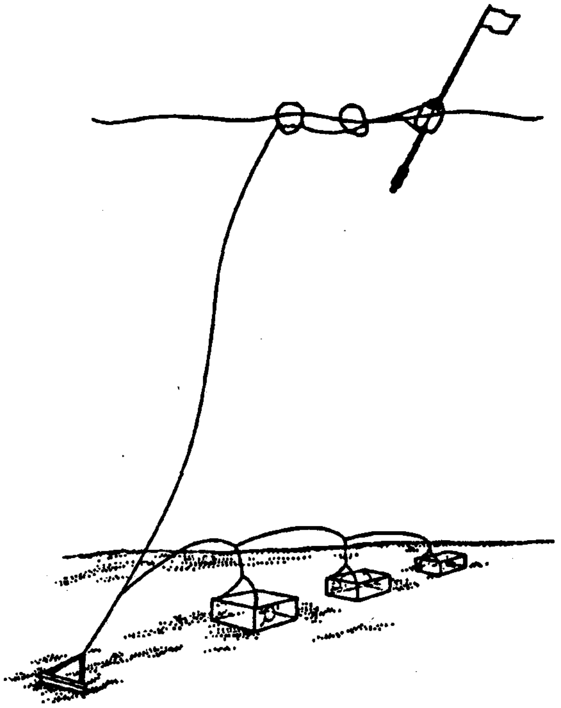
NOAA Technical Memorandum
NMFS-SEFSC-365

Proceedings of the 1987 SEAMAP Passive Gear Assessment Workshop at Mayaguez, Puerto Rico



compiled by
James A. Bohnsack
&
Amy Woodhead
August 1995

U. S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Science Center
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U. S. Department of Commerce
Ronald H. Brown, Secretary

National Oceanic and Atmospheric Administration
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Notice

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Preface

In 1987 a Passive Gear Workshop was held in Puerto Rico. The publication of these proceedings was identified as a priority item and considerable effort was made by participants to develop manuscripts. Because of changes in personnel, the proceedings were never published. In 1991 I volunteered to coordinate the assembly of the proceedings. I took on this project because of my belief that a great deal of useful effort and information was produced as a result of the workshop. Unfortunately, the audio tapes made of the workshop no longer existed and hard copies of most manuscripts were missing. Initially, only three manuscripts could be located. After considerable effort, we are pleased to produce this document. To all of the participants, I apologize for the lengthy delay in getting this publication produced and appreciate everyone's patience. We thank the many people who have helped produce these proceedings: Walter Nelson, Nikki Bane, Sophia Howard, Carole Goodyear, and Sandra Lauraeno. We particularly thank these components of the SEAMAP program for sponsoring the workshop and the NMFS and GSMFC for providing travel support for the speakers. In addition, we wish to thank the GSMFC staff for recording the processing and providing transcripts of the workshop.

James A. Bohnsack

SOUTHEAST AREA MONITORING AND ASSESSMENT PROGRAM (SEAMAP)

The Southeast Area Monitoring and Assessment Program (SEAMAP) is a State/Federal/university program for collection, management and dissemination of fishery-independent data and information in the southeastern United States. The Program presently consists of three operational components: SEAMAP-Gulf of Mexico, which began in 1981, SEAMAP-South Atlantic, implemented in 1983, and SEAMAP-Caribbean, which began in 1988. The history, conceptual framework and program organization, goals, and activities of the components are detailed in the SEAMAP Management Plan.

Each SEAMAP component operates independently. They plan, conduct surveys, and disseminate information in accordance with administrative policies and guidelines of the Department of Commerce and the National Oceanic and Atmospheric Administration.

Activities and operations of each SEAMAP component are wholly defined by the respective managing units: the SEAMAP-Gulf Subcommittee of the Gulf States Marine Fisheries Commission's Technical Coordinating Committee, and the SEAMAP-South Atlantic Committee of the Atlantic States Marine Fisheries Commission's South Atlantic Board. These committees consist of designated representatives from each member State, the National Marine Fisheries Service, and the respective Fishery Management Councils. They meet several times a year to review operations, examine priorities and plan future activities. Daily operations are carried out by the respective SEAMAP Coordinators, assisted by staffs of the two Commissions and Puerto Rico Department of Natural and Environmental Resources, and personnel associated with the SEAMAP Information System, SEAMAP Ichthyoplankton Archiving Center, and SEAMAP Invertebrate Plankton Archiving Center.

The SEAMAP Program currently conducts most of its major monitoring and assessment surveys with trawl gear, plankton nets and environmental sampling devices. In keeping with activities outlined in the Operations Plans, SEAMAP wishes to evaluate the suitability of longlines, traps and other passive gear methods for monitoring and assessment purposes. Past experience (a Trawl Calibrations Workshop in March 1983, and a joint SEAMAP-PESCA research needs workshop in August 1986) has shown the value of open dialogue among fishery researchers and managers, and has led to this joint SEAMAP-PUERTO RICO SEA GRANT Passive Gear Assessment Workshop. These proceedings document the presentations and discussions.

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Co-hosted by SEAMAP and the University of Puerto Rico, Mayaguez/Sea Grant
Mayaguez Hilton, Mayaguez, Puerto Rico.
Thursday and Friday August 27, 28 1987.

Moderator: Manuel Hernandez Avila, University of Puerto Rico Sea Grant
Organized by Nikki Bane

The SEAMAP Program extends its sincere gratitude to the staff of Puerto Rico Sea Grant, and especially Mrs. Evangelina Hernandez, for assisting in the development of this workshop, and for providing the participants and their spouses with the traditional, warm Puerto Rican hospitality.

TRAPPING SURVEYS FOR STOCK ABUNDANCE

Robert J. Miller

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Trapping is an inexpensive and versatile survey method, but provides only fair to poor estimates of the density of the target species. Before discussing the pros and cons of surveying with traps, I will mention two alternative methods sometimes overlooked.

Published biomass values for species, or groups of species, are sometimes more uniform than we might expect. Table 1 shows close agreement among average finfish biomass for coastal areas in the northeast Atlantic. Table 2 summarizes American lobster biomass, all measured by divers, from several areas in New England and eastern Canada. All but the first three values and the two zero values for Narrangansett Bay were known to be in good lobster fishing areas. The range of the remaining 12 values is 5.4 - 15.6 g/m^2 are not large considering the number of investigators and locations represented. Table 3 is groundfish biomass as determined by trawl surveys for major fishing grounds in the north Atlantic.

Table 1. Mean biomass (g/m^2 live) of fish communities in coastal areas of the northeast Atlantic (Jansson et al. 1985).

AREA	BIOMASS
Northern Baltic, mud-sand, with macrophytes, > 1m.	4.5
Northern Baltic, mud-sand, with macrophytes, < 1m.	3.0
Northern Baltic, hard and soft bottom, 1-20m.	4.3
West coast Sweden, silty clay, with macrophytes, < 1m.	6.0
North Sea, soft bottom, < 5m.	6.0

Annual yield to a fishery per unit area of fishing ground may also be an acceptable alternative to measuring stock density. This can be obtained from good statistics on the location fished and the landed weight; dockside interviews or fishermen's logbooks are the usual sources. In Newfoundland, an annual snow crab yield of 0.9 t/km^2 proved to be a useful rule of thumb. In Nova Scotia the means of the 20 best years of lobster landings for each of 7 counties were 1.2, 1.0, 2.1, 2.1, 3.7, 1.5, and 2.0 t/km^2, not bad considering the crude estimates of the area of fishing grounds and the mediocre quality of record keeping in the late 1800's when most of the highest catches occurred.

Returning to the topic of traps, they are useful to the fisheries biologist for the same reasons they are useful to fishermen. They fish unattended, a large area can be surveyed (fished) in a day, they can be fished from large or small boats, requirements for deck equipment and vessel power are modest, they are suitable for most bottom types, can fish over a large depth range, the catch is in the hand for biological sampling, the catch is usually live, and they are inexpensive and robust.

Estimating absolute stock size, or stock density, from trapping is difficult because traps must be calibrated for the catchability coefficient (q) and many factors strongly influence q. The catchability coefficient (also called effective area fished) is simply calculated as the ratio of catch per trap (C/f) to animal density (D) with units as shown:

$$q\ (\text{m}^2/\text{trap}) = \frac{C/f\ (\text{no. animals/trap})}{D\ (\text{no. animals/m}^2)}$$

Although q has units of m^2/trap, it represents the actual area of attraction only if 100% of the animals are captured from within, and 0% from outside the area. Since this is virtually impossible the actual area of attraction is larger than q, but by an unknown amount. D should be measured by a method independent of trapping, preferably by a visual counting technique. Tag-recapture and fishing success (DeLury, Leslie) methods give biased results for decapod crustacea because assumptions of the methods are virtually never met. If the estimate of q is robust, then trap catches and q can be used to estimate animal density at time and places other than when and where D was measured.

The list of factors affecting catchability is discouraging to anyone who wants to use traps to estimate animal density. The relationships shown in Figure 1 are taken from about 40 publications, mostly on decapod crustaceans. The list is not complete, and of course some relationships have better data support than others. Each factor is discussed by example.

Animal Size: If length of Cancer crab or American lobster is doubled, q increases by at least 10 fold. This includes only sizes retained by the trap meshes. Catchability decreases slightly for large spiny lobsters.

Molt Cycle: For a few days to weeks immediately before and after molting, decapods do not trap; but catchability of the postmolt animal is about double that of the intermolt animal.

Predators: American lobsters in crab traps or octopus in western Australian lobster traps can reduce catch by more than half. Dead conspecifics in a trap reduces the catch by more than half for several crab and lobster species.

Sex: For mature males, mature females without eggs, and females with eggs of the European lobster, catchabilities are in the ratio of 3:2:1.

Soak Time: The vertical axis in Figure 1 should be changed from catchability to catch/trap for this figure. With increasing soak time the catch increases to some asymptotic value which is presumed to be a function of animal density. Catch in a trap that is easy to enter reaches the asymptotic value more quickly. Fishermen usually overestimate the time necessary to reach the asymptotic catch. For experimentally fished traps peak catches of sablefish were reached in 1 day, peak catches of two species of Cancer crab in <1 day, and peak catches of a spider crab in 2 days.

Trap Size: The asymptotic catch is sometimes called the saturation catch and is nearly always reached before the trap is physically full. Saturation is probably caused by animals in the traps, by olfactory or visual cues, intimidating those outside the trap. The proportional increase in catch for reef fish and a Cancer crab was greater than the increase in bottom area of the traps.

Bait: Increasing bait from 1 to 3 kg/trap doubled the catch of a spider crab.

Light: Both lunar and diurnal cycles affect catchability. Spiny lobsters are more catchable at new moon rather than full moon. Spiny lobster, Norway lobster, American lobster, and other decapods have been shown to be several times more catchable during night than day.

Temperature: Catchability of European lobster doubled from 7 - 14°C; catchability of Australian rock lobster increased 50% from 18 - 24°C; and American lobster was uncatchable below 3°C.

Water motion: Near bottom current speed >25 cm/s would virtually prevent movement of European lobster, including response to bait odor. The critical speed for the oscillating current caused by waves would be even lower. Water motion would restrict movement in most lobster habitats in Britain a significant portion of

Table 2. Field biomass measurements in live weight for *Homarus americanus*. (Miller 1985)

LOCATION	MONTH	DEPTH (m)	BOTTOM TYPE	AREA SAMPLED (m^2)[a]	LOBSTER BIOMASS (g.m^{-2})	SOURCE
Southern Gulf of St. Lawrence	June	< 5	Irish moss beds; flat bedrock ledges	2900	0.4	Scarratt 1973a
	July	< 5	medium rough	900	3.9	
	May-Aug.	< 5	boulder strewn	6300	4.1	
	Spring & Fall	~ 17	Rocky	753[b]	12.6	Scarratt 1968
	July-Sept.	~ 17	Man-made boulder reef	10020[c]	11.0	Scarratt 1973b
Nova Scotia Atlantic coast	Aug.-Oct.	3-9	Boulders on sand gravel	6700[d]	5.4	Bernstein, Campbell 1983
	Sept.	4-8	Kelp bed; boulders on gravel barrens;	600	12.8	R.J. Miller, unpubl. data
		4-8	boulders on gravel	600	9.8	
	Year-round	5-12	Boulder & cobble on sand & clay	~ 360[e]	9.2	Elner, Hamet 1984
Maine Station 1.	Year-round	6-12	Boulders & rocks on bedrock	13500[f]	9.0	Cooper et al. 1975
Station 2.		6-12			9.1	
Station 3.		12-18	Boulders & rocks on sand		9.3	
Station 4.		12-18			7.2	
Narragansett Bay, Rhode Is.	Summer	< 10	Boulders	250	17.3	Fogarty 1976
		< 10	Gravel		0	
		< 10	Mussel bed on sand		0	
Long Is. Sound	Year-round	7-9	Boulders on mud	5500[g]	15.6	Stewart 1973

[a] Total area of all samples.

[b] Three sampling dates over 2 years.

[c] Once each of 4 years.

[d] Four dates.

[e] Six dates.

[f] 25 successive months.

[g] 24 consecutive months.

Table 3. Groundfish biomass (g/m^2 live) as determined from trawl surveys.

AREA	YEAR	BIOMASS	SOURCE
Georges Bank	1964-66	12.9	Cohen et al. 1982
North Sea		1.6	Crisp 1975
Nova Scotia	1970	4.0	Sinclair et al. 1984
Shelf	1975	4.1	
	1980	4.7	
Southern Gulf	1970	2.3	Sinclair et al. 1984
of St.	1975	3.5	
Lawrence	1980	6.3	

Table 4. Catchability coefficients (q) in m2/trap.

SPECIES	SIZE	q	SOURCE
Panulirus cygnus	> 3cm c.l.	25-174	Chittlborough 1970
Panulirus cygnus	> 5cm c.l.	33-120	Morgan 1974
Chionoecetes opilio	> 9cm c.w.	2500-3300	Miller 1975
Geryon maritae	> 6cm c.w.	2160	Melville-Smith 1986
Homarus americanus	> 5cm c.l.	96-99	Miller unpubl.
Cancer irrorartus	> 6cm c.w.	102-308	Miller unpubl.
5 taxa of tropical	> 10cm to	140-350	Miller & Hunte 1987
reef fish	> 20cm f.l.		

c.l.-carapace length, c.w.-carpace width, f.l.- fork length

the time.

