has been capitalization for the industry on the island. Flying fish is therefore needed all year to sustain this capitalization.

Small, open-deck vessels, 7 to 9 meters in length and constructed from wood or fiberglass (pirogues/bum boats) make up the majority of the fishing fleet. Outboard engines commonly ranging from 45 to 90 horsepower (Hp) propel them. The vessels are usually without modern equipment, communication systems or cold storage facilities.

IDENTIFIED NATIONAL ISSUES OF REGIONAL RELEVANCE FOR FLYING FISH MANAGEMENT

National issues of regional relevance for the management of flying fish are important for the entire fishery. The development of Tobago's Fishing Industry has suffered many set backs over the years. Among the many factors inhibiting the fishing industry's growth and development are the following:

i) *Weak Administration* — Inadequate institutional capacity for the administration of the Fisheries Sector. Inadequate fisheries surveillance and enforcement capacity,

ii) *Inadequate Infrastructure* — Sub-standard or non-existent fish landing port facilities at the main fish landing sites. Adequate facilities are required at landing sites to facilitate commercial fishing and to meet both ISO and HACCP standards,

iii) Sub-standard or non-existent cold storage and fish holding facilities at the main seaport and airport,

iv) *Inadequate Technology* — Limited post harvest management technology, necessary to ensure quality and reduce wastage of fish. Insufficient training done- this is needed so as to suitably qualify fishermen and processors in quality assurance, marketing etc.,

v) *Other* — The need for improved cooperation among fishermen, processors and other users of the resource cannot be over-emphasized. There have

been positive steps in this direction with the formation of the All Tobago Fisher-folk Association (ATFA) and the regular meeting of the Fishing Industry Group chaired by the Department of Marine Resources, THA and facilitated by TIDCO, Tobago;

vi) Limited or non-existent national standards to ensure international market compliance of the local fish and fishing product, and

vii) Problems re access to beaches, as well as the provision of adequate facilities for the industry at some landing sites.

ACKNOWLEDGEMENTS

Gratitude is extended to Ms. Andre Henry who helped with the interviews, Mr. Terrence Holmes, Fisheries Assistant who assisted in verifying costing and expenses for the fishing fleet and Ms. Keisha Henry for reviewing the draft. In addition, our sincere gratitude goes out to the many fishermen and boat owners who participated in the survey and provided the much-needed information towards preparation of this report.

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Session Introduction: Conservation of Multi-species Reef Fish Spawning Aggregations

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Most commercially important reef fish species form transient spawning aggregations at specific times and locations in order to reproduce. These aggregations are extremely vulnerable to overfishing. Spawning aggregations of the most well studied species, nassau grouper, have been heavily overfished, and in some cases, extirpated. Spawning stock surveys at nine aggregation sites in Belize during January 2001 revealed six nassau grouper aggregations as critically threatened, with less than 400 individuals, and the healthiest site had less than 6,000 fish, just a fraction of historical aggregations. Several other species were aggregated at and during the nassau grouper aggregations. In addition, a single promontory harbored 26 reef species spawning aggregations through various seasons suggesting that promontories used for spawning by one species, may be used by many species. Examples of multi-species spawning aggregations at reef promontories and channels can also be found in Mexico, Komodo, and Palau. It is possible that the oceanographic, bathymetric and physical oceanographic characteristics of these promontories and channels make them optimal locations for spawning for a variety of reef species. The time and location of two spawning aggregations was predicted using satellite imagery and a knowledge of the seasonality of spawning by species and verified in the field. These techniques might help reveal additional spawning sites throughout the region. Reef promontories, harboring multi-species spawning aggregations should figure more prominently in marine reserve designs.

KEY WORDS: Spawning aggregations, conservation

Conservación de las Agregaciones Reproductivas Multiples de Especies Arrecifales

Las especies de mayor valor comercial en los arrecifes de coral forman agregaciones reproductivas transitorias en momentos y localidades específicas para reproducirse. Estas agregaciones son extremadamente vulnerables a la sobrepesca. Agregaciones reproductivas de la especie más estudiada, el Mero de Nassau, ha sido sobre pescada, y en algunos casos, exterminada. Muestreos en nueve sitios de agregación en Belice durante enero 2001 reveló que seis agregaciones del Mero Nassau están amenazado críticamente, con menos de 400 individuos, y el sitio más

sano tenía menos de 6.000 individuos, apenas una fracción de agregaciones históricas. Varias otras especies estubierón agregadas durante las agregaciones de Nassau. Además, un solo promontory mantenia 26 agregaciones reproductivas de especies de arrecife durante las diferentes estaciones, lo que sugieren que los promontorios usados por una especie pueden tambien ser utilisadas por otras especies. Ejemplos de multiple agregaciones reproductivas en los promontorios y los canales del arrecife se pueden también encontrar en México, Komodo, y Palau. Es posible que las características oceanográficas, bathymetric y la oceanográfia fisica de estos promontorios y canales contribuye a que estas localidades sean óptimas para la agregacion reproductivas de una gran variedad de especies arrecifales. La época y la localización de dos agregaciones reproductivas fueron estimadas usando imágenes de satélites y con un conocimiento de la temporada reproductiva para esa especie y esta se fue verificada en el campo. Estas técnicas pudien ayudar a revelar nuevos sitios de agregaciones reproductivas a través de la región. Promontorios del arrecife, que contienen varias agregaciones reproductivas deben ser más prominente en el diseño de reservas marinas.

El simposio de hoy fue diseñado para compartir la información existente sobre el estado y las tendencias de las agregaciones reproductivas en la región, junto con la descripcion de algunos sitios específicos, con la finalidad de proporcionar una idea general de cómo las agregaciones reproductivas pueden ser identificadas, supervisadas y conservadas. Nos sentimos muy honrados de tener este año representantes de toda la región del Caribe, e incluso del mundo. Esperamos que el próximo año tengamos muchas presentaciones de la region divulgando nuevas agregaciones reproductivas dentro del Caribe. Nosotros esperamos que un amplio compartimiento de los conceptos, las dinámicas y la vulnerabilidad de las agregaciónes reproductivas, podemos ayudar a promover la conservación de estas áreas a través del del Caribe, promoviendo una red regional de reservas.

PALABRAS CLAVES: Agregaciones reproductivas, conservación

Primeros Indicios sobre la Formación de Agregaciones de Reproducción de Meros (Epinephelinae; Epinephelini) en el Banco de Campeche, México

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RESUMEN

Desde 1997, entre los meses de febrero y abril, pescadores del estado de Yucatán han realizado capturas masivas de cuna de piedra *Mycteroperca venenosa*, en los "Bajos del Norte" del Banco de Campeche. Esta región, ubicada a 130 millas náuticas al norte de la costa yucateca, esta conformada por numerosos bajos de tipo arrecifal (5-20 m de profundidad). Del 4 al 13 de febrero de 2001 se realizó, a bordo de una embarcación pesquera, una salida hasta los "Bajos del Norte" con el objeto de estudiar una probable agregación de reproducción de *M. venenosa*. Para este fin se utilizaron tanto métodos directos: observaciones submarinas por buceo autónomo, como indirectos: determinación del grado de desarrollo sexual de los organismos por análisis histológico de las gónadas. Ocho especies de los géneros *Cephalopholis, Epinephelus y Mycteroperca* fueron identificadas in situ por censo visual y/o en las capturas realizadas por los pescadores. No se observó por buceo la formación de agregaciones de reproducción típicas. Sin embargo, las capturas de meros realizadas durante los 10 días de pesca alcanzaron un volumen total de 2,435 kg. Las especies más abundantes en las capturas fueron *Mycteroperca venenosa*, *Epinephelus guttatus*, *M. tigris* y *M. bonaci*. La mayoría o la totalidad de los organismos hembras y machos, cuyas gónadas fueron analizadas, se encontraban sexualmente activos. En caso de las hembras, no se observó la presencia de ovocitos hialinos o folículos post-ovulatorios en los ovarios. Sin embargo, se notó la presencia de ovocitos en fin de vitelogénesis secundaria en los ovarios del 100% de las hembras de *E. guttatus*; 64% de *M. venenosa*; 75% de *M. bonaci* y 58% de *M. tigris*. Más del 98% de los machos analizados estaban sexualmente activos. Estudios complementarios son necesarios para confirmar la formación de agregaciones de reproducción de meros en esta zona y contribuir así a la gestion racional de este recurso de alto valor comercial.

PALABRAS CLAVES: Meros, agregaciones de reproducción, Yucatán

First Evidences on the Formation of Spawning Aggregations of Groupers (Epinephelinae; Epinephelini) from the Campeche Bank, Mexico.

ABSTRACT

Since 1997, between February and April, fishermen from the state of Yucatan have been capturing large amounts of yellowfin grouper *Mycteroperca venenosa* from "Bajos del Norte" on the Campeche Bank. This area, located at 130 knots north of the Yucatan coast, is conformed by numerous shallow coral reef banks (5 - 20 m depth). From February 4 - 13, 2001, a trip to "Bajos del Norte" was undertaken aboard a fishing boat with the objective to study a probable spawning aggregation of *M. venenosa*. For this purpose, direct and indirect methods (SCUBA diving observations and fish sexual development stages determined by histological analysis of gonads) were used. Eight species from the genera *Cephalopholis*, *Epinephelus* and *Mycteroperca* were identified by visual census and/or through the capture done by fishermen. No typical spawning aggregation activity was observed during SCUBA diving. Notwithstanding, the groupers catch done during the five days of fishing, reached a total of 2,435 kilograms. The more abundant species in the whole catch were *Mycteroperca venenosa*, *Epinephelus guttatus*, *M. tigris* and *M. bonaci*. The majority or total of females and males, which gonads were analyzed, were sexually active. For females, hyaline oocytes or postovulatory follicles were not observed. However, oocytes in late secondary vitellogenesis were noted in ovaries of 100% *E. guttatus* females, 64% *of M. venenosa* females, 75% of *M. bonaci* females and 58% of *M. tigris* females. More than 98% of analyzed males were sexually active. More studies are necessary to confirm the formation of groupers spawning aggregations in this region and to contribute to the management of this commercial high value resource.

KEY WORDS: Groupers, spawning aggregations, Yucatan

INTRODUCCIÓN

Durante su época de reproducción, los adultos de diversas especies de peces tropicales de las familias Serranidae, Lutjanidae, Caesionidae, Mugilidae, Labridae, Scaridae, Acanthuridae y Siganidae forman agregaciones en lugares específicos y periodos determinados, para liberar sus gametos. Estas agregaciones constituyen unos de los ejemplos más espectaculares de las diversas estrategias de reproducción que desarrollan los organismos presentes en los ambientes de arrecifes coralinos. Una agregación de reproducción puede ser definida como un amontonamiento de peces de una misma especie, que se juntan para emitir sus gametos, y cuya densidad o cantidad de individuos es significativamente más alta que la observada, en la misma zona de agregación, durante el periodo de inactividad sexual. Las investigaciones

sobre las agregaciones de reproducciyn de peces son escasas por el hecho de que este tipo de estudio es generalmente difícil de realizar. A menudo son eventos efímeros que ocurren en lugares muy remotos, muchas veces cuando prevalecen condiciones climáticas desfavorables y, si suceden en zonas de fácil acceso, estas agregaciones ya desaparecieron o fueron reducidas en importancia por la pesca (Domeier y Colin 1997).

Varias especies de meros (Epinephelinae, Epinephelini) realizan migraciones de reproducciyn y forman agregaciones de centenares a miles de individuos durante varios días, en sitios específicos de extensión limitada, y a veces en sincronía con las fases lunares (Domeier y Colin 1997). A la fecha se ha podido comprobar la formación de agregaciones de reproducción típicas para *E. adscensionis* (Colin et al. 1987), *E. guttatus* (Colin et al. 1987, Shapiro et al. 1993a and b, Sadovy et al. 1994), *E. itajara* (Colin 1994), *E. striatus* (Smith 1972, Olsen y Laplace 1979, Colin et al. 1987, Colin 1992, Aguilar-Perera 1994, Carter et al. 1994, Sadovy y Colin 1995, Aguilar-Perera y Aguilar-Dávila 1996), *M. bonaci* (Carter 1989, Carter y Perrine 1994, Eklund et al. 2000), *M. tigris* (Sadovy y Domeier 1994) y *M. venenosa* (Bannerot en Domeier y Colin 1997). Otras especies como *M. microlepis* y *M. phenax* forman agregaciones más modestas en cuanto al número de individuos involucrados, y en áreas más extensas (Gilmore y Jones, 1992; Coleman et al. 1996; Koenig et al. 1996). Algunas especies como *Cephalopholis cruentata*, *C. fulva* y probablemente *E. morio* no forman agregaciones para la reproducción (Coleman et al. 1996).

Debido al hecho de que, año tras año, las agregaciones de reproducción de meros se forman muy a menudo en los mismos sitios geográficos y durante el mismo periodo del año, estas son particularmente vulnerables a la pesca comercial. Las especies que presentan tal comportamiento de reproducción parecen muy propicias a la sobreexplotación pesquera (Sadovy 1997, Coleman et al. 2000).

En el Banco de Campeche, se explotan comercialmente 17 especies de meros de los géneros *Cephalopholis, Epinephelus* y *Mycteroperca* (Colás-Marrufo et al. 1998, Tuz-Sulub, 1999). Ninguna agregación de reproducción de meros a sido reportada a la fecha para el Banco de Campeche, a pesar de que la reproducción de varias especies ha sido observada en ésta región (Brulé et al. 1999, Renán 1999, Brulé et al. 2000, Colás-Marrufo y Brulé 2000, Renán et al. 2001). La formación de una agregación de reproducción de *E. striatus* en el sur del Caribe mexicano, en Mahahual, Quintana Roo, constituye el único reporte actualmente disponible sobre este tema para las aguas mexicanas (Aguilar-Perera 1994, Aguilar-Perera y Aguilar-Dávila 1996). Sin embargo, desde 1997 pescadores del estado de Yucatán van realizando capturas masivas de meros, en particular de cuna de piedra *M. venenosa*, durante el fin del invierno-inicio de la primavera, en una zona del Banco de Campeche conocida como los *Bajos del Norte*, ubicada en el extremo norte de la plataforma continental de Yucatán (Cervera-Cervera, com.pers.). El propósito del presente trabajo fue de determinar, a través del anáisis de criterios directos como indirectos, si esta zona podría ser considerada como un lugar potencial de agregaciones de reproducción de meros.

MATERIAL Y MÉTODOS

Del 4 al 13 de febrero de 2001 se participó en una salida de pesca comercial a los *Bajos del Norte* a bordo de la embarcación pesquera *Cherna 10*, propiedad de la Sociedad Cooperativa de Producción pesquera "*Jurisdicción de Cooperativas*" del puerto de Progreso, Yucatán. Desde 1997, los pescadores profesionales de ésta embarcación se dedican a la captura de peces de escamas en ésta zona, durante los meses de febrero hasta mayo por ser el periodo más propicios para la captura "masiva" de ciertas especies de meros como *E. guttatus*, *M. venenosa* y *E. striatus* (Tuz-Sulub, com.pers.). Los *Bajos del Norte* (23°10'- 23°27' N y 88°40' - 88°59' O) corresponden a una zona de bajos fondos, con características arrecifales, localizada en la plataforma continental yucateca a 130 millas náuticas al Norte del puerto de Dzilam de Bravo. Durante los diez días de pesca, que incluyó el de luna llena (8 de febrero), se exploraron un total de nueve sitios de pesca con profundidades entre 7 y 27 m, cuyas posiciones geográficas fueron determinadas con la ayuda de un GPS (Figura 1).

Con base al estudio presentado por Domeier y Colin (1997), se utilizaron métodos directos e indirectos para caracterizar los principales factores ambientales de la zona y determinar si los meros presentes en los sitios explorados formaban agregaciones de reproducción.

Métodos Directos

Por buceo autónomo, con equipo Scuba, se caracterizó el tipo de fondo y de cobertura de cada sitio, se identificaron a las especie presentes, se estimó el número de individuos de cada una de ellas, y se observó el patrón de coloración y comportamiento de los organismos (cortejo nupcial, emisión de gametos). Se realizaron una o dos inmersiones por sitio, entre las 10:00 - 11:00 y 13:00 - 14:00 horas, respectivamente. Fotografías y filmaciones submarinas fueron tomadas con cámaras automáticas de 35 mm y 8mm, respectivamente, en los sitios donde se observaron agrupaciones de meros. Las impresiones y grabaciones fueron utilizadas en laboratorio, para analizar con mayor detenimiento, la estructura del substrato y el comportamiento de los organismos. Además, para cada sitio se registraron los parámetros de temperatura del agua, a proximidad del fondo, por medio de un sensor térmico digital y la profundidad con ayuda de un profundímetro manual.

Métodos Indirectos

Se analizaron las capturas comerciales realizadas durante los 10 días de pesca en la zona. Los organismos fueron capturados con arpón entre las 10:00 y 15:00 horas, entre profundidades de 7m a 37m, durante tres inmersiones diarias realizadas con la ayuda de una compresora de aire. A bordo de la embarcación, se identificaron a las diferentes especies pescadas. A partir de las bitácoras de captura de los pescadores se determinó, por sitio, la importancia en peso (kg de pescados eviscerados; Pe) que representaron las diferentes especies, agrupadas de manera tradicional en las dos categorías siguientes: *Meros grandes* (individuos cuyo Pe > 2 kg) y *Meros chicos* (Pe < 2kg).

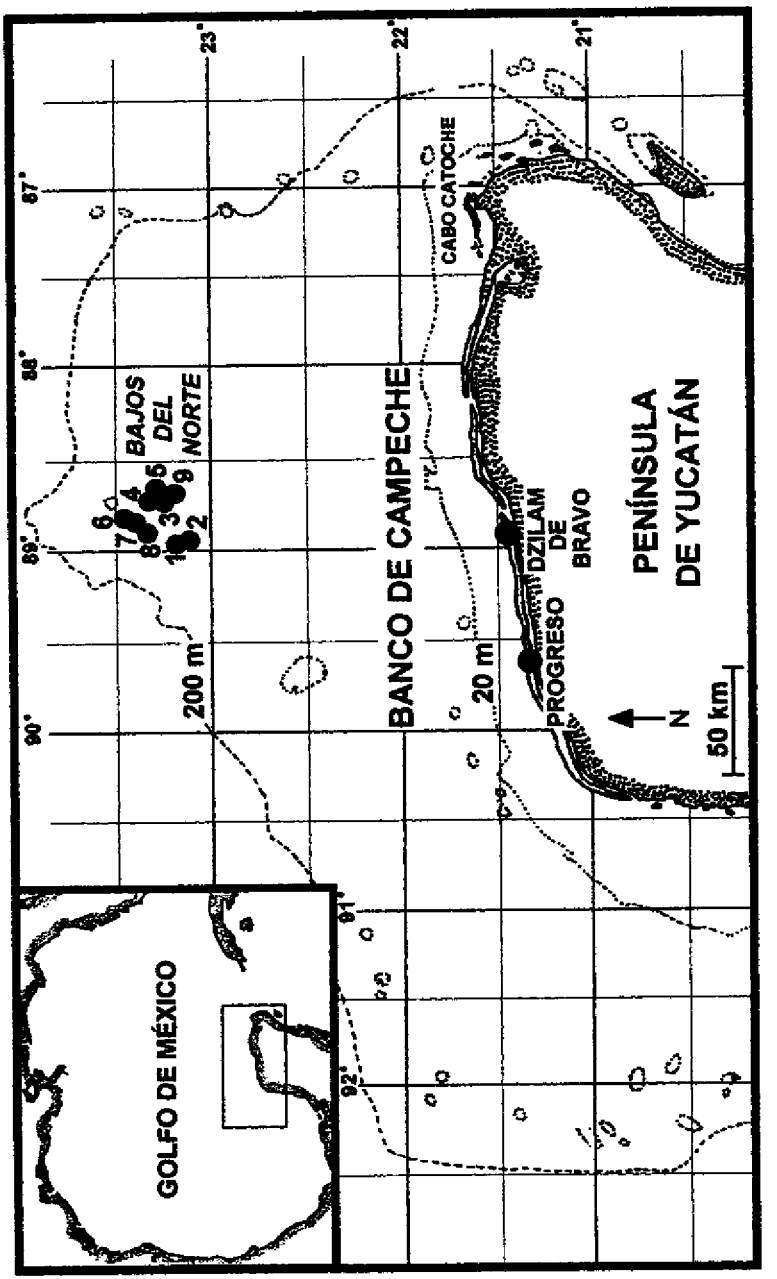


Figura 1. Ubicación geográfica de la región de los *Bajos del Norte* en la plataforma continental de la Península de Yucatán (Banco de Campeche). Se indican los nueve sitios de estudio analizados en esta zona, entre el 4 y 13 de febrero de 2001.

Por otro lado, especimenes de cada especie fueron medidos (longitud total: Lt y longitud furcal: Lf), pesados (peso total: Pt y peso del pez eviscerado: Pe) y sus gónadas fueron extraídas y pesadas (Pg). El sexo y el estadio de desarrollo sexual de estos organismos fueron determinados utilizando criterios microscópicos (histología) y ponderal (índice gonadosomático: IGS = 100*Pg/Pe). Para el estudio histológico de las glándulas sexuales, una muestra de gónada fue fijada en líquido de Bouin, deshidratada, incluida en paraplast, cortada a un espesor de 6 µm, teñida por el Tricromo en un tiempo (Gabe 1968) y montada en resina sintética. El examen de los cortes histológicos fue realizado tomando en cuenta los criterios utilizados por Moe (1969) y Brulé et al. (1999) para el estudio de la gametogénesis y la definición de las clases sexuales en *E. morio*.

RESULTADOS

Características Ambientales de la Zona

Los fondos de la zona de los *Bajos del Norte* están conformados por numerosos salientes o picos que emergen desde el suelo submarino hacia la superficie, hasta alcanzar profundidades que varían entre 5 y 20 m en promedio. Estas salientes presentan extensiones que fluctúan desde los 500 m^2 hasta los 2 km^2 aproximadamente, y cada una de ellas esta aislada de las demás por cantiles de hasta 70 m de profundidad.

El substrato de los sitios puede ser considerado como de tipo arrecifal, de formación reciente. Por lo general, los fondos de los nueve sitios presentaron un alto porcentaje de cobertura coralina viva (hasta 90% de la superficie), principalmente constituida de pequeños cabezos de corales masivos de las especies *Montastraea annularis*. y *Diploria strigosa*. En menor grado, se observó la presencia de una gran variedad de octocorales de los géneros *Plexaura sp*. y *Pseudoplexaura sp*, de esponjas (*Caliesponja sp*.) y de algunas algas cálcareas. De manera escasa se encontraron grupos de macro-algas y pequeños parches aislados de corales ramificados de los géneros *Acropora sp*. y *Porites sp*. No se observó ninguna cobertura de pastos marinos. La más alta complejidad estructural coralina (principalmente formada por corales masivos e incrustantes) fue observada en los sitios 6 y 7. En cada uno de los sitios visitados la velocidad de la corriente fue casi inexistente. La importancia despreciable de la corriente marina, aunado a la ausencia de sedimentos finos en los fondos, con la excepción de depósitos de arena presentes en los canales arrecifales, permitieron tener una visibilidad submarina perfecta durante el estudio directo de los sitios. La profundidad en los sitios fluctuó entre 7 m (sitio 9) y 27 m (sitio 5) y la temperatura del agua, a proximidad del fondo, entre 17.5°C (sitio 4) y 18.1°C (sitio 2) (Tabla 1).

Tabla 1. Posición geográfica y profundidad de los nueve sitios de *los Bajos del Norte* analizados por observaciones directas. Fecha y horario de muestreo, temperatura del agua y especies de meros encontradas para cada uno de los sitios explorados del 4 y 13 de febrero de 2001. Cc: *Cephalopholis cruentata*; Cf: *C. Fulva*; Ea: *Epinephelus adscensionis*, E.g: *E. guttatus*; Mb: *Mycteroperca bonaci*; Mi: *M. interstitialis*; Mt: *M. tigris*; Mv: *M. venenosa*.

Sitio	Posición geográfica	Profundidad (m)	Fecha de muestreo	Hora de muestreo	T°C del agua**	Especies de meros
1	23°11'N-88°59'O	25	04.02.01	10.00-11:00 AM 13:00-14:00 PM	18.0	Eg, Mb, Mt, Mv
2	23°09'N-88°57'O	22	06.02.01	10.00-11:00 AM	18.1	Cf, Eg, Mt, Mv
3	23°15'N-88°43'O	22	07.02.01	10.00-11:00 AM 13:00-14:00 PM	17.9	Cc, Mb, Mt, Mv
4	23°18'N-88°43'O	25	08.02.01*	10.00-11:00 AM 13:00-14:00 PM	17.5	Eg, Mb, Mt
5	23°17'N-88°40'O	27	09/10.02.01	10.00-11:00 AM 13:00-14:00 PM	17.7/17.8	Cc, Eg, Mb, Mt, Mv
6	23°27'N-88°47'O	13	11.02.01	10.00-11:00 AM	18.0	Cc, Cf, Ea, Mb, Mi, Mv
7	23°24'N-88°49'O	22	11.02.01	10.00-11:00 AM	18.0	Cf, Ea, Eg, Mt
8	23°22'N-88°53'O	20	12.02.01	10.00-11:00 AM	18.0	Mb, Mt, Mv
9	23°14'N-88°42'O	7	13.02.01	10.00-11:00 AM	17.9	Mb, Mt

* luna llena

* * a proximidad del fondo

Identificación y Comportamiento de las Especies

Las observaciones submarinas directas así como las realizadas por medio de fotografías y video-grabaciones permitieron identificar ocho especies de meros en los Bajos del Norte: *C. cruentata, C. fulva, E. adscensionis, E. guttatus, M. bonaci, M. interstitialis, M. tigris* y *M. venenosa* (Tabla 1).

Especimenes de *E. guttatus* y *M. interstitialis* presentaron un comportamiento gregario y cambios en el patrón de coloración. En particular, en el sitio 5 (9/10 de febrero) se observó una agrupación importante de especimenes de *E. guttatus* cuya densidad se estimó a 48 individuos en 20 metros lineales, en un área de superficie no mayor a 1 km^2. Los peces formaban pequeños grupos de 6-8 individuos, a proximidad del fondo, siempre con uno de ellos, de tamaño más grande, ubicado más arriba de sus compañeros y del substrato. Los organismos cerca del fondo presentaban un color uniforme pálido, con puntos oscuros en todo el cuerpo, y un borde oscuro en las aletas caudal, dorsal y pectorales. El individuo encima de los demás presentaba un color pálido con bandas o rayas oscuras claramente definidas sobre los costados del cuerpo. En el sitio 6 se observó un grupo de 5-6 individuos de *M. interstitialis* de los cuales algunos cambiaban de color en cuestión de segundos, pasando de un patrón de coloración oscuro hasta uno pálido claro con manchas oscuras de forma irregular en los costados.

Finalmente, se observó en el sitio 7 a un ejemplar de *M. tigris* con cabeza de color pálida-amarilla, aletas pectorales negras y una mancha blanca en la parte posterior del abdomen.

Análisis de las Capturas Comerciales

Las capturas comerciales de meros realizadas en los nueve sitios de pesca fueron constituidas por especimenes de *E. guttatus, E. striatus, M. bonaci, M. interstitialis, M. tigris* y *M. venenosa*. En base a los datos proporcionados por los pescadores se calculó que la captura global de meros alcanzó durante los 10 días de pesca un volumen mínimo de 2,435 kg. Las especies que predominaron en las capturas fueron *M. venenosa* y *M. bonaci* para la categoría *Meros grandes* y *E. guttatus* para la categoría *Meros chicos* (Tabla 2). Se observó que los días de pesca 9 y 10 de febrero fueron los más productivos en volumen capturado de *Meros chicos* (350 y 503 kg, respectivamente) y en particular de ejemplares de *E. guttatus*.

Estado del Desarrollo Sexual de los Organismos Capturados

Se realizó el examen histológico de las gónadas de un total de 252 organismos de las especies *M. venenosa, E. guttatus, M. tigris, M. bonaci, E. striatus y M. interstitialis*, obtenidos de la captura comercial (Tabla 3). Todos los individuos capturados fueron analizados, con la excepción de los de las especies *E. guttatus* y *M. venenosa* para las cuales no fue posible analizar más de la mitad de las capturas realizadas, por ser las especies que fueron las más abundantes en el volumen de producción obtenido. Para *M. venenosa, E. guttatus, M. tigris* y *M. bonaci*, se observó siempre que más de 50% de los individuos analizados por sitio estaban sexualmente activos, con las hembras generalmente en etapas avanzadas de

ovogénesis (ovocitos en fin de vitelogénesis secundaria en los ovarios) o en post-desove, y los machos en varias etapas de la espermatogénesis y espermiogénesis (cistes a espermatocitos, espermátidas y espermatozoides en los testículos) o en emisión. Para *E. striatus* y *M. interstitialis*, los únicos organismos capturados fueron machos sexualmente activos, en fin de espermatogénesis o espermiogénesis avanzada. Altos valores máximos del IGS individual fueron observados para hembras de *E. guttatus* (42.2%), *M. venenosa* (7.1%), *M. tigris* (4.6%) y *M. bonaci* (4.2%) así como para machos de *E. guttatus* (18.7%), *M. venenosa* (9.8%) y *E. striatus* (12.9%).

Tabla 2. Capturas comerciales, expresadas en kilogramos de peso de pez eviscerado (Pe), obtenidas entre el 4 y 13 de febrero de 2001 en los *Bajos del Norte*. El 08.02.01 (sitio 4) se capturó únicamente a un ejemplar de *M. bonaci* de 21 kg Pe. Para el 13.02.01 (sitio 9) no se elaboró el registro pesquero del día. Eg: *E. guttatus*; Mb: *M. bonaci*; Mt: *M. tigris*; Mv: *M. venenosa*.

		Categoría de meros	
Sitio	Fecha de pesca	*Grandes* (Pe > 2kg) (Mb/Mv/Mt)	*Chicos* (Pe < 2kg) (Eg/Mv/Mt)***
1	04.02.01	188**	155
2	06.02.01	186*	139
3	07.02.01	95**	30
4	08.02.01	—	—
5	09.02.01	147*	350
	10.02.01	27**	503
6	11.02.01	190**	30
7	11.02.01	135**	60
8	12.02.01	150**	50
9	13.02.01	—	—
Total		1,118	1,317

* Predominaron los ejemplares de *M. bonaci* en las capturas
** Predominaron los ejemplares de *M. venenosa* en las capturas.
*** Predominaron los ejemplares de *E. guttatus* en las capturas

Tabla 3. Sexo, estado de madurez sexual, intervalos de IGS, tallas y pesos para los organismos analizados a partir de las capturas comerciales realizadas en los *Bajos del Norte*, del 4 al 13 de febrero de 2001. O - Especimenes inmaduros o en reposo sexual: hembras con ovocitos previtelogénos en los ovarios y machos con cistes a espermatogonias en los testículos. ● - Especimenes sexualmente activos: hembras en maduración con ovocitos en vitelogénesis primaria (a), en inicio (b) o fin (c) de vitelogénesis secundaria; hembras en postdesove con ovocitos vitelogénos en atresia (at) y machos en maduración con cistes a espermatocitos, espermátidas y espermatozoides (m); machos en emisión con preponderancia de espermatozoides libres en canales intralobulares y senos colectores (e).

		Sitio									IGS**		Tallas	Pesos
Especie	Sexo*	1	2	3	4	5	6	7	8	9	(%)	N	(Lt, cm)	(Pe, kg)
*M. venenosa****	H	O/●a,b,c	—	—	—	O/●c	O/●c	O/●a,c	O/●c	O/●a,c	0.20-7.12	62	43-77	1.1-6.4
	M	●m	—	—	—	●m	●m	—	●m	—	0.21-9.75	32	61-88	3.3-10.8
E. guttatus	H	—	—	—	—	●c	—	—	—	—	1.46-42.2	65	32-43	0.5-1.6
	M	—	—	—	—	●m	—	—	—	—	0.34-18.7	20	38-47	0.8-1.9
*M. tigris****	H	●a,b,c	—	—	—	—	—	—	O/●a,c	—	0.41-4.55	13	38-49	0.7-1.7
	M	●m	—	—	—	—	●m	—	●m	—	0.36-1.31	23	48-61	1.5-3.1
*M. bonaci****	H	●c	—	—	●at	O/●c	O/●c	—	O/●a,c	O/●a,b,c	0.20-4.21	21	87-122	8.7-23.7
	M	●e	●e	●e	O/●e	●m,e	●e	—	—	—	0.21-0.44	9	118-129	21.0-26.6
E. striatus	H	—	—	—	—	—	—	—	—	—	—	0	—	—
	M	—	●m	—	—	●m	●m	—	●m	—	6.9-12.9	4	46-88	1.4-11.5
M. interstitialis	H	O	—	—	—	—	—	—	—	—	—	1	45	1.1
	M	●m	—	—	—	—	—	—	—	—	—	2	51 y 52	1.2 y 1.3

* H: hembra; M: macho

** IGS para los organismos sexualmente activos (●)

*** Organismos sexualmente activos por sitio: *M. venenosa* – hembras: 72% (sitio 1); 50% (sitio 5); 67% (sitio 6); 75% (sitio 7); 78% (sitio 8); 70% (sitio 9) *M. tigris* –hembras: 80% (sitio 8). *M. bonaci* – hembras: 67% (sitio 5); 80% (sitio 6); 86% (sitio 8) y 50% (sitio 9); machos: 50% (sitio 4).

DISCUSIÓN

En los *Bajos del Norte* se identificó la presencia de nueve especies de meros de los géneros *Cephalopholis* (2 especies), *Epinephelus* (3 especies) y *Mycteroperca* (4 especies). Varios indicios basados en el análisis de criterios directos como indirectos permitieron suponer que estos lugares representan sitios de agregaciones de reproducción para algunas de estas especies.

El volumen importante de captura de meros obtenido durante los 10 días de pesca (> a 2,435 kg) en una área de extensión limitada, se debe probablemente a una concentración del recurso en ésta zona durante el mes de febrero. De hecho, basados en conocimientos empíricos, los pescadores explotan los meros en los *Bajos del Norte* exclusivamente de febrero hasta mayo, por ser el periodo más productivo del año para la pesca de estos peces en esta región. Este comportamiento gregario, durante el fin de invierno-inicio de la primavera, puede ser relacionado con la actividad de reproducción de las especies encontradas. En efecto, *E. guttatus* se reproduce entre enero y abril en Jamaica, Puerto Rico y Venezuela (Sadovy 1996); *M. venenosa* entre febrero y junio en Jamaica, Puerto Rico y Cuba (Bullock y Smith 1991, García-Cagide y García 1996); *M. tigris* entre diciembre y abril en Puerto Rico (Sadovy y Domeier 1994); *M. bonaci* entre enero y marzo en Florida y en el Banco de Campeche (Crabtree y Bullock 1998, Renán 1999, Renán et al. 2001); *E. striatus* entre diciembre y abril en Jamaica, las Islas Caimán, Cuba, Belice y México (Thompson y Munro 1978, Colin et al. 1987, Claro et al. 1990, Tucker et al. 1993, Carter et al. 1994, Aguilar-Perera 1994, Aguilar-Perera y Aguilar-Dávila 1996) y *M. interstitialis* durante abril y mayo en Florida (Bullock y Murphy 1994).

Se notó a través de la realización de observaciones submarinas, la formación de varios pequeños grupos de individuos de *E. guttatus*. También se identificaron para los ejemplares de esta especie, patrones de coloración muy similares a los descritos por Colin et al. (1987) y Shapiro et al. (1993a) para especimenes machos y hembras de *E. guttatus* observados en agregación de reproducción en Puerto Rico. El patrón de coloración presentado por el ejemplar de *M. tigris* en el sitio 7 de los *Bajos del Norte*, fue semejante al exhibido por los machos de esta misma especie en una agregación de reproducción de Puerto Rico analizada por Sadovy et al. (1994). Sin embargo, nunca se observó algún cortejo nupcial ni tampoco emisión de gametos por parte de las especies encontradas.

A partir de las capturas comerciales realizadas en febrero 2001, fue posible observar que la mayoría de los especimenes analizados para las especies *E. guttatus*, *M. venenosa*, *M. tigris*, *M. bonaci*, *E. striatus* y *M. interstitialis*, estaban sexualmente activos y se encontraban en las etapas terminales de la vitelogénesis para las hembras o de la espermiogénesis para los machos. Sin embargo, ninguna hembra con ovocitos hialinos o folículos post-ovulatorios en los ovarios, criterios indicativos de un desove próximo o reciente, fue capturada durante el periodo de estudio.

Con base en los resultados obtenidos, *E. guttatus* y probablemente *M. venenosa* son las especies que presentaron los indicios más evidentes de formación de agregaciones de reproducción en los *Bajos del Norte*. Estos meros predominaron en

el volumen total de captura obtenido durante los 10 días de pesca; presentaron, tanto en ejemplares hembras como machos, valores altos de IGS y células sexuales en estadios muy avanzados de la gametogénesis; y en el caso de *E. guttatus* una tendencia a agruparse en un lugar determinado (sitio 5) e individuos que presentaron patrones de coloración típicos asociados con el acto reproductor.

En general, se conoce poco sobre la ubicación geográfica de los sitios de reproducción de los peces arrecifales de importancia comercial (Sadovy 1996). Cuando los reproductores se agrupan en lugares determinados para emitir sus gametos, las características de las agregaciones de reproducción formadas pueden ser muy variables según las especies consideradas. Según Domeier y Colin (1997), dos tipos de agregaciones pueden ser distinguidas: las *Permanentes* (*Resident Spawning Aggregations*) y las *Transitorias (Transient Spawning Aggregations*). Las *Permanentes* ocurren a menudo en el área de distribución habitual de los reproductores y se forman diariamente durante pocas horas, pero a lo largo de un periodo de tiempo amplio que, en caso extremo, puede abarcar todo el año. Las *Transitorias* ocurren en lugares ajenos al área de distribución habitual de los reproductores y implican, por parte de ellos, la realización de migraciones de una duración de varios días o semanas. Estas agregaciones se forman durante varios días o semanas consecutivos, a lo largo de un periodo de tiempo limitado a uno o dos meses del año. *M. venenosa* y *E. guttatus* forman agregaciones de reproducción de tipo *Transitoria*, que ocurren en sincronía con los periodos de luna llena, en Bahamas, Belice y Honduras para la primera y en Bermudas, Belice, Puerto Rico, Jamaica y las Islas Vírgenes para la segunda (Domeier y Colin 1994).

Se ha observado frecuentemente un uso compartido de los mismos sitios de desove por parte de varias especies de meros y pargos pero en épocas del año diferentes para cada una de ellas. Tal es el caso de *E. guttatus*, *E. striatus*, *M. venenosa* y *Lutjanus synagris* en las Islas Vírgenes (Beets y Friedlander en Sadovy 1996) o también *E. striatus*, *M. bonaci* y *L. jocu* en Belice (Carter 1989). Al contrario, en otras regiones, como en las Bermudas, diferentes especies desovan durante la misma época pero en sitios distintos: entre 33 y 37m de profundidad para *E. striatus* y entre 18 y 27 m para *E. guttatus* (Burnett-Herkes en Thresher 1984).

Durante la formación de una agregación, la modalidad de apareamiento (por pareja o en grupos) adoptado por los organismos de una especie determinada, puede ser deducida del valor de la proporción relativa que representa el peso de los testículos en relación con el peso de los machos (i.e. IGS). Los machos de las especies que se reproducen a través de la formación de parejas presentan testículos reducidos, de poco peso, y valores de IGS bajos; mientras que los machos de las especies que desovan en grupos, presentan testículos muy desarrollados, de fuerte peso, y valores de IGS elevados. Los altos valores máximos de IGS de machos de *E. guttatus* (18.7%), *M. venenosa* (9.8%) y *E. striatus* (12.9%) capturados en los *Bajos del Norte* dejan suponer que estas especies deben de desovar en grupos. Esta conclusión confirma las observaciones realizadas en otras regiones sobre *E. striatus* pero contradice lo establecido para *E. guttatus*, lo cual es considerado como una especie cuyos individuos forman parejas durante el desove (Domeier y Colin 1994).

Con relación a *M. venenosa* no se dispone de reporte sobre su modalidad de apareamiento.

Para poner en evidencia sin ambigüedad la formación de agregaciones de reproducción de meros en los *Bajos del Norte*, en particular para *E. guttatus* y *M. venenosa*, es indispensable realizar estudios más completos en esta zona, analizando todos los meses durante los cuales los pescadores explotan el recurso (febrero-mayo), durante varios años consecutivos, y tomando en cuenta la metodología propuesta por Domeier y Colin (1994). La localización precisa de los hábitats críticos donde se forman las agregaciones de reproducción así como el periodo durante el cual éstas ocurren, son informaciones de suma importancia para pretender alcanzar un manejo sustentable y la protección de especies de peces de alto valor comercial y muy vulnerables a la explotación pesquera, como son los meros.

AGRADECIMIENTOS

Agradecemos sinceramente a los Srs. J.L. Carillo-Galaz (Presidente), J.A. Manzano Meza (Tesorero) y H. Manzano-Hú (Patrón del *Cherna 10*) de la Fed. Reg. de Soc. Coops. de la Ind. Pesq. de la zona Centro y Poniente del Edo. de Yucatán F.C.L. por el apoyo recibido en la realización del presente estudio. Los ejemplares utilizados en el análisis histológico fueron proporcionados por: Mosca, Rata, Sorrullo, Chac, Diablo, Bimbo, Cash, Araña, Mass y Nena, todos miembros de la tripulación del *Cherna 10*.

Todos nuestros agradecimientos para el Gobierno del Estado de Yucatán, la Secretaria de Educación del Gobierno del Estado de Yucatán, en particular para el Director de Educación Media Superior y Superior, Lic. Raúl Burgos Fajardo, y para el H. Ayuntamiento de la Ciudad de Mérida, en particular para la C.P. Ana Rosa Payán Cervera, por el apoyo económico recibido para la presentación en congreso del presente trabajo.

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Development of a Caribbean Regional Conservation Strategy for Reef Fish Spawning Aggregations

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ABSTRACT

Intensive fishing of spawning aggregations (SPAGs) has led to the degradation of many sites on a global scale. Recent scientific studies have confirmed the decline or demise of many aggregations. The need to take action to ensure the protection of spawning aggregations led to the formation of the Society for the Conservation of Reef Fish Aggregations (SCRFA). Many of the economically important reef fish species e.g. groupers and snappers, share life history characteristics which make these species particularly vulnerable to overexploitation. The formation of spawning aggregations by most of these species exacerbates this vulnerability. The documentation and evaluation of the status of spawning aggregations of groupers and snappers in the region indicates that most sites have been suffering declines in landings. In particular, the Nassau grouper has been significantly impacted by fishing pressure with the disappearance of a number of sites in different countries. A conservation strategy for spawning aggregations in the Caribbean region is presented comprising the following seven elements:

i) Elimination of fishing mortality at vulnerable SPAG sites,
ii) Incorporation of known SPAG sites into planning programs for Marine Protected Areas (MPAs) to provide permanent protection of the sites,
iii) Development and implementation of monitoring programs to evaluate the effect of management /conservation measures,
iv) Development of community-based management programs for SPAG sites,
v) Provision of viable economic alternatives to those user groups who are displaced from SPAG sites, and
vi) Application of gear restrictions to reduce catchability if closure of SPAG sites cannot be implemented, 7) Use of economic/market measures such as sales or export restrictions to reduce fishing activity at SPAGs.

KEY WORDS: Spawning aggregations, Caribbean, conservation, groupers, snappers

INTRODUCTION

Reef fish spawning aggregations (SPAGs) are severely threatened on a global scale. Intensive fishing of spawning aggregations by coastal fishing communities as well as the exploitation of SPAGs for the Live Reef Food Fish Trade (LRFFT) in the Indo-Pacific has degraded many SPAGs on a global basis. The results of recent

scientific studies have confirmed the decline or demise of many aggregations and there is growing international concern for the future of these sites. The need to take action to ensure the protection of spawning aggregations led to the formation of the Society for the Conservation of Reef Fish Aggregations (SCRFA). SCRFA came into existence at a meeting of the American Society of Ichthyologists and Herpetologists at La Paz, Baja California Sur, Mexico, in June of 2000 when a number of biologists with research experience with spawning aggregations in both the Atlantic and the Pacific met to consider a possible course of action. The Society held its first formal meeting at the 9th International Coral Reef Symposium during October 2000 in Bali, Indonesia. Members of SCRFA agreed that there are vast and growing threats to reef fish spawning aggregations, particularly groupers (Musick et al. 2000) and that a widely shared strategy for conservation of these aggregations is urgently needed. The members presently comprise research biologists, but they recognize the need to involve marine reserve managers, policy makers, and representatives from the fishing industry.

The Nature Conservancy (TNC), in sharing these concerns about the future of SPAGs, believes that the conservation of reef fish spawning aggregations is important to many marine sites and to the health of tropical marine ecosystems in general. In pursuance of this belief, TNC decided to support the development of a spawning aggregation (SPAG) conservation strategy for the Caribbean/Latin America region and to integrate this strategy with one being prepared for the Asia Pacific region to produce an international SPAG conservation strategy.

BACKGROUND

Many of the economically important reef fish species e.g. groupers and snappers, share a suite of life history characteristics which make these species particularly vulnerable to overexploitation (Koenig et al. 1996). Certain features of their reproductive behaviour and ecology tend to further exacerbate this problem. In general, these species exhibit the following characteristics as outlined by Coleman et al. (2000):

i) Slow growth,
ii) Late sexual maturity,
iii) High site fidelity,
iv) Spawning migrations to established sites,
v) Complex social structure, and
vi) Sex reversal (groupers).

The complex life history of many species of grouper and the formation of spawning aggregations by groupers and snappers helps to explain why conventional fishery management measures have largely failed to adequately address the problem of overfishing on these important groups (Sadovy 1994).

Studies have indicated that natural mortality rates are very low in many of these large, long-lived species (Coleman et al. 2000), and this implies that to maintain populations at sustainable harvest levels that only a small proportion of the species

biomass (possibly only 10%) can be harvested annually (Coleman et al. 2000). In contrast, fishing mortality rates are generally much higher, and fishing effort typically removes the oldest and largest individuals. Over time this leads to a truncation of the size distribution in the population with the largest size classes absent. The largest fish typically make the greatest contribution to the reproductive output of the population, e.g. a single gag grouper (*Mycteroperca microlepis*) at age eight produces as many eggs as 48 gag at age three (Collins et al. 1998). In particular, the catchability at spawning aggregation sites is much higher than during non-aggregation periods and thus, the level of fishing mortality which can be inflicted with directed fishing is extremely high. This vulnerability is further increased by the high level of site fidelity exhibited by most groupers (e.g. red hind *Epinephelus guttatus*, Luckhurst 1998, 2000) and snappers (e.g. cubera snapper *Lutjanus cyanopterus*, Heyman et al. 2001). This aspect of their reproductive biology makes fishes returning to the same SPAG site susceptible to harvest on a repeated basis.

SUMMARY OF CURRENT STATUS OF SPAWNING AGGREGATIONS BY COUNTRY IN THE GREATER CARIBBEAN REGION

A first step in determining SPAG status was to generate a list of the species documented to form spawning aggregations in the region, based on the criteria outlined by Domeier and Colin (1997). This list is dominated by the commercially important groupers (Serranidae) and snappers (Lutjanidae) although, other commercially important species in the region e.g., jacks (Carangidae) and grunts (Haemulidae) are also known to form SPAGS (Auil-Marshalleck 1993). However, there are relatively few observations of these latter two groups. As a consequence, the list is restricted to groupers and snappers only, with eight and seven species respectively (Table 1).

The documentation and evaluation of the status of SPAGs of groupers and snappers in the region (Table 2) is based on the best information available. The documentation of SPAGs in the different countries or jurisdictions in the region is variable. Some SPAG sites have been exploited for decades (Carter et al. 1994) while others have only recently been documented (Aguilar-Perera and Aguilar-Davila 1996). Evaluation of their current status is highly variable. In some instances, there is published information and data on given sites while for many others, there is only anecdotal information.

It is clear from Table 2 that the majority of SPAG sites appear to be suffering declines in landings and that the Nassau grouper in particular has been significantly impacted by fishing pressure with the disappearance of a number of SPAGs in different countries (Sadovy and Eklund 1999). The only species /sites which appear to be stable are those which have specific management measures in place for SPAGs (principally seasonal area closures). It is not possible to prove cause and effect, but these findings strongly suggest that active management of SPAGs (centered on limiting fishing mortality) can be highly beneficial to the populations under exploitation (Bohnsack 1989).

Table 1. List of grouper and snapper species documented to form spawning aggregations in the greater Caribbean region. These species are included on the basis of published accounts of spawning or documentation by scientific observers of one or more of the criteria associated with spawning aggregations as designated by Domeier and Colin (1997).

Family	Species	Common Name
Serranidae	*Epinephelus adscensionis*	Rock hind
	E. guttatus	Red hind
	E. itajara	Goliath Grouper
	E. striatus	Nassau grouper
	Mycteroperca bonaci	Black grouper
	M. microlepis	Gag grouper
	M. tigris	Tiger grouper
	M. venenosa	Yellowfin grouper
Lutjanidae	*Lutjanus analis*	Mutton snapper
	L. apodus	Schoolmaster
	L. cyanopterus	Cubera snapper
	L. griseus	Gray snapper
	L. jocu	Dog snapper
	L. synagris	Lane snapper
	Ocyurus chrysurus	Yellowtail snapper

CARIBBEAN REGIONAL CONSERVATION STRATEGY FOR REEF FISH SPAWNING AGGREGATIONS

The ability to undertake the strategy which has been developed will be dependent to some degree on the governmental and legislative framework existing in each country. If legislation for a resource management action already exists in a given jurisdiction, then the main element necessary to carry out the action is political will. In a related manner, this same element must be present to create the necessary legislation if it does not already exist. The conservation of SPAG sites will have to be evaluated on an individual basis to determine the community and national impacts before selecting the appropriate management elements of the strategy.

A guiding principle of this strategy is that SPAGs should be managed as an integral part of the entire reef ecosystem. The removal of a large biomass of top predators e.g. groupers and snappers, at SPAG sites is likely to have a significant effect on reef fish community structure and function. Conservation measures implemented in isolation will likely have a lower probability of long term success if the effects on ecosystem function are not taken into account.

Given the lack of in-depth knowledge of the dynamics of SPAGs, the precautionary approach to fisheries management has been invoked throughout this strategy. The greater the uncertainty in the understanding of SPAGs, the more conservative the management /conservation measures should be.

Table 2. Summary of current status of spawning aggregations (SPAGs) in the greater Caribbean area by country and species. Only the commercially exploited species of grouper and snapper are listed. Countries (or jurisdictions) with documented spawning aggregations are listed from north to south. Status refers primarily to documented fishery landings but may include fishery independent evaluation of given aggregation sites. Status reflects an overall trend in recent years but may not accurately reflect the current status (2001) as changes can occur rapidly at SPAG sites.

Country/ State	Total SPAG Sites	Species Involved	Current Status (Landings)	Reference / Source
Bermuda	3	Red Hind	Stable	Luckhurst, 1996; MS
	4	Nassau Grouper	Disappeared	Luckhurst, 1996
Bahamas	22	Nassau Grouper	Declines Heavily expl.	Braynen, pers. comm., Ray et al., 2000
Turks and Caicos Islands	5	Nassau Grouper	Lightly exploited	Clerveaux, pers. comm.
Florida	3	Cubera snapper	Declines	Lindeman et al., 2000
25 total sites including :	1	Dog snapper	?	Lindeman et al., 2000
Dry Tortugas	8	Gray snapper	?	Lindeman et al., 2000
Key West area	1	Lane snapper	?	Lindeman et al., 2000
Gulf Coast	4	Mutton snapper	Declines	Lindeman et al., 2000
	2	Schoolmaster snap	?	Lindeman et al., 2000
	1	Yellowtail snap	?	Lindeman et al., 2000
	?	Black grouper	Declines ?	Eklund et al., 2000
	2?	Gag grouper	Declines	Coleman et al., 1996
	?	Scamp	Declines	Coleman et al., 1996
	>4?	Goliath grouper	Protected	Sadovy & Eklund, 1999
Cuba (21 total sites)	10	Cubera snapper	Declines	Claro and Lindeman, in press
	3	Dog snapper	Declines	Claro and Lindeman, in press
	3	Gray snapper	Declines	Claro and Lindeman, in press
	13	Lane snapper	Declines	Claro and Lindeman, in press
	12	Mutton snapper	Declines	Claro and Lindeman, in press
	5	Black grouper	Declines	Claro and Lindeman, in press

Table 2 (cont.)

Country/ State	No. SPAG Sites	Species	Current Status (Landings)	Reference / Source
	9	Nassau grouper	Declines	Sadovy & Eklund, 1999
	6	Yellowfin grouper	Declines	Claro and Lindeman, in press
Mexico - Quintana Roo	7	Nassau grouper	Declines / 1 Disappeared	Aguilar-Perera and Davis, 1996
Campeche	1	Yellowfin grouper	Heavily expl.?	Tuz-Sulub, in press
Bank	1	Red hind	Mod. expl. ?	
Belize	1	Cubera snapper	Heavily expl.	Heyman, pers. comm.
(13 total sites)	4	Dog snapper	Heavily expl.	Heyman, pers. comm.
	3	Mutton snapper	Heavily expl.	Heyman, pers. comm.
	?	Yellowtail snap.	?	Heyman, pers. comm.
	9	Nassau grouper	Declines / Disappeared	Paz and Grimshaw,2001 Sala et al., 2001
	5	Black grouper	Lightly expl?	Heyman, 2001
	4	Tiger grouper	Lightly expl?	Heyman, 2001
	2	Yellowfin grouper	Lightly expl?	Heyman, 2001
	?	Red hind	Lightly expl?	Heyman, 2001
Honduras - Guanaja	1	Nassau grouper	Disappeared?	Fine, 1992; Sadovy & Eklund, 1999
Cayman Islands	6	Nassau grouper	Declines	Bush et al, MS
	5	Tiger grouper	Lightly expl.	Bush, pers. comm.
	2	Mutton snapper	Lightly expl.	Bush, pers. comm.
Jamaica	1	Lane snapper	Heavily expl	Aiken, pers. comm.
Dominican Republic	1	Nassau grouper	Disappeared?	Sadovy & Eklund, 1999
Puerto Rico	4	Red hind	Declines	Matos-Caraballo, 1997
	1	Tiger grouper	Declines	Matos-Caraballo et al, MS
	3	Nassau grouper	Disappeared	Sadovy & Eklund, 1999
	1	Mutton snapper	Declines?	Garcia-Moliner, 2000
U.S. Virgin Is.	3	Red hind	Stable	Beets & Friedlander, '99
	3	Nassau grouper	Disappeared	Olsen & Laplace, 1976
British Virgin Islands	3	Red hind	Lightly expl.	Eristhee, pers. comm.
	1	Nassau grouper	Lightly expl.	Eristhee, pers. comm.

MAIN ELEMENTS OF CONSERVATION STRATEGY

The elements of the SPAG Conservation Strategy listed below are generally in priority order but the strategy will need to be adapted to the individual conditions determined for each site under consideration:

i) *Eliminate fishing mortality at vulnerable SPAG sites* — Limited data suggests that fishing at a number of SPAG sites in the region is not sustainable in the longer term with the existing gear types in use and the fishing effort presently being exerted (Sadovy 1999). Permanent closure of a SPAG site will lead to the elimination of fishing mortality at the site. However, if this is not possible, seasonal (temporary) closure of a SPAG site should be pursued as an essential alternative as it will help substantially reduce fishing mortality during the critical spawning period. Temporal and /or spatial buffer zones should be included in seasonal closures. Fishing at the SPAG site (or along established spawning migration routes) in the period leading up to the closure, as fish are starting to aggregate, may still lead to substantial fishing mortality. Thus, permanent closure is the preferred option (see #2).

A sense of urgency should be invoked for management /conservation action bearing in mind that SPAGs have historically shown dramatic declines, often in a short time frame. Data suggests that the groupers appear to be more vulnerable to fishing pressure than the snappers (Sadovy 1996, Coleman et al. 2000) and Nassau groupers have been shown to exhibit dramatic declines (e.g. Luckhurst 1996) over a 3 - 5 year period under sustained heavy fishing pressure (Olson and LaPlace 1979, Sala et al. 2001). The removal of a large proportion of the spawning fish at a given site in several consecutive years has led to the disappearance of a number of SPAGs in the region (Sadovy and Eklund 1999). Limited information about these sites suggests that they do not re-appear. This finding indicates that there may be a threshold effect whereby reproductive behaviour is negatively impacted if a given minimum number of fish are not present at the SPAG site.

ii) *Incorporate known SPAG sites into planning programs for marine protected areas (MPAs) to provide permanent protection of the sites* — In general, the enforcement of fisheries regulations in the Caribbean has not been particularly successful due in part to the lack of resources and infrastructure and also the number of different regulations which address taxon or area-specific issues. The creation of MPAs addresses a number of ecological and regulatory issues (Plan Development Team 1990). In general, the enforcement of the no-take provision of an MPA is easier when the boundaries of the given area are well-defined and the rationale for its creation is understood by the various resource user groups. The incorporation of SPAGs into no-take MPAs would accomplish several of the objectives presented here including protection of the spawning populations from fishing pressure and helping to maintain ecosystem

structure and function (Lindeman et al. 2000). The longevity of SPAG sites (Colin 1996) makes their incorporation into an MPA an attractive conservation /management option.

The documentation of multi-species use of the same SPAG site greatly strengthens the rationale for incorporation of the site into an MPA. This is because a proportion of the spawning population of a number of different species will all be afforded protection during the period of maximum vulnerability and this protection will help ensure normal ecosystem structure and function. A number of such multi-species SPAG sites have already been identified in Belize (Heyman pers. comm.) and the recognition of the ecological importance of such sites is being promoted to help ensure their protection. Furthermore, the identification of the key features of these SPAG sites will allow researchers to predict and evaluate sites throughout the region including perhaps SPAG sites which are as yet undetected. The identification of such sites could afford researchers the opportunity to study such unfished sites to better understand their dynamics and to be pro-active in affording them protection.

iii) *Develop and implement monitoring programs to evaluate the effect of management/conservation measures* — Scientists, managers, and fishermen need to gather more information to better understand the dynamics of SPAGs and to examine different management /conservation measures as applied to a given SPAG site. Careful monitoring of selected sites should be planned when measures are implemented. These measures when applied should be viewed as fishery experiments from which much can be potentially learned about the system under study. The involvement in the monitoring process by different user groups should increase the sense of stewardship of the resources and provides direct feedback to the community about management and conservation actions.

iv) *Develop community-based management programs for SPAG sites to the fullest extent possible* — Historically, a "top-down" approach to the management of tropical marine resources has generally been ineffective. Rarely have sufficient resources, either human or material, been available to carry out government mandates in the context of marine resource management. User groups, mainly fishers, generally view management regulations as government attempts to reduce their ability to make a living from harvesting fishery resources. They are not often in support of restrictions of their fishing activities. From the government perspective, there is a need, in fact a responsibility, to manage the fishery resources of the country as these are common property resources belonging to all citizens of the country. Unfortunately, an adequate explanation as to the need for the management of fishery resources is often not provided to the user groups affected by the management measures.

Full participation in the management process by all of the user groups affected by management measures will greatly increase the probability of

success. Scientists (particularly those from outside government service) can help to provide the conceptual framework to the affected communities for the recommended management action. Fishers are empiricists and it often requires much discussion to gain their support for a measure based on a concept. However, the concept of protecting the reproductive process is so fundamental to human thinking that the conservation of SPAGs is usually not very difficult to accept. A full discussion of the proposed action and its consequences is a necessary step to garner the support of the community (King and Faasili 1999). Partnerships between government departments and NGOs is frequently an effective means of increasing support for management measures.

v) *Provide viable economic alternatives to those user groups who are displaced from SPAG sites as a result of management action.* — This is an important and necessary step in helping to ensure the long term success of management measures implemented for conserving SPAGs. An evaluation of the economic importance of the landings from SPAGs, as a proportion of the annual revenue earned by fishers (e.g. Sala et al. 2001) should be undertaken to assist with planning and training activities. Unless adequate provisions are made for fishers for the transition away from SPAG fishing, there is likely to be continued economic pressure on fishers to continue harvesting at SPAGs. The employment opportunities for displaced fishers providing alternative sources of income will most often take advantage of the skills and experience gained by fishers over the years, e.g. knowledge of coral reef fauna, boat handling, etc. In Belize, training is being provided to fishers as SCUBA diving guides and as fishing guides for sportfishing as an alternative to SPAG fishing (pers. obs., Heyman pers. comm.). Additional alternate activities are the development of aquaculture, particularly floating cage culture, which is already well-developed for groupers in southeast Asia. This form of mariculture can be conducted primarily as a low-tech grow-out operation and can be readily adopted by fishermen. However, careful consideration must be given to promoting aquaculture as it can have significant negative effects on the marine environment through pollution and destructive fishing practices to obtain juveniles for grow-out.

vi) *If permanent or temporary closure of SPAG sites cannot be implemented, then gear restrictions should be applied to reduce catchability.* — There is evidence which suggests that the use of certain gear types, e.g. Antillian fish traps (Luckhurst 1996) and spearfishing for harvesting at SPAG sites increases fishing mortality rates. Marked declines in catches have been noted at sites following the introduction of these gear types. Fish traps are a passive gear type and fish 24 hours a day thus applying constant fishing pressure on aggregated fish in contrast to an active gear such as hook and line fishing. Spearfishing is a form of selective predation with the largest fish usually being the targets. Therefore, the only gear type which should

be permitted at SPAG sites is hook and line fishing. As sea conditions can often disrupt this active form of fishing activity, there may be a reduction in fishing pressure during the critical aggregation period and thus a reduction in fishing mortality.

vii) *If other forms of restriction of fishing activity at SPAGs cannot be implemented, then use economic/market measures such as sales or export restrictions.* — The most commonly used measures are a seasonal ban on possession or sale of a given species or an export ban for those high value species which are shipped out of the country. However, interventions in the marketplace should be secondary to reducing or preventing the harvest of the target species at SPAG sites, which is the primary goal. Where strong economic incentives exist for SPAG fishing, some intervention in the market will almost certainly be necessary.

The implementation of this SPAG Conservation Strategy will require the cooperation of many different agencies throughout the region including various government agencies, NGOs involved in marine conservation, research institutions such as marine stations and academic institutions. In each country or jurisdiction, conservation and management plans will have to be developed (if they do not already exist) according to the priorities of each individual country (e.g. Belize, Paz and Grimshaw 2001). In addition, the time frame for the execution of each individual plan will have to be established. Partnerships and funding mechanisms for implementation of the plans will also have to be established. Partnerships with international organizations e.g. UNEP (United Nations Environment Program), National agencies, Universities and NGOs will have to be formulated. The Society for the Conservation of Reef Fish Aggregations (SCRFA) is identified as an important partner for the scientific aspects of SPAG conservation and management. The experience of some SCRFA members in the Asia-Pacific can be very helpful in providing perspectives on the current situation in the Caribbean.

A concerted effort needs to be made to disseminate information about the existence and status of SPAGs throughout the region to raise awareness and develop a commitment for action. The use of the electronic media, the Internet, and the production of pamphlets and articles should all be viewed as mechanisms to broadly distribute this information about SPAGs and their status in the region.

ACKNOWLEDGMENTS

The following persons, listed by country or jurisdiction, provided information and data (much of it unpublished), which were invaluable in producing this report: The Bahamas - Michael Braynen, Kathleen Sullivan-Sealey; Turks and Caicos Islands - Wesley Clerveaux; Cuba - Rodolfo Claro, Ken Lindeman; Florida - Ken Lindeman, Peter Gladding; Belize - Will Heyman; Cayman Islands - Philippe Bush; Jamaica - Karl Aiken; Puerto Rico - Daniel Matos-Caraballo; U.S. Virgin Islands - Rick Nemeth; British Virgin Islands - Newton Eristhee. I thank all of these persons for their time and effort in providing information but any errors in the compilation

of this information or in the interpretation are solely my responsibility.

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Reducing the Impacts of Fishing and Tourism on Fish Spawning Aggregations in the Great Barrier Reef Marine Park

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ABSTRACT

The Great Barrier Reef Marine Park Authority (GBRMPA) is taking steps to ensure that fish spawning aggregation sites (FSAS) in the Great Barrier Reef Marine Park (GBRMP) are not being overexploited by fishing and disturbed by tourism. There is concern that commercial and recreational fishers are targeting FSAS in the GBRMP; and the presence of divers and fish feeding may affect the normal spawning behaviour of fishes at these sites. The GBRMPA is attempting to mitigate the impacts of these activities to ensure the maintenance of FSAS and the aggregating fish that depend on them. In this paper I discuss the introduction of seasonal closures and prohibition of fishing for species caught in the Queensland tropical coral reef finfish fishery; the rezoning of the GBRMP, which will help protect FSAS via a network of no-take areas; and the locations of mooring, pontoon, and anchoring sites in relation to FSAS.

KEY WORDS: Aggregation, reef-fish, spawn

INTRODUCTION

The Great Barrier Reef Marine Park (GBRMP) is the world's largest coral reef ecosystem and marine protected area, extending over 2,000 km along Australia's east coast, with some 3,000 reefs and 900 islands. In recognition of its importance to both the Australian and the international community, the GBRMP is managed by the Government of Australia and is a World Heritage Area. The Great Barrier Reef Marine Park Authority (GBRMPA) is responsible for managing this important area and works closely with government fisheries management agencies to ensure fisheries in the GBRMP are ecologically sustainable.

The GBRMPA is taking steps to protect fish spawning aggregations in the GBRMP from impacts of fishing and water-based activities associated with tourism. There are two areas of concern. Firstly, there is concern that reef finfish stocks may be overfished, partly as a result of targeted and incidental fishing on spawning aggregations throughout the GBRMP. Secondly, there is concern that water-based activities associated with tourism structures such as moorings, pontoons and reef anchorages in or close to fish spawning aggregation sites (FSAS) could disrupt the normal spawning behaviour of aggregating fishes.

DISCUSSION

Fish Spawning Aggregation Sites in the GBRMP

To date, 133 species of fish in 21 families have been reported to form spawning aggregations, either in the GBRMP or elsewhere in their geographical range. Forty-nine species from 12 families have been observed to form spawning aggregations in the GBRMP, and 84 other species that also inhabit the Great Barrier Reef (GBR) have been reported to form spawning aggregations in other locations (Russell 2001).

Information held by the GBRMPA on the locations of FSAS in the GBRMP suggests that two different types of FSAS are used by fish species such as common coral trout *Plectropomus leopardus*. These are given the term primary FSAS and secondary FSAS (Samoilys 1997, Zeller 1997). Primary FSAS are key sites visited consistently each year by fish such as *Plectropomus spp.*, maori wrasse *Cheilinus undulatus*, barramundi cod *Cromileptes altivelis* and potato cod *Epinephelus tukula* for spawning. These sites may be characterised by geomorphological and topographical features, depth profile and flow dynamics that offer highly specific characteristics that facilitate territory establishment, courting and spawning rushes. Secondary FSAS, visited sporadically each spawning season by *P. leopardus* and other species for spawning purposes, share some of the characteristics of primary FSAS. It is thought that each reef in the GBRMP has one or more primary FSAS and several secondary FSAS. The main spawning season for species that use primary FSAS is October through December. Fish species such as *Plectropomus spp.* move to FSAS each spawning season on the reef they inhabit, but do not move between reefs (Davies 2000).

The Need for Protection from Fishing

In the GBRMP, the tropical coral reef finfish fishery is made up of commercial and recreational fishers, including fishing tours (charter), using hook and line and spear (recreational only) to target demersal reef fishes. The major fishes targeted include species in the families Lethrinidae, Lutjanidae and Serranidae (Brown et al. 1994, QFMA 1996). There are about 300 commercial fishing operations actively targeting coral reef finfish. A further 1300 commercial fishers are licensed to take coral reef finfish, but presently operate primarily in other fisheries. The commercial catch is about 3000 tonnes per year; most of this catch is now exported live into Asia. *P. leopardus* dominates the catches, comprising about 45% of the catch (Mapstone et al. 1996). Some 120 fishing charter vessels take about 265 tonnes. Some 800,000 Queensland-based recreational fishers (QFMA 1999a) catch about 1500 tonnes of reef finfish per year.

There is concern about the sustainability of fishing spawning aggregations of *Plectropomus spp.*, *Epinephelus spp.*, *C. undulates* and *C. altivelis* in the GBRMP. Reports of targeted fishing on FSAS have been made to the GBRMPA and the managers of the coral reef finfish fishery, the Queensland Fisheries Service (QFS). Increased fishing pressure occurs from September to November (Mapstone et al. 1996, Turnbull and Samoilys 1997), which corresponds with the spawning season for *P.*

leopardus as well as other important fishery species. Davies (2000) suggests that an increase in catchability of *P. leopardus* on mid-shelf reefs in the Cairns Section of the GBRMP during September is attributable to fish aggregating to spawn. Catchability of *P. leopardus* is likely to increase as a result of the aggregated distribution of fish in locations that can be efficiently exploited by fishers and the heightened feeding activity of the fish associated with spawning (Johannes and Squire 1988, Samoilys and Squire 1994, Davies 2000, Russell 2001).

Within the past 10 years, spawning aggregations of *P. leopardus* (Samoilys, M., pers. comm. 1999), blue spot trout *Plectropomus laevis*, and *C. undulatus* (Squire, L., pers. comm. 1999.), have diminished in size and number at various locations in the northern part of the GBRMP. Aggregations of *C. undulatus* and *P. laevis* documented by Johannes and Squire (1988) no longer form at Ribbon and Jewell Reefs (Squire, L., pers. comm. 2000). Recently, it has been found that one of two main spawning aggregations of *P. leopardus* on reefs near Cairns has diminished over the past few years, most likely due to overfishing (Samoilys, M., pers. comm. 1999).

GBRMPA's Strategy to Protect FSAS from Fishing

Currently, the GBRMPA reef zoning plans indirectly provide for protection of some FSAS from fishing, through the protective zoning of reefs throughout the GBRMP, although protection of FSAS was not part of the original intent of the zoning plans. About 20% of the reefal area is closed to reef fish fishing. In the near future, the GBRMP will undergo a rezoning as part of the GBRMPA Representative Areas Program (Day et al. in press), and the locations of primary FSAS will be considered in the identification of areas in need of protection. This strategy involves high-level protection of whole reefs and groups of reefs that represent specific bioregions in the GBRMP.

Site-specific spawning closures to exclude fishers from known FSAS seasonally or permanently have been considered by the GBRMPA. However, it is considered that such closures would be ineffective in practice. This strategy may be beneficial if there were a few key FSAS in the GBRMP. Potentially every reef in the GBRMP has one or more primary FSAS, and it is not known which FSAS are more important for supplying new recruits to surrounding areas. Considering the size of the GBRMP, small site closures would be extremely difficult to enforce without some form of satellite tracking device on all fishing vessels and/or a labour-intensive enforcement program. Closures may also highlight the location of FSAS and increase the risk of targeted poaching.

The GBRMPA and the QFS are considering broader reef-wide strategies that protect fish spawning aggregations from overexploitation in the GBRMP.

In July 1999, the Queensland government released a draft Management Plan for Queensland Tropical Coral Reef Fish Species (QFMA 1999b). The draft plan included provisions for the protection of fish spawning aggregations by prohibiting the possession of reef finfish for nine-day periods in October and November in the northern regions of the GBR, and November and December in the southern regions of the GBR. This north/south, staggered closure strategy was proposed because it was thought that

Plectropomus spp. spawn later in the southern regions of the GBR. The proposed nine-day closure in each month would commence four days before the new moon; *P. leopardus* spawns during the new moon. It was anticipated that other fishes that aggregate to spawn at the same time would also benefit from the closures. In response to this proposal, the GBRMPA proposes that the nine-day closures extend reef wide during October-December. It is unclear if there is a north/south variation in spawning times on the GBR for *Plectropomus spp.*, and there are inherent enforcement difficulties considering the closures prohibit the possession of reef finfish in different areas at different times.

Seasonal fishing closures are considered an effective way of ensuring aggregating fishes are protected from fishing during the main spawning season in the GBRMP. The proposed nine-day, new-moon closures during October–December would help ensure reproductive success of fishes that aggregate to spawn at this time. It could be argued that a closure over the entire three-month main spawning period for *Plectropomus spp.* is a more effective option. However, the nine-day new moon closures are only one part of a broader strategy for this fishery. Other management measures include conservative size limits, recreational bag limits and reduction in commercial licences.

Seasonal closures for particular species have been considered, but this option is not being progressed. This will not reduce the disturbance of spawning fish if the protected species is caught and returned to the water. This strategy also has inherent enforcement difficulties, considering that some fish are filleted on board the boats.

Several species of fish in the GBRMPA have iconic status. These are large fish with "character" and value for visitors to the reef, and are an integral part of the Great Barrier Reef World Heritage Area. A more stringent management strategy is being proposed for iconic species that may be vulnerable to fishing pressure because of their low natural abundance, large size, inquisitive nature, reproductive biology, or particular spawning site requirements. The GBRMPA is advocating the total protection of *C. undulatus*, *C. altivelis* and *E. tukula*. It has also been suggested that several other smaller *Epinephelus spp.* and *Cephalopholis* spp. should be afforded similar complete protection because of their reproductive biology and potential vulnerability. Information suggests that the high-value, commercial species such as *C. undulatus* have very specific spawning sites and utilise fewer spawning sites than *Plectropomus* spp.. Consequently, their populations would be affected to a greater degree if fishers targeted or incidentally fished their spawning sites. It has been proposed by some commercial fishers that a catch limit of one fish per boat for *C. undulatus* and *C. altivelis* would, if enforced effectively, prevent these fish being taken in large numbers from spawning sites. However, the GBRMPA considers if these species are to be protected, a more precautionary and enforceable approach to their conservation would be to prohibit this take. This management strategy has already been introduced for *C. undulatus* in Western Australia because of concerns about unsustainable fishing.

The management plan for the Queensland coral reef finfish fishery is expected to be in place in the second half of 2002. It is likely that the new moon closures will be introduced and the vulnerable species will be protected. If the management plan does not address the above concerns adequately, the GBRMPA will consider using its

legislative mandate.

The Need for Protection from Tourism Water-based Activities

Commercial tourism is a major industry in the GBRMP. Tourists visited the GBRMP for some 1.3 million visitor days in 1998 – 1999 (GBRMPA Environmental Management Charge data), with an estimate of over 500,000 tourists diving or snorkeling in the GBRMP each year (Aiello 1996). More than 90% of these tourists visited the Cairns-Port Douglas and Whitsunday regions, which cover 4% of the GBRMP.