Bottom relief: This variable has not been tested experimentally, but two deep water crab species living on flat bottom had catchabilities of over 1000 m^2, whereas decapods and fish living on coral reefs or boulder strewn bottom, had catchabilities in the 10's and 100's of m^2.

Table 4 shows the wide range of catchabilities available to date. In Chittleborough's (1970) study of *Panulirus* a total of 9 measurements were made in different years and on different reefs, but all in the same month with moon phase, soak time, and temperature standardized. Even so, the range was 25 - 174 m^2/trap with a c.v. of 57%. Morgan's (1974) measurements on *Panulirus* were made on a single reef in 34 of 38 consecutive months. After standardizing for soak time, moon phase, temperature, salinity, and fraction of the population in a postmolt condition, the range was still 33 - 120 m^2/trap with a c.v. of 38%.

Two deep water crab species had the highest catchabilities. Spider crab catchability measured in the autumn, one in each of four similar habitats, was 2500 - 3300 m^2 with a c.v. of 29% (Miller 1975). A single value for *Geryon* was 2160 m^2 (Melville-Smith 1986).

Catchabilities of tropical finfish on two similar reefs were 141 and 148 m^2 for parrotfish, and 194 and 135 m^2 for surgeonfish. Three other taxa measured on one reef each were 335, 346, and 348 m^2 (Miller and Hunte 1987). Catchabilities could not be measured for most taxa because the fish could not be counted reliably or they moved onto the reef only at night.

American lobster and Cancer crab were fished on adjacent areas of rocky bottom with and without dense seaweed cover (Miller unpbl.). Catchabilities were in good agreement between habitats: 96 vs 99 m^2 for lobsters in lobster traps, 102 vs 127 m^2 for crabs in lobster traps, and 258 vs 308 m^2 for crabs in crab traps. When crabs and lobsters were divided into size classes agreement between habitats was not as good but still within a factor of two. Catchability of different sizes differed greatly as mentioned previously.

Using trap catches as an index of abundance rather than an absolute measure of abundance does not require a measure of the catchability coefficient, but does require the assumption that it is constant from time to time and place to place. Unfortunately this is a "catch 22", because the only way of knowing for sure that q is constant is to measure it. A second best alternative is to recognize the factors affecting q and try to control them in the survey design.

I recommend the following elements for a trapping survey design, even at the risk of preaching to the converted. Omissions from published reports on trapping studies suggest we all occasionally need reminding of the basics.

Write down a simple statement of the survey purpose and give everyone involved a copy. For example: To compare the 1987 with the 1984-86 lobster catch per trap haul on the reef in Bung Hole Tickle (using 15, 0.5 x 1.0 x 1.0 m wire traps baited with 1 kg of frozen squid and soaked for 20 - 24 hrs.). Field surveying includes strong temptations to deviate from the original purpose by introducing unintended variables: bait, trap design, soak time, and fishing area for example. Not only must the biologist control his own curiosity, but a fishing crew can apply considerable pressure to maximize the daily catch at the expense of survey results. Fishermen rarely appreciate the value of randomization or replication.

Do presurvey trapping; space traps uniformly over the area selected and eliminate any portion with unusually high or low catches. Also, decide what precision is needed and calculate how many trap hauls are required to reach it, e.g. the number of trap hauls necessary to detect a 30% year to year change in mean catch.

To protect against bias, during a survey placement of traps over the survey area should be randomized, as should the order of fishing different survey areas. A fishery scientist should never go fishing without a random numbers table.

The survey should be at the same time each year to help standardize for stage of reproductive cycle, molt cycle, day length, moon phase, tidal currents, and temperature.

Be very particular about uniformity in trap design, bait quality, bait quantity, and soak time.

Keep the survey design inexpensive enough and logistically simple enough that it can be sustained year after year. Most surveys are only useful as a time series. It is not necessary to mimic commercial fishing methods. These will differ among fishermen, years, and locations, and are beyond our control.

If annual mortality rates are to be calculated from trap catches, the relative catchabilities of different sized animals should be measured. Assuming equal catchability will underestimate mortality of decapods because larger individuals have higher catchabilities.

Summary

- Traps are useful for surveying a large area inexpensively.
- Animal abundance cannot be estimated with high precision or accuracy using traps.

- Visual counts of animal abundance is the only good method of measuring the trap catchability coefficient.

- A survey design using traps should include: a clear statement of the survey purpose, preliminary trapping to determine required sample size and area(s) of uniform catch rates, randomization in both space and time, simple logistics, recognition of important variables affecting catchability of the target species, and standardization of as many of these variables as practical.

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PASSIVE GEARS IN THE CARIBBEAN

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The value of passive gears in resource monitoring and assessment, from both a fisheries-independent and fisheries-dependent point of view, is discussed. Fisheries-dependent surveys may be adequate for monitoring simple trends in a fishery but are not adequate for stock assessments. Fisheries-independent studies, however, having suitable experimental design, are suitable for the purpose of monitoring and assessment of marine resources. Data gathered from fisherman interviews over an 18 year period in Puerto Rico illustrate the importance of passive gear fisheries in the Caribbean. Trends indicate that landings from traps, gill-nets, and trot-line are on the decline even though effort has increased. All published assessments to date suggest the local fisheries are overfished. The potential and advantages of direct observation of commercial fisheries resources through visual means is addressed.

Passive Gears in the Caribbean

One of the main objectives of this paper is to pose an answer to the question "Are passive gears sufficient for the purpose of monitoring and assessment of marine fisheries resources?" Another is to describe current trends in fish and shellfish landings in Puerto Rico through monitoring passive gear catches with a fisheries-dependent survey.

With regard to the capabilities of passive gear studies, a researcher has to ask first, whether the available data are reliable and second, whether "monitoring" and "assessment" can be achieved. In fisheries-independent studies, such as those of the SEAMAP Program, data reliability is potentially high since one is in control of how, when, and where the gear is fished and what and how much is caught. This is generally in contrast to fisheries-dependent studies where often many factors can not be controlled. Consequently, fisheries-dependent studies generally cannot satisfy the requirements needed for proper fisheries assessment. Since fisheries resources are held in public trust by the government, which is ultimately responsible for the condition of that resource, a mechanism needs to be provided so that adequate data is available for proper stock assessment of commercially important resources. This could be accomplished by providing for permanent fisheries-independent programs.

The terms monitoring and assessment are often combined or used interchangeably by scientists, managers, and policy makers. Since monitoring can be accomplished with assessment data, this does not present a problem as long as enough reliable data, in sufficient detail are available. However, the reverse is not always true. Generally, in ecological and fisheries studies, monitoring means following a variable for some length of time or dimension of space to detect a relative or absolute change from the current status. An example would be the monthly reporting of biomass of fish landings from passive gears for an area. Fisheries assessment, on the other hand, is a much more rigorous practice, where precise and accurate measurements of several variables are needed as input to fisheries models, ultimately, to predict a level of fishing activity which would give a maximum yield per recruit. The distinction between monitoring and assessment is important in deciding the value of passive gear studies.

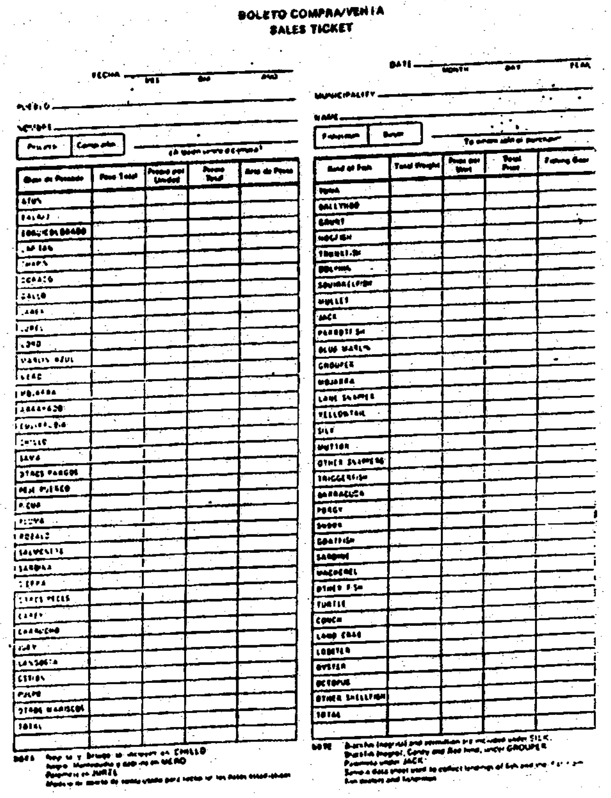
For the Caribbean area, it has been traditional to use fisheries-dependent catch and effort data derived from the fishery when considering management of commercially important stocks. While these data are important, their usefulness in terms of stock assessment of commercial fish stocks is questionable because of their fisheries-dependent nature and since widespread unreporting and misreporting exists. Even in areas where a great deal of effort has been put into the attainment of these data (e.g. Georges Bank and Gulf of Maine) fisheries biologists have pointed out their questionable accuracy (e.g. Serchuk et al. 1979, 1980, NMFS 1980). The data however, can be quite useful for monitoring the relative trends in landings over time and may reflect the relative abundance of resources.

Several reports have been published by island governments which described ongoing fisheries programs and local landings using, primarily, passive gears (Suarez-Caabro 1980, 1973, Juhl and Suarez-Caabro 1971, 1972, 1973, Suarez-Caabro and Rolon 1974, Rolon 1975, Cole 1976, Suarez-Caabro and Abreu Volmar 1976, Abreu Volmar 1976, Weiler and Suarez-Caabro 1980, Hartsuijker and Nicholson 1981, Mudre and Laplace 1979, Olsen 1975, Olsen and Sylvester 1976, Sylvester et al. 1977, Munro 1973, Stevenson 1981). Other published reports have derived results from a combination of the government's fisheries-dependent data and fisheries-independent data on passive gears (Appeldoorn and Lindeman 1985, Appeldoorn 1986, Stephenson 1978) for stock assessments of various elements of the commercial fisheries.

Visual Assessment Potentials

In addition to passive gears, direct observation of commercial resources through visual means (i.e. using scuba, submersible, and R.O.V.) offer much potential in areas, such as the Caribbean, where water clarity is not a problem. Also, visual techniques are attractive in areas where stocks are overfished since they are non-destructive in the sense that they remove no individuals from populations. Unlike most passive gears, several key habitat types, not capable of being adequately sampled with known passive gears, can be sampled using a visual method without unsurmountable gear selectivity problems.

Visual techniques offer a direct approach to fisheries assessment and should involve both mapping and surveying of resources, as suggested by Caddy and Bazigos (1985). First, a depth stratified map of key habitats (e.g. reef, sand flats, mangroves, grass beds, mud, algal plains, etc.) which are important in terms of their areal extent or their critical function (e.g. nursery, spawning, refuge, or forage area) needs to be constructed. This could be accomplished through one or a combination of means, such as scuba observations; from existing charts; interviews with fishermen; areal photographs; and satellite imagery, depending on available funds. Once completed the map could be used as the basis for a resource survey to determine overall biomass of different



BOLETO COMPRA/VENTA
SALES TICKET

Figure 1. A bilingual version of the "sales ticket" used by port agents in the collection of landings data from fishermen.

commercial resources. Eventually, estimates of mean biomass per species (or species group) per unit area could be determined. Using this "standing crop" information in conjunction with appropriate biological data so that "production" for the various species could be determined, a proper fisheries assessment leading to an estimate of potential yield could be achieved. Even though estimates of size might be determined using visual techniques some field collections are usually required to gather accurate information on species identification, size, age, and sex.

Passive Gear Landings

Passive gears have traditionally dominated the artesanal fisheries of the Caribbean in terms of the number of units fished, biomass, and value of fish landed (Sylvester and Dammann 1972, Munro 1973, FAO 1985, Suarez-Caabro 1979, Stevenson and Stuart-Sharkey 1980, Calderon and Collazo 1983, Garcia-Moliner and Kimmel 1985). These gears are comprised primarily of fish traps of a variety of shapes but also include several types of nets as well as trot lines. A "high tech" longline fishery, primarily directed towards the capture of swordfish, also exists in the Caribbean and is centered along the southern portion of the Lesser Antillian chain. Few local island fishermen participate, however, whereas most of the effort involves foreign and U.S. mainland fishermen.

In Puerto Rico, as described by Weiler and Suarez-Caabro (1980), landings data have been recorded on sales tickets (Fig.1) by fishermen or commercial buyers. Weight of catch in pounds for each gear type per species or species or group were noted. Completed tickets have been recovered weekly in fishing centers around the island (Fig. 2) and tabulated at the Fisheries Research Laboratory of CODREMAR. Figure 3 illustrates the trends in yearly landings for all gears between 1969 and 1986. While the data may be biased due to data collection efficiency, nonreporting, and misreporting, the data collection program has remained relatively consistent for this 18 year period. In other words, the absolute nature of the data may be in error but, in a relative sense, the decreasing trend observed is probably real. Similar trends are being measured or observed in the U.S. Virgin Islands (Denton Moore, personal communication) and elsewhere in the Caribbean as reported at a recent workshop on shared stocks of the Lesser Antilles (Robin Mahon, personal communication).

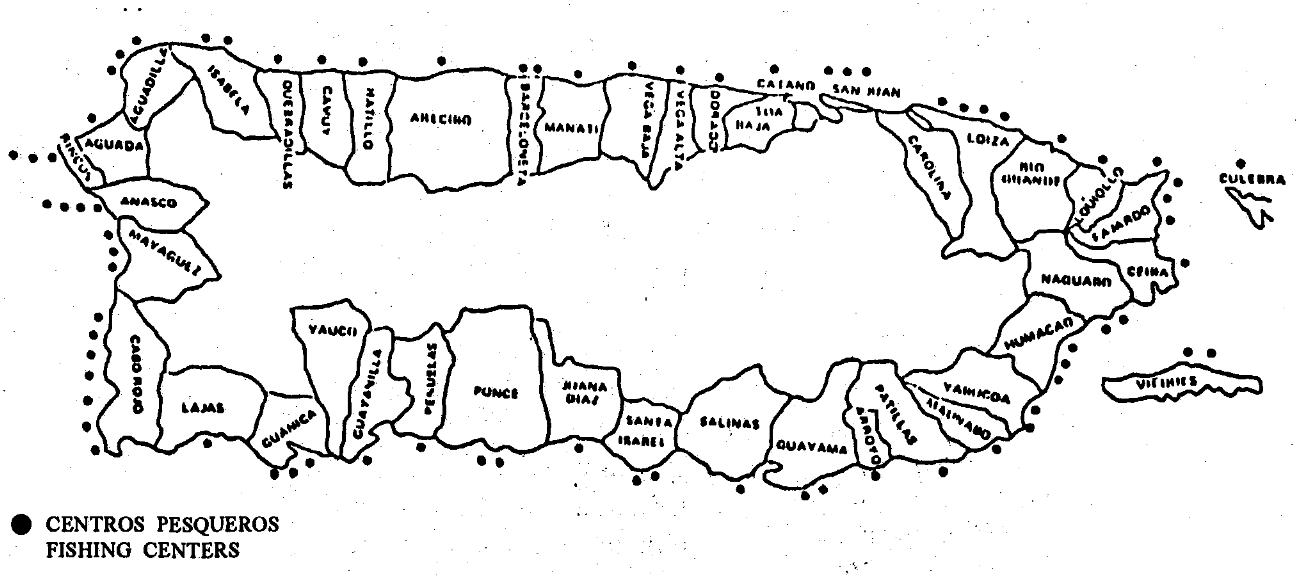


Figure 2. The coastal municipalities and fishing centers visited by port agents to collect landings data from fishermen.