It is possible that large numbers of snorkelers and divers could inhibit the formation of fish spawning aggregations or disturb normal spawning behaviour, subsequently affecting the reproductive success of aggregating fishes (Sadovy, Y., pers. comm. 2000). The presence of individual research divers at FSAS has been reported to disrupt the spawning behaviour of several fish species, including *Acanthurus spp.* (Randall 1961a, b), red hind *Epinephelus guttatus* (Shapiro et al. 1993b), *Plectropomus* spp. (Samoilys, M., pers. comm. 1999, Carlos and Samoilys 1993, Squire, L. and Hartney, T., pers. comm. 2001) and *Scarus* spp. (Randall and Randall 1963), possibly a predator evasion response. Aggregating fish commonly seek shelter if they are approached or disturbed by a diver, and the colour patterns exhibited by courting males, e.g. *P. laevis* (Carlos and Samoilys 1993) and *Acanthurus* spp. (Randall 1961a, 1961b), have been observed to change back to non-reproductive colour when disturbed by a diver. During October 2001, spawning aggregations of *P. leopardus*, globehead parrotfish *Scarus globiceps*, and red bass *Lutjanus bohar* were observed to move away from divers and modify their aggregating behaviour when approached by several divers participating in a GBRMPA FSAS identification and assessment training course.

Damage to coral, primarily by boat anchors, but also by some divers and snorkellers has been reported in the GBRMP (Tourism Review Steering Committee 1997, Hawkins and Roberts 1992, Rouphael and Inglis 1995). Reef sites used heavily by divers may have more damaged coral colonies than reefs with low diver activity (Hawkins and Roberts 1992). However, coral damage by divers may not be a significant impact on FSAS. It is possible that major alteration of coral substrate may change the topographical characteristics of an area and possibly cause fish to choose another less favourable area to spawn, or not spawn at all, although this has not been verified.

Another potential threat to FSAS is fish feeding. Daily fish feeding, a popular activity at tourist sites, can attract groups of predatory fishes, which may normally feed at other locations. The presence of these predators could prevent the formation of spawning aggregations of smaller fishes at these sites. For example, it has been suggested that regular feeding of *E. tukula* and *L. bohar* at the Cod Hole, northern GBRMP, has resulted in the cessation of large spawning aggregations of *Acanthurus spp.* and other fishes from frequenting the site because of the presence of predators (Squire, L., pers. comm. 2000).

GBRMPA's Strategy to Protect FSAS from Tourism Water-based Activities

During the 1990s, more than 500 moorings and 20 pontoons were installed throughout the GBRMP. These structures have been situated to take advantage of water currents, clear water and protection from prevailing winds. Several moorings and pontoons are believed to be positioned in or adjacent to primary FSAS. In 1997, the GBRMPA developed a working policy to only permit new moorings and pontoons to be installed at least 100 metres away from primary FSAS. Subsequently, the *Cairns Area Plan of Management* (GBRMPA 1999) required consideration of the locations of FSAS when locating moorings, pontoons and Reef Anchorages, and site planning of reefal areas for tourism activities included an FSAS assessment by qualified Authority FSAS assessors.

The GBRMPA is collating information and maintaining a database on the locations and physical and temporal characteristics of FSAS in the GBRMP. This information is for a limited number of fish species of commercial, recreational and conservation importance, for example, *Plectropomus spp.* and *C. undulatus*, and to date is for a limited number of reefs in the GBRMP. The information has been obtained from scientists, commercial fishers, tourism operators and from site assessments conducted by FSAS identification and assessment officers.

Currently, the GBRMPA has six officers trained in the identification and assessment of FSAS. These officers were trained during two courses in October 2000 and October 2001, during which attempts were made to determine the physical characteristics of a primary FSAS in the GBRMP, using several known primary FSAS as an indicator of these characteristics. There seem to be variations between FSAS longitudinally and latitudinally in the GBRMP, and variations between the spawning site preferences for different species, thereby complicating the development of a standard assessment process. Subsequently, until more information is obtained on what reef characteristics are necessary for particular reef fish to spawn, assessments required for identifying the most appropriate locations for moorings etc., will be done only during the peak spawning time, and involve identifying spawning fish behaviour.

CONCLUSION

The protection of spawning fish in the GBRMP is a key focus for the GBRMPA. Precautionary management arrangements to protect FSAS and the fish when they aggregate at these sites to spawn are being developed using the best available information, although this information is limited.

The GBRMPA is concerned that FSAS may be unsustainably fished in the GBRMP. There are some examples in the GBRMP and many examples outside Australia of overexploitation of reef fish as a result of fishing FSAS. Protecting FSAS in the GBRMP through the use of marine protected areas is one management tool that will help ensure reproductive success of reef fish. However, considering the size of the GBRMP, the numbers of reefs, the numbers of FSAS, and the unknown variations in spawning times for different species, seasonal closures during the peak spawning months are also being considered. Nine-day closures to reef fish fishing are proposed

over the new moon in October, November and December. For iconic and vulnerable species, such as *C. undulatus, E. tukula* and *C. altivelis*, complete protection is necessary. The GBRMPA is working closely with fisheries managers to progress these strategies. However, closures and protection measures under the *Great Barrier Reef Marine Park Act 1975* will be considered if Queensland fisheries management planning for coral reef finfish is delayed or management strategies are not adequate.

With respect to managing the impacts of water-based, tourism activities on primary FSAS, the GBRMPA is taking a precautionary approach when determining the most appropriate locations for moorings, pontoons and anchorage areas. The GBRMPA's FSAS identification and assessment officers are gathering more information on the characteristics of FSAS, and potential impacts, to further develop these management arrangements.

It is clear that FSAS and the fish when they aggregate to spawn at these sites need protection from human impacts. The GBRMPA has a legislative obligation and is working proactively to reduce the potential impacts on spawning fish and help ensure reproductive success of reef fishes in the GBRMP in the long term.

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Capacity Building and Community Involvement in Marine Protected Area Implementation

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ABSTRACT

The local community of resource users in the area of the Marine Protected Areas (MPA) needs to be enlisted as a co-management partner in its siting, planning, implementation and operation through a "bottom-up" approach. Experience has shown that the imposition of MPAs without broad participation, consensus and acceptability is a recipe for failure. However, not all resource users have the appropriate local institutions and skills for co-management, thus any co-management arrangement for an MPA will require both institution- and capacity-building. This paper presents factors related to capacity building and community involvement that can lead to the successful planning and implementation of MPAs.

KEY WORDS: Marine protected areas, co-management, capacity building

MARINE PROTECTED AREAS

Marine protected areas (MPAs) have been advocated by some as the solution for all fisheries and coastal ecosystem management problems. It is felt by some that MPAs can be scientifically designed and imposed from the top to achieve aquatic resource conservation, with little or no participation from the resource users in the area. The worldwide experience so far with MPAs has been mixed. There are many "paper parks" and failed MPAs around the world.

A number of factors have emerged from experience to improve the success of MPA implementation. MPAs need to be nested within a framework of integrated ecosystem or coastal area management. MPA objectives need to be clear and compatible with local conditions. The local community of resource users in the area of the MPA needs to be enlisted as partners in its siting, planning, implementation, and operation through a "bottom-up" approach. Experience has shown that the imposition of MPAs without broad participation, consensus and acceptability is a recipe for failure. Governance issues (rights, rules, organization, legal) must also take a high priority in planning and implementation. It is crucial, therefore, to understand the social, economic, political, and institutional context for establishing MPAs. On their own and without outside support, the community generally does not have the human resources and capacity to plan and manage the MPA. In most cases, it may be better to co-manage the MPA.

CO-MANAGEMENT

Co-management is defined as a partnership arrangement in which government, the community of local resource users, external change agents, and other resource stakeholders share the responsibility and authority for making decisions about management of the MPA. Through consultation, the partners develop an agreement that specifies their roles, responsibilities, and rights in management of the MPA. Not all resource users have the appropriate local institutions and skills for co-management, thus any co-management initiative will require both institution- and capacity-building.

This is especially true in the Caribbean-region where resource user capacity to engage in co-management is generally low and hindered by lack of community organizations, lack of traditions and experience with collective action, lack of social preparation, and limited empowerment. However, fishers generally express interest and support for participation and co-management. Capacity building and community involvement in MPA management is a long-term process, costly, risky, often not sustainable, and often not successful. Experience in the Philippines has shown that just community organizing can take three to five years. The development of institutions for coastal resource self-governance in St. Lucia has taken up to 10 years.

Research and practical experience from around the world has revealed factors which can lead to the successful planning and implementation of MPAs (Pollnac et al. 2001, Pomeroy et al. 2001).

CAPACITY BUILDING AND COMMUNITY INVOLVEMENT SUCCESS FACTORS FOR MPA IMPLEMENTATION

Participation by Those Affected

Most individuals affected by the MPA are included in the group that makes decisions about and can change the arrangements.

Individual Incentive Structure

An individual incentive structure (economic, social, political) must be present that induces individuals to want to participate in the MPA. Individuals must feel that the private benefits to be obtained from the MPA will outweigh private costs, especially in the long run. MPAs will often involve giving up individual short-term benefits for real and perceived long-term benefits. For the individual, the costs of decision-making, especially in terms of time involved, cannot be to high or participation will fall. Often the short-term costs are high in terms of lost income or livelihood. For a poor fisher with a family to feed, the incentive structure to support the MPA must be clear and large. Risk is involved for the individual in supporting the MPA. Individual behaviour cannot be changed unless the person has an incentive to want to change.

Sense of Ownership of the MPA and the Co-management Process

Those involved in the MPA and co-management must feel that it not only benefits them, but that they have a strong sense of participation in, commitment to, and ownership of the MPA. Those external to the community working on the MPA, such as a non-governmental organization (NGO), must ensure that the people recognize themselves as participants in and owners of the process. Forums for discussion about the MPA should be established early, be open to all, and encourage open and free dialogue on the issues. Partners in the MPA (fishers, government, NGO) roles, goals, purpose, operation, style and limitations must be made clear and transparent. Trust and mutual respect between partners must grow out of a sense of commitment, meeting objectives and targets, and open dialogue. Partners' views and ideas must be respected.

Leadership

Local leaders set an example for others to follow, set out courses of action, and provide energy and direction. Local elite may be the traditional leaders, but they may not be the most appropriate for MPA or co-management. New leaders may need to be drawn from or developed in the community. These individuals may be more acceptable and respected by their peers.

Individual and Community Empowerment

Empowerment is concerned with capacity building of individuals and the community in order for them to have greater social awareness, to gain greater autonomy over decision-making, and in establishing a balance in community power relations. Empowerment covers a range of actions including enhancing community access to information and services, ensuring community participation, consciousness raising, business and enterprise management skills, and gaining control over the utilization and management of coastal resources. Information and knowledge generation and sharing are key to empowerment.

Capacity Building

Empowerment is enhanced by capacity building through education and training efforts that raise the level of information and knowledge of those involved in the MPA and co-management. The capacity of the partners for collective action, cooperation, power sharing, dialogue, and leadership must be developed and strengthened. MPA management will require new skills and technologies that must be learned. Capacity building must address not only technical and managerial dimensions, but also attitudes and behavioural patterns of resource users. A range of capacity building methods can be used including fisher-to-fisher sharing, exchange visits, video and audio, and hands-on experience.

Social Preparation and Value Formation

The inability to sustain MPAs and co-management may be partly attributed to the insufficient time allocated to social preparation, value formation, and rapport

building within the community. Social preparation should always precede technical and material interventions. Cutting corners during the social preparation phase to yield to pressures to produce material accomplishments is likely to weaken the foundation for self-reliance in the community. Good social preparation is manifested in positive attitudes toward collective action and in the readiness of community members to take on the responsibility for MPA management.

Community Organization

The existence of a legitimate (to the community) community organization is vital to represent resource users interests and influencing decision-making. The organization must have the legal right to exist, be autonomous of government, and endorsed and credible to the people. Core groups, a sub-unit of the organization, can be formed for initial implementation and for specific activities.

Economic and Community Development

In order to maintain interest and participation in the MPA and co-management, it useful to start small, gain small successes, gain confidence and trust, and grow from there. Since MPAs often take some time to show impacts, it may be necessary to have associated projects such as alternative livelihoods, community infrastructure and services to reduce the negative impacts of the MPA.

Institutional Sustainability

Many MPA and co-management initiatives fail when the money and external agents leave the area. A critical question to be asked early in MPA design is what to do when the money stops. Self-sustained financing must be considered at the start of the MPA design process. A phase-out plan and project turnover should also be built into planning as the NGO or other external change agent leaves and the community takes over MPA management.

External Change Agents

External change agents (NGOs, academic and research institutions, religious organizations, government agencies) are often needed to guide, but not directly intervene, in MPA design and implementation. External change agents help define problems; provide independent advice, ideas and expertise; provide training and technical assistance; guide joint problem solving and decision-making, and assist in developing the MPA and co-management plan. The community should not become dependent upon the change agent as they will eventually leave the area. The relationship should be limited and there should be a planned phase-out of assistance.

DISCUSSION

None of the factors presented above exist in isolation, but each supports and links to another to make the complex process and arrangements for MPAs and co-management work. Also, these are not the only factors involved in capacity building and community involvement in MPA implementation. If nothing else, local people need to be at the center of decision-making about MPA siting, design and implementation. The active and long-term participation of local resource users in the MPA will increase the chance for success. Implementation is often a balancing act to meet these factors as timing and linkages in the MPA and co-management process are important.

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Monitoring Changes in the Fully Protected Zones of the Florida Keys National Marine Sanctuary

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ABSTRACT

The Florida Keys National Marine Sanctuary is a 9,850 km^2 marine protected area managed by the U.S. National Oceanic and Atmospheric Administration and the State of Florida. A comprehensive management plan was implemented in 1997 to protect and conserve marine resources of the Florida Keys, which include mangrove, seagrass, and coral reef habitats and their associated communities. One innovative aspect of the management plan is the creation of a network of 23 fully protected zones (marine reserves; 24 as of July 2001) that are designed to protect biodiversity and sensitive habitats, reduce user conflicts, and lessen concentrated impacts to marine organisms at heavily used reefs. An ongoing monitoring program is designed to determine effects of no-take protection on heavily exploited fishes and invertebrates, benthic communities, and human activities. Data on the abundance and size of fish, spiny lobster, and queen conch; algal cover; coral cover, diversity, and recruitment; and zone usage are collected from fully protected zones and adjacent reference sites. Preliminary reports indicate increases in the number and size of certain heavily exploited species such as spiny lobster within the fully protected zones. Slower-growing benthic species such as corals and sponges have not shown significant changes within protected areas, possibly because of the short period since implementation of the zoning plan (four years).

KEY WORDS: Florida Keys, marine protected areas, monitoring

INTRODUCTION

The only emergent coral reefs found off the continental U.S. are located in the Florida Keys, from south of Miami to the Dry Tortugas (Figure 1). The Florida Reef Tract comprises one of the largest coral reef systems of its type in the world, arching 356 km east and south of the Keys at a distance of 4.8 to 11.3 km offshore. Because the Upper and Lower Keys are protected from direct flow of water from the Gulf of Mexico, they are considered to have greater reef development than the Middle Keys (Robbin 1981, Shinn et al. 1989). All but the northernmost extent of the Florida Reef Tract lies within the boundaries of the Florida Keys National Marine Sanctuary (FKNMS or Sanctuary). The Sanctuary was designated in 1990 to protect and conserve nationally significant biological and cultural marine resources of the area, including critical coral reef habitats.

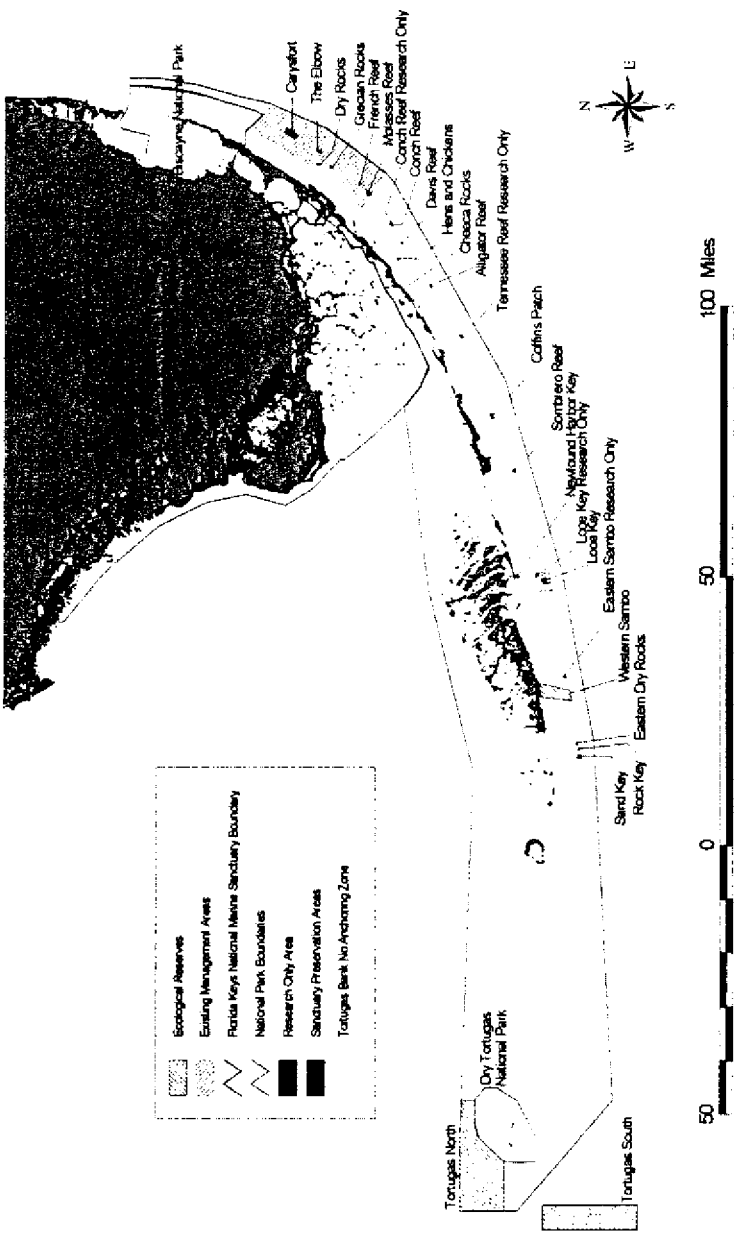


Figure 1. Map of the Florida Keys National Marine Sanctuary, showing the fully protected areas (Ecological reserves, Research-only Areas, and Sanctuary Preservation Areas.

The Florida Keys National Marine Sanctuary covers 9,850 km^2. Over half of the Sanctuary is located in State of Florida territorial waters; the rest (42%) is in Federal waters. While there are many references in the popular literature describing the Florida Reef Tract as a barrier reef, there is a strong belief in the scientific community that it does not fit the definition of such a system. The Florida Reef Tract is more accurately described as a bank reef system, comprised of an almost continuous reef community with elongated reef habitats that lie parallel to one another and resemble a typical barrier reef system. Overall, the reef system along the Florida Keys consists of several distinct habitat types including nearshore patch reefs, mid-channel reefs, offshore patch reefs, seagrass beds, back reefs/reef flat, hardbottom communities, bank or transitional reefs, intermediate reefs, deep reefs, outlier reefs, and sand/soft bottom areas.

One of the most noticeable features of the bank reefs of the Florida Keys is seaward-facing spur-and-groove formations, constructional features formed in part by wave energy (U.S. DOC 1996). Tops of spurs were composed mainly of *Acropora palmata*, especially at depths less than five meters, until the demise of acroporids throughout much of the Caribbean region in the early 1980s. Grooves contain carbonate sand and reef rubble. These features may extend 1 to 2 km off the main reef, from depths of 1 to 10 m. Primary corals found in this area include the *Montastrea annularis* complex and *Montastrea cavernosa*, *Siderastrea siderea*, and *Millepora* spp. *Porites astreoides*, *P. porites*, and *Agaricia agaricites* are also common species. *Acropora cervicornis* and *A. palmata*, formerly common or dominant species at depths of 3 - 15 m, are present in very low abundance at this time. In addition to bank reefs, over 6,000 patch reefs that are circular to oval in shape lie along the Florida Reef Tract in 2 to 9 m of water.

Numerous studies have been completed that describe the inhabitants of the Florida Keys coral reef community. Over 520 species of fish have been identified from the Florida Keys overall (Starck 1968), which includes over 260 species of reef fish (Bohnsack et al. 1999). Three-hundred sixty-seven (367) taxa of algae have been identified (Littler and Littler 2000), as well as 117 species of sponges (Levy et al. 1996), 89 species of polychaete worms (Levy et al. 1996), and 128 species of echinoderms (Hendler et al. 1995). Surveys of fire corals, octocorals, stony corals, zooanthids, and corallimorpharians (false corals) found two species of fire coral, 55 species of octocoral, and 63 taxa of stony corals (U.S. DOC 1996, Levy et al. 1996).

With the designation of the Florida Keys National Marine Sanctuary in 1990, the entire coral reef tract of the Florida Keys was afforded certain levels of protection. Oil and hydrocarbon exploration, mining, and large shipping traffic and their resulting impacts are excluded from the Sanctuary. Anchoring on corals in shallow water is prohibited, as is touching coral, collecting living or dead coral, and taking live rock, a product of the aquarium trade. The Sanctuary has the authority to address discharges within its boundary as well as potential pollutants that originate from outside the Sanctuary, offering protection of water quality that is critical for coral reef health and vitality.

FKNMS FULLY PROTECTED ZONES

In addition to Sanctuary-wide regulations that address direct and indirect impacts to coral reef resources, the creation of fully protected zones preserves specific reef areas more completely. A network of 24 fully protected zones, which cover approximately 6% of the Sanctuary but protect 65% of shallow bank reef habitats and 10% of coral resources overall, were implemented in 1997 and 2001 (Figure 1). Lobstering, fishing, spearfishing, shell collecting, and other consumptive activities are prohibited in these areas. Most of the smaller zones (Sanctuary Preservation Areas) are located along the offshore reef tract and encompass the most heavily used spur-and-groove coral formations. The 30.8 km^2 Western Sambo Ecological Reserve protects offshore reef as well as all other habitats, including mangrove fringe, seagrasses, hardbottom communities, and patch reefs. The 517.9 km^2 Tortugas Ecological Reserve, established in July 2001 after a three-year collaborative design and planning process, is located in the westernmost portion of the Florida Reef Tract (Figure 1). The Tortugas Ecological Reserve conserves important deep-water reef resources and fish communities unique to this region of the Florida Keys. The Tortugas Ecological Reserve is also significant because it adjoins a proposed 157.8 km^2 Research Natural Area in the Dry Tortugas National Park, a zone where shallow seagrass, coral, sand, and mangrove communities will be conserved. Together, the Sanctuary s Tortugas Ecological Reserve and the National Park s Research Natural Area fully protect nearshore to deep reef habitats of the Tortugas region and form the largest, permanent marine reserve in the United States.

FKNMS ZONE MONITORING PROGRAM

A monitoring program that will determine effects of zoning on biodiversity, ecosystem structure and function, and human activities is measuring performance of these 24 fully protected zones. The Zone Monitoring Program uses a combination of academic and government scientists as well as volunteers to look at changes in ecosystem structure (species abundance and size) and function (processes such as fish grazing rates) that result from the cessation of human consumptive activities. Data on the abundance and size of fish and mobile invertebrates, macroalgal cover and biomass, changes in coral cover and diversity, coral recruitment, and zone usage are collected from inside reserve areas and adjacent reference sites. Below are brief summaries of findings to date of the effects of fully protected zones on these parameters.

Monitoring efforts during the three years since zone implementation (1997 - 2000) indicate that some heavily exploited species exhibit differences in abundance and size between fully protected zones and reference sites. Specifically, legal-sized spiny lobsters continue to be more abundant in Sanctuary Preservation Areas (SPAs) than in reference sites of comparable habitat (Cox et al. 2000). The average size of lobsters is larger and remains above the legal minimum size limit in the no-take SPAs, whereas lobsters found at reference sites have remained below legal size. This trend also holds true for the Western Sambo Ecological Reserve, where the mean size of lobsters within the reserve has been significantly larger than in reference areas in both the open and closed fishing seasons (Cox et al. 2002). Additionally, catch rates (number of lobsters per trap) are

higher within the Western Sambo Ecological Reserve than within two adjacent fished areas at all times of the year (Gregory 2002).

Overall, a high degree of variability has been documented with regard to reef fish abundance and size between no-take areas and reference sites (Bohnsack et al. 2002). At this time, clear trends for all exploited reef fish species have not been demonstrated. However, as would be expected with the added protection of no-take management, some species have shown increased abundance in the Sanctuary Preservation Areas over time (Bohnsack et al. 2002). Abundance data analyzed through 2000 show that mean densities (number of individuals per sample) for three of four exploited fish species are higher in the SPAs than in fished reference sites. Complementing these data is an overall increase in abundance of four species of snapper (Lutjanidae) and hogfish (*Lachnolaimus maximus*) at seven out of nine no-take areas monitored by volunteers before and after their establishment in 1997 (REEF 2002). As a result of these monitoring efforts, over 240 reef fish species have been documented in the Sanctuary, many for the first time.

As would be expected, the effects of no-take protection on animals such as queen conch and sea urchins that are not directly exploited and the slower-growing, bottom-dwelling species such as hard and soft corals and sponges (Miller et al. 2002) have not yet become apparent. A queen conch monitoring program has found no statistically significant differences in conch aggregation sizes, density, or abundance between no-take areas and reference sites (Glazer 2002). Two separate teams continue to document very low abundances of sea urchins, especially the long-spined urchin (*Diadema antillarum*; Fogarty and Enstrom 2002, Miller et al. 2002).

In general, the Sanctuary s coral reef monitoring projects have documented a high degree of variability over space (habitat type and region) and time for several ecosystem parameters such as coral cover, species richness, recruitment, and density of benthic invertebrates (Jaap et al. 2002, Miller et al. 2002, Ogden et al. 2002). At this time no consistent differences in coral recruitment between the no-take areas and reference sites have been observed (Miller et al. 2002, Ogden et al. 2002). Juvenile mortality rates varied between habitats and years, which is likely due to the effect of several large storm events in 1998 and 1999 (Ogden et al. 2002). Additionally, no significant differences in the percent cover of hard corals and sponges were noted between protected areas and reference sites (Miller et al. 2002). As documented by one monitoring program, coral cover has remained consistent within no-take and reference sites, suggesting that regional influences may be affecting coral health (Miller et al. 2002). Monitoring of macroalgal biomass indicates variability based on season, water depth, and region, with no major differences between no-take and reference sites noted at this time (Ogden et al. 2002). Preliminary field experiments on algal grazing rates suggest decreased herbivory within the no-take zones, but a significant trend has not yet been established. Researchers monitoring these parameters caution that the high variability of benthic components over space and time necessitates looking at the effects of no-take regulations on a decadal time scale.

Similar to the findings for the biological components of the Sanctuary s Zone Monitoring Program, socioeconomic monitoring indicates that zone usage is highly seasonal (McClellan and Tobias 2002). Non-consumptive diving charters frequent outer reef areas, both inside and outside of the no-take zones, primarily during the summer months. Fishing activity is also highly variable, which is to be expected given the sheer number of economically important recreational and commercial fisheries in the Florida Keys. Commercial lobster fishing comprises the majority of vessel activity observed by one monitoring program. Initial data suggest compliance with no-take regulations is relatively high because little illegal use of the no-take zones has been observed (McClellan and Tobias 2002). Preliminary data on financial performance of commercial fishermen indicate that displacement from the Western Sambo Ecological Reserve did not cause short-term financial losses (Murray et al. 2002). Additional socioeconomic research is underway (Leeworthy et al. 2002, Smith et al. 2002).

CONCLUSION

Coupling biological data with socioeconomic and use information is critical to assess both the ecological status of and community attitudes towards the Sanctuary s zone network. As evidenced by results after just three years, continued monitoring inside and outside of the no-take areas is necessary before trends can be identified. In 2002, State and Federal resource managers will reevaluate the use of zones as a management tool. At that time a comprehensive picture of how the zones are performing in light of natural variability will be presented.

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Co-management of Laughing Bird Caye National Park

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ABSTRACT

Laughing Bird Caye national Park is an ideal one-day excursion for tourists visiting Placencia, a Belizean village booming with tourism. Nearly every tourist visits the Park, and visitors' impacts are becoming evident. Degradation would severely damage the tourism industry that, along with large-scale shrimp aquaculture, is replacing fishing as major local economic activities. In 1996, a group of community members formed the Friends of Laughing Bird Caye committee (FOLBC) and registered the NGO aimed at protecting and promoting the sustainability of the natural resources off the coast of Placencia. However, management of the park continued to be voluntary and minimal due to the NGO's lack of capacity. Yet they installed buoys, replaced trees, established a voluntary no-fishing zone, and engaged in environmental education. Also in 1996, the National Park was declared a World Heritage Site along with six other protected areas known as the Belize Barrier Reef System. In June 2001 FOLBC signed an agreement with the Forestry Department for co-management of Laughing Bird Caye. The Marine Protected Area (MPA) is now formally under community-based management. The Coastal Zone Management Authority and Institute assisted to build FOLBC capacity, and in March 2001 provided a Reserve Manager, Ranger and boat. FOLBC acquired another ranger and has vigorously sought ties with a wide community of interested stakeholders, including other NGOs and donor agencies, to continue the process of building capacity for managing the MPA. The impacts of Hurricane Iris on the caye and NGO resulted in serious setbacks.

KEY WORDS: Belize, co-management, Laughing Bird Caye

INTRODUCTION

Belize is the location of the world's second largest and very diverse barrier reef ecosystem. It lies on the rim of a continental shelf approximately 257 km (160 miles) long and 15 - 40 km wide. Laughing Bird Caye is a 0.56 hectare island in the Belize Barrier Reef System lying halfway between Placencia village and the barrier reef at latitude 16°26.59'n longitude 88°11.85'W. The caye has a sandy beach on the leeward side that slopes slowly to moderate depth. In shallow water several patch reefs that are covered with rich undersea life including corals, sponges, anemones and fish surround the caye.

Laughing Bird Caye is a popular one-day excursion for tourists. Degradation would severely damage the tourism industry. Friends of Laughing Bird Caye is focused on preserving this area. The group includes the Placencia Audubon chapter, Placencia Village Council, Tour Guide Association, Belize Tourism Industry and

Association, Placencia Fishermen's Cooperative and residents of surrounding villages such as Siene Bight, Independence, Hopkins and Monkey River. Their lobbying led to the declaration of the caye as a National Park in 1991 by a Government of Belize statutory instrument (S.I.167) under the jurisdiction of the Forestry Department. In 1996, Statutory Instrument 94 expanded the Park to 4,048 hectares and included the surrounding faro, a unique geologic formation. Between these dates, and for a while afterwards, the park had no proper management. The communities concerned about impacts on the Caye saw stronger management was essential and urgent. In 1996 the IUCN designated seven protected areas representing the Belize Barrier Reef System as a collective World Heritage Site, Laughing Bird Caye being one of the seven. It must be noted that over forty percent of the country is under protection. Due to the country's effort toward conservation through sustainable management of its natural resources it is seen as taking a leading role in conservation of the environment. Unlike other countries, designation of protected areas in Belize is not reactive, due primarily to threats to the areas, but proactive mostly because of appreciation for environmental values.

FRIENDS OF LAUGHING BIRD CAYE (FOLBC)

Friends of Laughing Bird Caye is a non-governmental organization that is dedicated to the sustainable development of the Placencia Peninsula for the use and benefit of the surrounding communities. Their principal concern is the Laughing Bird Caye National Park. However, they are seeking to broaden their scope to include Gladden Spit Marine Reserve. Gladden is well known for its spawning aggregation site and whale shark sightings. The national park falls under the jurisdiction of the Forest Department. On 5th July 2001, Friends of Laughing Bird Caye was given permission to co-manage the park, which is in keeping to the Forestry Department's goal of community participation in the management of, and support for, national parks. A new management plan was formulated which included updating the previous management plan, starting environmental education, and hiring and training two rangers, a biologist, a park manager/reserve manager, and an administrative assistant. The project will allow for purchasing equipment to be used by the rangers, installation of mooring and marker buoys, placing necessary infrastructure on the island and basic environmental monitoring.

FOLBC receives help for institutional strengthening from various donor agencies such as the Global Environment Facility (GEF), World Wildlife Fund (WWF), The Nature Conservancy (TNC), and local Coastal Zone Management Authority and Institute (CZMAI). They also receive technical support from CZMAI and the Fisheries Department.

CO-MANAGEMENT

Co-management is a relatively new concept to Belize that has become very popular. There are several co-management agreements between Government

departments and community-based organizations, usually NGOs. The Fisheries and Forestry Departments have both signed co-management agreements with various NGOs, but they have different criteria, rules, and polices governing their respective agreements. The Department of Forestry has an agreement with Friends of Laughing Bird Caye since Laughing Bird Caye National Park falls under its jurisdiction. The signed Memorandum of Understanding delegates the majority of management responsibility to Friends of Laughing Bird Caye. Hence, responsibilities lie with the FOLBC to formulate, implement, and enforce management measures. However, Forestry still has the right to intercede within such responsibilities.

MANAGING LAUGHING BIRD CAYE

There are three main reasons for the protection of the area. One is that it is known to be a popular nesting area for birds, especially the Laughing Gulls (*Larus atricilla*). Secondly, it is a popular tourist destination. The park receives approximately 100 visitors per day in the peak tourist season and approximately 60 visitors daily in the low season. The third reason is because of its uniqueness. Laughing Bird Caye National Park is a faro. The faro superficially resembles an oceanic atoll, but the origin of faro atolls is obscure, although some scientists believe that they are former calcium carbonate plateaus that have been severely eroded. The park area was being stressed primarily by two major factors: heavy tourism and illegal fishing activities. Fishermen and tourists are the two major user groups whose activities need effective management and control.

The rangers, whose jobs are to safeguard the natural resources, monitor the flow of tourists to the National Park. They have started recording the number of boats and visitors to the caye every day. These data have been put in a database. The data have been recorded only for the past five months and are inaccurate since many events have hindered data gathering. Such events that are beyond staff control are weather, loss of utilities such as water and electricity, and limitations on fuel supplies for boats. A ticketing system was to have been put into place in November 2001 for the opening of the tourist season. The tickets and fees would have helped achieve management plan goals and assist the park in becoming more financially independent and self-sustainable.

Facilities and infrastructure for the National Park are progressing, including compost toilets, a multi-purpose building, mooring and marker buoy,s and the preparation for the set up of the biology laboratory. Dive shops will have to purchase the tickets at the park office in Placencia before going to the park. However, the ranger will have limited number of tickets for sale on the caye. It is very important to note that not only do the rangers monitor the national park, but so do the tour guides. FOLBC has had consultations with the tour guides, fishermen, and hotels. ,All of these stakeholders have supported FOLBC.

Due to the multi-purpose use of the caye, a zoning scheme was essential in order to facilitate sustainability. ,The island was zoned into five sections. ,The preservation

zone is a no-entry, restricted area. ,This is due to the nesting area at the north end of the island. ,There is a no-swimming channel/zone that boats should use in order to get to the island. ,The recreational zone is the area that will house the picnic area, the restrooms and the information centre. ,The buffer zone is between the preservation zone and the recreation area. ,The last zone is the marine recreational zone, which is where moorings will be installed or dive boats will be able to anchor. It is important to mention the one-mile no-fishing zone around the caye that was suggested by the fishermen themselves. As mentioned previously, FOLBC is being strongly supported by all stakeholders

Environmental programs are also being carried out with primary schools. Workshops have been conducted with teachers from all the neighbouring communities. This was to investigate the level at which the children are taught about conservation and nature. The goal of the FOLBC's environmental educator was to find a way to incorporate a conservation course into the curriculum. Unfortunately, this was not accomplished due to many obstacles including a natural disaster.

HURRICANE IRIS

On 8 October 2001, Hurricane Iris, a category four hurricane, devastated parts of southern Belize. It came packing 149 mph winds, gusting to 200 mph. It slammed into the southern coast of Belize just north of Monkey River early on a Monday night with a storm surge of up to almost five metres. Laughing Bird Caye National Park was in the path of Hurricane Iris. Friends of Laughing Bird Caye staff conducted an assessment of the park on 23 October 2001. The delay in the assessment was out of FOLBC's hands. The reason was that the National Emergency Management Organization (NEMO) appropriated FOLBC's boat, and it was impossible to get out to the caye before then. The results of the assessments are striking.

Damage Overview

The caye was severely damaged by the winds, waves and surge that Hurricane Iris brought. There is a new channel of water separating the north end from the rest of the island, and two crater-like holes on the southern part that are filled with water. The south end of the caye has only 17.7% of the coconut trees standing, of which 39.3% will need some form of restoration. All of the mangroves on the north end were washed out and the area is now bare of any kind of vegetation.

Laughing Bird Caye has changed in size and shape. Its geographical features do not match those recorded on maps and with GIS points of reference. The north end was reduced to one third of its original size, and now resembles an island on its own. The south end was extended a few metres further to the south, reduced on the western side and increased on the east. Actual measurements will be recorded and compared to past data.

The marine and terrestrial life in the National Park was also extensively affected. The creatures of the park that one could once find in the sea were put on land. Table 1 shows the list of the most common dead organisms found in abundance on the island as a result of the wave and surge of this hurricane.

Table 1. List of dead organisms on Laughing Bird Caye after Hurricane Iris

Organism	Organism
Pelican	Measled cowries
Giant tube sponge	Pink conch
Sea rods	Stone crabs
Van Hyning's cockle	Hermit crabs
Zigzag scallop	Brittle stars
Common dove shell	Coquina clam

Due to the dead organisms found on the island, the area acquired a putrid odor. Conchs were strewn all over the island with the animals dead inside their shells. One could only find pieces of more fragile shells and crab claws. The place resembled cemetery rather than a beautiful island. The white sand beach was no longer enticing. The shoreline, up to five metres inland, was covered with green algae also seen floating near shore on the water.

Reef Assessment

Coastal Zone Management Authority and Institute with the collaboration of Laughing Bird Caye, other protected areas, and the Fisheries Department conducted an assessment of the damage caused to southern reefs. The assessment was carried out on 16-17th October 2001. The final report is entitled "Ecological Status of Belize's Southern Reef Systems — Impacts of Hurricane Iris". The paper reports impacts from minor to severe damages, varying between sites. It states:

> "Discernible mechanical reef damage appears to be positively correlated to the narrow path traveled by Hurricane Iris...the greatest damage was observed at Laughing Bird Caye National Park, with over 60% of assessed colonies displaying mechanical damage along the fore reef of this faro... Damage incurred includes complete defoliation and uproot of its mangrove trees, moderate to severe land erosion, and the emergence of a channel (approximately 15ft in width) that completely intersects the island... The impact from Hurricane Iris is expected to have long term ecological consequences for the Laughing Bird Caye National Park" (Bood 2001).

A rapid assessment of hard corals colonies at selected sites was carried out during this field assessment. The selection of the sites was based on the path traveled by Hurricane Iris. Observations of noticeable impacts on hard corals such

as mechanical damage were recorded. The survey only examined hard corals and does not reflect damages to benthic invertebrates or fish populations.

A finding of the assessment is that the forereef near Laughing Bird Caye received the greatest impact "with an average recent mortality of 19.6% and hurricane (mechanical) damage of 70.1% among assessed coral colonies" (Bood 2001). The *Acropora cervicornis* (Staghorn coral), *Porites asteroids* (Mustard Hill coral), *Montastraea annularis* complex (Boulder Star coral), and *Siderastrea siderea* (Massive Starlet coral) received the greatest mechanical damage due to the hurricane. It was observed that gorgonians were also severely impacted, but they were not assessed. A month previously, this site exhibited a mortality of 2.8%, bleaching of 43.75% and mechanical damage of <1% (Mcfield et al. unpublished data from 2001 Mesoamerican Reef Survey). After Hurricane Iris there was an observable difference with mortality of 19.6%, mechanical damage of 70.69% and bleaching of 44.83%. Table 2 compares the status of Laughing Bird Caye a month before and a week after Hurricane Iris.

Table 2. Comparison of coral reef status before and after the impact of Hurricane Iris on the Laughing Bird Caye National Park. Source: Mesoamerican Reef Survey

Month	Mechanical Damage	Bleaching	Mortality
September 2001	<1%	43.7%	2.8%
October 2001	70.69%	44.8%	19.6

Impact on FOLBC and Recovery

Friends of Laughing Bird Caye was also affected in Placencia village where its office is based. The village was 95% destroyed when Hurricane Iris swept over Placencia. FOLBC's office is located at the point of the peninsula along the shoreline. The office received moderate damage to the building as well as loss of equipment and supplies. Damage to the building was due to the slamming of the waves and the almost five metre surge that came over land. It destroyed the conference room (walls, roof and ceiling) and front desk area. The west side of the building received damage due to settling of water. The amount of water that settled throughout the office measured only 30 cm deep, unlike other buildings that had high water marks of up to 1.5 m above ground on them. The loss of equipment such as computers was due to water damage.

FOLBC will be replanting mangroves on the island as well as resistant coconut trees. This will help prevent the further erosion of the island since it is subject to strong currents and heavy wave action. It is an effort to get the island back to normal as well as to get wildlife back on the island. There will be a monitoring program set up to observe the pace of recovery of the coral colonies. FOLBC is seeking funding for the renovation of the office and purchase of replacement equipment.

CONCLUSION

Co-management of protected areas will go a long way to ensure that future generations will be able to enjoy the natural beauty of Belize. It is very important for the organization to try to get things back to their status before Hurricane Iris. This will take a lot of effort on behalf of the staff and lots of financial and technical support from various organizations. The damages brought about by Hurricane Iris will take a long time to recover. However, it is through the capacity for management acquired from networks of collaborating agencies that the recovery of FOLBC is almost certain, despite the adversity.

ACKNOWLEDGEMENT

It is unfortunate that during the coral reef assessment Friends of Laughing Bird Caye lost their biologist, Luke D'Silva. He will be greatly missed by many. The "Ecological Status of Belize's Southern Reef System- Impacts of Hurricane Iris" was dedicated to Luke.

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Poder Verde para Áreas Naturales Protegidas en México Enfocadas a la Conservación y Mejoramiento de la Calidad de Vida

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ABSTRACT

A cooperative Mexico-USA program in renewable energies was formed between Sandia National Laboratories (SNL) and the Mexican Secretariat of Environment and Natural Resources (SEMARNAP). Facilities in ten remote Natural Protected Areas (NPAS) in southern Mexico were powered by renewable energy technologies. The goal was to demonstrate that renewable energy technologies are a valuable tool for meeting the power requirements of conservation, research and education activities. This joint effort has produced important results, and awareness is growing regarding the benefits of renewable energy technology for protecting the environment, and at the same time improving the quality of life for researchers and communities. The Mexican state of Quintana Roo has the majority of NPAs in Mexico; most are coastal marine. The Banco Chinchorro Biosphere Reserve (BCHBR) is an extension of SNL's program, since the BCHBR administration acquired a wind system to power its facilities. We describe projects and lessons learned in five coastal marine NPAs in Quintana Roo. Renewable energy both encouraged economic growth and raised the quality of life within the communities in NPAs, thus aiding regional sustainable development and reducing the impact on natural resources.

KEY WORDS: Community development, marine protected areas, renewable energy.

INTRODUCCIÓN

México decretó su primer Área Natural Protegida (ANP) a fines del siglo XIX, iniciando su carrera en las energías renovables a fines de los 1940s, con la primera fábrica de colectores solares y el uso de molinos viento para bombeo de agua. Por tanto, México se puede considerar un pionero en estas dos importantes áreas para la protección del medio ambiente y uso apropiado de los recursos naturales.

El programa mexicano de energías renovables de los Laboratorios Nacionales Sandia (SNL) de los Estados Unidos de Norteamérica inició en 1993. El

Departamento de Energía de los Estados Unidos (DOE) y la Agencia de los Estados Unidos para el Desarrollo Internacional (USAID), invierten más de un millón de dólares en 6 años para el desarrollo y promoción de las fuentes de energía renovable, principalmente abarcando los campos de agricultura, ganadería y ANPs, y como segundo termino aquellos que podrían ayudar a las comunidades rurales y microempresas.

Las ANPs primordiales de este programa se ubican en la región sureste de la republica Mexicana, en los estados de Chiapas, Oaxaca, Campeche, Yucatán y Quintana Roo. En total se han instalado cerca de 25 kW en sistemas de energía renovable, tanto solar como eólica. Solamente en las regiones costeras de la península de Yucatán se han instalado 17.0 kW en 6 años. Estos sistemas aunque en su mayoría, para beneficio directo de los usuarios de las estaciones de las ANPs de la Secretaria del Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP, actualmente SEMARNAT), han también proporcionado servicio de agua potable a comunidades y energizado un hotel eco turístico como parte del programa de difusión y promoción de estas tecnologías.

Entre los socios principales en este programa se puede mencionar: Conservación Internacional, World Wild Fund, The Nature Conservancy, Amigos de Sian Ka'an, Pronatura Península de Yucatán y el Instituto de Historia Natural.

Las lecciones aprendidas abarcan aspectos muy importantes en los tópicos de desarrollo tecnológico, impacto ambiental, aspectos sociales y aspectos económicos.

ÁREA DE ESTUDIO

Aún considerando que los proyectos de demostración del programa abarcan una extensión muy amplia (desde Oaxaca hasta Quintana Roo), este documento solamente se enfoca a las áreas marinas y costeras de la península de Yucatán y con énfasis en las costas de Quintana Roo.

Los sitios de estos proyectos fueron los siguientes: Reserva de la biosfera de Ría Lagartos, Área de Protección de Flora y Fauna de Yum Balam, Parque Nacional Isla Contoy, Reserva de la Biosfera Sian Ka'an, Reserva de la Biosfera Banco Chinchorro y Parque Nacional Arrecifes de X-Calak.

LOS RECURSOS RENOVABLES

Las regiones costeras son muy favorecidas en recurso solar, con niveles que van de 4.2 a 5.2 kWh/m^2-día (Almanza et al. 1997) como promedio diario anual. El recurso eólico, siempre es variable e impredecible, sin embargo para estas regines se ha determinado que los valores se ubican desde 4.5 hasta 6.0 m/seg. como velocidad media-diaria-anual @ 30 msnnt, con densidades de potencia de 150 a 300 W/m^2, lo que lo clasifica como región clase 4, los vientos predominantes provienen del SE y E, y una menor influencia de vientos del norte. (Duran et al. 1994).

Estos recursos naturales, que representan una fuente limpia de energía, proporcionan a las costas de la península de Yucatán 1.45×10^{10} kWh/día, solamente de energía solar, si tomamos una franja de 3 km a lo largo de los 1000 km de litoral.

SNL ha llevado a cabo el monitoreo del recurso eólico disponible y ha estimado un factor de planta promedio del 22% (Duran et al. 1994) (Factor de planta es el por ciento del tiempo en que las máquinas eólicas operarían al 100% de su capacidad), esto quiere decir que un sistema eólico de 500 Watts podría generar 2400 Wh/día.

Debido a que los sistemas fotovoltáicos tienen una eficiencia del 10% como promedio, se puede determinar que en esta región se podría generar al menos 1.45×10^9 kWh/día. En términos prácticos un sistema solar de 500 Watts podría generar 1800 Wh/dia.

A manera de referencia práctica, una persona en el medio rural consume 250 Wh/día, mientras que en el medio urbano este valor es de 1,000 – 1,250 Wh/dia de energía eléctrica (Romero-Paredes et al. 1999).

SISTEMAS INSTALADOS EN LAS ANPs

A través del programa mexicano de energías renovables del SNL se instalaron en la zona costera de la península de Yucatán 16.96 kW, de los cuales 15.7 kW fueron con energía eólica y 1.26 kW con energía fotovoltáica.

Estos sistemas han suministrado energía a las estaciones de investigación, casetas de guardias, campamentos de protección de tortugas y estaciones de trabajo. Entre las aplicaciones destacan las siguientes: bombeo de agua, iluminación interior y exterior, sistemas de radiocomunicación, energía para operar computadoras y equipo de laboratorio y audiovisual (Figura 1). Otras experiencias, como el uso de sistemas fotovoltáicos para la formación de arrecifes artificiales, también han sido reportadas; experiencias como ésta se han realizado en las costas de Quintana Roo.

El contar con condiciones de trabajo más confortables y seguras permite que los investigadores y trabajadores permanezcan mas tiempo en las estaciones de investigación y vigilancia, reduciendo sus costos de operación por concepto de traslados y consumo de combustibles para sus plantas de generación de energía a base de combustibles fósiles. Adicionalmente, estas estaciones de trabajo han sido usadas como sitios idóneos para la realización de cursos de capacitación en temas como educación ambiental y ecoturismo. Solamente en Banco Chinchorro, estudiantes e investigadores de diversas instituciones invierten en promedio 15 días de cada mes en esta estación.

La señalización marítima es otra de las aplicaciones que ha tenido la energía fotovoltáica, aunque esta no ha sido incluida en el programa de SNL.

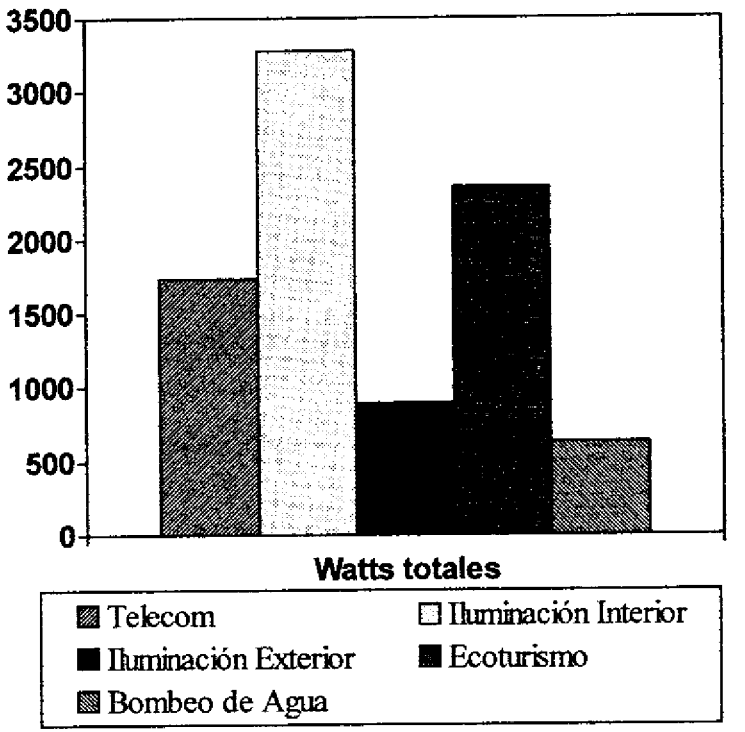


Figura 1. Proyectos por tipo en cuanto a potencia instalada.

LECCIONES APRENDIDAS

Aunque las tecnologías solar y eólica se consideran como maduras y aptas para regiones apartadas y con reducidos niveles de mantenimiento, un numero de experiencias nos han enseñado que aún falta mucho por hacer en aspectos como capacitación y buenas prácticas de instalación, operación y mantenimiento, así como aspectos sociales.

Aspectos Tecnológicos

La tecnología como tal es altamente confiable, siempre que el integrador del sistema sea una persona con experiencia, lo cual en muchos lugares no existe. Esto da como resultado sistemas que presentan fallas continuas y en ocasiones los usuarios regresan a tecnologías antiguas y contaminantes como las plantas generadoras a base de combustibles fósiles.

Las partes más débiles de los sistemas son las baterías y los sistemas de control.

La mejor solución encontrada es que las baterías sean selladas y libres de mantenimiento, y que los controles sean de "estado sólido" lo que permite que la confiabilidad aumente considerablemente y las medidas de mantenimiento se reduzcan.

Debido a que en algunas estaciones se ajusta el sistema para las temporadas de alta demanda de energía, los sistemas son subutilizados en las temporadas bajas. Esto ha provocado falta de atención del usuario habiendo bancos de baterías que se dañan permanentemente por falta de mantenimiento; la forma de evitar este problema es usando baterías libres de mantenimiento. Por otra parte, la capacitación a los usuarios debe ser en forma permanente debido a la rotación de personal en las ANPs.

Aspectos Sociales

Cuando una ANP adopta la tecnología renovable y se preocupa por dar mantenimiento apropiado al sistema los resultados son altamente positivos. Este tipo de experiencias permite que las comunidades rurales ubicadas en las cercanías o dentro de las ANPs adopten también estas tecnologías. Por el contrario cuando los resultados son negativos muy difícilmente se verá como una opción para solucionar sus problemas de energía. Entre los casos más relevantes que se pueden mencionar está la región de la costa de Quintana Roo, desde Tulum hasta Punta Allen, en donde varios hoteles han adoptado energías renovables para satisfacer sus necesidades y promocionar sus desarrollos como "verdes", dándole un valor agregado a sus inversiones. Otro caso es Banco Chinchorro, donde los pescadores han adoptado la tecnología como su mejor aliado.

Para sitios donde no hay alternativa de otras fuentes de energía eléctrica, más que plantas eléctricas de combustión y sistemas de energía renovable, los usuarios han optado por fuentes limpias, siendo su principal incentivo el consumo nulo de combustibles que representa un costo elevado y alto riesgo de transportación y almacenamiento.

La implementación de proyectos en comunidades aún no se ha dado como parte de un programa de SNL, pero de acuerdo a las encuestas realizadas se sabe que ha existen comunidades costeras como Punta Allen que cuentan con sistemas solares patrocinados por el gobierno estatal, algunos de éstos sistemas han sido subutilizados o abandonados por falta de trabajo social antes de su implementación. Un caso similar se observo en X-Calak, donde el sistema de 71.2 kW fue abandonado por falta de una infraestructura institucional que asumiera la responsabilidad del sistema (Romero-Paredes et al. 1997, Orozco y Kissmann 1999).

Aspectos Económicos

Estudios recientes hechos por el SNL en México, revelan que los costos de inversión de los sistemas de energía renovable llegan a ser hasta siete veces el costo de inversión de los sistemas convencionales de generación a base de combustión. Pero los costos de operación y mantenimiento de estos últimos hacen que los tiempos de amortización de los sistemas renovables lleguen a ser de quatro años como promedio; además de la mitigación del impacto ambiental, el cual no es posible evaluarlo económicamente.

Los niveles de inversión de estas tecnologías se dan en $USD/W instalado, así un sistema fotovoltáico podría llegar a rangos de $15 a $ 30 USD/W, mientras que los sistemas eólicos se ubican entre los $9 y $20 USD/W. (Romero-Paredes 2000)

Estos niveles de inversión llegan ha ser prohibitivos para muchos de los casos, a pesar que los períodos de amortización son bajos. Es por esto que programas como el de SNL permiten conocer las tecnologías con una mínima inversión.

Aspectos Ecológicos

A pesar de que estas tecnologías se consideran limpias y de muy bajo impacto ambiental, existe un elemento que a largo plazo puede convertirse en un problema ecológico. Una vez que ha concluído el tiempo de vida útil de las baterías de los sistemas, éstas deberán ser retiradas de las ANPs y llevadas a centros de reciclaje o confinamiento. Esta práctica no esta instituída en muchos países, por lo que deberá ser una de las labores de los usuarios y vendedores de sistemas.

Otro de los impactos ambientales observados son el riesgo que corren las aves frente a los sistemas eólicos. En los sistemas instalados en Quintana Roo, se han reportado 5 aves mortalmente impactadas por las palas de estas maquinas. Aunque la mortandad aparenta ser muy baja, existen medios para evitarla, como colocar lámparas de destello que avisen a las aves nocturnas de la presencia de un obstáculo.

También se ha reportado que las máquinas eólicas de 10 kW instaladas a menos de 40 metros de casas habitación producen un ruido poco tolerable cuando la intensidad del viento supera los 15 m/s, mientras que las maquinas de 500 Watts o menos no producen ruido intolerante.

PERSPECTIVAS DE LAS ENERGÍAS RENOVABLES EN LAS ZONAS COSTERAS

Para las pequeñas comunidades costeras y los campamentos de pescadores en Quintana Roo, las energías renovables representan una alternativa técnicamente factible y económicamente viable.

Un sistema eólico de 1500 W ubicado en un sitio con velocidad media anual de 4 m/s, podrá dar servicio a 2 4 -30 personas, lo que equivale de 4 a 8 familias. El costo de inversión por familia podría ser del orden de $2,000 USD. Un sistema solar para las mismas condiciones y nivel de servicio podría llegar a costar $5,000 USD. Sin embargo los sistemas solares pueden ser desde 50 W cubriendo

necesidades muy básicas de iluminación y la inversión sería de menos de $1,000 USD por familia.

Bajo un programa de financiamiento para la adquisición de estos sistemas, las comunidades que viven en las ANPs o en las zonas de amortiguación, podrían participar en forma activa en preservar los recursos naturales al no contaminar con ruido o gases de combustión.

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Integrated Management of Marine Protected Areas in Grenada

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ABSTRACT

The creation of Marine Protected Areas (MPAs) is a major component of sustainable development in Grenada, allowing for human use of marine and coastal resources without progressive degradation. Integrated management of the multiple-zoned Molinere/Beausejour MPA allowed for the empowerment of adjacent communities and built capacity for contributing to the decision making process. Through consultation, issues arising from user conflicts were addressed and the advice obtained made it possible to geographically demarcate the zonation pattern. Consultation with the community and major resource users allowed for the establishment of a system of moorings at positions appropriate for yachts, dive boats and charter boats, minimizing potential conflicts with the traditional use of the area for fishing. Continued and systematic consultation with community and other stakeholders elucidated the need for solid waste management in the area. This resulted in a joint approach to the problem by the Environmental Health Department, Grenada Solid Waste Management Authority, and the MPA project. A simultaneous beach, coastline and underwater cleanup resulted in beach shoreline operations being handled by community and school groups, and day boat charter companies. The Grenada SCUBA Divers Association and other local dive operators handled the underwater operations. The cleanup campaign acted as a catalyst for continued and greater community participation in the management of the MPA. Meetings with representatives from the communities were held to raise the awareness of the MPA and the importance of the marine reserves zones. At these meetings the concerns of those affected by the restrictions inherent in reserve areas were considered and the possibility for alternative sources of income examined.

KEY WORDS: Grenada, integrated, management, Marine Protected Area

INTRODUCTION

The State of Grenada, which includes the islands of Carriacou and Petite Martinique and several small, uninhabited islands, is located between latitudes 11° 59' and 12° 20' North and longitudes 61° 36' and 61° 48' West. Grenada is the largest and main island with a coastline of about 121 km and an area of 312 km^2. Carriacou is located 23 km to the northeast of Grenada has an area of 34 km^2 Petite Martinique is 2.3 km^2 and lies east of the northern section of Carriacou.

The thrust towards the creation of marine protected areas (MPAs) in Grenada originated in the Fisheries Division, Ministry of Agriculture, and two areas were

declared as MPAs. In 1996, joint support for the development of MPAs in Grenada was obtained from the French Fund For Environmental Management (FFEM) (through the Agence Franciase De Developpment – AFD) under the Protection and Valorisation of Reefs in the Lesser Antilles and the Government of Grenada (GOG). Hence, resources became available for the genesis of MPAs in Grenada.

Assessment of the marine and coastal resources was undertaken during the compilation of the Environmental Profile and surveys conducted by the Fisheries Biology Unit of the Fisheries Division. Two areas of Grenada were proposed for MPAs. The Moliniere area along the west coast has the best reef system, while Woburn Bay has the best mangrove and seagrass systems in Grenada. These areas are subjected to heavy fishing pressure. Reef fish and lobsters are harvested mainly at Moliniere; while lobsters, white sea urchins or sea-eggs (presently closed fishery), conch and reef fish are harvested at Woburn. Yachts mainly overnight at Moliniere/Beausejour in the bays. This area is also used mainly for SCUBA diving and snorkeling by tourists. However, spear and line fishing are also common practice. Woburn Bay has heavier yacht traffic and some may remain anchored for months. Conflict arises due to the multiple uses of the areas by seine fishermen, pot fishermen and yachts.

The conservation, preservation and sustainable use of representative samples of marine and coastal ecosystems, through the formation of marine protected areas are necessary for small island developing states (SIDS). Using appropriate management strategies such as the multi-zone system and an integrated community participatory approach (co-management), economic benefits can be derived by maintaining the integrity of the resources, eliminating user conflicts and obtaining protection and enhancement of the environment.

PROJECT OUTLINE

Project Objectives

The objectives of the MPA project are:

i) Protection, rehabilitation, and management of coral reefs and other coastal ecosystems,
ii) Protection and management of biodiversity, stocks, habitats and nursery areas,
iii) Provide educational opportunities for the locals and visitors alike,
iv) Provide aesthetic enhancement of the area, and
v) Minimize user conflicts among the resource users.

Project location

The Moliniere/Beausejour MPA (Figure 1) is located on the western coast of Grenada and spans a length of about 2.5 km. This area is within the parish of St. Georges specifically the St. Georges northwest district. Adjacent communities include Happy Hill, Moliniere and Beausejour.

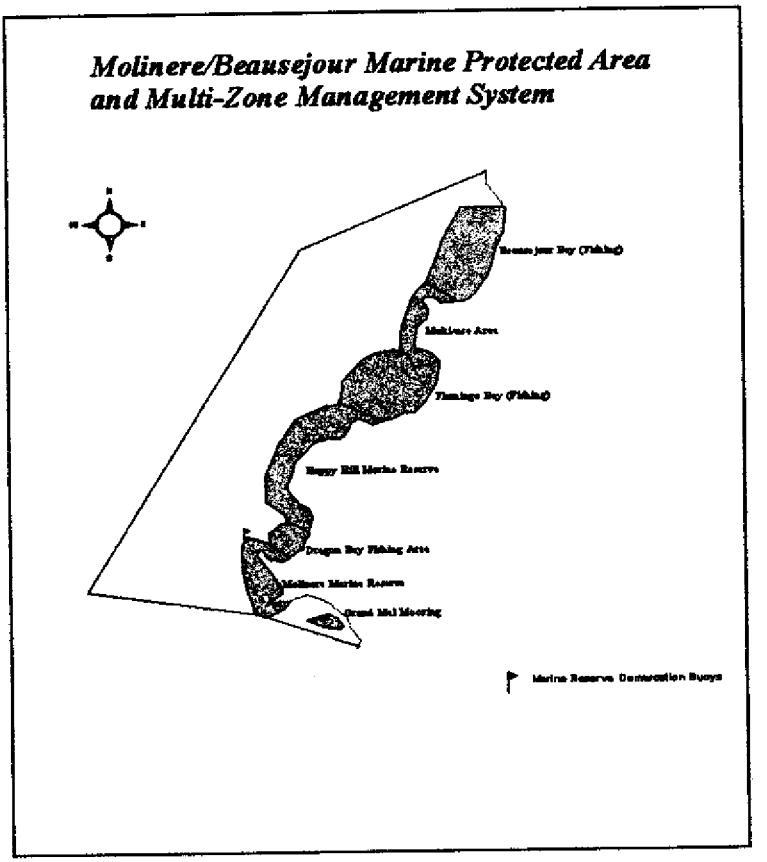


Figure 1. Map of Moliniere/Beausejour MPA

The Woburn/Clarks Court Bay MPA (Figure 2) is located on the southeastern end of the island, and is also within the parish of St. Georges. The enclosing coastline is about 1.5 km, and is bordered by the communities of Woburn and Woodlands.

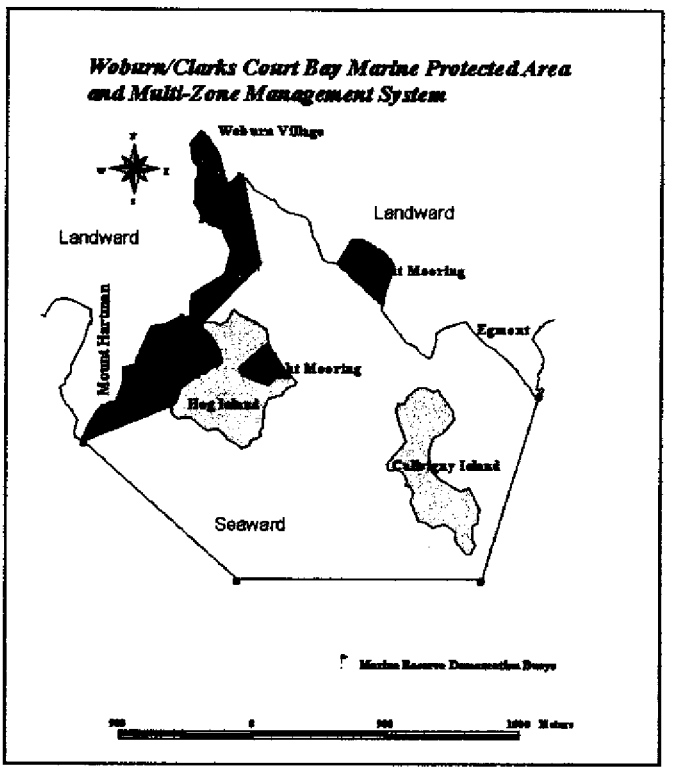


Figure 2. Map of Woburn Bay MPA

Legal framework

Stakeholders were an integral part of the process of formulation and revision of the MPA regulations. Draft copies of the regulations were reviewed by stakeholders and consultations held to discuss changes and make amendments. Hence the regulations are a product of a wide cross-section of stakeholders' contributions. The participatory aspects of drafting the regulations allowed for consensus and compromise among the different resource users. The main provisions include:

i) Spatial delimitation of the multi-zone management system,
ii) Composition and procedures of the management committee,
iii) Prohibitions within the MPAs, and
iv) User registration and fees.

CAPACITY BUILDING

Staffing

In 2001 a Project Manager and Warden were employed by the Ministry of Agriculture and attached to the Fisheries Division. The Project Manager was given responsibility for the implementation of the project under the guidance of the Chief Fisheries Officer.

Once the implementation phase is at a stage where the infrastructure (mooring for dive boats and yachts) and the regulations are in place, a minimum of two wardens will be needed for operations. They will provide support to the project by collecting fees, supervising diving operations in the reserve areas, conduct patrols, collect data and provide support for ecosystem monitoring.

The Complement of staff planned for the project is shown in Table 1:

Table 1. Suggested MPA staffing requirements

Staff Position	Required Skills
Project Manager	Resource management, administration, conflict resolution
Wardens	Enforcement, diving, maintenance
Secretary	Secretarial, in office administration

Community and Other Types of Capacity

As a requirement of the funding agency and agreed to by the Government of Grenada, a management committee (Table 2) must be formed and be functional, providing guidance to the project.

Table 2. Composition of the Management Committee

Membership	Area of Interest
Ministry of Agriculture	Fisheries Management
Grenada Ports Authority	Port Jurisdiction
Ministry of Finance	Economic Returns
Grenada Board of Tourism	Ecotourism
Ministry of Tourism	Parks and Protected Areas
Fishermen/Community	Resource Uses
Grenada SCUBA Diving Association	Resource Uses
Science and Technology Council	Scientific Advice
Coast Guard	Enforcement

The communities adjacent to the Moliniere/Beausejour MPA, which will be affected by the implementation of the MPA Regulations, indicated that the extent of their representation in the management committee was insufficient. As a result, it was suggested that a local fishermen's committee should be formed and chaired by their representative on the management committee. This will allow their concerns, in a coherent and thorough way, to reach the management committee with the feasibility of greater weight being given to all aspects to be considered.

Financial constraints on capacity

Funds for the employment of wardens and a secretary are currently not available. However, additional funds were requested from government for a Phase 2 of the project implementation. Once these funds become available then the project will be staffed, allowing for easier implementation. Availability of funds also restricts the possibility of attachments and training at the regional and extra-regional level, hence opportunities for exposure to the operations of fully functional MPAs are limited.

COMMUNITY INVOLVEMENT

It is the intention of the project to involve stakeholders and communities in every aspect of the decision-making. This necessitates working closely with various communities, and organizations. Communities include:

i) Brizan 367 people
ii) Beausejour 417 people
iii) Happy Hill 786 people
iv) Moliniere 356 people
v) Grand Mal 717 people
vi) Mt. Moritz 596 people

Organisations that are important for the smooth and harmonious implementation and operation of the MPA project are:

i) Grenada SCUBA Diving Association (GSDA)
ii) Mooring and Yachting Association of Grenada (MAYAG)
iii) Grenada Community Development Agency (GRENCODA)

Consultations were held with personnel from these organizations and the communities at various stages of the project implementation. Issues on user conflicts were noted and discussed, and possible solutions formulated. The result was a proposed multi-zone management system with areas demarcated.

Continued consultation with all stakeholders and discussions on a one-to-one basis reviewed the zonation pattern, its potential effectiveness and shortcomings. The proposed demarcations were adjusted and readjusted, and the product was presented in a stakeholder consultation. This allowed for discussion and cross debate among all the resource users, and resulted in agreement over the revised zonation pattern.

Fishermen's consultation

With the probing exercise and project costing completed for installation of moorings and demarcation buoys, a consultation was held with fishermen to review the multi-zone management system. The prohibitions stipulated for the marine reserve areas (no-take areas) were outlined and discussions entertained.

The possibility of alternative sources of income was discussed for persons who may be affected by the declaration of no-take areas. Some participants in the meeting expressed interest in micro-projects and mention was made of up-river kayak, glass-bottom boating and others.

OTHER INITIATIVES

Installation of Moorings

Moorings are required for dive boats, day charter boat and yachts. In order to ensure that there is minimum conflict among the resource users with regards to the position and number of moorings a consultation was held. It was divided into two parts:

i) A round table discussion where stakeholders gave technical advice and discussed the positions and number of moorings to be installed;
ii) A field trip to ground-truth what was agreed on during the meeting.

Subsequently, a map showing the locations of the various types of moorings was produced and the services of an installation contractor sought.

Solid waste cleanup

A recurring complaint among resource users concerned solid waste disposal in the communities adjacent to the MPA. A request was made to have action taken on the indiscriminate solid waste disposal impacting negatively on the MPA. Hence, various organizations were approached and the problems discussed amongst the:

i) Grenada Solid Waste Management Authority
ii) Environmental Health Department
iii) Grenada Community Development Agency
iv) Grenada SCUBA Diving Association

A plan of action was formulated and a survey was conducted in the communities to identify sources of the problem and to educate households. Residents were briefed on the appropriate methods of waste disposal and the problems created by disposing of refuse indiscriminately.

A cleanup campaign was then scheduled to coincide with the International Coastal Cleanup Day. Students, teachers and community residents participated in the cleanup along the coastline while GSDA conducted the underwater operation.

CONCLUSIONS

The MPA project in Grenada is still in its implementation phase, which limits the ability to assess the sustainability of the successes with the operational aspects described here. Financial and human resources are limited, causing lags in the implementation of the project. Systematic stakeholder consultations and community participation are important aspects of implementation that allow:

i) Smooth and harmonious project implementation;

ii) A sense of ownership of the project;
iii) Willingness to participate in all aspects of the project implementation and possible operation;
iv) Familiarity with all aspects of the management system fostering easier enforcement;
v) Assistance in executing the various components of the management strategy.

Willingness to assist with the implementation of the MPA project was expressed by all of the organizations that use the resources. Frequent advice was given by persons who are familiar with the operations of MPAs in other countries. Hence, they indicated where difficulties might be experienced and how adjustments can be made to overcome the hurdles. This compensated, to some extent, for the lack of capacity in the formal management structure. To date, the human connectivity of the project has been crucial to implementation.

Connectivity and the Evolution of Self-recruitment Mechanisms in Marine Populations

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ABSTRACT

In evolutionary terms, a species cannot evolve unless a mechanism exists that ensures that a reasonable proportion of its offspring repopulates the natal area. Thus, in a marine demersal environment a closed ontogenetic gyre or loop is essential for the development of a core stock of a species. Larvae that are lost from such a gyre either die, settle in areas in which they cannot successfully replenish themselves, or settle in an area in which another stock can be established. Stocks can be connected by occasional influxes of larvae from other areas, and the stocks will thus form a genetically homogeneous meta-population. If stocks become wholly isolated as a result of changes in oceanographic conditions, a new species will evolve. If evolutionary processes have favored the adoption of life stages and behavioural traits that enhance self-recruitment, a corollary will be that most demersal marine habitats areas must be largely inhabited by locally spawned stocks and that few recruits can be expected to arrive from adjacent areas unless they are very close and directly up-current. Consequently, marine protected areas that are surrounded by grossly depleted fish stocks will take a very long time to develop significant spawning stock biomasses of exploited species.

KEY WORDS: Recruitment, evolution, marine reserves

INTRODUCTION

Much has been written in recent years about the degree to which individual stocks (sometimes called local populations) of benthic marine fish and invertebrates are replenished by their own progeny, as opposed to being repopulated to a significant degree by propagules produced by distant components of a meta-population (Johannes 1978, Leis 1991, Roberts 1997, Jones et al. 1999, Swearer et al. 1999, Crowder et al. 2000, Cowen et al. 2000). Much attention has been paid to the mechanisms that might enable larvae or post-larvae to return to their natal sites. However, singularly little attention seems to have been given to the evolution of self-recruitment mechanisms and the implication of such adaptations for the management of stocks and the location of marine protected areas and fishery reserves.

In the following pages it will be briefly argued that all shelf-dwelling marine benthic species must have evolved from single stocks that were able to replenish themselves with their own progeny. Consequently, all species must have, or have had, within their distribution a core stock that is self-replenished to a very high

degree, whereas other components of the meta-population will have rates of self-replenishment ranging from high to zero.

THE EVOLUTION OF SELF-REPLENISHING MECHANISMS

The earliest forms of marine animal life, either planktonic or benthic, presumably reproduced by simple fission. Self-recruitment therefore was not a problem and parts of stocks would only have been extinguished if they were carried by currents into adverse environments. Later life forms presumably had simple, short-lived, larvae such as planulae, and the early reproductive mechanisms must have been suited to maximizing settlement of larvae in the natal area or nearby. They would have functioned best in enclosed or semi-enclosed bodies of water such as lagoons or estuaries or deep ocean areas in which circulation rates or exchange rates were negligible and a significant proportion of larvae were retained close to the parent stock.

However, for those animals that colonized relatively shallow benthic habitats of continental or island shelves with significant ocean currents, the difficulties of retaining significant numbers of propagules would have increased. Larvae that drifted passively would be swept away from their natal habitat and the stock would never be replenished. Larvae that were carried out of a self-replenishing ontogenetic gyre would either be taken into deep water and perish or settle in new habitats far from the parent stock. In these habitats they might be able to replenish themselves and become peripheral stocks if they were in a suitable gyre. Alternatively, they might form a terminal stock that was able to survive but, if able to breed, was unable to replenish itself because of unfavorable circulation patterns. Thus, meta-populations would have come into being, inter-connected by occasional or frequent exchanges of propagules. If one or more component stocks of a meta-population became isolated as a result of oceanographic changes, then new species would have evolved.