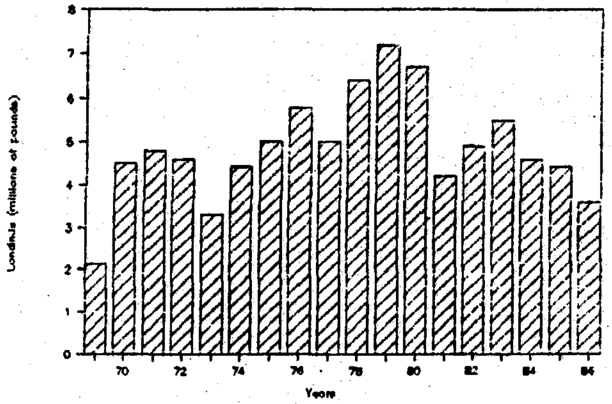


Figure 3. Yearly landings of fish and shellfish in Puerto Rico. Data collected through yearly government-sponsored fisheries-dependent surveys, Fisheries Research Laboratory, CODREMAR.

Fish traps (Fig. 4), or "nasas" in Spanish, are the most predominant and most productive fishing gear used in Puerto Rico and are fished in virtually all habitats from depths of 2 to 200 fathoms. An estimate of yield per trap per year derived from data from Weiler and Suarez-Caabro (1980) for 1975-1978 is 300 lbs, while after 1982 the estimate drops to 100 lbs (data from Garcia-Moliner and Kimmel 1985). The contribution of trap landings to total yearly landings has also decreased from over 50% to below 40% during the same period. The species composition of trap landings is shown in Table 1. For all species there was a reduction in total catch. For most there was a corresponding decrease or little change in their relative contribution to total trap landings. The exception being parrotfishes and the "other fish" category. Fish species, such as parrotfish, squirrelfish and surgeonfish, once considered to be of low commercial value, are now becoming more economically important as the more sought after species, such as grouper and snapper, continue to disappear. This may be a probable consequence of overfishing.

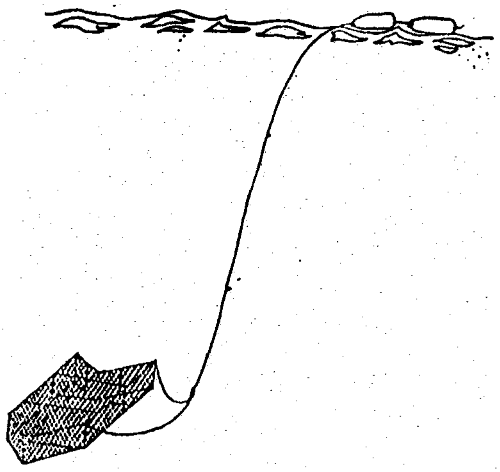


Figure 4. Chevron-shaped or arrow-head fish traps commonly utilized in the Caribbean. Approximate dimensions are 48" long, 36" wide, 18" deep.

Gill nets (Fig. 5), or "transmallos" in Spanish, generally in lengths of 50 to 100 fathoms with a depth of 6 ft and with stretched mesh sizes between 1.5 and 2.5 inches, are fished in turbid waters near mangroves, river mouths, or over shallow grass beds. Catches comprised an average of 7% of the total landings prior to 1979 (Weiler and Suarez-Caabro 1980) but, since 1983, have increased to 11% (Garcia-Moliner and Kimmel 1985). An estimate of yield per net per year, derived as above for traps, for 1975-1978 is 500 lbs while after 1982 the estimate decreased to 400 lbs (Garcia-Moliner and Kimmel 1985). For most species listed in Table 2 there was a decrease or little change in their relative contribution to total net landings. The exception, again, in the case of parrotfishes. This example of decreasing yearly landings in spite of increased fishing effort, along with an increase in relative contribution of parrotfishes to the total catch, may be a reflection of the intense fishing pressure on limited resources.

Trot-lines, or "palangres" in Spanish, are composed of various sizes of tarred or treated nylon seine twine and are fished in lengths of 100 to 200 fathoms with hooks spaced at one fathom intervals. Trot-lines are fished in either inshore shallow waters (1-5 fathoms) on sand or mud-bottoms, generally where waters are turbid or in offshore areas

Table 1. Reported annual landings (in thousands of pounds) and the percent contribution to total fish trap landings of selected species groups in Puerto Rico for the period of 1969 - 1986. Source of Data - historical files, Fisheries Research Laboratory, CODREMAR. Number in parenthesis represents the percentage of total fish trap landings to total yearly landings.

Species	1977		1978		1983		1984		1985	
Group	lbs	%T	lbs	%T	lbs	%T	lbs	%T	lbs	%
Grunts	890	31	884	27	311	21	282	21	231	20
Groupers	469	16	599	18	176	12	191	14	188	16
Parrotfishes	213	7	206	6	137	9	149	11	144	13
Snappers	288	10	537	16	222	15	180	13	190	16
Goatfishes	295	10	296	9	168	11	134	10	60	5
Triggerfishes	86	3	101	3	85	6	70	5	47	4
Other Fishes	327	11	314	9	235	16	85	6	157	14
Total Fish	2568	88	2937	89	1334	89	1198	89	1017	89
Lobsters	334	11	368	11	162	11	145	11	128	11
Total Traps Landings	2908	(57)	3313	(53)	1501	(36)	1351	(39)	1149	(35)
Total Yearly Landings	5078		6412		4186		3486		3311	

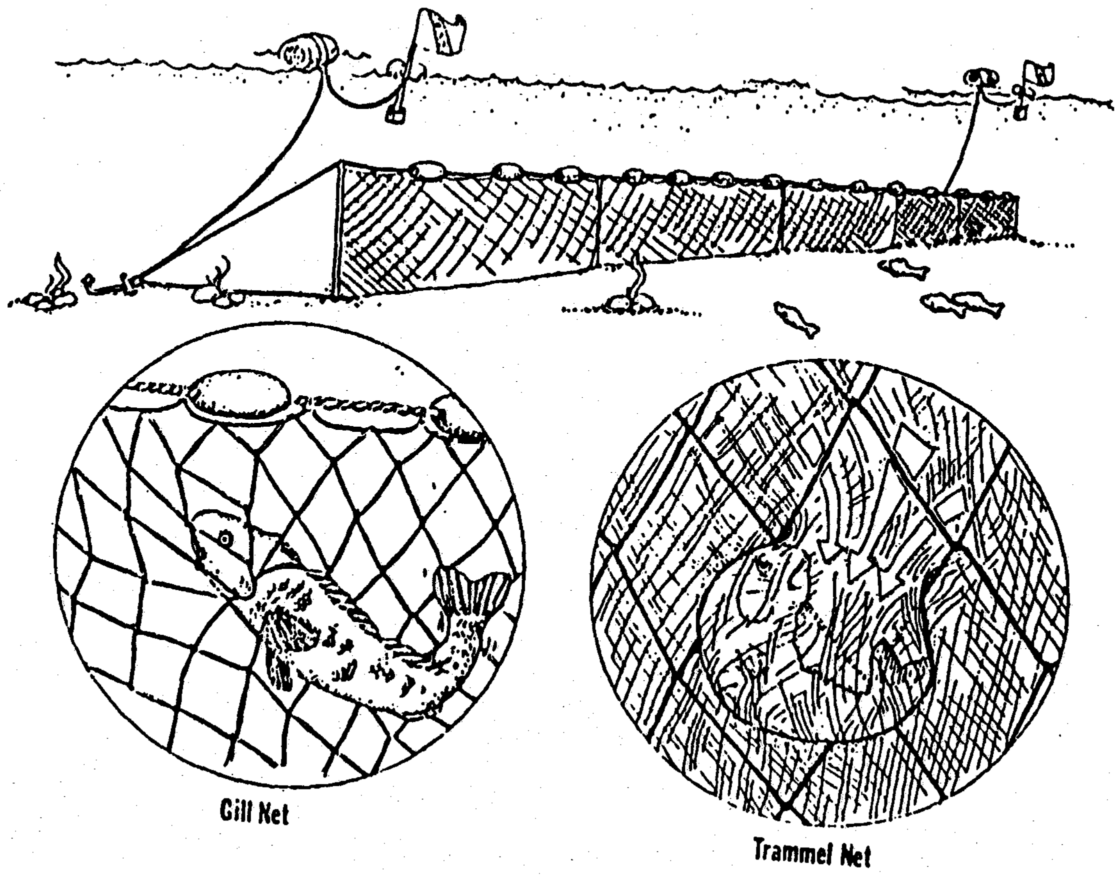


Figure 5. Gill net and trammel net (from Dumont and Sundstrom 1961).

Table 2. Reported annual landings (in thousands of pounds) and the percent contribution to total gill net landings of selected species groups in Puerto Rico for the period to 1969 - 1986. Source of Data - historical files, Fisheries Research Laboratory, CODREMAR. Number in parenthesis represents the percentage of total gill net landings to total yearly landings.

Species	1977		1978		1983		1984		1985	
Group	lbs	%T	lbs	%T	lbs	%T	lbs	%T	lbs	%T
Parrotfishes	16	5	40	9	83	19	89	25	86	20
Grunts	75	22	100	22	70	16	52	15	56	13
Mullet	67	19	86	19	43	10	29	8	45	10
Snappers	30	9	37	8	43	10	28	8	49	11
Snook	25	7	27	6	24	6	23	7	19	4
Mackerel	9	3	10	2	21	5	14	4	17	4
Mojarras	24	7	28	6	13	3	12	3	9	2
Other Fish	100	29	126	28	129	30	104	30	149	35
Total gill Net Landings	346	(7)	454	(7)	426	(10)	351	(10)	430	(13)
Total Yearly Landings	5078		6412		4186		4486		3311	

Table 3. Reported annual landings (in thousands of pounds) and the percent contribution to total trot-line landings of selected species groups in Puerto Rico for the period of 1969 - 1986. Source of Data - historical files, Fisheries Research Laboratory, CODREMAR. Number in parenthesis represents the percentage of total trot-line landings to total yearly landings.

Species	1977		1978		1983		1984		1985	
Group	lbs	%T	lbs	%T	lbs	%T	lbs	%T	lbs	%T
Snappers	10	91	33	97	25	92	20	83	18	67
Sharks	—	—	—	—	1	4	3	13	2	7
Other	1	9	1	3	1	4	1	4	7	26
Total Trot-line Landings	11	(1)	34	(1)	27	(1)	24	(1)	27	(1)
Total Yearly Landings	5078		6412		4186		3486		3311	

near reefs on sand-mud bottoms (60-200 fathoms). Over 65% of the fishes landed with trot-lines are snappers but their contribution to total annual landings is less than 1% (Table 3).

Results of Published Resource Assessments

Several assessments of Puerto Rico's commercial fisheries resources have been made. Stevenson (1978) reported the results of yield-per-recruit assessments on 7 species based on trap fishing on the Cabo Rojo shelf in 1973-74. At that time 2 species were found to be slightly overfished: the red hind and the white grunt. These 2 species constituted over 50% of the catch. The other 5 species were not overfished at that time, but they were also of lesser economic importance: squirrelfish, goatfish, and parrotfish. Fishing effort has increased dramatically since 1973-74, so conditions can be expected to have deteriorated significantly.

The above conclusion was supported by a study of the La Parguera grunt resource reported by Appeldoorn and Lindeman (1985). Using data supplied by CODREMAR, they found the grunt resource to have been overfished since 1978-79, and by 1983 fishing effort was four times that predicted to achieve MSY.

Boardman and Weiler (1980) reported results of an experimental trap-fishing survey conducted during 1976-78 at depths of 40 to 100 fathoms by personnel of the Commercial Fisheries Laboratory, and compared them to previous surveys. Although a survey alone is not sufficient to assess the status of a resource relative to MSY, it can be used to document trends. Boardman and Weiler concluded that catch rates had declined since 1970-72, and that this was due to increased pressure due to the rapidly expanding fleet of snapper boats during this period.

Lastly, Nelson and Appeldoorn (1985) reported the results of a joint submersible based visual survey and longline survey of the deepwater fishery resources (100-500 fathoms). Predicted abundances of snappers and groupers obtained from each method were very similar, and very low (3lb/100 sq. yd.). While the survey could not make an assessment relative to MSY, it did show that, regardless of the level of fishing, the potential resource at these depths was minimal and would not sustain any extensive fishing.

Summary

Fisheries-dependent surveys using passive gears are adequate for monitoring trends for some variables, if data can be properly standardized, but are not adequate for stock assessments. However, passive gear data from fisheries-independent surveys (or data from quantitative visual methods) is desirable for the combined objective of monitoring and assessing the status of stocks. Local governments have the ultimate responsibility for the condition of fishery resources, and therefore should provide a mechanism for adequate monitoring and assessment on a permanent basis.

Most fish and shellfish in the Caribbean are caught by passive gears with traps, gill nets, and longlines being the most important in terms of biomass landed. Passive gear landings monitored through a fisheries-dependent survey in Puerto Rico suggest resources are under heavy fishing pressure and fisheries are in a state of decline. All published assessments support the hypothesis of declining resources for the Caribbean area.