During the course of evolution several reproductive strategies have evolved in demersal marine organisms that clearly serve to reduce the chances of dispersal of propagules. These include viviparity (some fishes), passage of most larval stages within an egg capsule (many mollusks, lobsters) and brooding of eggs in nests (damsel fish), pouches or brood chambers (some oysters, ascidians, sea horses), egg masses (caridean shrimp, pipefish, spiny lobsters, apogonids). However, these are all relatively uncommon and represent advanced adaptations. For most shallow, marine, benthic animals one or more relatively long-lived planktonic larval stages are the norm, and this is at odds with the apparent need to ensure that individual stocks are effectively replenished. They appear to function more effectively for dispersal of the species. The possible reasons for the evolution and maintenance of a pelagic stage in reef fishes has been comprehensively discussed by Bonhomme and Planes (2000). Their arguments apply equally to most other marine benthos.

However, if this phenomenon of a planktonic and, for some species, a later pelagic larval phase is placed in its evolutionary context it makes more sense.

Larvae produced by a core stock need to survive and return, at some stage, to their natal habitat. Drifting in the plankton might have advantages in terms of release from benthic predators and availability of plankton food, but disadvantages in terms of self-recruitment. However, it is suggested that all marine larvae have behavioral, sensory or morphological adaptations that will, *if oceanographic conditions are right*, enhance their ability to return, with some degree of success, to their natal habitats. For many species, ontogenetic movements from nursery areas to adult habitat make this a three-stage process, and spawning migrations from the adult habitat may add another dimension to the ontogenetic gyre.

The "Fundamental Theorem of Natural Selection" (Fisher 1930) states that a population will very rapidly assimilate any adaptation that gives an organism a greater chance of reproducing itself. This is a mathematical fact. Consequently, I argue that seemingly useless or ineffective features of an animal's behaviour or morphology might only make sense in the context of the original core stock. For other stocks, the adaptations might be effective to some degree or be quite useless or even fatal. But that is irrelevant as long as the core stock is replenished. Of course, adaptations that are more widely useful to component stocks of a meta-population will also be rapidly adopted. It is not argued that core stocks will be unfailingly replenished year after year. Variability in ecological conditions is still the main factor affecting successful settlement of year-classes and order-of-magnitude variations in settlement rates are normal events in most species (Coe 1956, Munro and Bell 1999).

Additionally, it is possible or even highly likely that in many cases the original core stocks will have been eliminated by oceanographic changes. However, if this did not lead to the extinction of the species then one or more of the other stocks must have taken up that role, and the original adaptations that ensured a high degree of self-replenishment must still be effective to some degree. Species that are very rare will be those that have lost their core stock and survive only by chance replenishment of local stocks by random events. In contrast, for abundant species there will be numerous stocks, some small, some large, which are self-recruiting.

It should be possible to identify a core stock because it will be one of those with the highest rates of recruitment relative to its spawning stock biomass (R/SSB). This would not be an absolute rule in that a small stock might have high recruitment from elsewhere simply by virtue of its oceanographic situation. For example, a terminal stock of a tropical species in North Carolina waters might get high rates of settlement of larvae that have become entrained in the Florida current, but do not survive well and never reproduce successfully. Also, areas with high topographic complexity, such as the Bahamas, might also be favored in terms of retention of larvae, simply because of the eddies and gyres that are caused by physical features.

THE CARIBBEAN SITUATION

The rather limited array of species of fish and invertebrates that inhabit the Caribbean presumably evolved from an even more limited number of species that

inhabited the area when the Caribbean became isolated from other coralline tropical seas. Meta-populations of these species are now mostly quite widespread in the Caribbean, from Trinidad to Bermuda. The shallow demersal benthic species separate into insular and shelf species with obvious differences in the ease with which post-larvae will be able to find suitable habitats at settlement. Species that inhabit isolated habitats such as coral reefs, mangroves, sea grasses, or rocky shores obviously have more difficulty in finding their natal habitat, or any other suitable habitat, than those that inhabit broad soft-bottom shelves.

If the fore-going arguments are correct, all Caribbean species, and particularly the reef-dwelling insular species, must have adaptations that assist the return of propagules to their natal reefs or, at least, to suitable shallow habitats. The degree to which larvae are exchanged between islands or reef areas will depend on proximity, oceanographic conditions and chance (Cowen et al. 2000). However, apart from exceptional situations, the evolutionary imperative will dictate that most successful settlers or recruits will be returning to the general area where they originated, if not to their natal reefs.

If propagules do have effects on "downstream" sink areas (Roberts 1998, Crowder et al. 2000) this should be reflected in significantly greater settlement and recruitment rates in such areas, in comparison with upstream "source" areas with similar spawning stock biomasses (SSBs). This would be fairly easily measurable by underwater visual censuses of SSBs and by monitoring settlement rates of post-larvae with light traps or abundances of pre-recruits in small-meshed Antillean fish traps (Munro 1999, Munro and Watson 1999).

The effect of heavy fishing will be to reduce spawning stock biomasses (SSBs) and weaken or break connections between Caribbean meta-populations. Severe over-fishing can reduce the SSBs to zero or negligible levels and reduce the influx of post-larvae to similar levels (Munro 1999, Munro and Watson 1999). When marine protected areas (MPAs) are created in seriously over-exploited areas, the build-up of stocks in the MPAs can be expected to be a very lengthy process.

Isolated islands can be expected to be "on their own" in terms of recruitment; whereas island chains and continental shelf populations will be to some degree interconnected, with terminal populations at the limits of the distribution of many species. On the basis of the arguments presented here it seems clear that marine protected areas are needed throughout the Caribbean and that, given the prevailing currents, the stocks of vulnerable reef fish, such as groupers, in the eastern Caribbean would be particularly vulnerable to being extinguished by overfishing.

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Capacity building for Protected Areas Management: The CaMPAM Approach

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ABSTRACT

Fisheries in the Caribbean are dependent to a large degree on relatively small areas of coral reefs, seagrass beds, and wetlands. Fisheries management in the Caribbean has evolved to address not only the fishing practices and management of specific species, but also the protection of the habitats vital to the maintenance of said fisheries. However, these important habitats are under increasing threat from natural and anthropogenic factors. The primary mechanism developed to protect such critical habitats, and by extension the associated fisheries, is the establishment of marine protected areas. Yet the pace of establishment of marine protected areas has not produced the level of habitat protection and fisheries enhancement projected. The main reason for this lower than expected return from marine protected area management, in addition to resource inadequacies, is inadequate management capacity. This paper provides an overview of how protected area networks in the Caribbean have facilitated, not only improved management effectiveness for marine protected areas, but also increased linkages between marine protected areas and fisheries management. The paper focuses on the Network of Caribbean Marine Protected Area Managers (CaMPAM), presenting it as a viable mechanism to enhance the capacities of Caribbean professionals involved in marine protected areas and fisheries management. This also includes potential linkages between CaMPAM and the Gulf and Caribbean Fisheries Institute (GCFI).

KEY WORDS: Capacity, management, Marine Protected Area

INTRODUCTION

Traditional approaches to fisheries management have focused primarily on regulation of fishing effort and catch levels. Such approaches generally target single species, and assume the presence of homogenous stocks. While the efficacy of conventional fisheries management paradigms may be debatable (National Research Council 2001), those approaches were always less applicable to Caribbean reef fisheries.

Management of Caribbean fisheries has for a long time recognized the need to protect relevant ecosystems. The utilization of coral reefs and wetlands as critical habitats by multiple species meant that fisheries management had to maintain a multiple-species focus in the regulation of fishing effort, as well as protection of habitats.

Unfortunately, the focus on regulation of fishing effort far outweighed the focus on habitat protection. However, there is increasing attention being given to the need to establish marine protected areas (MPAs) for the purpose of fisheries management.

A large number of benefits from MPAs have been identified (Sobel 1996 and Salm et al. 2000). Those benefits most relevant to fisheries include:

i) Reduced fishing gear impacts;
ii) Maintenance of high quality feeding areas for fish and wildlife;
iii) Protection of spawning fish stocks;
iv) Increased spawning stock biomass;
v) Increased spawning density;
vi) Improved stock fecundity;
vii) Provision of undisturbed spawning conditions, habitats, sites;
viii) Increased egg and larval production;
ix) Enhancement of recruitment;
x) Provision of spill over of adults and juveniles to areas outside MPAs;
xi) Reduced chances of recruitment overfishing;
xii) Reduced overfishing of vulnerable species;
xiii) Protection of diversity of fishing opportunities;
xiv) Protection of intra-specific genetics from fishery selection;
xv) Enhancement of recovery from stock collapses and management failures;
xvi) Reduced bycatch fishing mortality;
xvii) Reduced conflicts among users;
xviii) Maintenance of recreational fisheries;
xix) Reduced variance of yield;
xx) Facilitation of stakeholder involvement in management;
xxi) Provision of fishery management data to improve fisheries;
xxii) Increased understanding and acceptance of fishery management; and
xxiii) Provision of controlled natural areas for assessing anthropogenic impacts, including fishing and other impacts.

More importantly, demonstration of the positive impacts of MPAs on fisheries (Appendix 1) has resulted in greater efforts being made to establish and have effective management of MPAs.

CARIBBEAN PROTECTED AREAS NETWORKS AND FISHERIES MANAGEMENT

Simply designating MPAs cannot be enough, by itself, to improve the state of fisheries and other marine resources, as those resources are affected by a wide range of factors, actors, and processes (Natural Resources Institute 1999). For

effectiveness, MPA design and management must address the full range of factors affecting marine resources. However, as several studies have shown, the human resources in the Caribbean are inadequate and insufficiently trained to deal with the full range of design and management issues.

One of the more effective mechanisms developed in the Caribbean to address this inadequate management capacity is the protected area network. Sharing of information, experiences and resources is strategically effective in a region where ecological realities are interconnected, resources are limited, management issues transcend local and regional boundaries and needs are common to many MPAs.

The first "Caribbean Parks and Protected Areas Network" was established in 1989 through the collaborative efforts of the Regional Coordinating Unit of UNEP-Caribbean Environment Programme, (UNEP-CEP/CAR) the Caribbean Conservation Association, and the Caribbean Natural Areas Institute, with additional support from the IUCN's Commission on National Parks and Protected Areas (now World Commission on Protected Areas). One of the main objectives of this network was the strengthening of protected areas management by enhancing the skills of its personnel (van't Hof and Gardner 1991).

One of the more notable achievements of the Caribbean Parks and Protected Areas Network was the preparation of a regional marine park project in 1990. The project, which was funded by the International Centre for Ocean Development (ICOD) and coordinated by the Caribbean Conservation Association (CCA), was titled "Marine Parks and Protected Areas Management Network". Under this project, ten pilot projects were implemented in ten different Caribbean countries. Of these, four projects were directly related to fisheries management. Three of these four (Barbados, Dominica, and St. Lucia) focused on establishment of MPAs by the relevant fishery management agency, while the fourth (Jamaica) was aimed at assessing the impact of the Montego Bay Marine Park on the fishing industry.

The efforts of the CCA-ICOD project to support a protected area network resulted in the formation of the Caribbean Marine Parks and Marine Protected Areas Managers Network (MPANET) in 1995. Though MPANET was focused primarily on the project activities taking place in the ten participating countries, it replaced the wider, and more informal, Caribbean Parks and Protected Areas Network.

In addition to providing much of the training under the CCA-ICOD project, MPANET also provided confirmation of the information on the training needs and priorities of MPAs in the Caribbean. The network also facilitated interaction among protected areas and fisheries personnel from a number of non-project countries, providing for information sharing on topics such as marine archeology. One factor that serves to confirm the value of MPANET to fisheries management is the agreement reached by CCA and the Organization of Eastern Caribbean States, Natural Resources Management Unit (OECS-NRMU) to provide joint secretariat support to MPANET.

Unfortunately, the structured support to MPANET ceased with the completion of the CCA-ICOD project in 1996, and with the cessation of funding support, MPANET went into a period of dormancy. However, this period of dormancy did

not last long, as MPANET was absorbed into the Network of Wider Caribbean Marine Protected Area Managers (CaMPAM), when this latest form of the Caribbean protected areas network was formed in 1998.

THE CaMPAM NETWORK

The Network of Wider Caribbean Marine Protected Area Managers (CaMPAM) was initiated in December 1997, during a meeting of more than fifty (50) persons from twenty two (22) countries of the Wider Caribbean Region and as an initiative of MPA practitioners, organizations such as NOAA, the US Fish and Wildlife Service and UNEP's Caribbean Environment Programme (Appendix 2).

The meeting was held to discuss ways to strengthen coastal and marine protected areas management in the Wider Caribbean, in particular through sharing and networking as this remained a priority need for all MPAs in the region. The discussions highlighted the fact that the main beneficiaries of CaMPAM would be MPAs and MPA managers, fisheries officers, and partner institutions (such as IUCN, CCA, FAO, etc.).

The participants agreed that the main activities for CaMPAM would be sharing of experiences and addressing management challenges through:

i) Training opportunities;
ii) Information exchange;
iii) Communication; and
iv) Problem solving.

The Regional Coordinating Unit of the Caribbean Environment Programme (UNEP-CAR/RCU) agreed to provide technical support to the CaMPAM Network, in keeping with the objectives of the Protocol on Specially Protected Areas and Wildlife (SPAW) for the Wider Caribbean Region. The 1990 SPAW Protocol to the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean (Cartagena Convention, 1983) is the only legal instrument for the region on biodiversity conservation and became international law in 2000. SPAW places emphasis on the ecosystem approach for the conservation of biodiversity and protects habitats and species of regional concern, including entire group of species such as coral reefs.

UNEP-CAR/RCU, as part of its continued support to the CaMPAM Network and in keeping with the objectives of the SPAW Protocol, subsequently established in 1999 a small grants fund (SGF) for MPAs within the SPAW programme of the Caribbean Environment Programme of UNEP.

The goals of the SGF are as follows:

i) To strengthen the management capability of MPA managers in the WCR;
ii) To strengthen the capacities of institutions managing MPAs;
iii) To develop and implement strategies for increased involvement of stakeholders in MPA management;
iv) To develop and implement training programmes, strategies, and tools for improved management of MPAs;

v) To act as a catalyst in attracting funds from other bilateral and multilateral initiatives for the purpose of addressing stated priority problems and issues;
vi) To promote "best management" MPAs sites to serve as sites for demonstration, training, and internship; and
vii) To promote horizontal exchanges of all types among MPAs, including twinning and mentoring programmes.

Appendix 3 contains additional information about the SGF of CaMPAM, including eligibility criteria and procedure for application.

Additionally, in an effort to respond to capacity building needs of MPA managers, the SPAW programme developed a comprehensive Training of Trainers programme on MPA management, organized through 2-week regional courses and followed by local training sessions developed and conducted by the trained MPA managers. The course modules cover all aspects of MPA management, including communication and training skills to allow for the multiplication and dissemination of the acquired knowledge. The course and accompanying manual are unique to the region. The manual has been made available by UNEP-CAR/RCU in CD-Rom format in both English and Spanish and it is also available from UNEP-CAR/RCU Webpage (www.cep.unep.org).

CaMPAM AND FISHERIES MANAGEMENT

The importance given to fisheries issues in CaMPAM is underscored by the following:

The same level of effort is expended in recruiting both MPA managers and fisheries officers, and the proportion of each is fairly similar.

i) The network has facilitated the discussion and information exchange of a number of fisheries-related topics/issues.
ii) IUCN, UNEP-CEP/CAR, and The Nature Conservancy collaborated with GCFI to organize a session on MPAs and fisheries during, and immediately following, the 1998 GCFI conference.
iii) There have been several attempts to integrate the fisheries officers participating in the OECS fisheries programme and the CARICOM Fisheries Resource Assessment and Management Program into CaMPAM. Individual fisheries officers are added to the network on an ongoing basis, but full programme linkages have not been established.
iv) A number of fisheries officers have received training under the Training of Trainers Courses in Marine Protected Areas Management conducted under the framework of SPAW by UNEP-CEP/CAR in collaboration with partners such as TNC. Of the nine (9) persons participating in the 1999 session, three (3) were fisheries officers, one (1) was a director responsible for MPA and fisheries, and a fifth was an administrator in a coastal protected area with responsibility for dealing with issues related to the

fishermen in the area. In the 2000 training session, 10 of the 15 participants were either fisheries officers or dealt with fisheries issues as part of their jobs.

v) The local training activities that followed the Training of Trainers courses included several sessions targeted at fishermen and/or fisheries issues.

vi) Projects funded through the CaMPAM small grants fund have also involved fisheries issues.

CaMPAM and SPAW programme activities for the 2002-2003 biennium that are of relevance to fisheries include the following:

i) Continued implementation of the small grants fund for MPAs.

ii) Implementation of the International Coral Reef Action Network (ICRAN) project. A major component of this project in the Caribbean is the development of four (4) demonstration sites, three (3) of which will deal with an aspect of fisheries (conflict resolution, alternative livelihoods, and multiuse areas involving fisheries).

iii) Implementation of projects dealing with mapping and assessment of coral reefs and other critical ecosystems (possibly including spawning aggregations areas), under the ICRAN project as well,

iv) Socio-economic valuation of coral reefs in the Wider Caribbean to be implemented under ICRAN.

v) "Reactivation" of the CaMPAM network, including additional Training of Trainers courses on MPA management.

vi) Fundraising for activities concerning sustainable fisheries, in particular; (a) inventory and no-take areas and determination of their effectiveness; (b) development of guidelines for determination of socio-economic impacts of no-take reserves; and (c) increased dialogue between fishers, fisheries, and MPA managers.

vii) Continued work with relevant regional and international organizations to develop turtle recovery plans, regional conch and spiny lobster management plans, regional action plans for marine mammals, and collection of information on spawning areas.

viii) Continued collaboration with relevant institutions in data collection, monitoring, data management, and preparation of educational materials.

ix) Continued training activities in all areas related to marine resources management.

CaMPAM AND GCFI

CaMPAM and the Gulf and Caribbean Fisheries Institute (GCFI) share similar genesis, both being founded as non-formal entities through the support of a more established institution. More importantly, both share a number of similar objectives including:

i) Promotion of information exchange on the use and management of marine resources in the Wider Caribbean Region,
ii) Interaction between a wide range of governmental, private, and civil society institutions, and
iii) Research on areas of relevance to marine resource management.

Although it appears that GCFI has concentrated on fisheries issues, its objectives suggest a potentially larger remit to deal with other marine resources. The benefits of both institutions collaborating on a more systematic basis include the following:

i) Access to a large network of professionals, whose research and work is complementary.
ii) Both institutions have institutional support, with CaMPAM probably bringing more to that arrangement through the Secretariat to the SPAW Protocol at UNEP's Regional Coordinating Unit (CAR/RCU) and other collaborating institutions.
iii) CaMPAM provides increased potential for fundraising for fisheries research and management, for training of fisheries officers and support staff, as well as a large potential support system for field research.
iv) The GCFI annual conference provides a forum for meeting, for sharing innovations, and potentially a mechanism for improving the scientific and technical quality of the research and work related to MPA and wildlife management.

Potential linkages between the two institutions could be established in the following areas:

i) Information Exchange
   Information exchange through the CaMPAM internet list,
   Establishment of discussion/working groups to deal with specific topics,
   Using the GCFI annual conference as a forum for peer review of technical work and network building.
ii) Research
   Designs to guide MPA design management options,
   GCFI members to provide more assistance with research on MPA and species management issues,
   MPAs to provide support at the site level for fisheries research, particularly where long-term monitoring is required,
   MPAs can provide support in testing fisheries management techniques.

iii) Training

CaMPAM will continue to provide training relevant to marine resources management,

MPAs provide opportunities for attachment of trainees to established sites.

iv) Publications

The Proceedings of the GCFI conference are usually published, and CaMPAM provides a mechanism and opportunity for wider distribution of that body of technical work,

UNEP-CAR/RCU, and its collaborating institutions, produces a large number and wide range of material relevant to MPA and fisheries. Collaboration should also take place on the preparation of articles for newsletters etc. and on the publication of materials.

v) CaMPAM Small Grants Fund

The small grants fund is available to support a wide range of activities relevant to MPAs and fisheries.

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APPENDIX 1
EXAMPLES OF EFFECTS OF MARINE RESERVES ON FISHERIES
(Roberts & Hawkins 2000)

Reserve Name and Location	Years of Protection	Habitat Type	Effects Reported
Leigh Marine Reserve, New Zealand	21	Warm-temperate rocky reef	The most common predatory fish, *Pagrus auratus*, was 6 times more common in the reserve than outside, while the spiny lobster, *Jasus edwardsii*, was 1.6 times more abundant, and had a bigger carapace (a part of their horny outer skeleton: average size=110mm in reserve, 94mm outside). In 18 years, sea urchin densities declined from 4.9m^2 to 1.4m^2 in the reserve, while urchin cover rose from 14% to 40% in unprotected areas (Babcock 1999).
Tawharanui Marine Park, New Zealand	14	Temperate rocky reef	The most common predatory fish, *Pagrus auratus*, was 9 times more common in the reserve than outside, while the spiny lobster, *Jasus edwardsii*, was 3.7 times more abundant, with a carapace about 16mm bigger (Babcock 1999).
Mayotte Island, Indian Ocean	3	Coral reef	Total numbers of species present did not differ between protected and unprotected areas. However, most large carnivores were more diverse and abundant in the reserve. The mean biomass of commercial species was 202g/m^2 in the reserve, compared to 79g/m^2 outside (Letourneur 1996).
Looe Key, Florida, USA	2	Coral reef	15 species that were targets of spear fishers increased in abundance after spearfishing was banned: snappers by 93%, grunts by 439% (Clark et al. 1989).
Cousin Island, Seychelles	15+	Coral reef	Groupers, emperors, and snappers were more abundant and diverse within the reserve than in fished sites (Jennings 1998).
Sainte Anne, Seychelles	11	Coral reef	Despite the fact that a few families retain fishing rights and poaching is fairly common in this reserve, the diversity of target

Reserve Name and Location	Years of Protection	Habitat Type	Effects Reported
			species and total fish biomass was higher than in heavily fished areas. The biomass of prey did not increase when predators were removed by fishing (Jennings et al. 1995, Jennings et al. 1996).
Merritt Island Wildlife Refuge, Florida, USA	28	Sub-tropical estuary	Experimental catch per unit effort (the amount caught for every unit of fishing effort) was 2.6 times greater in the reserve for all game fish combined, 2.4 times for spotted sea trout (*Cynoscion nebulosus*), 6.3 times for red drum (*Sciaenops ocellata*), 12.8 for black drum (*Pogonius cromis*), 5.3 for snook (*Centropomus undecimalis*), and 2.6 for striped mullet (*Mugil cephalus*). Fish in the refuge were larger and more abundant, and anglers were preferentially targeting the reserve boundary (Johnson et al. 1999).
Kisite Marine National Park, Kenya	5	Coral reef	Snappers, emperors, and groupers were more abundant in the park and appear to be spilling over into fishing grounds. Protection did not affect species number of diversity (Watson et al. 1996).
Punta El Lacho, Chile	2	Temperate rocky intertidal	The commercially important marine snail, the Loco (*Concholepas concholepas*), increased in density from 5 to 14 times, and doubled in body size following protection (Castilla & Duran 1985).
Barbados Marine Reserve	11	Coral reef	Large, trapable fish were approximately twice as abundant in the protected area, and 18 of 24 species were bigger (Rakitin & Kramer 1996, Chapman & Kramer 1999).
Exuma Cays Land and Sea Park, Bahamas	36	Tropical seagrass meadow	The average density of adult queen conch (*Strombus gigas*) was 15 times higher in the reserve, and late stage larval densities were 4-17 times higher (Stoner & Ray 1996).

Reserve Name and Location	Years of Protection	Habitat Type	Effects Reported
Exuma Cays Land and Sea Park, Bahamas	10	Coral reef	The reproductive output of Nassau grouper (*Epinephelus striatus*) was 6 times greater in the reserve (Sluka et al. 1997).
Hawaii Marine Life Conservation Districts	Not reported	Coral reef	Fishes were 63% more abundant in areas protected from fishing (Grigg 1994).
De Hoop Marine Reserve, South Africa	2	Warm-temperate rocky reef	Experimental catch per unit effort increased by up to five-fold for 6 out of 10 of the most commercially important species (Bennett & Attwood 1991).
Saba Marine Park, Saba, Netherlands Antilles	4	Coral reef	In the no-take zone the biomass of target species was over twice that in fishing grounds (Polunin & Roberts 1993).
Hol Chan Marine Reserve, Belize	4	Coral reef	Biomass of target species in the reserve was on average almost double that in fishing grounds, while in certain parts of the reserve it was 10 times greater (Polunin & Roberts 1993, Roberts & Polunin 1994).
Anse Chastanet Reserve, St. Lucia	2	Coral reef	Total biomass of commercially important species was more than double that in fishing grounds, and the reserve contained 3 easily caught species found nowhere else (Roberts & Hawkins 1997).
Ras Mohammed Marine Park, Egypt	15	Coral reef	Mean biomass of fish was 1.2 times greater on protected reefs, while differences for 7 target species were much greater. Individuals of the lunartail grouper (*Variola louti*) were 3 times larger in the reserve (Roberts & Polunin 1993).
Kisite Marine National Park and Mpunguti Marine National Reserve, Kenya	Kisite 20, Mpunguti 0 (open to fishing using traditional methods	Coral reef	Abundances of key commercial species (groupers, snappers, and emperors) were up 10 times higher in the fully-protected Kisite Marine National Park compared to the fished Mpunguti reserve. Furthermore, keystone species such as triggerfish (a predator of urchins) were also more abundant in the Kisite Park, while their urchin prey were much more abundant in the fished Mpunguti reserve (Watson & Ormond 1994).

Reserve Name and Location	Years of Protection	Habitat Type	Effects Reported
Three Kenyan Marine Parks: Malindi, Watamu, Kisite	Malindi 24 Watamu 20 Kisite 19	Coral reef	Reserves helped to support regional diversity by protecting species that were unable to persist in fished areas. Of the 110 species recorded on protected reefs, 52 were not found in fished areas (McClanahan 1994).
South Lagoon Marine Park, New Caledonia	5	Coral reef	Within protected areas the species richness of fish populations increased by 67%, density by 160%, and biomass by 246%, but the average size of most species did not increase (Wantiez et al. 1997).
Banyuls-Cerbere Marine Reserve, France	6	Warm-temperate rocky reef	18 target species were bigger in reserves (Bell 1983).
Shady Cove, San Juan Islands, Washington, USA	7	Temperate rocky reef	Lingcod (*Ophiodon elongatus*) were nearly 3 times more abundant in the reserve (Palsson & Pacunski 1995).
Edmonds Underwater Park, Washington, USA	27	Temperate rocky reef	The number of rockfish eggs and larvae originating from within the park is 55 times greater than outside. For lingcod (*Ophiodon elongatus*), the figure is 20 times as many (Palsson & Pacunski 1995).
Anacapa Island, Channel Islands, California, USA	20	Warm-temperate rocky reef	Densities of the commercially exploited red sea urchin (*Strongylocentrotus franciscanus*) were 9 times higher in the reserve than in nearby fished areas (Gary Davis, quoted in Fujita 1998).
Tsitsikamma National Park, South Africa	22	Rocky reef	Of the 3 species studied, 1 was 4 times more abundant in the reserve and another 13 times more. Bream (*Petrus rupestris*) were on average twice as large when protected. The biggest individuals for all species were found in the reserve, and maximum sizes in fished areas were depressed (Buxton & Smale 1989).
Sumilon Island Reserve, The Philippines	10	Coral reef	18 months after fishing was resumed in the reserve, catch per unit effort fell by a half, and the total yield of fish was 54% less, despite a greater area available for fishing (Alcala & Russ 1990).

Reserve Name and Location	Years of Protection	Habitat Type	Effects Reported
Apo Island Reserve, The Philippines	6	Coral reef	The biomass of large predators increased 8-fold in the reserve. In fishing grounds, mean density and species richness of large predators also increased (Russ & Alcala 1996).
Kyoto Preture Closure, Japan	4	Temperate sand and mud bottom	The proportion of large male snow crabs (*Chionoecetes opilio*) rose by 32% in the closed area (Yamasaki & Kuwahara 1990).
Maria Island Reserve, Tasmania	6	Termperate rocky reef	The densities of rock lobster (*Jasus rubra*) and bastard trumpeter fish (*Iatridopsis forsteri*) increased by 1 and 2 orders of magnitude respectively within the reserve. The numbers of species also increased for fish, invertebrates, and algae, as did the densities of fish larger than 33cm (Edgar & Barrett 1999).

APPENDIX 2:
BACKGROUND INFORMATION ON THE CaMPAM NETWORK

The ecological realities of the marine and coastal environment are such that some of the management issues to be addressed transcend local and regional boundaries. Co-operation at the regional level, therefore, is critical to achieve goals of conservation and sustainable use of our coastal and marine environment. In this context, a group of more than 50 partners in marine protected area management, from 22 countries of the Wider Caribbean Region, attended a five-day workshop (Miami, 1-3 December 1997) to identify ways of strengthening marine and coastal protected area management. The participants proposed that a network be developed for marine and coastal protected areas (MPA) for the Wider Caribbean to achieve the conservation goals for which the areas were established (CaMPAM).

Mission Statement

Enhancement of marine and coastal area management in the Wider Caribbean Region through sharing and collaboration to strengthen our national and regional systems of existing and future marine and coastal protected areas.

Membership

The main beneficiaries of CaMPAM are MPAs and their managers. Membership is flexible to respond to national circumstances, and may include

existing, relevant networking efforts (such as those of IUCN, CCA, CARICOMP, FAO, etc.) institutions, and partners.

General activities agreed on to be carried out throughout CaMPAM membership include sharing experiences and addressing management challenges by facilitating:

i) Training activities
ii) Information exchange
iii) Ccommunication
iv) Problem-solving

General Principles

During the meeting, the following principles were identified to guide further development of CaMPAM:

i) Clear and realistic (not over-ambitious) objectives,
ii) Transparent mission,
iii) Adequate mechanism for communication and information exchange as a minimal requirement for effective operation,
iv) Determine own niche, complementing and involving (as appropriate) existing relevant efforts/mechanisms,
v) Active leadership,
vi) Define minimal level of organizational structure, not funding-dependent, to ensure co-ordination, communication and power to convene meetings,
vii) Balance between technical, scientific, political and institutional dimensions,
viii) Representative of regional and national groups,
ix) Active membership, identifying clear incentives and benefits and assuming ownership and responsibility,
x) Degree of flexibility and adaptability,
xi) Network-wide activities (horizontal) and activities a the national/local level (vertical), e.g. pilot activities, and
xii) Ensure sustainability.

Immediate Activities

Develop communication mechanisms, including:

i) Informal communication through e-mail, telephone and fax,
ii) News groups on specific issues/themes, such as conflict resolution, user fees, zoning, sustainability, and fisheries no-take zones in MPAs,
iii) Electronic list-server,
iv) Training needs and related announcements,
v) Enlisting other MPAs, relevant NGOs, and institutions etc., to participate in the networking effort and process of development,
vi) Preparation of a calendar of events,
vii) Developing a webpage,

viii) Utilizing existing newsletters, e.g. CEPNEWS, until CaMPAM newsletter is born (if necessary)

Facilitation

At the request of the participants, the United Nations Environment Programme's Regional Co-ordinating Unit (UNEP CAR/RCU) and Biscayne National Park agreed to assist with facilitation of the first phase. Biscayne National Park assumed the role of facilitator with the technical support of the UNEP/RCU, fully engaging CaMPAM participants in the development and leadership of the network. The participants agreed that a formal organization should not be established at this time, in order to allow the network to fully clarify its objectives and define its niche through a participatory process.

The participants gave high priority to the early establishment of communication mechanisms (news groups, list servers, and routine e-mail communications) and agreed to work with the facilitator/Secretariat to implement this goal. For those without access to computer technology (e-mail and Internet access), participants agreed to communicate via facsimilie, telephone and mail.

Participants agreed to assume responsibility for, and play an active role in further developing this approach and continuing the networking begun at this meeting.

APPENDIX 3
STRUCTURE OF THE SMALL GRANTS FUND FOR MPAs

The CaMPAM SGF is designed to provide strategic inputs required to improve management of MPAs in the Wider Caribbean Region (WCR). Within this scope, the SGF will concentrate on the following areas of focus:

i) Development of management/administrative systems, with special emphasis on financial management systems. This includes preparation of management plans and development of cost recovery systems;
ii) Development of information, education, and awareness strategies and materials;
iii) Damage assessments and restoration;
iv) Development of legislation and enforcement procedures;
v) Staff training;
vi) Resource assessments of marine and coastal resources (organisms, ecosystems, etc.) within the MPA;
vii) Purchase and/or upgrade of selected equipment, including marker and mooring buoys and field monitoring equipment (equipment requiring extensive maintenance/support, such as computers, will not be considered); and
viii) Economic feasibility studies and/or development of strategies for alternative, non-destructive, sustainable economic activities.

Eligibility Criteria

Grants will not be made to individuals or international organisations. The project proponent (organisation that submits the project proposal) should have direct management responsibility for the MPA, and may include the following categories of institutions:

i) Government agencies;
ii) Community-based organisations and environmental non-governmental organisations;
iii) Caribbean universities and relevant research and/ or tertiary academic institutions; and
iv) Private sector entities (fund disbursement on a reimbursable basis only).

More specifically, the following criteria should apply:

i) The applying institution must be a MPA management institution.
ii) The MPA must be established by law, and must have a functional organisation structure in place.
iii) Only MPAs within the Wider Caribbean Region are eligible.
iv) Institutions must agree to submit a Terminal Report (based on the format prepared by UNEP-CAR/RCU) to UNEP-CAR/RCU within 3 months of termination of the project.
v) Priority will be given to MPAs that participate actively in the CaMPAM network;
vi) MPAs must agree to participate in the project evaluation exercise to be conducted by an institution or person unilaterally named by UNEP-CAR/RCU.
vii) MPAs must submit copies of their Institutional Development Plan, MPA Management Plan, and most recent Annual Report. Where funds are required for the purpose of preparing the management plan, the Institutional Development Plan and the Annual Report will suffice.
viii) Priority will be given to MPAs from countries that are Contracting Parties to the Cartagena Convention and its Protocols, and are current in their contributions to the Caribbean Trust Fund.
ix) Priority will be given to proposals that form part of a larger project, or will receive co-financing from the local institution or other donors.

Funding Requirements

The CaMPAM SGF can provide support as either financial assistance or technical assistance, up to a maximum of US$8,000.00. Where technical assistance is required, UNEP-CAR/RCU reserves the right of final approval of the consultant(s) to be used. Where financial support is to be provided, the SGF will cover only direct costs such as training, transportation (between islands/international), field equipment, and other similar costs.

Where the proposal to UNEP-CAR/RCU forms a part of a larger project, or

where projects are co-financed by other agencies, a copy of the project proposal submitted to, or approved by, the other funding agency should be submitted with the proposal to UNEP-CAR/RCU.

Application Procedures

Application forms are available from the UNEP-CAR/RCU website at: http://www.cep.unep.org/programmes/spaw/MPA/mpa.htm. Applications can be submitted to the UNEP-CAR/RCU at any time. Proposals will be subjected to a preliminary screening by staff of UNEP-CAR/RCU, which will provide feedback to the project proponent. Proposals that are deemed to be complete will be submitted to a Project Review Panel (PRP) for peer review.

Challenges of Building Co-management Arrangements for Management of the Protected Areas System in the Turks and Caicos Islands: Example of the Princess Alexandra National Park

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ABSTRACT

Management of Protected Areas in the Turks and Caicos Islands has undergone numerous institutional changes in its quest to develop into a self-financing and integrated system. Established in 1987, the Princess Alexandra National Park was the country's first protected area, and the Government of the Turks and Caicos Islands further expanded this number by 32 in 1992. The responsibility for the system of protected areas has been transferred among several related Government Departments over the past 14 years, each with its limitations. In 1998, management of the Princess Alexandra National Park, along with two other marine parks was devolved to a separate entity through the Coastal Resource Management Project. Jointly sponsored by the Governments of the United Kingdom and Turks and Caicos Islands, the primary objective of the Project is 'to adopt and implement sustainable management mechanisms for designated national parks and marine protected areas for the benefit of a wide range of stakeholders'. Embodying the principle of co-management, the CRMP is developing a number of partnerships in managing the marine parks and has delegated responsibility of some activities to other organizations. The process of developing co-management institutions however, has not been the *modus operandi* in the Islands resulting in multiple challenges. Co-management becomes more of a constraint in the face of non-cohesive communities and an unsustained process of building ownership of the resource among key stakeholders. Therefore, the Government and other stakeholders are learning that in order for co-management to work, there must be clear agreements of roles and responsibilities of managing parties, a climate of cooperation, respect and transparency, and perhaps, most importantly, well defined benefits to key stakeholder groups.

KEY WORDS: Co-management, Marine Protected Areas, Turks and Caicos Islands

INTRODUCTION

Description of the Islands

The Turks and Caicos Islands is a small archipelago of low-lying islands located at the southeastern tip of the Bahamas platform, lying approximately 400 km SE of Florida, USA and 125 km North of Haiti. The Country comprises two groups of islands, the Turks Islands and the Caicos Islands, which are separated by a 30 km, and 2200 m deep Turks Islands Passage. Grand Turk, Salt Cay and a number of cays make up the Turks Islands. The Caicos Islands comprise six main islands: East, West, South, North, and Middle Caicos, and Providenciales, the first two islands being uninhabited. The islands have a total landmass of approximately 500km^2 and are completely surrounded by abyssal oceanic depths (Figure 1). The islands are geologically young, made up mainly oolitic limestone (Wanless and Dravis, 1989); the climate is arid, with an annual average rainfall of about 45mm and a temperature range from 25° C to 29°C.

Still a British Crown Colony, the Country is governed by an Executive Council, consisting of three *ex officio* members and six appointed by the governor from the elected Legislative Council.