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PASSIVE ASSESSMENT TECHNIQUES FOR SHALLOW WATERS REEF RESOURCES

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Introduction

To discuss passive gear assessment, one must understand the unique data needs of tropical shallow-water reef fisheries. These fisheries are different from others because of the large number of species for which data are needed (Munro and Williams 1985). Kimmel (this proceedings) shows nicely the many species and families in the Puerto Rico shallow-water reef fish fishery. Usually, no one species comprises a major portion of the catch. In Jamaica, one study showed that fish traps captured 97 species, of which 21 accounted for more than 1% of the catch by weight and none accounted for more than 12% of the catch. Weight or abundance is not an indication of value. Lobster accounted for only 2.7% of the catch by number but represented 25% of the total value.

Data collection is further complicated by the extremely patchy distribution of most reef resources in any given area. Most reef fisheries are heterogeneous by nature, composed of different recreational and commercial components that use many different fishing gears and operate out of multiple ports.

The major effect of these characteristics associated with shallow-water reef fisheries is that extremely large sample sizes are required to statistically define catch, landings, and biometric population parameters with reasonable confidence limits. Many catch parameters are not distributed normally (Bannerot and Austin 1983) and thus require large sample sizes for statistical comparisons (Green 1979).

Methods

Here I select passive gear methods appropriate for assessing shallow-water reef fisheries and discuss their advantages and disadvantages. Methods are compared and a possible new monitoring technique is proposed that combines a visual method with existing video technology. Literature cited is representive but not necessarily exhaustive.

Results

Three passive assessment techniques have potential for use in routine monitoring and assessment. One is fishery-dependent (fish traps) and two are fishery-independent (visual and video assessment). Ideally, passive methods should allow estimation of species composition, relative abundance, geographical distribution, frequency-of-occurrence, and age or size distributions.

Fishery-Dependent Methods

Three major gear types are used in shallow-water reef fisheries: fish traps, hook-and-line, and various gill nets. The latter two techniques are usually unsuitable for routine passive assessment. Hook-and-line is expensive because of the labor involved and it effectively samples only a restricted number of species, mostly top predators. Nets sample more species but are difficult to use and standardize.

Fish traps offer the greatest potential of fishery-dependent gears for passive assessment. Fish traps are good for collecting a broad range of species and size categories and the catch may reflect what is happening in the trap fishery. Fishes can be handled, allowing collection of precise bionumeric data.

The disadvantages of traps include the cost and labor necessary to collect adequate samples, and the fact that fish traps are selective for only certain species and sizes. Catches are influenced by such factors as the use of baited or unbaited traps; type, quantity, and quality of the bait; depth and soak time; and bottom type fished. Catches may also be affected by trap size, type, mesh, and entrance characteristics, and by hauling procedure. Miller (1983, this proceedings) discusses in more detail problems of trap catchability and standardization. The net result is that the high variance of individual catches requires large sample sizes to adequately define some parameters for statistical purposes. Secondary problems of trap sampling are the competition with fishermen and the injury or mortality to sampled fishes.

Fishery-Independent Methods

Visual Sampling Methods.

Shallow-water reef environments are ideal habitats for using visual methods. Numerous "active" visual methods have been developed (e.g. transect swims, random searches, etc.) but will not be treated here because they are not passive techniques.

Bohnsack and Bannerot (1986) developed a passive visual method using a stationary observer. The method offers numerous advantages. A large number of individuals and species can be rapidly censused. Collected data show community composition, abundance, frequency-of-occurrence, and sizes. The method is simple, rapid, and efficient. It is less expensive than other sampling methods, when the amount of data collected is considered. Large sample sizes for statistical purposes can be obtained easily and quickly. The method can be used in most shallow-water habitats and if necessary, only a selected species can be treated. Bohnsack and Bannerot (1986) provided further discussion of the method's advantages and disadvantages for stock assessment, relative to other visual techniques.

Although visual sampling has many advantages, it is not suitable for use in high seas, strong currents, deep water, or poor visibility. Visual sampling of crepuscular and nocturnal animals is also ineffective. Sample collection is limited by water temperature, decompression limits, and physical and mental fatigue. There is a lack of comparability and standardization between various visual methods. Large, conspicuous, abundant, and midwater species are more likely to be sampled than small, cryptic, rare, and secretive species. Raw data provide an index of density, but not actual density without applying species-specific and habitat-specific correction factors. Handling and analyzing large quantities of data may be a problem for some fishery programs.

Video Sampling Methods.

ROV's. (Remote Operated Vehicles) Remote operated vehicles (ROV's) are maneuverable video cameras operated from a surface vessel by an attached cable. ROV's usually are deployed in an active search mode but could be used for passive assessment in a manner similar to the stationary visual sampling technique discussed above. The advantages are that video observations can be done in deeper water and under conditions where using divers is dangerous or inappropriate. Unfortunately, ROV's are expensive to purchase, maintain, and operate, making them unlikely ever to be practical for routine stock assessment. A surface vessel and crew must be tied up while only a small area and few samples can be collected.

SCRAM. (Self-Contained Remote Automated Monitoring) Many of the problems associated with ROV's may be obviated and useful passive assessment information provided by using SCRAM modules (Fig. 1). The SCRAM concept involves deployment of multiple, inexpensive

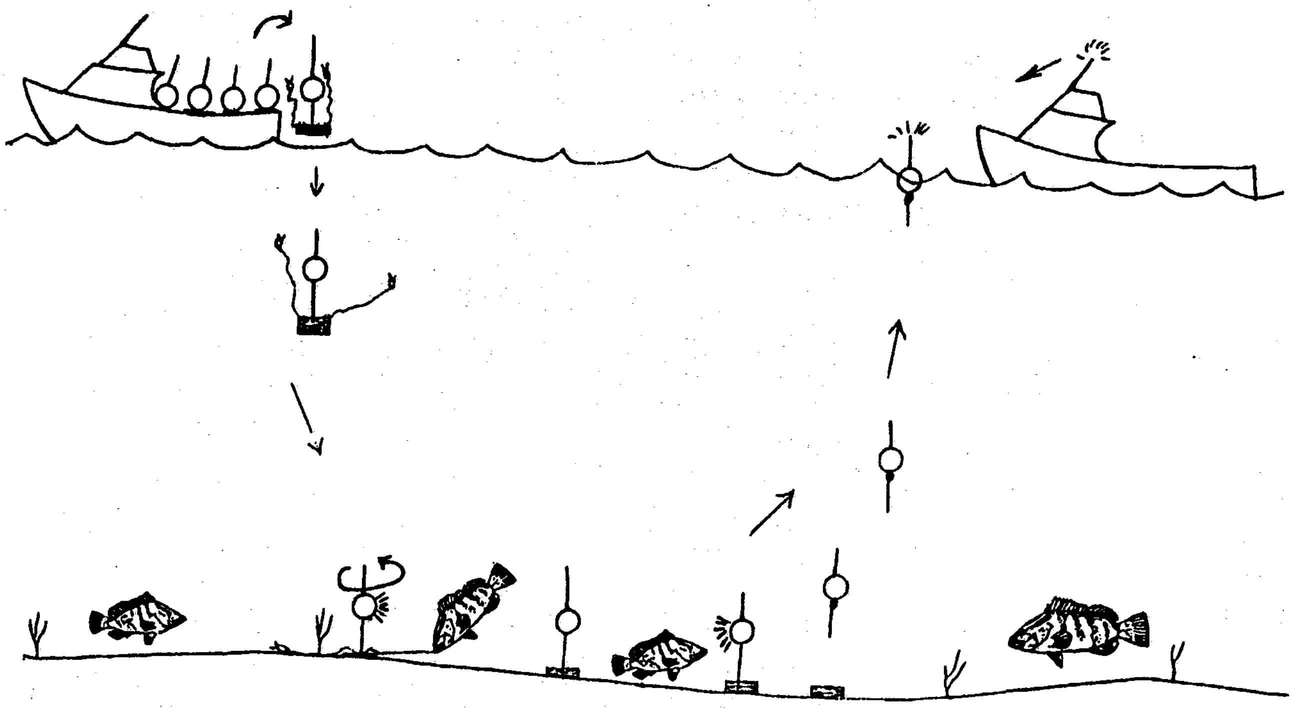

Figure 1. Conceptual diagram of SCRAM system. Video modules are dropped overboard at random in the survey area. At regular intervals or when triggered by tugging on bait, the camera makes a 360 degree sweep. Modules may be baited or unbaited and attached or unattached to a longline for retrieval. A time-release mechanism releases weights.

video cameras in self-contained modules. Each module would consist of a gimbaled video camera in a glass housing attached to a time-release weight. A vessel cruising over the sample area would drop numerous modules overboard where they would sink to the bottom and periodically make automatic videotapes while slowly rotating 360^0. The cameras would float about 1.5 m off the bottom for optimal viewing. Modules could be baited or unbaited and left unattached or attached by a longline. A time-release mechanism would release modules for surface vessel retrieval. Video tape analysis could be done on board the ship or in shore laboratories. SCRAM data would be analogous to visual point sampling and treated similarly.

The advantages of the SCRAM approach over ROV's are that large areas can be sampled simultaneously, and large sample sizes obtained at relatively low cost. SCRAM modules can be used in deeper water and under conditions where divers cannot be used. Much of the earlier discussion for and against visual sampling applies to SCRAM sampling (e.g. samples are not destructive to the habitat or fishery and adequate visibility conditions must exist).

The major disadvantage of SCRAM's is that the utility of this approach has not been demonstrated. Despite the fact that the necessary technology is currently available, considerable research must be done to develop and optimize this technology. For example, what is the relative efficiency of divers versus video cameras? What are the optimum video monitors, lenses, focal lengths, scanning duration, and analysis procedures? How many scans and what rotation rate is best for accurate identification? Should modules be baited or unbaited? Should samples be taken hourly for 24 hours, or less frequently? Can and should samples be collected under crepuscular and nocturnal conditions? Would flashes or continuous light sources be better than natural light? Would it be more efficient to rotate the camera within a housing, rotate the entire housing, or rotate a mirror above a fixed camera? High initial start-up costs for research, and managerial resistance to new technology can be anticipated. However, in the long run, costs might be reasonable, especially if off-the-shelf, low-cost technology can be employed.

Discussion

No one best method exists for monitoring and assessing tropical shallow-water reef habitats. A combination of methods would be ideal. The best method for any situation would depend on the questions asked. In general, assessment methods should at least be able to detect significant community and population changes.

Fishery-dependent assessment methods suffer from a critical problem: data continuity is lost when fishery restrictions are imposed. Fishermen may become more clandestine or less cooperative, especially when voluntary data collection systems are in place. Quotas, for example, may be circumvented by misidentifying or not reporting fishes (Matlock 1986). Even if the data collected are accurate, they may no longer provide sufficient information to assess stocks. A good example is the recent assessment of red snapper (*Lutjanus campechanus*) in the Gulf of Mexico (Parrack and McClellan 1986) done after a minimum size limit of 12 in (31 cm) was imposed on the fishery. Fishery-dependent data showed an absence of smaller fishes; however, it was impossible to tell whether this absence reflected compliance with the regulations or whether recruitment declined. With fishery-dependent data, there is no way to monitor stocks in areas temporarily or permanently closed to fishing.

One problem of some fishery-dependent assessment programs is the problem of creeping obsolescence. Data are often collected only for a restricted list of "target" species, even though other species make up part of the catch. Although suitable for short-term objectives, these data tend to become useless later when examining ecosystem changes or looking at historical patterns for species that had not been previously targeted. Species that were once of no interest often become important, especially in tropical fisheries. If fishery-dependent data are collected, then effort should be directed at collecting data on all species caught by sampled gear. In most cases, this requires only a little extra effort since the additional species usually comprise only a small portion of the catch. However, trends for these additional species could provide important information for fishery management.

Fishery-independent use of standardized fishing methods also presents some problems. Destructive sampling may be unsuitable for areas such as marine sanctuaries. Also, fishery scientists may be trapped into using inefficient methods or risk losing comparability. Most fishery scientists are unlikely to be as skilled at fishing as commercial fishermen, so their efforts are likely to be inefficient. Fishing technology is constantly being modified and improved, but changing standard methods to improve efficiency destroys the historical comparability and consistency necessary for stock assessment (Miller, these proceedings).

Fish traps are seen as the most effective method for collecting hands-on biostatistical information and fishery-dependent data. Non-destructive, fishery-independent, visual and video methods presented here have some advantages over fish traps for passive assessment and provide a potentially valuable tool for fishery assessment.

Conclusions

1. Tropical shallow-water reef fisheries are different from temperate fisheries in the large number of species for which catch and population data are needed.

2. No one best method exists for monitoring assessment.

3. Visual assessment is probably the most effective fishery-independent method for monitoring shallow-water reef fish communities.

4. The SCRAM approach may provide a practical alternative assessment method for conditions where diving is impractical.

5. More emphasis is needed on using non-destructive fishery-independent stock assessment.

6. If fishery-dependent data are collected, then effort should be directed toward collecting data on all species caught by sampled gear, not just "target" species.

Acknowledgments

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METHOD FOR ESTIMATING GILL NET SELECTIVITY ACCORDING TO FISH / MESH INTERACTION AND RELATIVE FISHING POWER

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Introduction

Estimation of gill net size selectivity is a subject of great importance in fisheries research because the results will allow, on the one hand, regulation of fishing activities, and on the other, optimization of the design and construction of gill nets used in commercial fishing. Research on gear selectivity covers both the technological aspects of the fishing gear, as well as the biological aspects of the resource, and allows us to become familiar with the interaction between the fish and the gear while the resource is being caught.

Holt's method (1963) for estimating selectivity curves is the widest used and is based on the application of a normal distribution of probabilities of the catch ratios of two or more nets, considering that there is a proportional relationship with the modal length of the fish and stretched mesh size.

There are other indirect methods that use the relationship between the fish's perimeter and its length (Hamely 1975), but there is no analytical approach that combines the data of the proportion of catch per size with data on opercular perimeter, length of fish, size of the stretched mesh, and the interaction that exists between the fish and the mesh while being caught.

In this paper we present a method that combines these parameters, emphasizing the aspects related to the fish/mesh interaction when different hanging ratio coefficients of commercial gill nets are used.

The theoretical justification of the methodology lies in taking into account the area of work (or perimeter) of the mesh as the physical parameter that is the determining factor in the selective process of gill nets.

This modified method is applied to the information compiled during an experimental study carried out in the State of Baja California Sur, where emphasis was placed on the yellow chub (*Kyphosus incisor*) selectivity of four (4) gill nets. The results are contrasted with those obtained by applying Holt's method (1963).