Ecology of the Islands

The most valuable assets to the TCI are its natural resources, which have been widely surveyed by Operation Raleigh, 1986 - 1987 and Cobham Resource Consultants (1988). The wetland areas are extensive, comprising mostly fresh and saltwater marshes, mangroves, inter tidal flats and ponds. Terrestrial vegetation is sparse due primarily to low rainfall, poor soils and rocky terrains. The majority of the vegetation throughout the islands is xerophytic, consisting largely of low shrubs and cacti.

The marine area is rich and varied (Operation Raleigh 1990). Patch and fringing reefs align most of the margins of the Caicos Platform and the Turks Banks. The Banks have supported a thriving fishery, particularly the spiny lobster (*Panulirus argus*) and the queen conch (*Strombus gigas*), for the past 40 years.

Healthy seagrass beds and mangrove colonies complete the coastal ecosystems in many areas. Other important coastal and marine resources include huge stretches of carbonate beaches, turtles, whales and bottle-nosed dolphins. The largest terrestrial animal is the rock iguana, *Cyclura carinata* surveyed by Gerber (1995). Other endemic reptiles include snakes and lizards. A large number of migratory and resident birds have been recorded for the islands. In 1993, Bradley recorded 190 species, the majority of which were migrant.

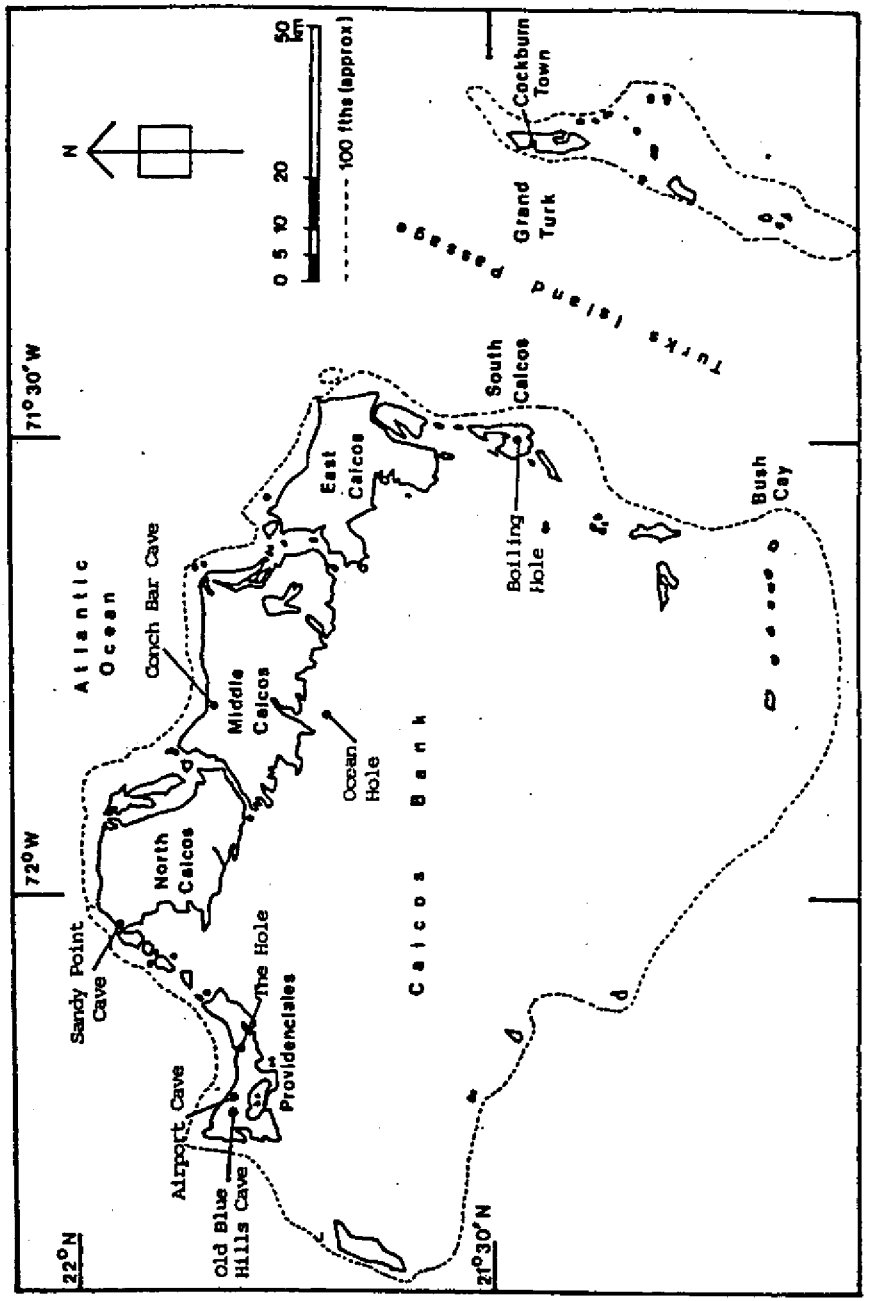


Figure 1. Map of the Turks and Caicos Islands

BACKGROUND

The Protected Areas System

The idea to set aside areas for protection of the natural environment was advanced from the early 1960s when scientific work was being undertaken on the conch fisheries; however, the first protected area was not legally designated until 1988 (Garland, 1996). Eventually the Protected Areas System was established in 1992 under the National Parks Order, which legally designated 33 protected areas separated into four categories. There are 11 national parks, 11 nature reserves, 7 historical sites and 4 Sanctuaries (Table 1).

Table 1. Designated protected areas under the Protected Areas System

Categories of Protected Areas
National Parks - are open to the public for recreational use, including camping, fishing and sailing; infrastructure development to facilitate enjoyment by the public is also permitted.
Nature Reserves - are areas managed for activities such as agriculture, arboriculture, sporting and recreational purposes subject to appropriate regulations
Historical Sites - are designated to protect objects of historical interest, and may be a part of a national park, nature reserve or sanctuary. Depending on their location, they are subject to regulations of that category of protected areas.
Sanctuaries - are defined as areas of natural ecology, which should be managed to prevent outside disturbance by humans. These areas are designed mainly for protection of sensitive habitats, and entry is by permit only.

The protected areas system covers an area of 705 km^2 , a substantial area in relation to the total land area, which is only 500 km^2. The protected areas are distributed throughout the main islands and offshore cays. Some areas are mainly terrestrial, while others are purely marine. A substantial part of the Protected Areas System has been designated as a wetland area and some underwater 17th Century wrecks have been designated as historical sites.

Evolving Management Capacity

The protected areas system has encountered frequent institutional changes over the years in developing an integrated system for management. These changes included several portfolio rearrangements, with at least five different Ministers and

six different Permanent Secretaries. Detailed by Garland (1995), a Department of Environment and National Heritage (DENH) was established in 1988 as a sub-unit of the Department of Physical Planning. Three years later, the unit separated from the Planning Department to form the first full Department, the Department of Environment, Heritage and Parks (DEHP). Supported by a vibrant National Parks Advisory Committee, the DEHP was successful in getting the National Parks Regulations (1992) enacted, management plans prepared for the marine parks in Providenciales and West Caicos, and a Business Plan which outlined a self-financing system to sustain management of the Protected Areas System. Despite considerable progress, the DEHP lacked the financial and human capacity (Wood 1993) to effectively manage protected areas. Consequently, management activities were limited to the procurement of mooring buoys and periodic surveillance in the marine parks, dependent solely on the availability of the Fisheries Patrol Vessel. Attention on the protected areas further subsided in 1995 when the Government implemented a Civil Service Reform Exercise and the DEHP merged with the Fisheries Department to form the Department of Environment and Coastal Resources (DECR). The new DECR lost three former staff of the DEHP and protected areas management became subsumed by fisheries priorities (Figure 2.).

Hereinafter, proposals for capital funding to implement the management plans were presented in the country policy dialogue between the Governments of the TCI and the United Kingdom for three consecutive years. The UK Government agreed that aid funding to the Protected Areas System was contingent on the implementation of a self-financing system to sustain management activities when project funds were expended. In 1998, the Government of the Turks and Caicos Islands established the Conservation Fund under the Appropriation Ordinance. The Conservation Fund is supported by an increase of 1% of the accommodation tax. The Coastal Resource Management Project was subsequently approved in the same year.

The Coastal Resource Management Project

The Coastal Resource Management Project, funded by the UK Department for International Development (DFID) has provided approximately US$1.8 million for the management of the system of protected areas in the TCI.

The CRMP is now in its third year of operation and employs ten staff members. The staff complement comprises the Project Manager, a Chief Parks Warden, five Park Wardens and a Scientific Monitoring Officer. A Technical Cooperation Officer (TCO) fills the position of Co-management Adviser and the Project contracts the Turks and Caicos National Trust (TCNT) to hire an Environmental Education Officer. To date the CRMP has been successful in achieving three of its five outputs:

i) Management Plans for key protected areas,
ii) Implementation of a Public Awareness Programme in collaboration with the TCNT,
iii) Preparation of an Action Plan for extending management throughout the system of Protected Areas

iv) Construction of a National Environmental, and
v) Establishment of the National Parks Service.

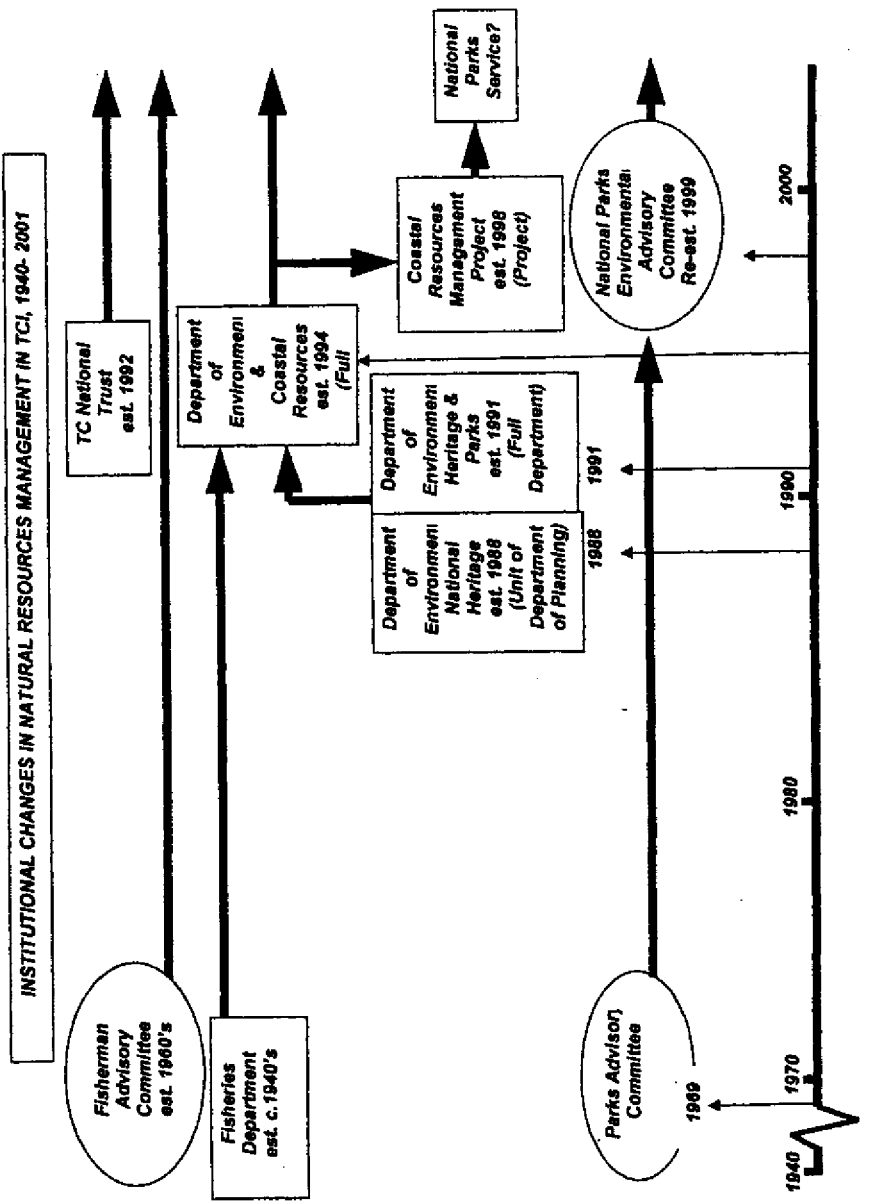


Figure 2. Institutional changes in natural resources management in TCI, 1940 - 2001

The CRMP also establishes a National Parks Environmental Advisory Committee (NPEAC) to discuss and advise the Project Manager/National Parks Director on the implementation of "park management programmes, public awareness programmes, opportunities for co-management options, selection and approval of micro-projects, and other environmental issues affecting the National Parks System". The NPEAC comprises representatives from the Hotel and Tourism Association, Watersports Association, Turks and Caicos National Trust, the Rotary Club, the Ministry of Natural Resources and the DECR.

This case study focuses primarily on the Princess Alexandra (Land and Sea) National Park as it was the first park established. In addition, the park displays many of the environmental problems and issues in tropical coastal areas. More importantly, the PANP has been the focal point for many of the activities in relation to co-management.

PRINCESS ALEXANDRA NATIONAL PARK

The Princess Alexandra National Park was the first legally established marine national park having been designated on March 4th, 1988. The Princess Alexandra National Park is located on the north coast of Providenciales and covers an area of 6,532 acres. The Princess Alexandra Nature Reserve is located within the Princess Alexandra National Park and comprises the entire land area of Little Water Cay, Mangrove Cay and Donna Cay (Figure 4.).

Ecology

Vegetation is limited to the shoreline areas of the PANP, as the boundary of the park extends only up to the high water mark. Wood 2000 classified this peripheral vegetation into two types of communities: Strand Dune Community, (*sea oats and herbaceous scrubs*) and Coastal Coppice Communities (*black torch, seven-year apple and sea grapes*). Mangrove communities comprising black, red and white mangroves are the dominant vegetation in the Princess Alexandra Nature Reserve. Several species of resident and migrant birds perch in the PANP including the brown pelican (*Pelecanus occidentalis*), ruddy turnstone (*Arenaria interpres*), osprey (*Pandion haliaetus*) and stilt sandpiper (*Calidris himantomus*) (Wood 2000). The rock iguanas (*Cyclura carinata*) and several species of lizards are the main terrestrial fauna.

The primary coastal and marine habitats are seagrass meadows, coral reef systems, and beaches and low dunes. Seagrass beds consist mainly of turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*) and sponges. Biannual surveys of the seagrass meadows by the CRMP show *Thalassia testudinum* as the dominant species of Sea grass. The reef systems in the PANP have been described by Wanless and Dravis (1989), and Operation Raleigh (1990). An almost continuous barrier reef extends along the boundary of the park, which is dominated

by massive colonies of Elkhorn coral (*Acropora palmata*) along the reef crest. Intermittent patch reefs are dispersed throughout the back reef lagoon.

The PANP is bordered on its southern side by some nine miles of continuos beach. The beach sand is derived mostly of foraminifer sands (Wanless and Dravis, 1989) and varies in width up to 100ft from the low water mark to the line of vegetation. Profile data on the beaches along the PANP proves that the beaches and sand dunes are very dynamic and in some places unstable. Consequently, serious erosion is occurring on the northeastern tip of the park, primarily due to hurricane induced changes in the 1980s.

Social Context and Ecological Sustainability

Landuse surrounding the PANP has recently been recorded by Homer (2000). The PANP is bordered by the Bight Community, one of the oldest communities in Providenciales, along with Grace Bay and Leeward Sub-divisions. While the entire island of Providenciales was transformed from an island of mainly subsistence fishing communities to one of high tourism development, the Bight Community has been mostly impacted. High land prices, slumps created by the influx of immigrant workers, and pollution of ground water are some of the most conspicuous impacts. Fueled by the construction of the first major hotel, Club Med in 1980 and an international airport in 1984, tourism mushroomed on the island of Providenciales over the last two decades. As a result, between the Bight and Grace Bay some 20 hotels and approximately 1700 bed capacity, with numerous support industries, formed the basis of the islands' tourism economy.

The socio-economic impacts of tourism development on the island of Providenciales are well documented by Hinds 1993. The boom tourism development has led to a rapid social change with significant immigration of investors from North America and Europe and migrant labor predominantly from Haiti, Dominican Republic and Jamaica. A recent Standard of Living Assessment Report (2000) recorded 42 different nationalities residing in Providenciales. The high turn over of residents, diverse cultures, new communities and young institutions, with few historic ties, social links and obligations present significant challenges to co-management. Turks and Caicos Islanders on Providenciales are themselves drawn from the six inhabited islands. Attracted by economic opportunities and newfound wealth there is a significant gap between the residents and the protected areas.

Like all common property resources, the PANP is vulnerable to over exploitation. Needless to say, various studies carried out to assess the ecological sustainability in face of the irrepressible development suggest that the resources are under threat (Cobham Resource Consultants 1988; Operation Raleigh 1990; Hinds 1993). Activities such as illegal fishing, beach loss from erosion, pollution from landbased sources, and reef destruction as a result of irresponsible divers, boat users and snorkelers are common. A co-management approach is now being developed to address these multi-faceted issues.

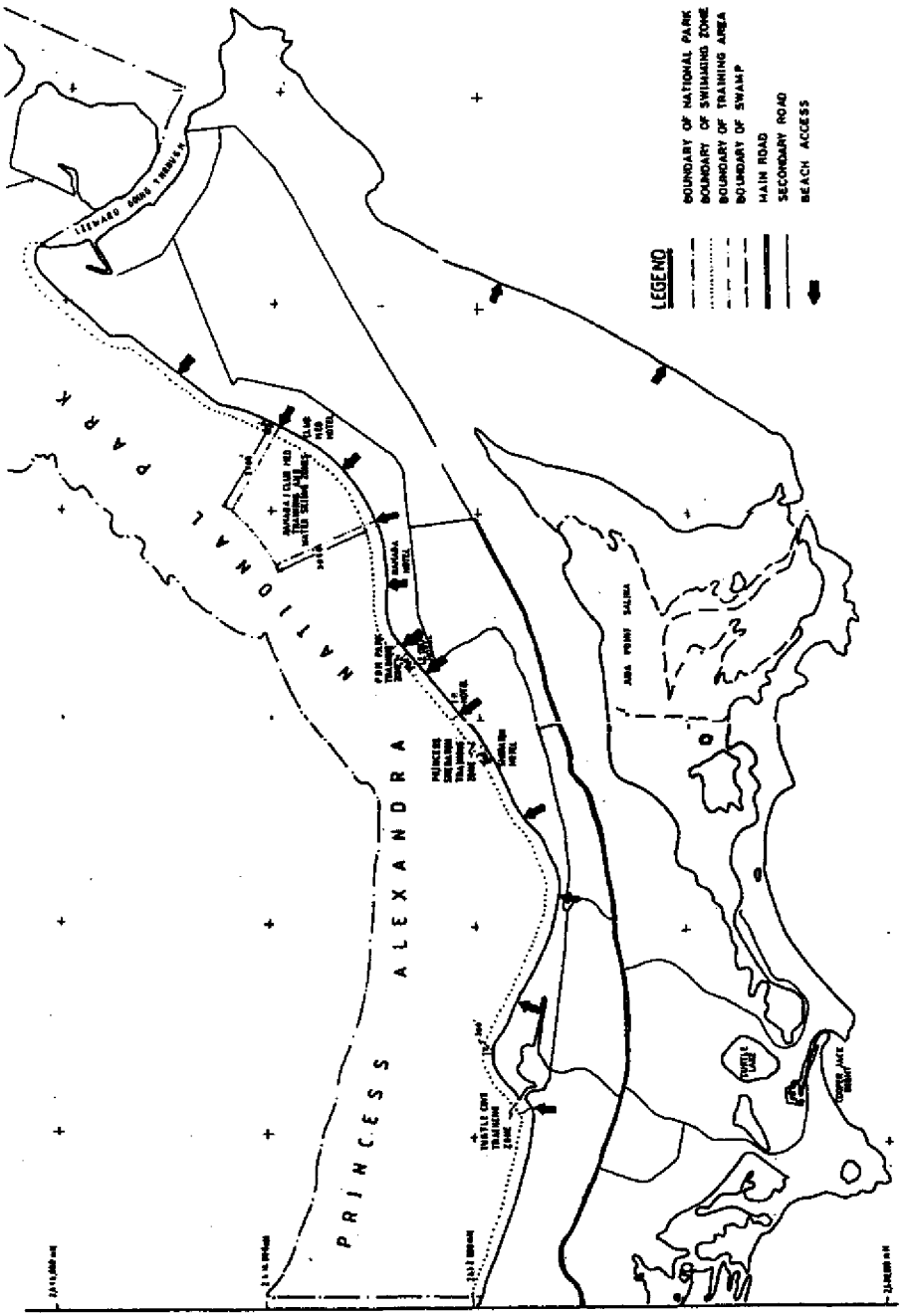


Figure 3. Map of the Princess Alexandra National Park

CO-MANAGEMENT

Co-management arose as a response to exclusionist protected areas policies worldwide and is a growing trend in resource management. Built on the theories of common property resources (Berkes et al. 1998, Ostrom et al. 1999), co-management recognizes that users have the potential and ability to collectively regulate and manage a common property resource. According to Berkes 1998 " the co-management solution stands on two basic assumptions. First, that local people need to have a stake in conservation and management. Second, that partnership of government agencies with local communities and other resource users is essential."

While a number of authors have attempted to define Co-management, as summarized by Berkes et al. (1998), this paper borrows the general definition coined by Barzetti (1993), "Co-management is the sharing of management responsibility". This definition is especially suited for Providenciales, where "the involvement of 'communities' in protected areas management means more than a group of people who share a common place of residence, but is expanded to include people who share a common function or link, such as the business community or tourists or a religious or kinship group". Barzetti (1993) described these groups as stakeholders, or people with an interest in protected areas.

History of Local Co-management Efforts

The principles of participatory management have been promoted in resource management from the establishment of a National Parks Advisory Committee in 1969 and a Fisheries Advisory Committee in 1966. One bold and admirable collaborative arrangement sanctioned by the Government was the creation of the National Trust Ordinance in 1992. The Ordinance creates the Turks and Caicos National Trust, a non-profit, non-governmental organization to assist the government in developing and implementing conservation initiatives.

The development of co-management in protected areas has, however, been greatly influenced by external partners, particularly funding partners. For example, the UK White Paper, which was recently signed by its Overseas Territories, states as one of its guiding principles 'to consult openly with interested parties on decisions affecting the environment'. More directly related to the TCI protected areas system is the Coastal Resource Management Project, which itself has as an underlying theme - participation and co-management.

Collaborative arrangements in resource management began during the early 1980s with the development of a mooring buoy system. These initiatives developed out of concern for the safety of recreational diving and for the protection of the coral reefs (Wood 1993a). In 1988, under the auspices of the Protection of Reefs and Islands from Degradation and Exploitation (PRIDE), a partnership was coined whereby the Government bore the cost of dive moorings, and PRIDE, co-ordinated their installment. Complete maintenance of the mooring buoy system was transferred to the Watersports Association following its creation in 1989, however, the government continues to finance most of the equipment. This participatory arrangement continued throughout the life of the DEHP and into the DECR.

Although this system existed for many year,s it was not organized and maintenance to the buoys was sporadic and selective. In addition, no proper systems were established by the various departments to monitor the effectiveness of this partnership arrangement.

More formal co-management arrangements in the protected areas system began in 1996 when management responsibilities for Little Water Cay, part of the Princess Alexandra Nature Reserve, was transferred to the Turks and Caicos National Trust. A Memorandum of Agreement, which formalized the arrangement provided for the National Trust to: construct broad walks on the Little Water Cay; co-ordinate training and meetings with stakeholders; conduct a feral animal program; and establish and administer a revenue generation programme. In return, the DECR was responsible for enforcement of the National Parks Regulations (1992) and enforcement of the ticketing and fee collection system. This joint venture is still in existence today and has improved over the years.

The CRMP and Co-management

The CRMP's Arrangement — Inherent in the CRMP is the principle of participatory management. This is reflected in the overall goal of the CRMP, which is " to adopt and implement sustainable management mechanisms for designated national parks and marine protected areas for the benefit of a wide range of stakeholders". While some co-management arrangements have been formally outlined in the CRMP memorandum, others have developed informally. The complex partnership arrangement outlined in the CRMP Memorandum (2000) makes the CRMP itself a cooperative arrangement. For example, the Project provided for the high-cost capital items in the parks including signs, buoys, vehicle, boat and staff for key protected areas in Providenciales and West Caicos. The CRMP has also implemented several management programmes, including data collection, patrols and surveillance, user surveys, outreach and maintenance. The DECR has retained all regulatory and enforcement functions of the areas and currently retains management responsibility for the protected areas in Grand Turk, South, North and Middle Caicos and the off shore Cays. In addition, management of several historical sites has been devolved to the National Trust. Unfortunately, this arrangement was not accompanied with clear operational procedures for staff of the different entities. Consequently, from the onset of the CRMP there was considerable conflict over roles, rights and responsibility. The establishment of the NPEAC is also an attempt at institutionalizing co-management, evident by its composition and its intended mode of operation.

The Public Awareness Programme — Several co-management arrangements are incorporated within the CRMP. Firstly, the CRMP contracts the TCNT to implement public awareness programmes on the protected areas in the communities and schools throughout the Turks and Caicos Islands. This arrangement is sanctioned by a Memorandum between the Government and the TCNT, which

provides for the CRMP to finance the salary for an Environmental Education Officer, public awareness programmes and core support to TCNT on an annual basis. In return, the TCNT has the responsibility to design, organize, and co-ordinate public awareness programmes to promote and educate the public on the protected areas system. The public awareness programme is now in operation, but it has suffered several setbacks during start-up due to the absence of proper guidelines for contracting staff through a non-governmental body and the lack of clarity on the qualifications, experience and full duties of the person recruited.

The MicroProjects Programme — A Small Grants Programme, locally known as the Micro-projects Programme, is one of the main vehicles of the CRMP, designed to develop partnerships in managing the natural environment. The Micro-projects Programme provides the opportunity for private individuals, local groups, local organizations, and others to become involve in the management of the natural, historical and cultural resources of the Turks and Caicos Islands. The Programme was launched in August 2000 and is funded by 20% of the Conservation Fund. The Micro-project programme became fully operational in April of this year following the appointment of a new National Parks Environmental Advisory Committee and the recruitment of two part-time staff to co-ordinate activities under the Programme. Subsequently, four projects were approved in September, however, implementation was delayed due to confusion over procedures for disbursements of funds from the Conservation Fund to the recipients.

The Water Quality Monitoring Programme — The CRMP has also sought to develop collaborative arrangements in implementing day to day management activities. For example, a water quality-monitoring programme to address potential land-based pollution on the Princess Alexandra National Park was initiated in 1999. Spearheaded by the former Resource Monitoring Adviser and a Consultant, the team comprised representatives from the Department of Environmental Health, Environment and Coastal Resources, CRMP and the Water and Sewerage Board. The team effectively operated for a period of ten months - sampling groundwater, natural runoff, effluent from wastewater treatment facilities, and finally the marine area. The data was analyzed locally and internationally, and the results were presented to senior decision-makers, including the Executive Council. The team has identified a number of threats to the water quality in Providenciales, and hopes to gain government support in taking action against perpetrators.

The Mooring Buoy Programme — The mooring buoys system, is another area where the CRMP has aimed to maintain the partnership arrangements, originally developed under the former departments. Since commencement of the CRMP in 1998, the staff has assumed complete responsibility for the procurement and installation of dive moorings, demarcation buoys and regulatory buoys in the marine parks in Providenciales and West Caicos. The staff has also been afforded local and

international training to support this management activity. While the system is more organized, input from the dive and watersports operators had significantly subsided. This is primarily due to the constant institutional changes in the PAS, and secondarily as a result of the lack of cohesiveness within the watersports sector. Consequently, the CRMP is now supporting efforts to revive user motivation in the system.

The Access Lanes — Some co-management arrangements have also informally developed around the PANP. For example, there are eleven official access lanes to the PANP. hotel and condominium developers, after 1995, were mandated by the Planning Department to landscape and beautify the access lane alongside their properties during construction. The developers complied, and have also assumed responsibility for their maintenance. Signage for the access lanes were procured under the CRMP, and at least one access lane has been developed by the Rotary Club, which is equipped with recreational facilities for children. Several hoteliers who have invested in upgrading and maintaining the access lanes alongside their property now use the access as extra parking lot for their establishments, in addition many of the landscapes are designed in a manner that portrays the access lane as a continuation of the hotel or condominium development. These actions are met with serious resentment from locals, who often feel unwelcome to the beach or the park.

CONSTRAINTS AND SETBACKS WITH CO-MANAGEMENT

Co-management is presently restricted between the CRMP and organized groups due to the demographic composition of communities in Providenciales. There are three main communities in Providenciales based on geophysical boundaries; however, since the early nineties a number of sub-communities emerged primarily due to factors of race, and ethnic background. The Communities are not all homogenous entities but divided along the lines of class or immigration status. One aspect of social fragmentation of the community is the marginalization of those persons from economically improvised countries such as Haiti and the Dominican Republic. Such people are isolated and under represented in formal community institutions, hence their voices are seldom heard.

Co-management and participatory management have not generally been the *modus operandi* of government bodies. Consequently, there is a reluctance and lack of support when initiating partnership arrangements and a lack of initiative to facilitate genuine commitment to participatory management. There is a lack of timely and consistent communication among all parties, especially the sharing of critical information by implementing partners. There is generally an absence of operating procedures and protocols for establishing co-management arrangements, resulting in undue delays, and confusion. Such conflict obstructs progress and implementation of programmes.

Partnership arrangements in general have been negatively impacted from the constant institutional changes and the high turn over of staff and senior decision-makers, and programmes and projects started by one organization are discontinued or ignored by another. The participatory agenda has been strongly driven from the outside, not actually being aware of the limited in-house capacity.

LESSONS LEARNT

In order for co-management to work:

i) Externally driven agendas are not always practical to the existing context and can do more harm than good. 'It is like fitting a square in a round peg'.
ii) Co-partners must be clear, from the onset, of their roles and responsibilities in any co-management arrangement. Consequently there must be a system of recourse when persons overstep their boundary.
iii) Collaborative arrangements will collapse in the absence of proper reporting and monitoring systems.
iv) Established guidelines and procedures are needed before initiating any partnership arrangement.
v) People must have a desire to participate.
vi) Adequate staff are needed to follow-up on collaborative arrangements already initiated, to ensure continuity.
vii) There must be clear lines of communication and a flow of information and feedback must be maintain at all levels.
viii) There must be support for the process at all levels, from Senior Decision makers to the stakeholder with the least influence.

CONCLUSION

Tourism is the economic mainstay of the TCI, which is based on the natural environment. Therefore, protection of the natural resource base is vital to the economic sustainability of the TCI. Several participatory and co-management initiatives have developed in the PAS in the TCI but have also met with challenges. While there are some extremist views on both sides of the collaboration spectrum, we should aim to find the appropriate arrangement for the situation. Some would argue that it is the Government's responsibility to ensure that the environment is properly managed, while others are of the view that participation offers a democratic and bottom-up planning process, thus gaining wide support for the process. For Providenciales, the situation supports the debate that "participation tends to elicit the participation of the most visible, high income, and mostly educated, while the least powerful and marginal, are by their nature, likely to be least visible" (Foell, 2000). It is therefore important to creatively design management programmes to encourage participation, yet at the same time recognize that in some situation more direct management might be appropriate.

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La Reserva de la Biosfera Banco Chinchorro

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ABSTRACT

Banco Chinchorro, located off the southern coast of Quintana Roo, Mexico, was declared as Biosphere reserve on 19 July 1996. This reserve (144, 360 ha) is classified by The National Biodiversity Commission as a Priority Region A-70, and the WWF considers it within the Global 200 priority areas. It is included in the 17 Marine Protected Areas in the Mesoamerican Barrier Reef System. Its great biodiversity, with endemic and threatened species, and its relative isolation makes Chinchorro a very important area for conservation and sustainable use of natural resources. Fishing, the main economic activity for the people from Xcalak, Mahahual and Chetumal, has grown since 1959, and is based on three fishermen cooperatives (92 members) focused on Queen conch (*Strombus gigas*) and lobster (*Panulirus argus*). As a part of a conservation strategy, the first goal was to prepare the Management Plan involving two years of work with fishermen to achieve agreement. On the other hand, 73 administrative rules and 13 fines for eight kinds of users of the Reserve were approved by both federal and state government, as well as academic group and NGOs. Various actions have improved the conservation of Banco Chinchorro. Surveillance and enforcement programs, funded by both the federal government and WWF, attempt to reduce illegal fishing. A monitoring program funded by federal government and NGOs was created. Several research projects have been carried out with help of different academic institutions and the Mexican Navy, related with reef biodiversity, physical and chemical oceanography, bathymetry, and conch and lobster population studies. As a management strategy, arrangements have been reached to achieve the lobster fishery certification.

KEY WORDS: Banco Chinchorro, Coral Reef, Fisheries, MPA, Mexico, Management

INTRODUCCIÓN

La Reserva de la Biosfera Banco Chinchorro (RBBCH) tiene una superficie de 144, 360 ha, que incluyen formaciones arrecifales, laguna arrecifal, cayos (lobos, centro y norte) y aguas oceánicas adyacentes. Es un complejo arrecifal coralino clasificado como falso atolón (Darwin 1842), atolón (Jordán y Martín 1987) o arrecife de plataforma (Chávez et al. 1985). Se localiza al Este de la costa del Municipio Othón P. Blanco, en el estado de Quintana Roo, a 100 km al Norte de las Islas Turneffe y del arrecife Lighthouse de Belice. Banco Chinchorro tiene forma elíptica irregular, con un eje longitudinal de 43.26 km y su eje transversal de 18.03 km en su parte más ancha. Está rodeado en su totalidad por una barrera arrecifal de

115 km de perímetro (Jordán y Martín 1987). El eje mayor está orientado de norte a sur en forma paralela a la costa de Quintana Roo.

La laguna arrecifal (60,000 ha) es somera, con variaciones de profundidad que disminuyen en dirección sur-norte. La mitad sur se caracteriza por numerosos parches y cordilleras coralinas interiores. Algunas cordilleras alcanzan 3 km de longitud y son paralelas al margen oriental del Banco. En la mitad norte no hay cordilleras y los parches se localizan principalmente al centro de la laguna (Jordán y Martín 1987).

En la laguna existen cuatro cayos que abarcan 581.91 ha o el 0.40% de la superficie total de la Reserva; de esta superficie 435.16 ha son de tierras emergidas y 146.75 ha son lagunas interiores. En el extremo norte se encuentra Cayo Norte, integrado por dos cayos (40.09 ha) en los que se encuentra principalmente vegetación arbórea y manglar; Cayo Centro, localizado hacia el centro del sistema y cerca del Margen Oriental, es el más grande (541.40 h) y cubierto por manglar, palmas y vegetación arbórea. El cuarto cayo, localizado en el extremo sur es Cayo Lobos, es el más pequeño (0.42 ha), cubierto parcialmente por vegetación arbustiva, rastrera y cinco palmas de coco; el cayo está constituido por arena gruesa y pedacería de coral y algas calcáreas.

Banco Chinchorro es el arrecife coralino de mayor dimensión y diversidad en México. La Reserva cuenta con ecosistemas, tales como: arrecifes, pastos marinos, manglares y arenales. Éstos albergan diversas especies que se encuentran bajo alguna categoría de protección a nivel nacional e internacional.

En la actualidad la RBBCH cuenta con Programa de Manejo y tiene como objetivo general asegurar el equilibrio y la continuidad de los procesos evolutivos ecológicos, garantizando la compatibilidad entre el aprovechamiento y la conservación de los recursos naturales de la Reserva.

Como parte de la estrategia para la declaración de Chinchorro con la categoría de Reserva de la Biosfera se requirió de una serie de estudios y la compilación trabajos previos con la finalidad de tener elementos suficientes que apoyaran la declaratoria. Con la ayuda de Amigos de Sian Ka'an, A.C. y diversas ONG's nacionales e internacionales se consiguieron fondos para la realización de tres campañas en las que se obtuvieron datos de: corales, peces, algas y esponjas en 415 transectos en las zonas de sotavento, laguna arrecifal, cresta arrecifal y arrecife frontal (Figura 1 y Tabla 1). El análisis de los datos permitió el reconocimiento de zonas bien desarrolladas y con características excepcionales debido a su alta diversidad y la presencia de especies con alguna categoría de protección.

Los corales contribuyen de manera significativa a la generación de un ambiente heterogéneo que entre mayor complejidad estructural presente, aumenta la cantidad de habitats, lo que sustenta una alta diversidad de especies del sistema arrecifal en su conjunto. Esta gran diversidad es típica de los ecosistemas arrecifales coralinos bien desarrollados y les permite soportar una trama trófica muy compleja.