We applied a modified method which takes into account the total catch of 8 experimental gill nets, and the fact that the selection process by size is independent of species selectivity.

Background Information

The theory developed to estimate gill net selectivity curves is based on the principle defended by Baranov (1948) and consists of establishing a linear relationship between the modal length or average length of the fish and the size of the stretched mesh. Andreev (1966) and Fridman (1973) use this relationship to determine the optimum size of gill net meshes by means of the following formula:

$$a = K \cdot l$$

Where: a = optimum mesh size (bar)

l = average length of the fish the net was designed for

K = empirically determined coefficient

Later Holt (1957, 1963) used this principle to develop his methodology for estimating selectivity curves for gill nets. This model is based on normal distribution and presently is the most widely used method in selectivity studies, as Hamley (1975) points out. The basic relationship of Holt's model is the following:

$$Lm = K \cdot M$$

Where: Lm = modal length of the fish

M = size of the stretched mesh

K = selection factor

Regier and Robson (1966) and Hamley (1972, 1975) have shown that from a practical point of view it is unlikely that all gill nets have the same level of catch efficiency and also the same frequency distribution of the sizes caught.

Regier and Robson (op. cit.) developed alternative analysis methods to adapt Holt's regular model and at the same time generated other more complex models; however, the problems detected by Hamley (1975) still persists.

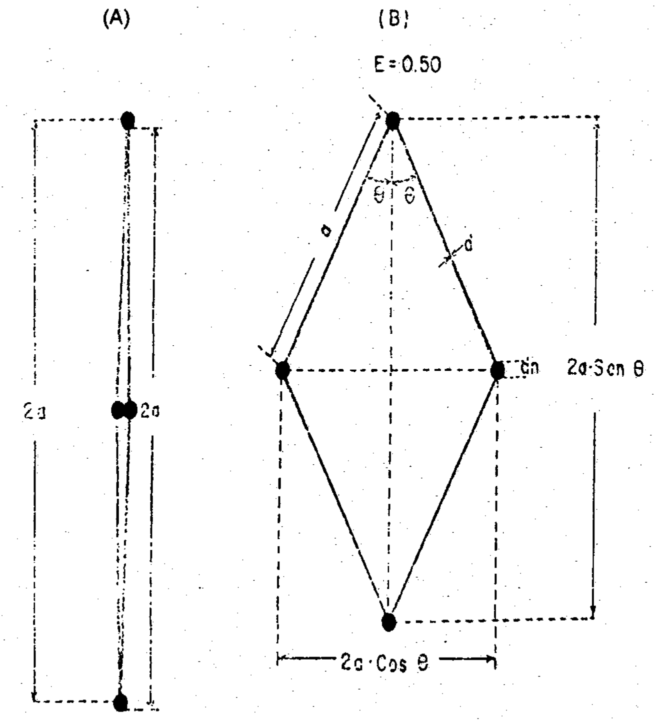


Figure 1. Geometry of the Mesh

Trent et. al. (1983) in his study on Spanish mackerel (*S. maculatus*), horse mackerel (*S. cavalla*), and bluefish (*Pomatomus saltratrix*) off the northwest and east coasts of Florida, found that variance in selectivity curves does not remain constant when the sizes of the experimental gill net meshes are increased.

Recently Clark and King (1986) estimated selectivity curves for Atlantic herring (*Clupea harengus* L.) using length/girth relations. They got the following conclusions:

- It is not neccessary to postulate behavioral differences to explain an increase in height and distribution width of gill net selection curves for a specie as mesh size increases.
- Their results support the conclusions of Pope et al (1975) who advised, on the basis of empirical data, that such assumptions are unlikely to be reliable, and that other methods should be used to adjust for gill net selection.

THEORETICAL FOUNDATIONS

Calculation of the working area and perimeter of the mesh.

The design and construction of gill nets is a determining factor in how they work mechanically since the proper combination of certain parameters such as diameter, color, twine material and resistance, size of the mesh, hanging ratio, and net flexibility have an impact during catch.

It is common for the size of the stretched mesh to be confused with the concept of mesh size; however, it is of vital importance to establish the difference from a mechanical point of view.

Figure 1(A) illustrates the basic geometry of a stretched mesh (a) measurement from the center of a given knot to the center of the opposite knot. Another way of measuring the size of the mesh is to consider the length of the bars joined by intermediate knots and add the length of a knot (Klust 1973). Figure 1(B) shows the shape of the mesh when it is hung onto a headrope with a 50.0% hanging ratio. The inside area of the mesh or the working area is a parameter that depends directly on the hanging ratio used.

Consequently the working area of the mesh depends on the working angle of the mesh, which in turn depends on the hanging ratio used when the net is being constructed.

Calculation of the working area of the mesh can be made by estimating the coefficients of horizontal opening (sin θ) and vertical opening (cos θ) by applying the following equation:

$$Am = 2a^2 \sin\theta \,.\, \cos\theta$$

Where: Am = the working area of the mesh

a = length of the bar

θ = working angle of the mesh

The size of the mesh (bar) is calculated by algebraically solving the following expression from the previous equation:

$$a = \sqrt{\frac{Am}{2\,(\sin\theta . \cos\theta)}}$$

We can also work with the concept of the working area of the mesh (P_m), which represents the perimeter of the mesh according to the opening coefficients. In this case we use the following equation:

$$P_m = 8\,(a \,.\, \sin\theta \,.\, \cos\theta)$$

Where: P_m = working perimeter

a = length of the bar

θ = working angle of the mesh

The size of the mesh (bar) can be estimated through the following equation:

$$a = \left(\frac{Am}{8\,(\sin\theta .\, \cos\theta)}\right)$$

Figure 2 also shows that by maintaining the size of the mesh (5.0 inches) constant, the working area (A_m) or the working perimeter (P_m) vary directly with the hanging ratio and the configuration of the mesh is also substantially modified.

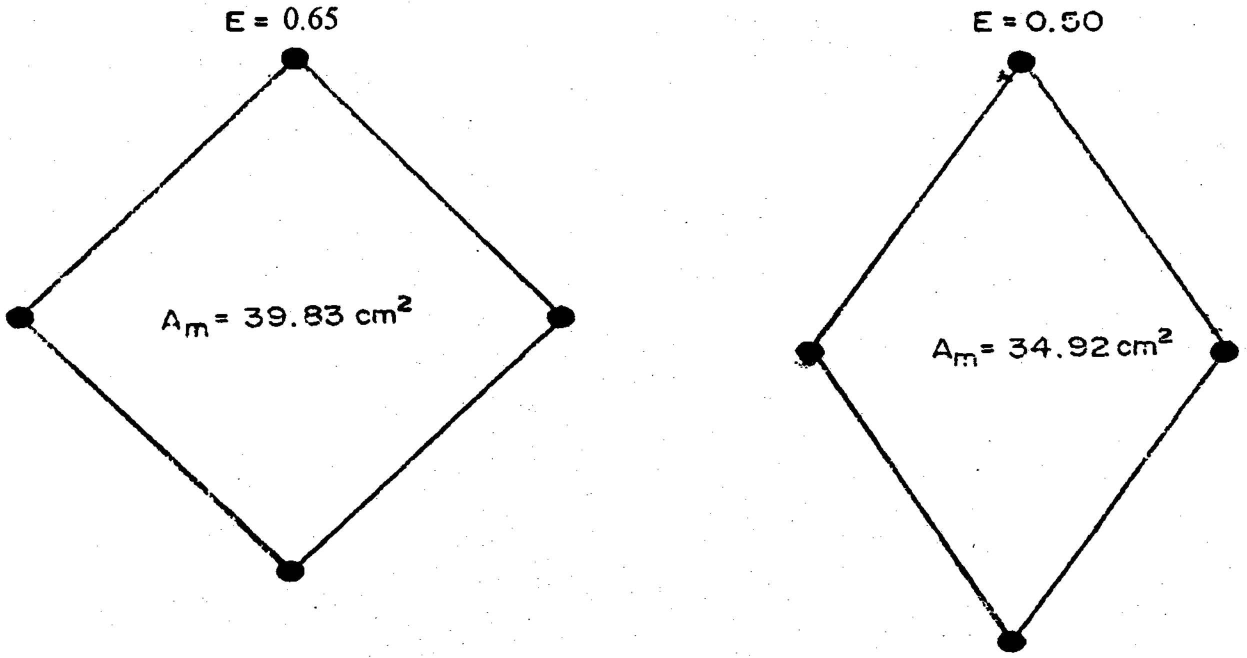


Figure 2. Geometric Configuration of a Mesh of 5.0 inches in Function to the Hanging Ratio

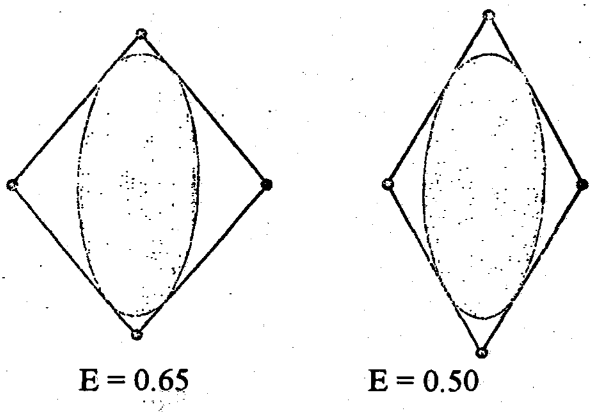


Figure 3. Interaction between the Fish/Mesh

Interaction between fish and mesh.

Taking into account the preceding information, if the area of the transversal section of a certain fish remains constant and if two gill nets with the same stretched mesh are used (5.0") and are hung at 65.0% and 50.0%, then the interaction between the fish and the mesh is different for each net (Fig. 3).

It is important to mention that when a hanging ratio of 65.0% is used, nets are constructed with less netting and are cheaper than when a hanging ratio of 50.0% is used for the same size net. Nets hung at 65.0% have the netting more tightly stretched over the headrope and therefore the mesh is tighter than when hung at 50.0% (Grande et. al. 1987a).

According to Fridman (op. cit.), catch efficiency depends heavily on the twine tension in the meshes. Evidently the effect of mesh tension can only be evaluated by comparing the results of two prototypes of net constructed with a different hanging ratio, maintaining constant the rest of the design parameters.

If we take into account that during the catch process (action) of a gill net the working area of the mesh (or the perimeter) remains constant and that the fish that are part of a stock or school have different sizes (length) and therefore vary in their morphology and geometry, then that net will catch only those fish whose opercular perimeter (girth) is compatible with the working area or perimeter of the mesh (selective process).

To make this analysis easier we should not consider the effects of the other parameters in the design of the net, such as the material, resistance, diameter, and color of the twine, nor should we consider the factors that influence the fish's behavior to increase or decrease the chance of escape. Therefore it is possible to establish the following basic equations:

(1a) $A_m = K_1 \cdot A_p$

Where: A_m = working area of the mesh

A_p = cross section of the fish at girth

K_1 = interaction coefficient between the fish and the mesh during the catch process

In practice it is wise to measure the opercular perimeter of the fish and to do this it is necessary to resort to the concept of working perimeter of the mesh in order to establish the following equation:

(1b) $P_m = K_1 \cdot S_p$

Where: P_m = working perimeter of the mesh

S_p = opercular perimeter of the fish

K_1 = interaction coefficient between the fish and the mesh during catch

On the other hand, the relationship between the opercular perimeter and the size of the fish is expressed in the following manner (Fig. 4):

(2) $S_p = K_2 \cdot L_f$

Where: S_p = opercular perimeter (or where it is snagged)

L_f = fork length

K_2 = coefficient of proportion, which depends on the fish's geometry (shape coefficient)

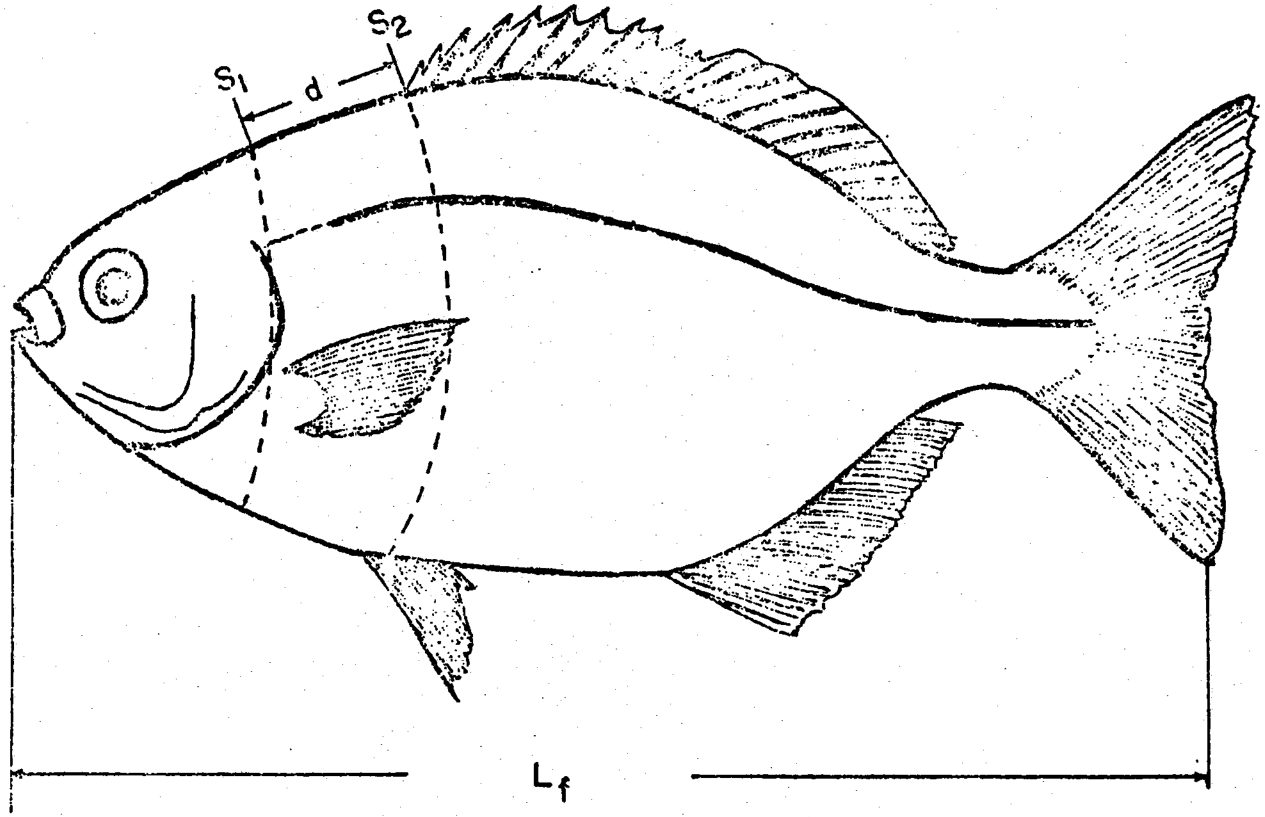


Figure 4. White or Yellow chub (*Kyphosus incisor*)

By combining the equations we obtain the following:

(3) $$P_m = \frac{K_2}{K_1} . L_f$$

The inverse relationship is expressed as:

(4) $$L_f = \frac{K_1}{K_2} . P_m$$

In virtue of the fact that this relationship is of special interest to estimate size selectivity we can define the relationship (K_1/K_2) as the coefficient of optimum size selection (K_{op}). Therefore the previous equation is expressed as follows:

$$L_f = K_{op} . P_m$$

This means that the fish-mesh interaction requires the estimate of two empirical coefficients that depend on the design of the net as well as on the morphological characteristics of the species expected to be caught.

Estimate of Selectivity Curves.

If we take into account the theoretical framework already described, we can go back to the normal model of estimating selectivity curves developed by Holt (1963). The catch equation by size that resulted is the following:

$$C_l = n.\ P_l.\ q_r .V.\ \exp^{-(l-lm)^2/2s^2}$$

Where:C = catch in number of fish length (l)

n = number of operations

P_l = number of fish length (l) caught by the fishing gear

V = vulnerability of the species to the fishing gear

q_r = relative fishing power of the gear referred to the average length (lm) of the normal selectivity curve with standard deviation (S) - the length for which this fishing gear is most efficient.

The practical application of the normal model states that the fishing power of the two gill nets is practically the same (Holt 1963); however, Hamley (1972) shows that the catch capacity of two or more gill nets is different. Leslie and Davis (1939) and Delury (1947) cited by Hamely (1972) establish that it is possible to evaluate the catchability coefficient of gill nets if and when they operate independently. The basic relationships are the following:

$$\left(\frac{C}{X}\right)_t = No.\ q - q\,\Sigma\,C_t$$

$$L_n\left(\frac{C}{X}\right)_t = L_n(\ No.\ q) - q\,\Sigma\,X_t$$

Where:C = catch

X = fishing effort

No = initial fish stock

q = catchability coefficient

t = time interval

The catchability coefficient estimated by any of these methods is used as an indicator of the relative fishing power of each net and is incorporated into the normal selectivity model.

Based on the described theoretical model, the suppositions of the modified model are as follows:

1. The catch proportions by size of 2 gill nets whose mesh working area take on a normal probability distribution.

2. Increases in the working areas or perimeters of the mesh lead to proportional increases in the modal lengths of the fish caught.

3. Fishing power or catchability coefficient determine the degree of catch efficiency of the gill nets and therefore the height of the selectivity curves.

4. Variance in selectivity curves does not necessarily remain constant since variance is influenced by the gill nets' catch process; that is, if the fish are gilled or entangled in the netting, and also by the variety of species caught and the catch efficiency level of each method.

5. Catch efficiency depends on the best combination of several physical parameters inherent in the design and construction of the net, as well as on biological parameters inherent to the species to be caught, and finally, the meteorological conditions prevailing during the catch process.

APPLICATION OF THE MODIFIED MODEL

An evaluation and optimization study of bottom gill nets off the east coast of Baja California Sur was carried out from April, 1985 - November, 1986 (Grande et. al. 1987a). Eleven types of selected gill nets were chosen as the most representative of the Baja California Sur area. The area of work covered from Loreto, Baja California to Los Frailes, Baja California (Fig. 5).

The nets were designed in such a way so as to be able to make the technical comparisons necessary in the indexes of catch and selectivity efficiency by size. Therefore, by maintaining constant the size of the net (length and height), the color of the twine (green), and the material (monofilament nylon), we experimented with the diameter of the twine (0.40 to 0.70 mm) and the size of the stretched mesh (8.89 to 17.78 cm.) against the hanging ratio, which was 65.0% and 50.0% (Fig. 6 and Table 1).

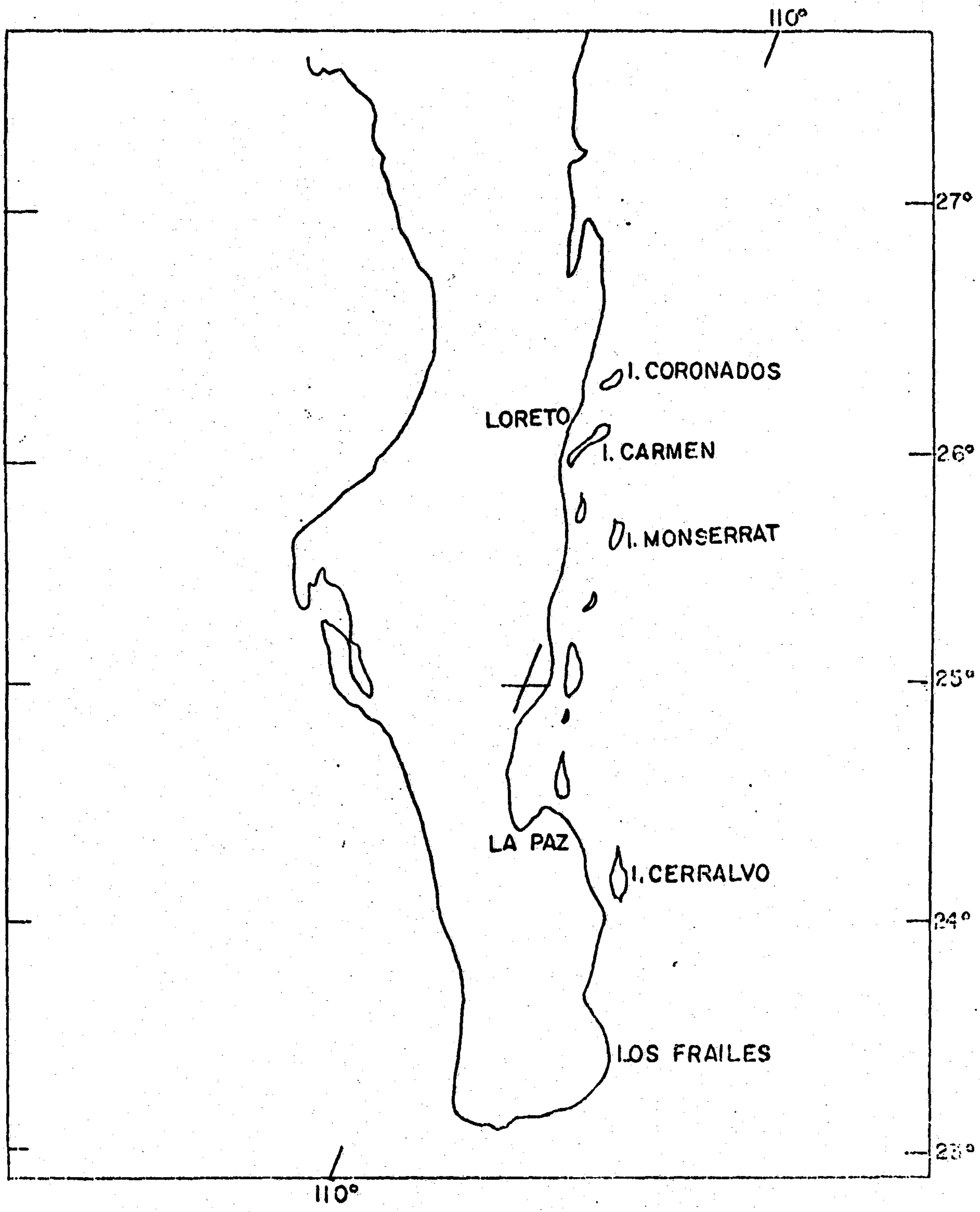


Figure 5. Study Area

For the effects of selectivity analysis we chose 8 nets which could be compared to each other. The other 3 nets were experimented with to meet the objectives of comparison of technical and economical efficiency.

During the period under study we carried out 8 fishing cruises, experimenting with an average of 6 nets per trip. The method used during the experiment was exploring the fishing area to locate the best grounds, taking into account the type of

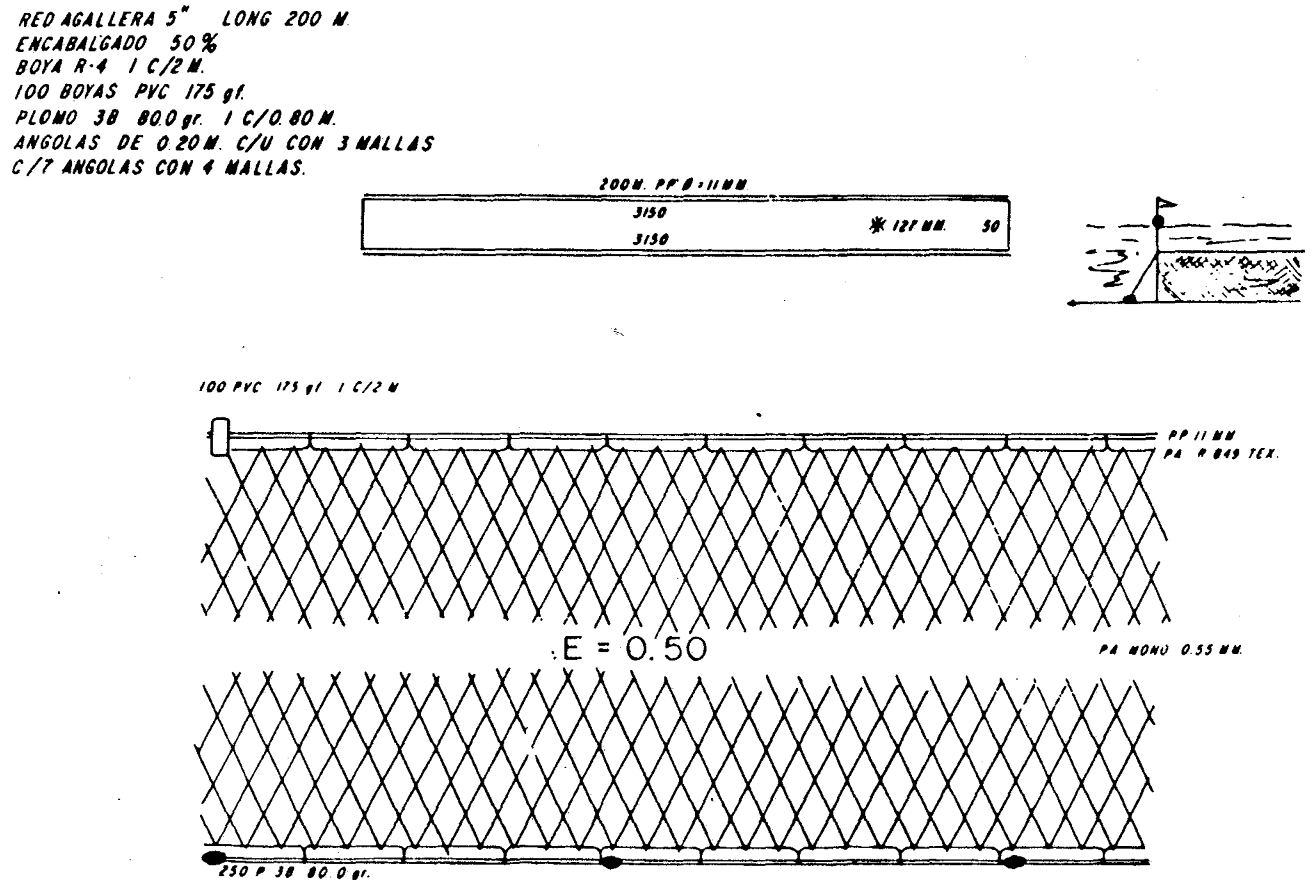


Figure 6. Gill Net Type Pamo 0.55/5.0/50

Table 1. Technical Characteristics of the Experimental Gill Nets.

Perimeter of Gill Net (PAMO)	Lgth (m)	Hght (m)	Size of Mesh (cm)	Hanging Ratio (%)	Working Area (m^2)	Buoyancy of Floats (KGF)	Weight of Sinkers (KGF)	N AP
0.40/3.5/65	200	3.36	8.89	65.0	671.3	17.5	21.31	0.490
0.40/3.5/50	200	3.85	8.89	50.0	769.8	17.5	21.31	0.432
0.55/5.0/65	200	4.82	12.7	65.0	967.0	17.5	19.91	0.492
0.55/6.0/65	200	5.77	15.24	65.0	1157.0	15.0	21.04	0.492
0.55/5.0/50	200	5.50	12.70	50.0	1099.0	17.5	21.31	0.433
0.55/6.0/50	200	6.58	15.24	50.0	1316.0	17.5	21.31	0.430
0.70/4.0/50	200	4.40	10.16	50.0	880.0	17.5	21.31	0.433
0.70/5.0/50	200	5.50	12.70	50.0	1099.0	17.5	21.31	0.433
0.70/7.0/65	200	6.74	17.78	65.0	1349.0	15.0	21.03	0.494
0.70/7.0/50	200	7.90	17.78	50.0	1539.9	17.5	19.91	0.434
*1.20/5.0/40	200	5.08	12.70	40.0	1018.0	16.0	21.10	0.480

PAMO = Twine of Nylon Monofilament
N AP = Efficiency of Netting Utilization

* PAMU = Twine of Nylon Multifilament

bottom, depth, and favorable currents to use the nets.

The nets were setted simultaneously in the selected sites in such a way that the catch would be intercomparable. The nets were handled in the traditional fashion used by the fishermen in Baja California Sur, from 7 p.m. till 7 a.m. the next day, varying the time by one hour more or one hour less. Therefore the fishing time was kept constant during all the attempts at experimental fishing and for all types of nets.

Mixed catches were separated by species and the fork length, opercular perimeter, and weight of the fish caught in each set were measured.