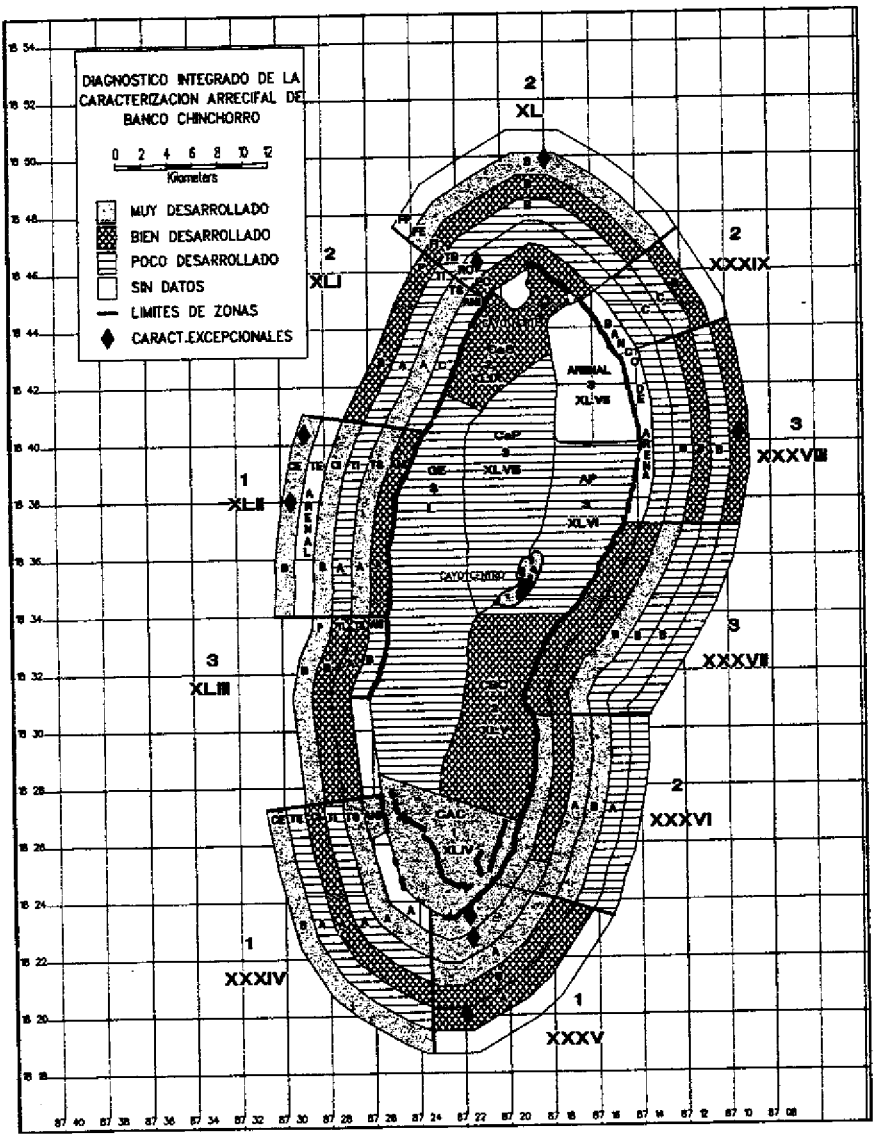


Figura 1. Caracterización arrecifal de Banco Chinchorro realizada por Amigos de Sian Ka'an, A.C. Las regiones han sido ensanchadas artificialmente para mayor claridad. La zona A representa una alta cobertura coralina con un arrecife muy bien desarrollado y una prioridad alta para conservación, la zona B representa una cobertura media con un arrecife bien desarrollado y una prioridad media, mientras que la zona C representa una cobertura baja, un arrecife poco desarrollado y una prioridad baja. Para referencia de los códigos de la zonificación, ver la Tabla 1.

Tabla. 1. Perfil transversal del sistema arrecifal de Banco Chinchorro y tabla descriptiva, elaborados por Amigos de Sian Ka'an, A.C.

Modelo de Zonación Arrecifal para Banco Chinchorro.

SOTAVENTO

Cordillera Exterior (CE): Macizos coralinos de poca altura, esponjas masivas y tubulares con distribución variegada. Corales como discos, gorgonáceos de profundidad. Sedimento muy fino. Caracol. Profundidad 80 a 110 ft.

Terraza Exterior (TE): Arenal con colonias dispersas de gorgonáceos y esponjas. Profundidad de 70 a 80 ft.

Cordillera Interior (CI): Macizos coralinos dispersos de poca altura y anchos, dominados por gorgonáceos y esponjas incrustantes, vasiformes y tubulares. Corales como discos, *Agaricia lamarcki*, *A. grahamae* y antipatarios. Sedimento fino. Caracol. Profundidad de 45 a 70 ft.

Terraza Interior (TI): Cabezos coralinos aislados ordenados como macizos anchos. Canales de arena amplios con colonias aisladas de gorgonáceos y esponjas. Sedimento muy fino. Caracol. Profundidad de 10 a 40 ft.

Transición Sotavento (TS): Macizos dispersos de *Montastrea annularis* y *M. faveolata* con esponjas, algas y gorgonáceos. Sedimento fino con algas cianofitas. Profundidad de 10 a 30 ft.

Anillo (ANI): Delimitado por matrices *de Acropora palmata* con Porites porites en la cima y gorgonáceos en la base. Parches pequeños de *Acropora cervicornis* en la parte más somera. Profundidad de 1 a 10 ft

LAGUNA ARRECIFAL

Macizos continuos o dispersos de *Montastrea annularis* y *M. faveolata.*, rodeados de bancos de arena. En la cima tapetes de *Porites porites*, gorgonáceos y algas cafés. Gran cobertura de coral, peces, corales de profundidad en ambientes crípticos (*Mycetophyllia* y *Scolomya*). Profundidad de 5 a 20 ft. O cabezos coralinos dispersos, parches de pastos marinos, algas, gorgonáceos y esponjas tubulares y rastreras. Profundidad de 5 a 12 ft.

CRESTA ARRECIFAL

Arrecife Posterior (PO): Cabezos medianos de *Montastrea annularis* y *Diploria clivosa* hacia la laguna arrecifal, *Acropora palmata* y *Acropora cervicornis* en la parte centro y *A. palmata* y *Agaricia tenuifolia* hacia la rompiente. Especies de *Porites* y *Millepora*; algas, pedacería y arena media. Profundidad de 0.5 a 7 ft.

Rompiente Arrecifal (RO): Matriz calcárea de *Acropora palmata*, hidrocorales pétreos, crecimientos aislados de *A. palmata*. Colonias pequeñas de *Porites astreoides* y *Agaricia tenuifolia*. Algas y pedacería gruesa. Profundidad de 0 a 3 ft.

Transición Barlovento (TB): Canales de arena y macizos calcáreos de *Acropora palmata* bien desarrollados, dominados por *Gorgonia flabellum, Millepora complanata, Porites astreoides* y *Agaricia tenuifolia;* o subzona poco desarrollada con laja calcárea, pedacería y algas cafés abundantes (*Sargassum* y *Turbinaria*). Profundidad de 10 a 40 ft.

ARRECIFE FRONTAL

Frontal Interior (FI): Canales de arena amplios y macizos delgados e incipientes de 1 a 2 m de altura, con gorgonáceos, algas y cabezos aislados de escleractinios. Colonias aisladas de *Acropora palmata* y *Montastrea annularis* hacia la transición barlovento y hacia la pendiente colonias de escleractinios pequeñas e incrustantes. Profundidad de 50 a 60 ft.

Frontal Exterior (FE): Canales de arena angostos con gorgonáceos y esponjas masivas. Macizos gruesos de hasta 5 m de altura, con gorgonáceos, esponjas grandes y colonias de escleractinios pequeñas e incrustantes. Profundidad de 80 a 120 ft.

Terraza: Parches de escleractinios, gorgonáceos de profundidad y esponjas masivas. Profundidad de 150 a 180 ft.

Frontal Profundo (FP): No hay sistema de canales y macizos. Algas, colonias de corales escleractinios aisladas, gorgonáceos de profundidad, antipatarios y esponjas masivas. Profundidad de 180 a 200 ft.

Cantil: Colonias de escleractinios incrustantes (como discos), antipatarios, esponjas masivas y gorgonáceos de profundidad. Profundidad mayor a 200 ft.

Entre los corales escleractíneos dominan *Montastrea annularis* (montaña), *M. cavernosa* (cerebro), *Porites astreoides* (estrella), *Agaricia tenuifolia* (lechuga) *A. agaricites* (lechuga), *Acropora palmata* (cuerno de alce), *A. cervicornis* (cuerno de venado); mientras que de los gorgonáceos las dominantes corresponden a *Eunicea mammosa, E. calyculata, Gorgonia flabellum* (abanico de mar), *G. mariae, Pseudopterogorgia hummelincki, P. americana* (pluma de mar), *Briareum asbestinum* (dedo) y *Plexaura flexuosa* (abanico). Los hidrozoarios están representados por *Millepora complanata* (coral de fuego) y *M. alcicornis* (coral de fuego).

Las características morfológicas, los procesos de sedimentación y corrientes de Banco Chinchorro han sido poco estudiados. Las diferencias hacia la parte interna al sur de la laguna arrecifal, aunado a la presencia de cordilleras internas paralelas a la cresta arrecifal, representan zonas con un mayor relieve, morfometría y diversidad.

El estudio batimétrico realizado por Gonzales et al. (En prensa) muestra un relieve a lo largo del eje mayor del Banco de norte a sur relacionado la existencia de una morfología de mayor relieve en la zona sur. Jordán y Martín (1987) indican que el cambio gradual en la morfología general y estructuras arrecifales a lo largo del eje mayor de Banco Chinchorro es la característica más interesante y parece estar relacionada al gradiente general de profundidad a lo largo de su eje mayor; el efecto este cambio gradual y extenso, establece la posibilidad de que la variabilidad de las estructuras arrecifales esté relacionada con la morfología impuesta por el substrato subyacente, así como por la exposición al efecto del oleaje en un gradiente de profundidad.

La presencia de especies incluidas en alguna categoría de protección (NOM-059), como las aves *Anas discors* y *Mycteria americana*, la existencia de 13 especies de reptiles de las cuales 10 están incluídas en algúna categoría de protección (e.g., *Crocodylus acutus* y *Boa constrictor*), el hecho de que especies de corales (e.g., *Plexaura homomalia, Acropora palmata* y *A. cervicornis*) estén incluidas en la NOM-059, nos indica la importancia que reviste el poder conservar la biodiversidad de Banco Chinchorro. Los pastos marinos están representados mayormente por *Thalassia testudinum*, el cual sirve como área de reproducción, crianza y alimentación a 206 especies de peces e invertebrados. Los manglares están representados *por Rhizophora mangle, Laguncularia racemosa, Conocarpus erectus y Avicennia germinans* todas incluidas en la NOM-059. Especies de tortugas (e.g., *Eretmochelys imbricata, Caretta caretta y Chelonia mydas*) también se encuentran protegidas por la legislación mexicana.

En la RBBCH la actividad pesquera está organizada y desarrollada sistemáticamente (Tabla 1). Se inició en los años 1940s debido al arribo de pescadores para la captura de tortugas marinas y la caza de cocodrilo. La pesca de escama (i.e., peces arrecifales) aparece en los 1960s y en 1973 la del caracol rosado (*Strombus gigas*). El caracol rosado, la langosta y la escama son las únicas pesquerías en la RBBCH y sólo 92 pescadores agrupados en tres Sociedades Cooperativas de Producción Pesquera (Andrés Quintana Roo, Pescadores del Banco

Chinchorro y Langosteros del Caribe) están autorizados para aprovecharlas (Tabla 2). La captura de las especies se efectúa en la laguna arrecifal y en el cordón de arrecifes coralinos que la delimitan, principalmente en la zona exterior del Margen Oriental o barlovento. Los pescadores libres no pueden trabajar en el Banco, pero se les ha otorgado autorización para pescar escama a un kilómetro o más de distancia en dirección a mar abierto a partir de los márgenes exteriores del mismo.

La captura total anual de caracol rosado de 1990 a 1997 fluctuó entre 27.25 ton y 54.34 ton. A partir de 1995 el Instituto Nacional de la Pesca (INP), a través del Centro Regional de Investigaciones Pesqueras de Puerto Morelos, fijó una cuota global de captura de 45 toneladas, distribuidas equitativamente entre las tres cooperativas. El INP la disminuyó a 30 toneladas en 1998, por lo que los registros de captura reflejan esta circunstancia estableciendo un volumen uniforme. La medida fue aplicada y bien recibida por las cooperativas ante la creciente dificultad para obtener volúmenes que mantuvieran rentable la pesquería y la disminución progresiva de la talla de los animales. Ante ésta situación los pescadores de las cooperativas propusieron auto imponerse una veda de dos años (1997 - 1998) para contribuir a la recuperación de la especie, hecho que no tiene antecedentes en ninguna parte del País, sin embargo, la condición era que la en ese entonces Secretaría de Medio Ambiente, Recursos Naturales y Pesca garantizara una vigilancia efectiva ya que es posible que la disminución de abundancia y tallas sea debida principalmente a la pesca ilegal, ya que los pescadores "piratas", no consideran tallas o vedas. La inspección y vigilancia no fue realizada de manera efectiva, por lo que los pescadores cooperativados retiraron su propuesta de veda por dos años. Cayo Lobos es el lugar preferido por los pescadores ilegales para establecer su base de operaciones, cuentan con lanchas de fibra de vidrio, generalmente de 25 pies y motores de hasta 115 caballos de fuerza, lo que les facilita evadir la vigilancia.

La langosta del caribe (*Panulirus argus*) sostiene otra pesquería de gran importancia en RBBCH. La producción entre 1990 y 1997 mostró fluctuaciones de 14.36 a 21.02 ton, pero la tendencia de la captura total anual se situó ligeramente por debajo de 15 toneladas. De acuerdo con un análisis preliminar de la población de langosta basado en frecuencias de talla de la temporada 1990 - 1991, no es recomendable aumentar el esfuerzo de pesca (número de pescadores, número de embarcaciones) o la mortalidad por pesca (Sosa-Cordero et al. 1996). En este sentido, conviene mantener vigente la práctica consensuada y estipulada en las Reglas Administrativas del Programa de Manejo y entre las tres Sociedades Cooperativas de Producción Pesquera con permiso o concesión de pesca de langosta para evitar el uso de compresor o buceo autónomo y el uso de redes como apoyo a las actividades pesqueras.

Tabla 2. Número de socios, aspirantes, embarcaciones y motores de las cooperativas en Banco Chinchorro.

COOPERATIVA	Socios	Aspirantes	Embarcaciones		Motores (HP)			Barco Nodriza
			Menores	Mayores	40	60	75	HP
Andrés Quintana Roo	34	8	15	1	10	4	0	250
Pescadores del Banco Chinchorro	26	13	13	1	13	0	0	150
Langosteros del Caribe	32	5	14	1	4	9	1	150
TOTAL	92	26	42	3	27	13	1	

La escama (peces arrecifales) es la tercera de las pesquerías practicadas en el sistema arrecifal coralino y la laguna. Las especies más representativas por el volumen que se captura, considerando producciones superiores a una tonelada durante los siete primeros años de la década de los noventa, son: chancay (*Haemulon album*), mero (*Epinephelus striatus*), huachinango (*Lutjanus vivanus, L. bucanella*) pargo (*Lutjanus analis, L.griseus, L. apodus*), picuda (*Sphyraena barracuda*), mojarra (*Gerres cinereus*) y coronado (*Seriola dumerilii*).

La compilación de gran parte de información sobre trabajos previos dio resultado la identificación de zonas prioritarias para conservación dentro de RBBCH. La legislación mexicana (Reglamento de la Ley General de Equilibrio Ecológico y la Protección al Ambiente) en Materia de Áreas Naturales Protegidas (ANP) determina que dentro de las Reservas de la Biosfera pueden existir zonas núcleo y de amortiguamiento. Esta zonificación deberá permitir la identificación y delimitar las porciones del territorio que la conforman, acorde con sus elementos biológicos, físicos y socioeconómicos, los cuales constituyen un esquema integral y dinámico.

El proceso de zonificación tomó en cuenta a todos los sectores involucrados en el Consejo Técnico Asesor de la Reserva (CTA) especialmente al sector pesquero, realizando salidas al campo con los pescadores y marcando con boyas las zonas propuestas. Este proceso llevó cinco reuniones de CTA en pleno y ocho reuniones exclusivamente con el sector pesquero, de este trabajo de concertación y negociación se obtuvieron tres zonas núcleo (Cayo Norte, Cayo Centro y Cayo Lobos); la zona de amortiguamiento tendrán como función principal orientar a que las actividades de aprovechamiento, que ahí se lleven a cabo, se conduzcan hacia el desarrollo sustentable, creando al mismo tiempo las condiciones necesarias para lograr la conservación de los ecosistemas de ésta a largo plazo y está constituida por: zona de pesca cooperativada, zona de pesca cooperativada deportiva de liberación, zona de pesca cooperativada, comercial y deportiva de liberación, zona de buceo y zonas de pecios (Programa de Manejo RBBCH 2000).

Dentro de la zonificación se establecen como áreas geográficas específicas para la realización de actividades, las siguientes:

i) Zonas núcleo (Cayos Norte, Centro y Lobos). Se permite desarrollar investigación científica, educación ambiental, restauración ecológica, protección y conservación ecológica y monitoreo ecológico.

ii) Zona de Pesca Cooperativada. Se permite recorridos y/o visitas en embarcaciones motorizadas, recorridos y/o visitas en embarcaciones no motorizadas, videograbación, fotografía y sonograbación comerciales, investigación científica, educación ambiental y pesca cooperativada comercial.

iii) Zona de Pesca Cooperativada, Deportiva de liberación. Se permite recorridos y/o visitas en embarcaciones motorizadas, recorridos y/o visitas en embarcaciones no motorizadas, videograbación, fotografía y sonograbación comerciales, investigación científica, educación ambiental, pesca deportivo-recreativa de liberación, restauración ecológica,

protección y conservación ecológica, monitoreo ecológico.

iv) Zona de Pesca Cooperativada, Comercial y Deportiva de liberación. Se permite recorridos y/o visitas en embarcaciones motorizadas, recorridos y/o visitas en embarcaciones no motorizadas, videograbación, fotografía y sonograbación comerciales, investigación científica, educación ambiental, pesca cooperativada comercial, pesca comercial, pesca deportivo-recreativa de liberación, restauración ecológica, protección y conservación ecológica, monitoreo ecológico y fondeo de espera sin otra actividad asociada.

v) Zona de Buceo. Se permite buceo libre, buceo autónomo diurno, buceo autónomo nocturno, natación recreativa, recorridos y/o visitas en embarcaciones motorizadas, recorridos y/o visitas en embarcaciones no motorizadas, videograbación, fotografía y sonograbación comerciales, investigación científica, educación ambiental, restauración ecológica, protección y conservación ecológica, monitoreo ecológico, fondeo de espera sin otra actividad asociada.

vi) Zonas de Pecios (Barcos Hundidos). Se permite buceo libre, natación recreativa, recorridos y/o visitas en embarcaciones motorizadas, recorridos y/o visitas en embarcaciones no motorizadas, videograbación, fotografía y sonograbación comerciales, investigación científica, educación ambiental, restauración ecológica, protección y conservación ecológica, monitoreo ecológico.

Cuando exista consenso entre el sector pesquero organizado y la autoridad, podrán establecerse Zonas de Repoblación Pesquera temporales, a fin de promover la recuperación del ecosistema arrecifal o para la recuperación de una especie en particular.

Las ANPs son actualmente un instrumento de política ecológica que, complementadas con su programa de Manejo, tienen como principal objetivo garantizar la compatibilidad entre el aprovechamiento de los recursos naturales y su conservación. El programa de Manejo de RBBCH es la culminación de una serie de actividades, talleres, reuniones de consulta social y de Consejo Técnico Asesor, en las que después de un trabajo de concertación se logró el consenso de los diferentes sectores sociales, gubernamentales y académicos para su aceptación. Asimismo se obtuvo el compromiso participativo de éstos para asegurar la conservación y el uso sustentable de los recursos naturales del área.

Como instrumento normativo de todas las actividades económicas, sociales, educativas y de investigación que se realizan en la reserva, a través de sus componentes y subcomponentes, este programa de manejo proyecta un manejo y administración que redunden en beneficio de todos los sectores participantes e interesados en la conservación de Banco Chinchorro, pero principalmente en la preservación de la riqueza natural de la zona para las futuras generaciones.

La problemática de RBBCH se compone de múltiples elementos que interaccionan y constituyen un complejo que requiere acciones conjuntas orientadas hacia aspectos cuya intensidad, extensión y magnitud los señalen como puntos clave

que faciliten la satisfacción de las necesidades y requerimientos para el manejo de la Reserva. Los elementos identificados con dicho enfoque abarcan tópicos variados a escala regional, nacional e internacional dentro de los siguientes aspectos: biológico, pesca comercial, turismo, seguridad en la navegación, los asentamientos humanos y apoyos al funcionamiento de la Reserva.

Biológicos

Los inventarios faunísticos y florísticos con los que se cuenta son parciales. Se desconoce la composición del zooplancton, fitoplancton, microzoobentos, microfitobentos entre otros, así como de grupos taxonómicos de los cuales no se tienen registros; tal es el caso de los equinodermos, medusas, anémonas, arácnidos, insectos y mamíferos. El blanqueamiento y otras enfermedades de los corales pétreos es un fenómeno que preocupa tanto a pescadores como a científicos y manejadores de los recursos. Desafortunadamente, aún no se cuenta con información sistemática para evaluar o determinar la magnitud del problema en RBBCH. Solamente se tienen comentarios de los pescadores que refieren la presencia e incremento del fenómeno en los años recientes. El personal de RBBCH ha constatado la existencia de enfermedades tales como: banda negra, banda amarilla y banda blanca causantes de mortandades masivas en países de la región, como Belice.

Pesca

La pesca ilegal es un problema persistente que involucra principalmente a pescadores nacionales. Se desconoce la magnitud del problema, pero se sabe que ocurre todo el año, especialmente en época de veda de langosta y caracol. Tal situación ocasiona irritación entre los pescadores autorizados, quienes están conscientes del impacto sobre el recurso y a su fuente de ingresos. La veda de caracol que los pescadores autorizados implantaron por dos años fue apoyada por ellos mismo, ya que se dieron cuenta de la disminución del recurso. Tal actitud es un buen indicador de la disponibilidad que tienen los pescadores para realizar acciones que contribuyan al buen manejo del recurso, por lo que ha sido tomada seriamente por el personal de RBBCH a fin de incorporar los intereses de ese sector productivo en las estrategias de manejo, tanto en el caso de ese recurso como de la langosta del caribe y de las especies de escama. Otro aspecto de los problemas pesqueros, es la incursión de pescadores libres en el sistema arrecifal. Estos últimos están autorizados a efectuar sus capturas por lo menos a un kilómetro de distancia del arrecife hacia mar abierto.

Turismo

Las actividades recreativas aún no representan una amenaza para el sistema arrecifal ya que se realizan todavía en forma esporádica. Esto provee una excelente oportunidad para el diseño y aplicación de medidas que garanticen que el desarrollo turístico se realice de manera ordenada, controlada y sustentable. Las actividades deberán realizarse siempre en coordinación con los sectores interesados y bajo la supervisión del personal de la Reserva; de forma tal que, el buceo libre o autónomo, los paseos y la observación del paisaje, constituyan una fuente de beneficios económicos, y se evite el deterioro de la biodiversidad submarina y terrestre.

Navegación y Señalamiento

El conocimiento disponible sobre la magnitud, distribución y comportamiento de las mareas y corrientes dentro de la laguna y en la zona marina aledaña a la RBBCH es muy limitado y no sistematizado, de tal forma que no existen cartas detalladas para la navegación y el monitoreo del sistema arrecifal. También se carece de señalamientos relativos a los canales de circulación en el interior de la laguna.

Asentamientos humanos (Pescadores)

La construcción de los palafitos, cabañas y palapas en Cayo Centro se ha realizado de manera independiente y según los intereses de cada uno de los pescadores. Esto ha ocasionado una ocupación caótica y desordenada del espacio y en algunos casos en el deterioro de la vegetación. Además, tales construcciones no cuentan con mecanismos de disposición ecológica de aguas negras por lo que representan una fuente de contaminación. La acumulación de desechos y desperdicios, provenientes de la pesca y de las actividades humanas cotidianas realizadas en la RBBCH, son problemas que deben eliminarse para evitar su diseminación hacia los otros cayos de la Reserva. Además, las corrientes marinas provenientes del sur acarrean desechos y desperdicios, tanto de origen continental como de embarcaciones de carga y de transporte de pasajeros, que llegan a los cayos o se depositan entre los parches coralinos.

Operativa

El tamaño, características biológicas, ubicación geográfica y el buen estado de conservación hacen que RBBCH necesite recursos humanos y financieros suficientes y oportunos para manejarla. La infraestructura y la plantilla de personal actual son insuficientes para satisfacer plenamente las necesidades de conservación, monitoreo, difusión, señalamiento, educación ambiental y desarrollo comunitario y sustentable del sistema, lo que señala la importancia de la incorporación de personal técnico y de apoyo, así como la diversificación de las fuentes de financiamiento. En el programa de manejo se incluye una estrategia global de financiamiento a corto, mediano y largo plazo, para fortalecer y enriquecer los programas, proyectos y acciones que permita avanzar sólida y continuamente hacia la consolidación de los objetivos de conservación, de manera simultánea a la obtención de beneficios que

contribuyan a elevar el nivel de vida de los actores económicos y sociales involucrados con ese ecosistema.

RBBCH representa un ecosistema de gran importancia para la sociedad en su conjunto, que, bajo normas y enfoques de gran visión y a diversos plazos, producirá beneficios directos que repercutirán incrementando su calidad de vida. Para impulsar la trayectoria que permita convertir en realidad el aprovechamiento sustentable en la RBBCH es necesario solucionar problemáticas y posibilidades de uso actuales y potenciales. La colaboración interinstitucional, así como la disposición de los pescadores, debe ser aprovechada para fomentar la vigilancia y lograr la eliminación de la pesca furtiva, que reduciría la presión sobre los recursos y contribuiría a evitar la intensificación de la problemática entre los pescadores.

Es necesario que los esquemas de funcionamiento de la RBBCH promuevan la coexistencia la pesca y turismo con los requerimientos técnico-operativos propios del personal encargado de su manejo. De manera simultánea, es imprescindible actualizar y enriquecer el conocimiento biológico y oceanográfico que fortalezca la difusión de las riquezas naturales, las actividades de educación ambiental y el monitoreo del estado de salud del arrecife coralino. Este último a su vez fortalecerá la evaluación y la toma de decisiones para el manejo integral de la Reserva. Considerando la problemática anteriormente mencionada resulta evidente la necesidad del establecimiento de la Base Operativa de RBBCH la cual tendrá como función principal ser punto de enlace entre todos los sectores que hacen uso de la misma.

En la Figura 2 se resume la problemática de la Reserva y en la Figura 3 las acciones que deben ser tomadas para lograr la conservación y uso sustentable de los recursos naturales de la misma. La infraestructura con que cuenta actualmente la RBBCH se ha obtenido por diversas fuentes. Donaciones: lancha de 25 pies, motor de 75 HP, donada por la Federación de Sociedades Cooperativas de Producción Pesquera del Estado de Quintana Roo. El Gobierno del Estado de Quintana Roo donó las instalaciones (palafito), el avión ultraligero y algunos equipos en Cayo Centro. Como parte de acuerdos interinstitucionales el Barco de Investigaciones Pesqueras "Bizcocho" ha pasado a formar parte de la Reserva. Por su parte el gobierno federal dentro de su presupuesto ha incluido la compra de camionetas y dos embarcaciones equipadas con dos motores de 75 HP cada una. Se cuenta además con oficinas en Cancún y Chetumal en las que se realizan todo los trabajos de coordinación las demás instituciones involucradas con la RBBCH. Anualmente, la RBBCH elabora su Programa Operativo Anual (POA) con todas las partidas que desea ejecutar el siguiente año. Este POA deberá estar de acuerdo a las actividades que han sido plasmadas en el los componentes y subcomponentes del programa de manejo.

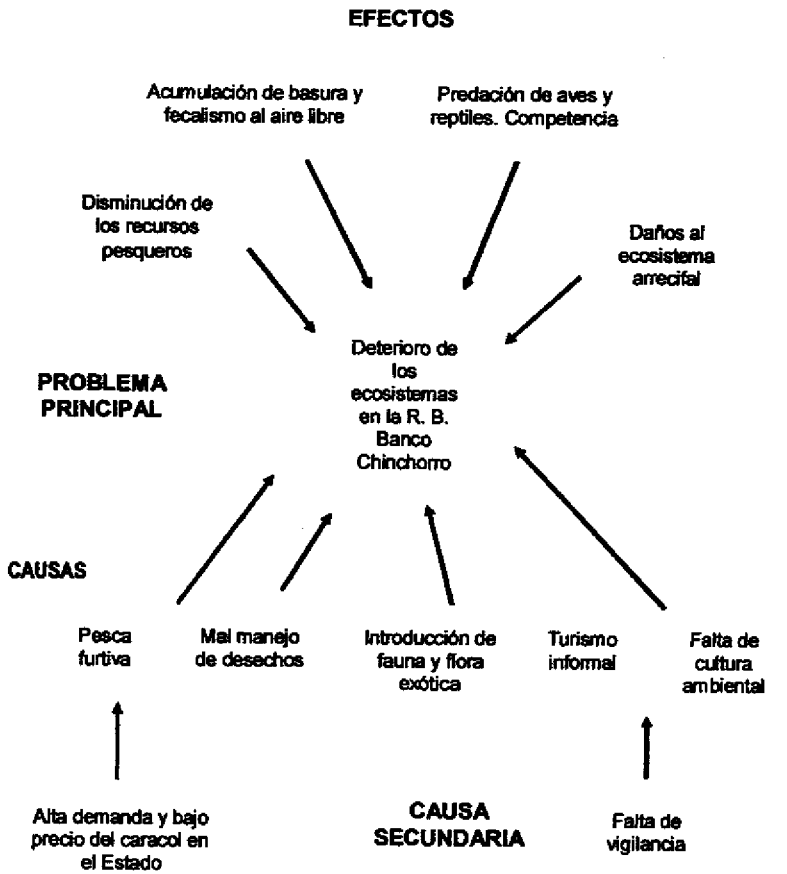


Figura 2. Identificación de la problemática de la Reserva



Figura 3. Acciones para la obtención de resultados

Gran parte del presupuesto que se requiere en Banco Chinchorro está enfocado a las actividades operativas, tales como: combustibles (gasolina y diesel), mantenimiento y refacciones de las embarcaciones y equipos y despensas para personal en el campo; siendo estos tres el 83 % del total del presupuesto operativo anual de la Reserva. La logística de las maniboras en RBBCH es muy costosa por su ubicación; 350 km de Cancún, a 122 de Chetumal además de estar 38.0 km del poblado de Mahahual. Esto incrementa de manera sustancial el gasto de combustibles y mantenimiento de camionetas.

En cuanto al personal administrativo de RBBCH, se tiene un director, un subdirector, un jefe de proyectos, un coordinador operativo y un auxiliar administrativo. Esto implica un monto anual por pago de salarios de $662,400.00 pesos ($71,225.00 USD). En el presente año RBBCH contó con un POA de $909,450.00 pesos ($95,732.00 USD, las partidas con mayor presupuesto son: mantenimiento y conservación de maquinaria, combustibles y lubricantes, compra de vehículos, despensas y refacciones. Los montos anteriores suman aproximadamente $166,000.00 USD para el manejo y conservación de RBBCH. Relacionando el presupuesto, infraestructura y personal con que cuenta RBBCH son insuficientes. Este problema ha sido subsanado en parte con fondos provenientes de otras instancias, como Altos Hornos de México, empresa que aportó el pago del capitán del Barco y un capitán de embarcación menor durante 10 meses. El pago de estos salarios se han logrado mantener en parte gracias a los fondos de WWF en el proyecto de inspección y vigilancia y por el proyecto NAWCCA de conservación de los humedales de la Reserva.

En la Tabla 3 se muestra parte de los recursos no fiscales que han sido aportados por instituciones nacionales e internacionales para coadyuvar en el proceso de manejo y conservación de la Reserva. Uno de los problemas que hemos enfrentado es el hecho de que la mayoría de las instituciones donantes no incluyen dentro de sus partidas el pago de salarios siendo la falta de personal uno de los mayores problemas para el manejo y conservación en áreas naturales protegidas.

La estrategia planteada para la conservación de los ecosistemas en RBBCH se incluyen en la Tabla 4. Se cuenta con el apoyo de instituciones federales, estatales, de educación superior, ONGs nacionales e internacionales. Este apoyo ha sido monetario en algunos casos pero el que consideramos de mayor valor es el humano en casos en dónde se ha requerido de personal especializado para realizar ciertas actividades de caracterización del sistema arrecifal, evaluación de pesquerías y monitoreo en arrecifes, cocodrilos, aves, entre otros.

La metodología que utilizada para la elaboración de la estrategia, resultados, indicadores y supuestos fue elaborada en el taller para Áreas Naturales Protegidas que serán incluidas dentro del programa de financiamiento del GEF en México dentro de los siguientes cinco años. Todo lo incluido forma parte del las acciones que han sido planteadas en el programa de manejo de la RBBCH, garantizando el avance en acciones que han sido consensuadas con todos los actores involucrados en el manejo y uso sustentable de los recursos naturales de la Reserva.

Tabla 3. Aportación de fondos para 2000-2001 por organizaciones nacionales e internacionales.

Proyecto	Monto (USD)	Fuente	Duración
Prog. Insp. y Vigilancia	$12,366	Coop. Pesqueras	1/6/00 – 1/2/01
Prog. Insp. y Vigilancia	$41,290	WWF	1/6/00 – 1/3/01
Boyas de Amarre y Letrinas	$16,185	Seacology	1/10/01 - 30/11/01
Emergente Personal	$22,473	SUMMIT	1/11/01 – 31/3/02
Prog. Insp. y Vigilancia	$6,639	WWF - Packard	1/11/01 – 31/3/02
Fondo Patrimonial	$204,301	SUMMIT	Primer depósito anual de ocho
Total	$303,254		

La RBBCH está enfocada al cumplimiento de los componentes inscritos en su Programa de Manejo, realizando actividades como: monitoreo en el sistema arrecifal, monitoreo de las poblaciones de cocodrilos, estudio de poblaciones de fauna introducida (ratas y gatos); estudio de zooplancton, estudio de agregaciones, fisico-química y corrientes, ECONAR, ordenamiento pesquero, evaluación de poblaciones de caracol rosado, energías renovables y capacidad de carga, programa de letrinización (saneamiento ambiental), limpieza de playas y obra de teatro infantil. Para la RBBCH ha sido de vital importancia la participación interinstitucional, ya que de esta forma se ha logrado la concertación y participación de todos los sectores involucrados en la conservación, uso y manejo de los recursos naturales presentes en Banco Chinchorro.

Tabla 4. Estrategias, resultados, indicadores y supuestos para lograr conservar los ecosistemas en la Reserva de la Biosfera Banco Chinchorro

ESTRATEGIA	INDICADORES	SUPUESTOS
Objetivo principal Conservar los ecosistemas de la R.B. Banco Chinchorro	Porcentaje de cobertura viva de corales se mantiene LB ? % - Meta ? (mismo) Superficie de corales ramificados se mantiene LB ? % - Meta ? (mismo) Porcentaje de cobertura de corales enfermos no aumenta. LB ? % - Meta ? Proporción relativa de algas no aumenta LB 40 % algas verdes – Meta se mantiene Frecuencia de avistamientos de aves migratorias se mantiene LB ? – Meta ?.	No recibimos directo un huracán de magnitud mayor a 3. Ningún barco, en especial petrolero, encalla en el Banco
Resultados R1. Se controla la pesca furtiva	Número de embarcaciones furtivas avistadas/horas de vigilancia/semana LB ?	La PROFEPA se activa
R2. Se manejan los desechos sólidos	Número de pescadores que utilizan letrinas Número de sitios donde se reduce la basura LB 0 – Meta	La Secretaría Estatal de Salud obliga al uso de letrinas.
R3. Se erradican la fauna y flora exóticas	Número de ratas y gatos registrados en muestreos de control. LB ? – Meta 0/año. Porcentaje de la superficie regenerada de vegetación rastrera de playa. LB 0 % – Meta 100 %/año.	Disminuye la incidencia de roedores en las grandes bodegas de abasto.
R4. Se aplica la normatividad turística	Número de toques en los corales en sitios de monitoreo de buceo. LB ? /mes – Meta 95 % visitantes/mes no toca. Porcentaje visitantes que conocen las reglas administrativas LB 50% - Meta 80 % visitantes/mes.	No aumenta la presión turística mas allá de la capacidad de carga establecida.
R5. Se incrementa el conocimiento de la reserva de los usuarios y de los pobladores de comunidades cercanas	Resultados de las evaluaciones de los eventos de difusión.	Que los niveles educativos del país se eleven.

AGRADECIMIENTOS

A todo el personal de la RBBCH por su trabajo y apoyo para la elaboración del presente documento. Agradecemos especialmente a los Drs. Robert Glazer y Kenyon Lindeman por su apoyo financiero para asistir a la 54va Reunión del Gulf and Caribbean Fisheries Institute. También queremos hacer patente nuestro agradecimiento a todas las personas e instituciones que de alguna forma han colaborado en las labores de conservación de Banco Chinchorro.

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A Caribbean-Wide Survey of No-take Marine Reserves: Spatial Coverage and Attributes of Effectiveness

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ABSTRACT

Fully-protected marine reserves can function at several spatial scales, from a single area encompassing few habitats, to local networks of many habitats, to large-scale networks connected by larval dispersal. However, the amount, spatial distribution, and associated administrative attributes of Caribbean marine reserves are collectively unknown. We compiled information on reserves from 21 countries in order to 1) assemble a spatial framework to aid development of networks of reserves at the most effective spatial scales, and 2) aid policy makers in establishing reserves that are science-based and possess optimal management attributes. Since 1961, there have been over 50 reserves established in the Caribbean (an additional 30 in Bermuda) with the rate of implementation increasing since the mid 1980's. Most reserves are small (< 1,200 ha) and few contain the range of habitats necessary for protecting species through their ontogeny. Habitats are often not fully characterized, and the role of reserves in protecting and networking different habitats cannot be ascertained. Reserves are distributed throughout the region, with the highest density in Mesoamerica; but significant geographic gaps exist. It is unlikely that reserve-enhanced larval dispersal significantly networks populations on a regional basis, although this may occur subregionally (e.g. Mesoamerica). Less than 20% of the reserves were scored as fully compliant, but half offer potentially significant levels of protection.