The effective work was carried out in 53 days of fishing, 177 sets or throws, for a total of 2,124 hours of fishing, for which 198,769 m^2 of netting was used. The overall catch was 6,563 fish of different species, equivalent to 7,547.7 kg. (Table 2). The percentage composition of the catch varied in each cruise (Fig. 7, Fig. 8), however, the most representative species in the catches (23.8%) was white or yellow chub (*Kyphosus incisor*). The selectivity's analysis of yellow chub (*K. incisor*) was for four types of nets; which are catching enough samples. These nets are coded C, D, E and F, and were constructed with meshes of 12.70 cm (5.0") and 15.2 cm (6.0") and hanging ratio of 50.0% and 65.0% (Grande et al 1987b). Measurements of the opercular perimeter in the gilling zone for chub (*K. incisor*) caught in each one of the nets under study is related to the fork length, in an effort to estimate the shape coefficient (K_2). Figures 9 to 12 show these relationships, and also indicate the straight line with the best statistical fit.

Values for the shape coefficient (K_2) also vary depending on the gill net used. Figure 13 shows the variation in this coefficient depending on the average lengths caught in the 4 nets under study. We can observe that the range of coefficient variation is narrow, between 0.7 and 0.8, and moves toward the right when the average catch length is increased.

Table 2. Results of Catch, Fishing Effort and Efficiency Index.

Results of Gill Net (PAMO)	**Fishing Effort**			**Total Capture**		**Efficiency Indices of Capture**					
	# of throws	Time (hrs)	Area (m^2)	No.	Kg.	C/Throw No.	C/Throw Kg.	C/Hour No.	C/Hour Kg.	C/100 m^2 No.	C/100 m^2 Kg
0.40/3.5/65	8	96	5362	915	470.5	114.3	58.82	9.53	4.90	17.06	8.77
0.40/3.5/50	2	24	1539	126	77.0	63.0	38.50	5.25	3.21	8.18	5.00
0.55/5.0/65	17	204	16439	499	564.3	29.3	33.19	2.44	2.76	3.03	3.43
0.55/6.0/65	12	144	13884	217	329.1	18.1	27.42	1.50	2.82	1.56	2.37
0.55/5.0/50	37	444	40663	2232	2384.1	60.3	64.43	5.03	5.37	5.49	5.86
0.55/6.0/50	12	144	15792	553	537.7	46.1	44.80	3.84	3.73	3.50	3.40
0.70/4.0/50	3	36	2640	22	14.4	7.3	4.80	0.61	0.40	0.83	0.54
0.70/5.0/50	30	384	35168	1021	1256	31.9	39.25	2.65	3.24	2.90	3.50
0.70/7.0/50	9	108	13859	179	465.0	19.8	51.66	1.66	4.30	1.29	3.35
0.70/7.0/65	23	276	31027	443	623.7	19.2	27.11	1.60	2.26	1.42	2.01
1.20/5.0/40	22	264	22396	356	825.9	16.1	37.54	1.35	3.13	1.59	3.70
	177	2124	198769	6563	7547	37.1	42.64	3.09	3.23	3.30	3.80

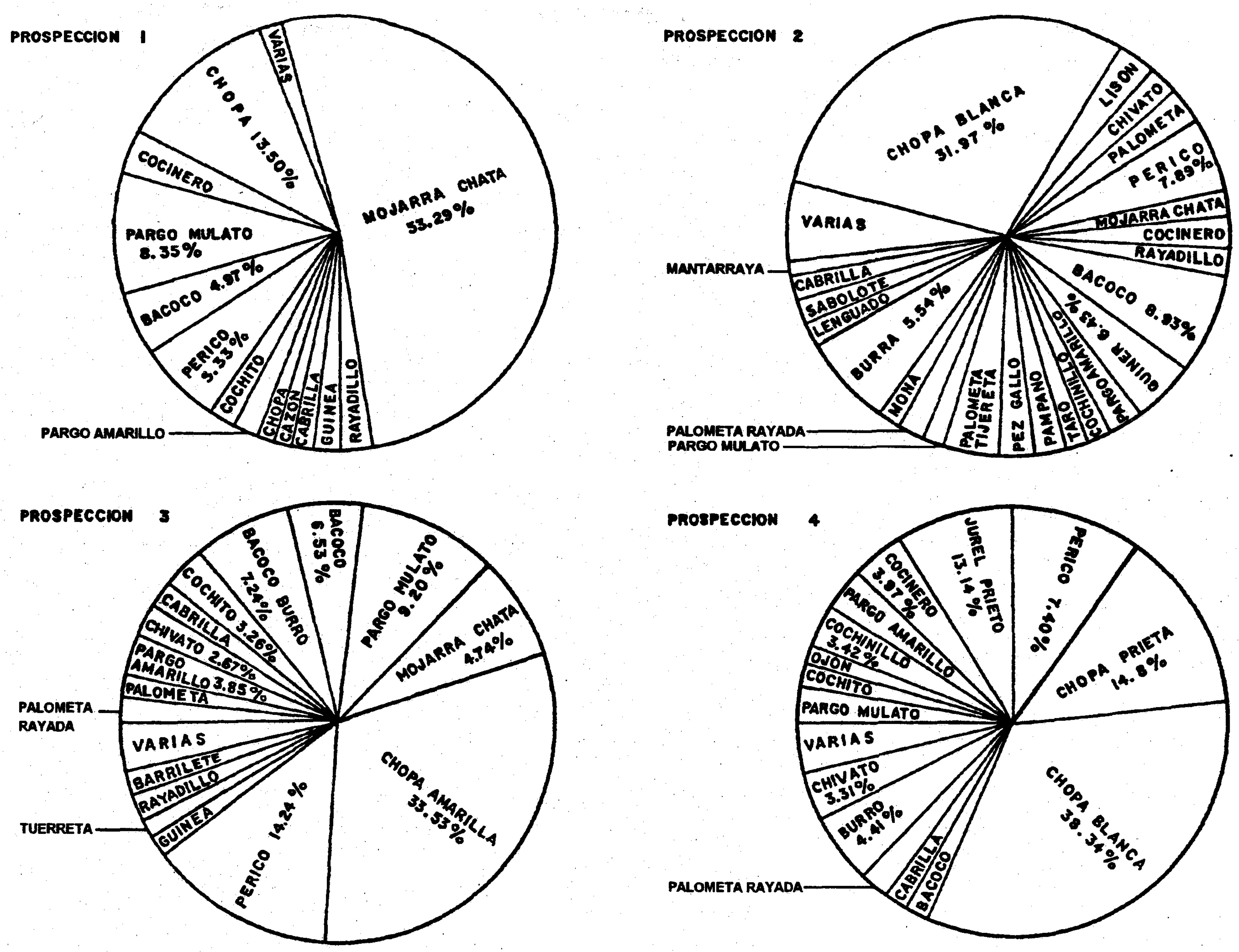


Figure 7. Catch Composition

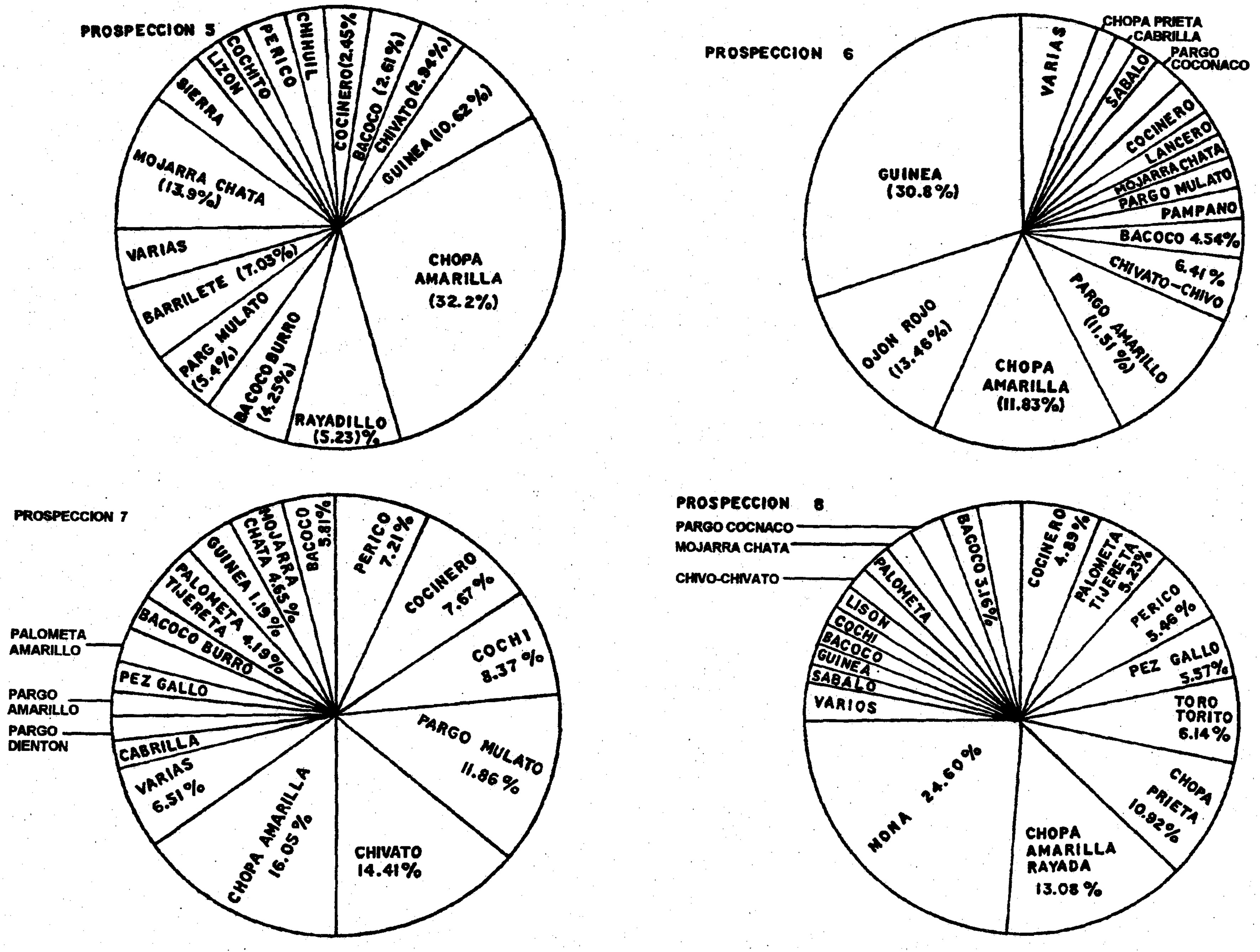
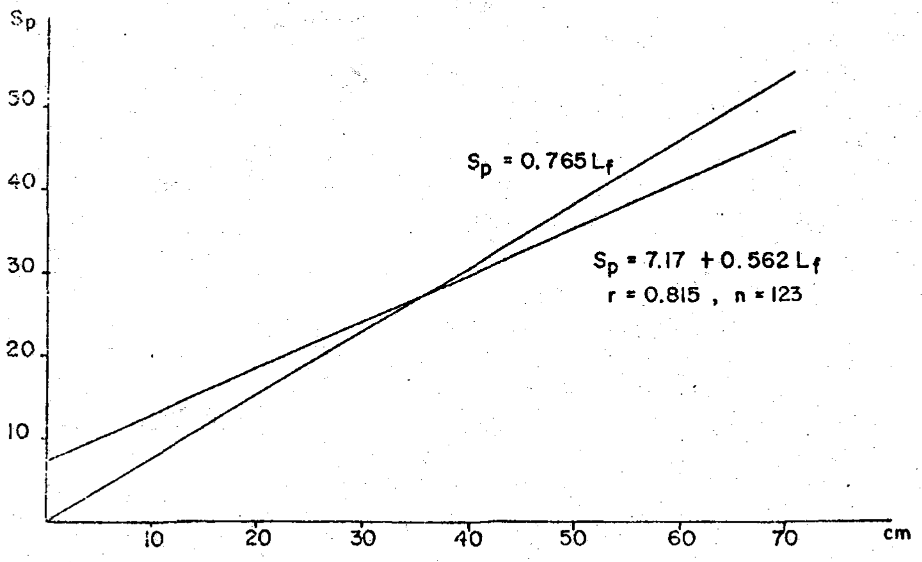
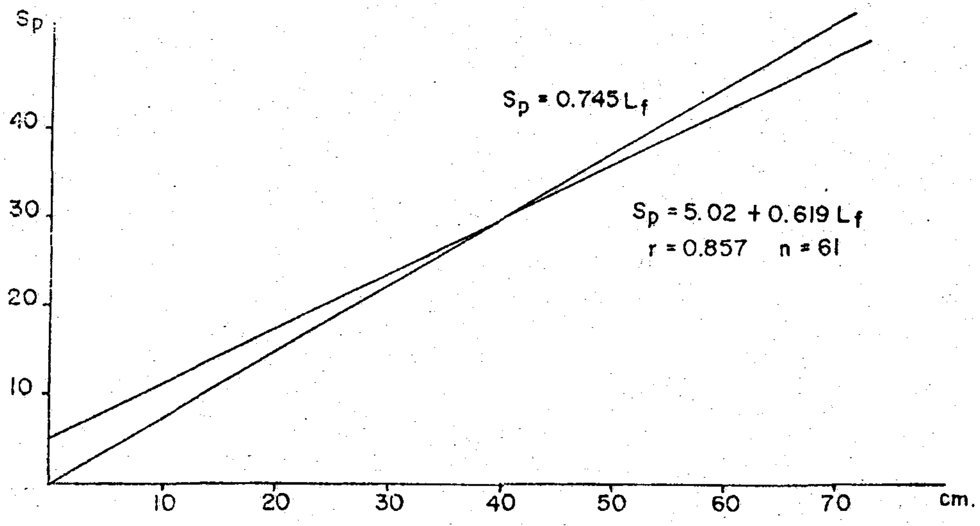