KEY WORDS: Marine reserves, spatial scales, networks

Estudio de Reservas Marinas en el Gran Caribe: Cobertura Espacial y Atributos de Efectividad

Las reservas marinas completamente protegidas pueden funcionar a varias escalas espaciales, desde una sola área conteniendo pocos hábitats, una red local con muchos hábitats, hasta redes a gran escala conectadas por dispersión de larvas. Sin embargo, en el Caribe se desconoce la cantidad, distribución espacial y atributos administrativos de las reservas marinas. Recopilamos información de 21 países con el propósito de 1) estructurar un marco de referencia espacial para ayudar al desarrollo de reservas basado en una escala espacial más efectiva y 2) ayudar a los administradores para establecer científicamente reservas que posean atributos óptimos de manejo. Desde 1961, se han establecido cerca de 50 reservas en el Caribe

(30 adicionales en Bermuda), con una tasa de implementación que ha incrementado desde 1980s. La mayoría de las reservas son pequeñas (< 1,200 ha) y pocas contienen un rango de hábitats necesario para proteger especies a través de su ciclo ontogenético. Los hábitats no están completamente caracterizados y no se puede comprobar el papel de las reservas en la protección ni el vínculo entre los diferentes hábitats. Las reservas están distribuidas a través de la región, con una densidad más alta en Mesoamérica; no obstante, aún existen vacíos geográficos. Es poco probable que la dispersión larval mejorada por las reservas vincule poblaciones a nivel regional, aunque esto puede ocurrir a nivel subregional (e.g., Mesoamérica). Menos del 20 % de las reservas se catalogaron como completamente adecuadas, pero la mitad ofrece niveles potenciales significativos de protección.

PALABRAS CLAVES: Reservas marinas, escalas espaciales, redes

Habitat Connectivity in Reef Fish Communities and Marine Reserve Design in Old Providence-Santa Catalina, Colombia

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ABSTRACT

On the insular platform of Old Providence/Santa Catalina, Colombia, we compared nearshore lagoonal patch reefs to those on the northern bank distant from the islands to determine the importance of habitat connectivity to fish community structure. Nearshore patch reefs had greater proximity to mangrove, seagrass and rocky shore habitats, and they had significantly more individuals. Nearshore reefs also tended to have a greater total biomass, more species, a higher proportion of predators of mobile invertebrates and small fishes, and a lower proportion of herbivores. Biomass of snappers and grunts at nearshore sites was four times

greater compared to bank sites, and was correlated with the amount of seagrass and sand/rubble habitat within 500 m of each patch reef. We also compared length-frequency distributions and abundances of grunts and snappers among all sites (deep and shallow forereefs, patch reefs and deep and shallow leeside slopes). The results were consistent with ontogenetic migrations from shallow sites, primarily seagrass and mangrove habitats, to deeper sites and to those further out on the bank. The evidence suggests that species differed in both distance and direction of dispersal, which may be affected by the abundance and distribution of preferred habitats. Marine reserves near the islands should target nearshore nursery areas and patch reefs harboring species of limited dispersal capability. Reserves on the northern bank would protect spawners of those species showing the greatest dispersal capability.

KEY WORDS: Marine reserve design, habitat connectivity, Colombia

Conectividad de Hábitat en las Comunidades de Peces Arrecifales y Diseño de Reservas Marinas en Old Providence-Santa Catalina, Colombia

Comparamos los parches arrecifales lagunares cercanos a la costa con aquellos distantes sobre el banco norteño en la plataforma insular de Providencia/Santa Catalina, Colombia, con el propósito de examinar la importancia de la conectividad de hábitat para la estructura comunitaria de peces. Los parches arrecifales cercanos a la costa se localizaron cerca de hábitats de mangle, pasto marino y playas rocosas, teniendo significativamente más individuos. Estos parches también tuvieron una biomasa total mayor, más especies, una alta proporción de predadores de invertebrados móviles y de pequeños peces, así como una baja proporción de herbívoros. La biomasa de pargos y roncos en sitios cercanos a la costa fue cuatro veces mayor comparada a la de los sitios del banco y fue correlacionada con la cantidad de pastos marinos y habitat de arena/cascajo dentro de 500 m de cada parche arrecifal. Comparamos también la distribución de frecuencias de longitud y abundancias de roncos y pargos de todos los sitios (arrecifes frontales profundos y someros, parches arrecifales y pendientes profundas y someras de sotavento). Los resultados fueron consistentes con las migraciones ontogenéticas desde sitios someros, principalmente hábitats de pastos marinos y mangles, hacia sitios más profundos y aquellos alejados del banco. La evidencia sugiere que las especies difirieron tanto en distancia y dirección de dispersión, las cuales quizá sean afectadas por la abundancia y distribución de hábitats preferidos. Las reservas marinas cerca de las islas deben incluir áreas costeras de vivero y parches arrecifales que contengan especies de capacidad dispersita limitada. Las reservas en el banco norteño deberían proteger a desovadotes de aquellas especies que tengan capacidad dispersiva mayor.

PALABRAS CLAVES: Reservas marinas, conectividad de hábitat, Colombia

Shifting Baselines, Marine Reserves, and Leopold's Biotic Ethic

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ABSTRACT

Different human expectations and environmental ethics are key factors preventing the creation of marine reserve networks. People are skeptical about the benefits of no-take marine reserves because they have adjusted to scarcity and have low expectations about the productive capability of marine ecosystems. Pauly (1995) described this as a shifting baseline in which each generation sets its expectations based on its direct experiences and discounts experiences of previous generations. I show evidence of a declining Caribbean baseline based on Nassau grouper landings from Cuba and the U.S, and review common and often conflicting types of conservation ethics existing in North America. No-take marine reserves can help reestablish human expectations about resource productivity by restoring past conditions in places. Leopold's biotic ethic provides a framework for achieving sustainable resource use based on laws of ecology and human self-interest. Because changing expectations usually requires direct local experience, education, and changes in conservation ethics, implementing successful marine reserve networks will probably be a slow, incremental process. Establishing no-take reserves can help restore human expectations and provide a common basis for conservation by providing a window to the past and a vision for the future.

KEY WORDS: Marine reserves, shifting baselines, Leopold's biotic ethic

Cambios en la Percepción, Reservas Marinas, y la Ética Biotica de Leopold

Las diferencias en las expectativas humanas y las éticas ambientales son factores dominantes que previenen la creación de redes de reservas marinas. La poblaciones son escépticas acerca de las ventajas y beneficios de las reservas marinas totalmente protegidas debido a que ellos se han ajustado a la escasez y tienen expectativas bajas acerca de la capacidad productiva de los ecosistemas marinos. Pauly (1995) describió esto como un cambio en la base, en la cual cada generación fija sus expectativas de acuerdo a sus experiencias directas y descuenta las experiencias de las generaciones anteriores. Aquí yo demuestro la evidencia de un cambio en la data en que se basa el Caribe basada en las descargas del mero de Nassau en Cuba y en los E.E.U.U., al mismo tiempo reviso los conflictos mas comunes y los que ocurren

más a menudo en el campo ético de la conservación existentes en Norteamérica. Reservas marinas que no permiten ningún tipo de captura pueden ayudar a restablecer las expectativas humanas sobre productividad de los recursos debido a que ayudan a restaurar las condiciones previas existentes en estos lugares. Las éticas bioticas de Leopold proporcionan un marco para alcanzar el uso sostenible del recurso basado en leyes deecología y en el interés humano. Debido a que para poder cambiar las expectativas generalmente se requiere tener experiencia local directa, conocer acerca de la educación, y hacer cambios en la ética de la conservación, el establecimiento exitoso de redes de reservas marinas será probablemente un proceso lento y incrementos. El establecimiento de reservas marinas que no permiten ningún tipo de captura puede ayudar a restaurar expectativas humanas y a proporcionar una base común para la conservación proporcionando una ventana al pasado y una visión al futuro.

PALABRAS CLAVES: Reservas marinas, ética biotica de Leopold

The Interaction of Retention, Recruitment, and Density-Dependent Mortality in the Spatial Placement of Marine Reserves

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ABSTRACT

Population density can affect rates of mortality and individual growth. We measured these for the non-exploited bluehead wrasse, *Thalassoma bifasciatum* at three sites around St. Croix, U.S. Virgin Islands. Previous work demonstrated that differences in degree of larval retention in these sites results in very large differences in recruitment intensity. Post-settlement mortality differed among sites and was positively related to recruitment density. Post-settlement growth differences were small. Because of strong mortality effects early in life, adult densities and size/age distributions differed among sites and did not reflect differences in recruitment rate. The site with the highest retention and recruitment (Butler Bay) had many small fish, while the two other sites with lower recruitment rates (Jacks Bay and Green Cay) had proportionally more large fish. These differences resulted in large differences in egg production. Per capita production was highest at the lowest density site (Green Cay). Total egg production at Green Cay was 75% that at Butler Bay, despite only having half the population size, and the highest overall production was at Jack's Bay, with low retention and moderate recruitment. In terms of marine reserve location,

sites predicted to have high retention and recruitment may not always be the sites of highest egg production due to density-dependent processes, and it is important to consider the relative values of self-recruitment and larval export in reserve design.

KEY WORDS: Marine reserves, density-dependent mortality, retention and recruitment

La Interacción de la Retención, Reclutamiento, y mortalidad Densidad-Dependiente en la Colocación Espacial de Reservas Marinas

La densidad demográfica puede afectar la tasa individual de mortalidad y crecimiento. Nosotros medimos éstas tazas para la especie bluehead wrasse, *Thalassoma bifasciatum*, la cual no se explota en tres sitios alrededor de St. Croix, Islas Virgenes de los E.E.U.U. Trabajos previos demuestran que las diferencias de grado de retención larval en estos sitios dan lugar a diferencias muy grandes en intensidad del reclutamiento. La mortalidad después del establecimiento de la larva diferenció entre sitios y fue relacionada positivamente con la densidad del reclutamiento. Las diferencias del crecimiento después del establecimiento de la larva fueron pequeñas. Debido a los fuertes efectos de la mortalidad al principio de la vida de las larvas, las densidades del adulto y las distribuciones de tamaño/edad diferenciaron entre sitios y no reflejaron diferencias en la taza del reclutamiento. El sitio con la retención y reclutamiento más alto (Butler Bay) tenía muchos pesces pequeños, mientras que los otros dos sitios con tazas más bajas del reclutamiento (Jacks Bay and Green Cay) tenían una mayor proporción de peces de mayor tamaño. Estas diferencias dieron lugar a mayores diferencias en la producción de huevos. La producción per capita fue más alta en el sitio con la menor densidad (Green Cay). La producción total de huevos en Green Cay era el 75% que en Butler Bay, a pesar de solamente tener mitad del tamaño de la población, y la producción total más alta fue observada en Jacks Bay, con una baja retención y un reclutamiento moderado. En términos de la localización de la reserva marina, los sitios predecidos para tener la más alta retención y el mayor reclutamiento no pueden siempre ser los sitios de la mayor producción de huevos debido a los procesos densidad-dependientes,. Tambien es importante considerar los valores relativos del reclutamiento y exportación larval en eldiseño de la reserva.

PALABRAS CLAVES: Reservas marinas, mortalidad densidad-dependiente, retención y reclutamiento

Cross-Shelf Habitat Utilization Patterns of Reef Fishes in Southwestern Puerto Rico

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ABSTRACT

In June 2000, the National Ocean Service and University of Puerto Rico initiated a long-term reef-fish-monitoring program in La Parguera, Puerto Rico. Objectives of this ongoing work are to: 1) develop spatially-explicit estimates of reef fish habitat utilization patterns to aid in defining essential habitats, and 2) provide a quantitative and ecologically sound foundation to delineate marine reserve boundaries. Central to this effort are recently completed digital and georeferenced benthic habitat maps for the near-shore waters of Puerto Rico. The GIS-based map served as a framework for development of a spatially stratified reef-fish-monitoring program across the shelf. Simultaneous collections of fish size and abundance data, and micro-scale habitat distribution and quality data were taken along a 25 x 4m transect for each monitoring station. Sampling included coral reef, mangrove, and seagrass habitats within three cross-shelf zones unique to the insular shelf of La Parguera (inner lagoon, outer lagoon, and bank-shelf). A total of 106 stations were surveyed during the first year of sampling. Over 50,000 fishes, representing 123 species and 36 families were counted. Analyses showed clear patterns of habitat utilization across the seascape, and ontogenetic shifts in habitat selection within some species. Results also indicated that habitat type was more important than cross-shelf location in determining spatial patterns among reef fishes in the study area. Mesoscale spatially-explicit logistic models were developed to estimate distribution and expected density of some species among habitats.

KEY WORDS: Cross-shelf habitat, habitat utilization, Puerto Rico

Patrones de Utilización de Hábitat de Peces Arrecifales a través de la Plataforma en el Suroeste de Puerto Rico

En junio 2000, el Servicio Nacional del Océano (NOS) de NOAA y la Universidad de Puerto Rico iniciaron un programa de monitoreo de peces arrecifales a largo plazo en La Parguera, Puerto Rico. Los objetivos de este trabajo en marcha son 1) estimar patrones de utilización de hábitat, espacialmente explícitos, de peces arrecifales con el propósito de asistir en la identificación de hábitats esenciales y 2) proveer una base cuantitativa y ecológica para delinear fronteras de reservas marinas. De gran importancia en este esfuerzo están los mapas de hábitats bénticos digitales y georeferenciados, recientemente completados para las aguas costeras de Puerto Rico. El mapa basado en GIS sirvió como marco de trabajo para el desarrollo de un programa de monitoreo de peces arrecifales espacialmente estratificado a través de la plataforma. Se tomaron simultáneamente datos de tallas y abundancias de peces, su distribución a micro escala y datos cualitativos a lo largo de transectos de 25 x 4 m para cada estación de monitoreo. El muestreo incluyó arrecifes coralinos, mangles y pastos marinos dentro de zonas a través de la plataforma peculiares a la región insular de la Parguera (laguna interna, laguna externa, y banco-plataforma). Se investigó un total de 106 estaciones durante el primer año de muestreo. Se contaron cerca de 50,000 peces, representando 123 especies y 36 familias. Los análisis mostraron patrones claros de utilización de hábitat a través del paisaje marino, así como cambios ontogenéticos en selección del hábitat dentro de algunas especies. Los resultados también indicaron que en la determinación de los patrones espaciales de los peces arrecifales del área de estudio, el tipo de hábitat fue más importante que la ubicación a través de la plataforma. Se desarrollaron modelos logísticos, espacialmente explícitos, a nivel de mesoescala para estimar la distribución y densidad esperada de algunas especies entre hábitats.

PALABRAS CLAVES: Hábitat a través de Plataforma, utilización de hábitat, Puerto Rico

Spawning Aggregation Sites of Snapper and Grouper Species(Lutjanidae and Serranidae) on the Insular Shelf of Cuba

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ABSTRACT

Twenty-one spawning aggregation sites on the Cuban shelf were identified for eight species of snappers (*Lutjanus*) and groupers (*Epinephelus* and *Mycteroperca*) using information from experienced fishers and field studies. Three sites are on the southeastern shelf, eight on the southwest shelf bordering the Golfo de Batabanó, two in the northwest, and eight in the north-central region along the margins of the Archipiélago de Sabana-Camagüey. These numbers may reflect sampling effort as much as absolute aggregation numbers, with most effort concentrated in the southwest and north-central regions. Additional studies, particularly field assessments, are needed to determine the current status and consistency of occurrence of many of these aggregations. Most sites occur near the shelf drop-off at depths of 20-50 m, over reef substrates. Some sites involve sequential use by multiple species over several seasons of the year. Fishing activities have impacted many of these aggregations, both during spawning events and during prior pre-spawning migrations. This information is being applied in the design of marine reserve networks for several Cuban archipelagos. Intraspecific variations in aggregation formation occur temporally among differing regions of Cuba. Such variations reinforce the need for expanded research efforts on spawning aggregations.

KEY WORDS: Spawning aggregations, snapper, grouper, Cuba

Utilización de las Congregaciones de Desove de Pargos y Mer para el Diseño de una Red de Áreas Marinas Protegidas en Cuba

Las congregaciones de desove de los peces constituyen un elemento fundamental para el diseño de las áreas marinas protegidas marinas (AMP), ya que constituyen sitios de producción concentrada y pueden ser relativamente pronosticables en el espacio y el tiempo. La información sobre su localización y los patrones de uso específico pueden ser utilizados para el diseño de las AMPs en: 1) la ubicación de zonas "intocables" para proteger las poblaciónes en desove; 2) definir la conectividad en el diseño de redes de sistemas de reservas inter-

relacionadas. La información sobre los patrones espaciales y temporales de las congregaciones de desove de los pargos y meros en Cuba, deberá ser integrada en la iniciativa para el diseño de una red nacional de AMPs. Aproximadamente 20 sitios han sido identificados, utilizando informaciones de pescadores experimentados y estudios de campo sobre las especies de *Lutjanus, Epinephelus* y *Mycteroperca.* La mayoría de los sitios conocidos se encuentran en la región occidental y nor-central de Cuba, lo cual es consecuencia de un mayor esfuerzo de muestreo en esas áreas. La mayoría de los sitios se encuentran en el borde del talud insular a profundidades de 20-40 m, sobre sustrato coralino. Algunos sitios son utilizados de forma secuencial por varias especies en diferentes estaciones del año. Se analizan las actividades pesqueras asociadas con esas congregaciones y se documentan casos de sobre-pesca relacionados con las migraciones de desove. S e ejemplifica como la información obtenida puede ser utilizada en el diseño de áreas protegidas en varias regiones de Cuba. Las notables variaciones geográficas en las congregaciones de desove evidencian la necesidad de incrementar los esfuerzos de investigación

PALABRAS CLAVES: Congregaciones de desove de los peces, *Lutjanus, Epinephelus, Mycteroperca,* Cuba

The Role of Long Distance Dispersal versus Local Retention in Replenishing Marine Populations

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ABSTRACT

Early models and evidence from genetics suggested that long distance dispersal of larvae is likely a common event leading to considerable population connectivity among distant populations. However, recent evidence strongly suggests that local retention is more the rule, and that long distance transport is likely insufficient to sustain marine populations over demographic timescales. We build on earlier model results to examine the probability of larval dispersal to downstream islands within different regions of the Caribbean at varying distances from source populations. Through repeated runs of an ocean circulation model (MICOM), coupled with a random flight model estimating larval sub-grid turbulent motion, we estimate the likelihood of particular circulation events transporting large numbers of larvae to

within 9km radii of downstream populations, as well as account for total accumulations of larvae over each year. Further, we incorporate realistic larval behavior and mortality estimates and production variability into our models. Our results are consistent with the hypothesis that marine populations must rely on mechanisms enhancing self-recruitment rather than depend on distant 'source' populations.

KEY WORDS: Larval dispersal, local retention, ocean circulation model

El Papel de la Dispersión a Gran Distancia versus Retención Local en el Reabastecimiento de Poblaciones Marinas

Modelos previos y evidencia genética han sugerido que la dispersión larval a larga distancia es un evento común que confiere una conectividad poblacional considerable entre poblaciones distantes. Sin embargo, evidencia reciente sugiere que la retención local es la regla mayor y que el transporte a larga distancia probablemente es insuficiente para sostener poblaciones marinas sobre escalas de tiempo demográficas. Nos basamos en resultados de modelos previos para examinar la probabilidad de dispersión larval hacia islas corriente abajo dentro de regiones diferentes del Caribe y a distancias variadas de la población fuente. A través de corridas repetidas de un modelo de circulación oceánica (MICOM), acoplado con un modelo de vuelo al azar que estima el movimiento turbulento de larvas, estimamos la probabilidad de eventos de circulación particulares en el transporte de grandes números de larvas dentro de un radio de 9 km de poblaciones corriente abajo, así como también examinamos la acumulación total de larvas cada año. Además, incorporamos a nuestros modelos el comportamiento larval y estimaciones de mortalidad y variabilidad de producción. Nuestros resultados son consistentes con la hipótesis de que las poblaciones marinas deben basarse en mecanismos que mejoren el auto-reclutamiento en lugar de depender de poblaciones "fuente" distantes.

PALABRAS CLAVES: Dispersión larval, retención local, modelo de circulación oceánica

Community Capacity Building in the Designation of the Tortugas Ecological Reserve

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The remote Tortugas region of the Florida Keys, located over 225 km from the continental United States, is an area of high coral diversity, excellent water quality, and productive fisheries. Located at the juncture of major ocean currents, the Tortugas potentially serves as a source and sink for marine larvae. The Florida Keys National Marine Sanctuary initiated a process in 1998 to create a fully protected ecological reserve in the Tortugas to conserve these resources. Reserve design emphasized community input and consensus-based decision-making. Critical to success was a diverse working group of stakeholders and government agencies. In July 2001, after receiving extensive public comment and the necessary agency approvals for designation, the Sanctuary implemented a 518 km^2 Tortugas Ecological Reserve. This fully protected marine reserve is expected to preserve biodiversity, maintain ecosystem integrity, and act as a reference site to discriminate between natural and anthropogenic changes to the ecosystem. The Tortugas Ecological Reserve complements the Sanctuary's existing network of 23 fully protected zones, instituted in 1997 to protect marine resources from overuse, conserve biodiversity, and separate uses. The Tortugas Ecological Reserve is the largest fully protected marine reserve in the United States.

KEY WORDS: Ecological reserves, stakeholders, Florida Keys

Función de la Comunidad en la Designación de la Reserva Ecológica de Tortugas

La región de Tortugas, localizada en los cayos de Florida a 225 km de las costas de Estados Unidos, es un área de alta densidad coralina, excelente calidad de agua y pesquerías productivas. Dada su ubicación en la unión de varias corrientes oceánicas importantes, Tortugas sirve potencialmente como sitio de fuente y retención para larvas marinas. Para conservar los recursos marinos únicos de esta región, el Santuario Marino Nacional de los cayos de Florida inició en 1998 un proceso para crear una reserva ecológica completamente protegida. El diseño de la reserva enfatizó la participación comunitaria y una toma de decisiones basada en consensos. De importancia crítica para el éxito estuvo un grupo de trabajo de agencias comunitarias y gubernamentales. En julio 2001, después de comentarios públicos extensos y las aprobaciones necesarias para la designación, el Santuario implementó la Reserva Ecológica Tortugas de 518 km^2. Se espera que esta reserva

marina completamente protegida puede conservar la biodiversidad, mantener la integridad del ecosistema y actuar como un sitio de referencia para discriminar entre los cambios naturales y antropogénicos en el ecosistema. La Reserva Ecológica de Tortugas complementa la red de 23 zonas completamente protegidas del Santuario instituido en 1997 para proteger los recursos marinos del sobre uso, conservar la biodiversidad y separar usos. La Reserva Ecológica Tortugas es la reserva marina completamente protegida más grande en los Estados Unidos.

PALABRAS CLAVES: Reserva ecológica, Cayos de Florida

Estimating Queen Conch (*Strombus gigas*) Home Ranges using Acoustic Telemetry: Implications for the Design of Marine Fishery Reserves

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ABSTRACT

Marine reserves (MRs) may function as a vital tool in the conservation and management of marine resources if source populations are managed for the benefit of those downstream. Consequently, it is critical to evaluate the home range of marine animals to ensure that MRs are large enough to protect source populations. We used acoustic telemetry to study movements of adult queen conch (*Strombus gigas*) within aggregations at two sites in the Florida Keys from June 1997 through July 1998. A total of 68 conch were tagged tracked for up to one year. Latitude and longitude of each conch were recorded biweekly and data used to estimate the minimum speed, degree of site fidelity, and home range of each animal. Conch showed significantly greater displacement/time during the summer. There were no significant differences in movement rate, site fidelity, or size of home range between males and females. Mean home range was 5.98 ha. Based on estimated home ranges of the aggregations, the size and location of the existing reserves at these two were inadequate to protect the conch aggregations should the fishery reopen.

KEY WORDS: Home range, marine reserves, queen conch, *Strombus gigas*

Las reservas marinas pesqueras (RMPs) pueden funcionar como un instrumento vital en la conservación y manejo de peces e invertebrados si las

poblaciones son manejadas para el beneficio de pesquerías aguas abajo. Por consiguiente, es crítico evaluar el territorio de animales marinos para asegurar que RMPs son lo suficientemente grandes para proteger poblaciones. Usamos telemetría acústica para estudiar los movimientos del cobo (*Strombus gigas*) dentro de agregaciones criadoras en dos sitios en los Cayos de la Florida, desde junio de 1997 hasta julio de 1998. Un total de 68 cobos fueron equipados con transmisores acústicos y observados por un año. La latitud y la longitud del cobo fueron registradas cada dos semanas y estos datos se usaron para estimar la velocidad mínima, la fidelidad al sitio, y el territorio de cada animal. Los cobos se movieron considerablemente más rápido durante el verano que durante otras estaciones. No hubo ninguna diferencia significativa entre la tasa de movimiento, la fidelidad al sitio, o los tamaños del territorio entre machos y hembras. El territorio promedio fue 5.98 ha. Evaluamos el tamaño y la posición de las reservas existentes en estos dos sitios comparándolos con los territorios de las agregaciones y encontramos que las reservas fueron inadecuadas para proteger las agregaciones de cobo si la pesquería se vuelve a abrir.

PALABRAS CLAVES: territorio, reservas marinas pesqueras, cobo, *Strombus gigas*

Community-based Development of Multiple-use Marine Protected Areas: Promoting Stewardship and Sharing Responsibility for Conservation in the San Andres Archipelago, Colombia

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ABSTRACT

The San Andres Archipelago in the western Caribbean includes some of the largest and most productive coral reef ecosystems in the hemisphere. Declared the Seaflower Biosphere Reserve by UNESCO in 2000, this Colombian archipelago has 3 inhabited islands, 5 atolls, and an oceanic area of 300,000 km^2, about 10% of the Caribbean Sea. CORALINA, the local representative of the National Environment System, is responsible for environmental planning, management, and education. While setting up the Seaflower Biosphere Reserve, this agency had hundreds of meetings with the islands' communities, listening to their concerns. Issues, conflicts, and threats to marine and coastal areas were identified during these consultations. In response, CORALINA developed a project to establish a multiple-use marine

protected area (MPA). Stakeholder consultation and community outreach programs were set up to facilitate participation in planning and implementation. Language and cultural differences, poverty, a history of powerlessness, and negative attitudes toward authorities are realities that have to be confronted when working with these communities. Although only in the design stage, the high level of stakeholder involvement in planning has resulted in widespread support of the MPA. Lessons have already been learned that lead to recommendations on engaging local communities in MPA development.

KEY WORDS: Marine Protected Areas, community-based development, Colombia

El Desarrollo de Áreas Marinas Protegidas basadas en Comunidades de uso Múltiple: Promoviendo la Administración y Compartir la Responsabilidad de la Conservación en el Archipiélago del San Andres, Colombia

El archipiélago de San Andres en el Caribe occidental incluye algunos de los ecosistemas arrecifales más grandes y más productivos en el hemisferio. Declarado como una reserva de la Seaflower biosfera por la UNESCO en el 2000, este archipiélago colombiano tiene 3 islas habitadas, 5 atolls, un área oceánica de 300.000 km^2, y cerca de 10% del mar del Caribe. CORALINA, el representante local del sistema nacional del ambiente, es responsable del planeamiento, la gerencia, y la educación ambientales de la reserva. Durante el proceso de establecimiento de la reserva de la biosfera de Seaflower, esta agencia tenía centenares de reuniones con las comunidades de las islas. Las preocupaciones, de la comunidad, los conflictos, y las amenazas para las áreas marinas y costeras fueron identificados durante estas consultas. En respuesta, CORALINA desarrolló un proyecto para establecer el uso múltiple de las áreas de protección marina (MPA). La consulta con los constituyentes y los programas de acercamiento con la comunidad fueron establecidos para facilitar la participación el planeamiento y su puesta en práctica. El idioma y las diferencias culturales, la pobreza, una historia de falta de poder y las actitudes negativas hacia autoridades son parte de las realidades que tienen que ser enfrentadas cuando se trabaja con estas comunidades. Aunque solamentese trata de la etapa del diseño, el alto nivel de participación de los constituyentes en el planeamiento de la reserva ha dado lugar a un amplio apoyo hacia los MPA. Las lecciones aprendidas conducen a las recomendaciones de envolver las comunidades locales en el desarrollo de MPA.

PALABRAS CLAVES: Áreas Marinas Protegidas, Desarrollo de Comunidades, Colombia

The Barbados (alias Folkestone) Marine Reserve, Barbados: A Late Bloomer?

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ABSTRACT

The Barbados Marine Reserve (BMR) is a 2.2 km^2 no-take marine reserve occuppying one of the most intensely used and impacted sections of the coast and comprises four zones: Scientific, Northern Watersports, Recreational, Southern Watersports. Establishment of the BMR in 1981 did little to change the *de facto* marine resource governance regime for the area. There was minimal consultation of stakeholders in determining the zoning and regulations. Fishers were negatively impacted, and no user group derived significant benefits from the reserve. A mandate to maximise revenues led the National Conservation Commission, responsible for BMR management, to virtually abandon the reserve. Efforts to spur institutional change were not effective, because of the centralized authority of the NCC and the belief that the BMR could not generate revenue. In 1998, the Government initiated a study to reform marine resource governance within the BMR and adjacent areas. Stakeholder consultation revealed complex patterns of use in the area. Recommendations, adopted by the Government in March, 2001 included establishing a broader Marine Protected Area (MPA) along an expanded coastline (from 2.6 km to 9.5 km) with seven types of management zones, and renaming the area as the Folkestone Marine Managed Area. Also proposed was a Marine Management Area Authority, within the Ministry of the Environment's Coastal Zone Management Unit, to designate and manage MPA's.

KEY WORDS: Marine reserve, stakeholders, Barbados

La Reserva Marina de Barbados (alias Folkestone), Barbados: ¿Un Último Desarrollo?

La Reserva Marina de Barbados (BMR) consiste de 2.2 km^2 donde no se permite ningún tipo de captura; esta reserva ocupa una de las secciones más utilizada y afectada de la costa de Barbados. Esta consiste de cuatro zonas: Científica, Deportes Marinos Norteños, Recreacional, y Deportes Marinos del Sur. El establecimiento del BMR en 1981 hizo poco para cambiar la administración de los

recursos por el régimen *de facto* existente en el área. Tampoco hubo consulta o participación de los costitullentes en la determinación de las zonas y regulaciones. Al mismo tiempo los pescadores fueron afectados negativamente y ningún grupo de usuarios derivó beneficios significativos de la reserva. Un mandato para maximizar los réditos hizo que a la Comisión Nacional de la Conservación (NCC), la cual era responsable de la gerencia de BMR, abandonara virtualmente la administración de la reserva. Los esfuerzos para estimular cambios institucionales no fueron eficaces, debido a la autoridad centralizada del NCC y a la creencia de que el BMR no podría generar el rédito. En 1998, el gobierno inició un estudio para reformar la admnistracion de los recursos marinos dentro del BMR y áreas adyacentes. La consulta de los constitullentes reveló patrones complejos del uso en el área. Las recomendaciones, adoptadas por el gobierno en marzo del 2001, incluyeron establecer un área marina protegida más amplia (MPA) a lo largo de una línea de la costa ampliada (de 2,6 kilómetros a 9,5 kilómetros) con siete tipos de zonas de manejo, y la retitulación del área como área de manejo marino de Folkestone. También se propuso la creación de una autoridad de manejo marino del área, dentro del Ministerio del Ambiente, bajo la unidad de Administración de áreas costeras, para señalar y manejar MPA.

PALABRAS CLAVES: Reserva marinas, Constitullentes, Barbados

Connectivity Between Coastal Habitats of Two Oceanic Caribbean Islands as Inferred From Ontogenetic Shifts by Coral Reef Fishes

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ABSTRACT

Mangroves and seagrass beds are considered important nursery habitats for juveniles of coral reef fishes. Studies have mostly focused on the fish community of just one habitat, so the connectivity between different coastal habitats is often unclear. In this study, density and size of reef fish were determined using a single sampling technique in four non-estuarine bay habitats and four reef zones in Curaçao and Bonaire (Netherlands Antilles). The data indicate that of the complete reef fish community at least 21 species show ontogenetic cross-shelf shifts in habitat utilization. The 21 species mainly utilized shallow-water habitats (mangroves,

seagrass beds, channel and shallow reef) as nursery habitats and the deeper coral reef zones (> 5 m depth) as adult life-stage habitats. Fish species utilized 1-3 different nursery habitats simultaneously, but habitat utilization clearly differed between species. Previous studies showed that the dependence on these nursery habitats is very high, based on reduced density or absence of adults on coral reefs where these habitats were absent. The strong connectivity between several coastal habitats during the ontogeny of various commercially important reef fish species is evidence for the inclusion of bay habitats within boundaries of fishery reserves or marine protected areas.

KEY WORDS: Fish habitats, connectivity, ontogeny

Conectividad entre Hábitats Costeros de Dos Islas Oceánicas Caribeñas con Base en Cambios Ontogenéticos por Peces Arrecifales Coralinos

Los manglares y pastos marinos son considerados importantes hábitats vivero de peces arrecifales coralinos. Varios estudios se han centrado en la comunidad íctica de un sólo habitat; por tanto, la conectividad entre diferentes hábitats es a menudo confusa. En este estudio se determinó la densidad y talla de peces arrecifales usando sólo una técnica de muestreo en cuatro hábitats no estuarinos de bahía y cuatro zonas arrecifales en Curaçao y Bonaire (Antillas Holandesas). Los datos indicaron que al menos 21 especies de la comunidad íctica arrecifal muestran cambios ontogenéticos en la utilización del hábitat a través de la plataforma. Las 21 especies utilizaron principalmente hábitats de aguas someras (mangles, pastos marinos, canal y arrecifes someros) como hábitats vivero y las zonas arrecifales coralinas más profundas (>5 m profundidad) como hábitats para adultos. Las especies de peces utilizaron 1-3 diferentes hábitats vivero simultáneamente, pero la utilización del hábitat difirió entre especies. Estudios previos, basados en densidad reducida o ausencia de adultos en arrecifes coralinos donde estos hábitats están ausentes, mostraron la dependencia sobre estos hábitats vivero es muy alta. La conectividad acentuada entre varios hábitats costeros durante la ontogenia de varias especies de peces arrecifales comercialmente importantes representa una evidencia para incluir hábitats de bahía dentro de los límites de las reservas pesqueras o áreas marinas protegidas.

PALABRAS CLAVES: Hábitats de peces, conectividad, ontogenia

The Extent and Spatial Scale of Connectivity among Reef Fish Populations: Implications for Marine Protected Areas Designated for Fisheries Enhancement

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ABSTRACT

Enthusiasm for the use of no-take marine protected areas (MPAs) as management tools for the protection and enhancement of coral reef fishes is widespread. However, evidence that such marine reserves actually enhance fishery yields is limited, primarily because of difficulties in quantifying the exchange of individuals -especially larvae- between local populations within and outside the protected area. Knowledge of the extent and spatial scale of this connectivity is of vital importance for the effective design and implementation of marine reserves intended as fishery management tools. We review our current understanding of connectivity among coral reef populations, including the role of important determining factors such as pelagic larval duration, larval behavior, and hydrodynamics. We also discuss artificial and natural tagging methods that potentially can be used to track movements of larvae between marine reserves and surrounding waters. To illustrate the application of such methods, we discuss ECONAR (Ecological CONnections Among Reefs), a new, regional-scale research project designed to measure the extent of connectivity among populations of coral reef fishes in the Mesoamerican Barrier Reef System.

KEY WORDS: Marine Protected Areas, spatial scale, connectivity

Alcance y Escala Espacial de la Conectividad entre Poblaciones de Peces Arrecifales: Implicaciones para Áreas Marinas Protegidas Designadas para Mejoramiento de Pesquerías

Es amplio el entusiasmo por el uso de áreas marinas prometidas (AMPs) como herramientas de manejo para la protección y mejoramiento de los peces arrecifales coralinos. Sin embargo, la evidencia de que tales reservas marinas mejoran el rendimiento pesquero es limitada, debido principalmente a las dificultades en cuantificar el intercambio de individuos –especialmente larvas– entre poblaciones locales dentro y fuera del área protegida. El conocimiento sobre el alcance y la escala espacial de esta conectividad es de importancia vital para el diseño efectivo

e implementación de reservas marinas como herramientas de manejo pesquero. Revisamos nuestro entendimiento actual de la conectividad entre poblaciones arrecifales coralinas, incluyendo el papel de factores importantes y determinantes como son la duración pelágica larval, el comportamiento larval y la hidrodinámica. Discutimos también los métodos de marcado artificial y natural que pueden ser usados potencialmente para rastrear movimientos de larvas entre reservas marinas y aguas adyacentes. Para ilustrar la aplicación de tales métodos, discutimos sobre ECONAR (Ecological CONnections Among Reefs = Connecciones Ecológicas Entre Arrefices), un nuevo proyecto de investigación, a escala regional, diseñado para medir el alcance de la conectividad entre poblaciones de peces arrecifales coralinos en el Sistema Arrecifal Mesoamericano.

PALABRAS CLAVES: Áreas Marinas Protegidas, escala espacial, conectividad