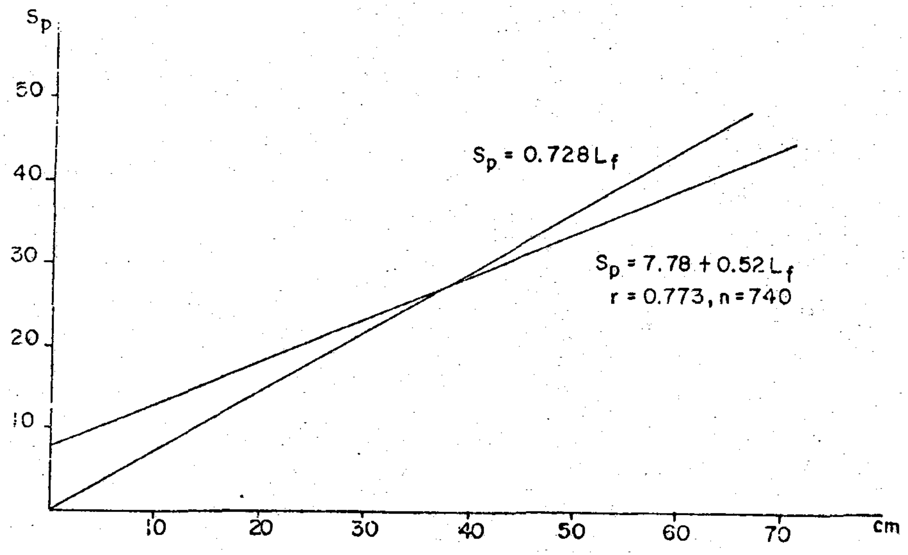
Figure 8. Catch Composition



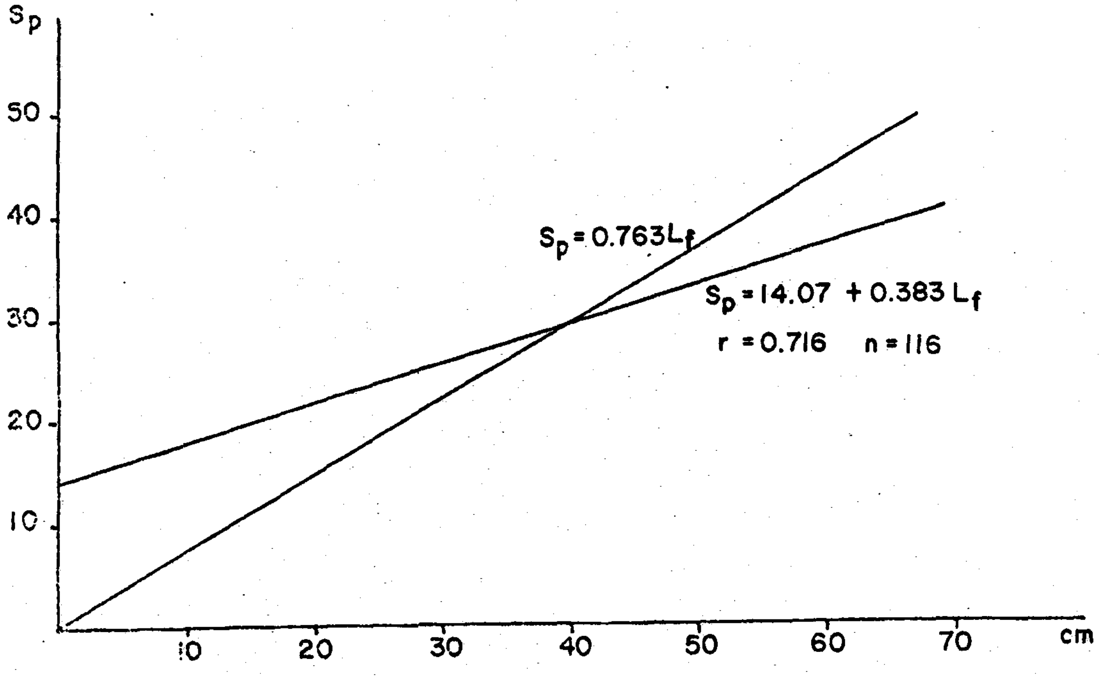
NET (C)



NET (D)



NET (E)



NET (F)

Relationship between Opercular Perimeter and Fork Length of Chub (Kyphosus incisor) for: **Figure 9**. NET (C), **Figure 10**. NET (D), **Figure 11**. NET (E), and **Figure 12**. NET (F).

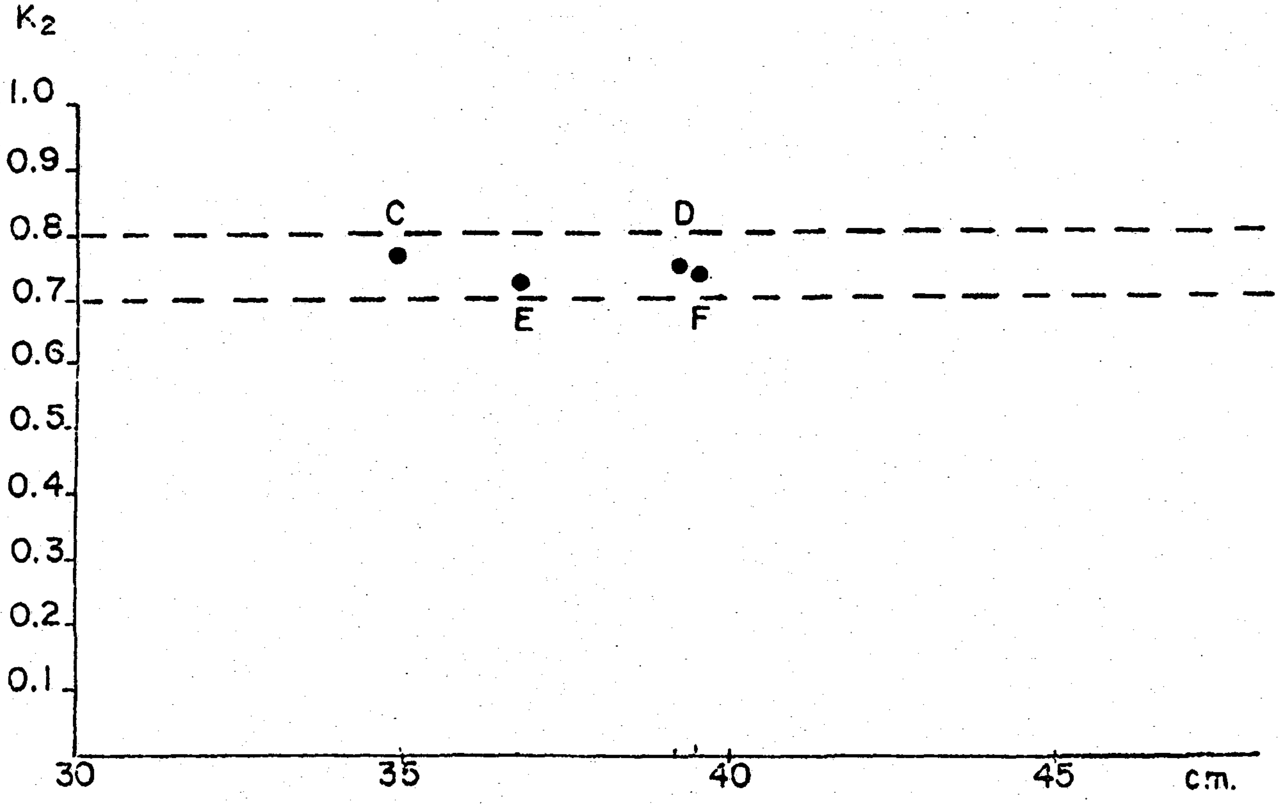


Figure 13. Variation of the Coefficient (K_2) in Function to the Fork Length of Chub (*Kyphosus incisor*)

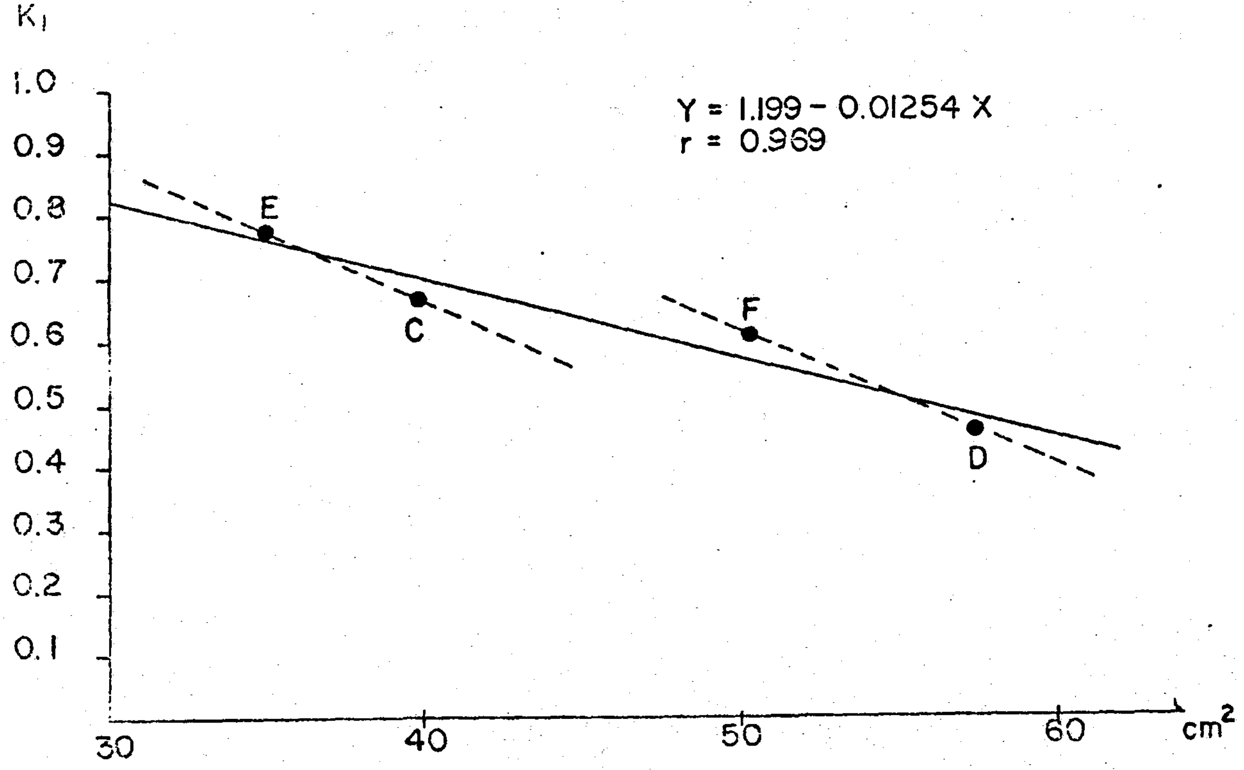


Figure 14. Variation of Coefficient (K_l) in Function to the Mesh's Working Area

The area for the girth of the fish is hard to calculate, especially since the shape of the fish (transversal cross section) is highly variable and not necessarily in the shape of a regular ellipse, since this depends on its biological condition at a given moment.

Based on this, and taking into account that the perimeter of the fish (Sp) can easily be measured, we decided that an approximation of the coefficient of interaction between the fish and the mesh (K_l) as the relationship between the opercular perimeter (Sp) and the working area of the mesh used (Am).

Figure 14 shows the variation of this coefficient depending on the working area of the mesh for the 4 nets being studied. We can observe a tendency toward a drop in value as the working area of the mesh increases. The disadvantage of this relationship lies in the combination of different units; that is, the fish's perimeter is measured in centimeters and the area of the mesh in cm^2.

Therefore it is best to use the working perimeter of the mesh (Pm) to obtain an adimensional coefficient (K_1).

Estimation of the catchability coefficient (q) of the gill nets used in the experiment was made by accepting that the fishing effort applied is independent between the various gill nets.

The relationship between the natural logarithm of CPUE with respect to accumulated fishing effort can be seen in Figure 15. The overall value of the catchability coefficient was $q=1.01032x\ 10^{-3}$, which was proportionately distributed among the 11 types of experimental gill nets.

Figure 16 shows the catch capacity of each type of net. We can see that net (E), built with a mesh size of 12.70 cm. (5.0"), monofilament twine of 0.55 mm, and with a 50.0% hanging ratio attained the highest efficiency.

The catch ratios for chub (*Kyphosus incisor*) for the 4 nets under consideration meet the theoretical requirement for normality (Fig. 17).

The theoretical supposition of proportionality with the mean length of the chub (*K. incisor*) and the sum of the net's working area is met, (Fig. 18 and Table 3). We can observe that the optimum selectivity coefficient (Kop) obtained by means of the best statistical fit, has a value of Kop = 0.7802.

When we use the working perimeter (Pm) of the mesh instead of the working area (Am), the value of the selectivity coefficient reaches a value of Kop = 1.3491 (Fig. 19 and Table 4).

The selectivity curves estimated according to the working area of the mesh and the relative fishing power or catch capacity (q) is illustrated in Figure 20. One can clearly see the differences in the catch efficiency of each gill net, especially net (E), which reaches a catch probability of almost 0.20 for size 27.24 cm.

It is important to mention that these curves were calculated by using the variance value arrived at from the analysis of each pair of nets. This means that the average value for variance of all the nets was not used, in line with the criteria defined by Holt (1963). The most important reason for proceeding in this fashion is the fact that the distributions of size frequency obtained for each gill net are quite different among themselves. Similar treatment was given by using the concept of working perimeter (Pm) of the mesh using independent variance for each selectivity curve (Fig. 21). In addition to this, calculations were made using the average value for variance. These curves are shown in Figure 22.

A quick analysis of statistical variation of the modal lengths calculated for the working area (Am) and the working perimeter (Pm) of the mesh, compared to the modal lengths observed in the size frequency distributions show that the coefficient of variation (Cv) calculated for the estimates of modal length according to the working area (Am), which reaches a value of Cv = 0.2221 (Table 5) and when it is calculated, in function to perimeter (Pm); the coefficient Cv = 0.1284.

These results set the guidelines for preferring in this case estimates of modal length according to the working perimeter of the mesh.

It is interesting to compare the selectivity curves estimated by applying the direct method described by Holt (1963). Figure 23 shows the relationship between the modal lengths and the sum of the sizes of the stretched mesh (Σmi). The selectivity factor estimated by means of the best statistical fit is K = 2.91. Table 6 has the calculations and we can observe that the lengths calculated are identical for each pair of nets. The standard deviation can only be calculated for the combination of nets (F/E). The estimated selectivity curves are shown in Figure 24 and we can see that by using this analytical method it is not possible to detect difference in the shape and height of the curves. In addition to this, it is also likely that we cannot discriminate the effect of the hanging ratio when the size of the mesh is held constant.

In virtue of the fact that the bottom gill nets used in tropical areas are not selective with respect to the species caught, we carried out the necessary calculations to estimate selectivity curves for the 8 experimental gill nets, taking into account the overall catch for each net without species discrimination. It was done this way because in practice fishermen use all the species caught by the nets.

Figures 25-27 show the results for the 8 previously mentioned gill nets. It is interesting to point out that in Figure 26 the proportional ratio with modal lengths and the

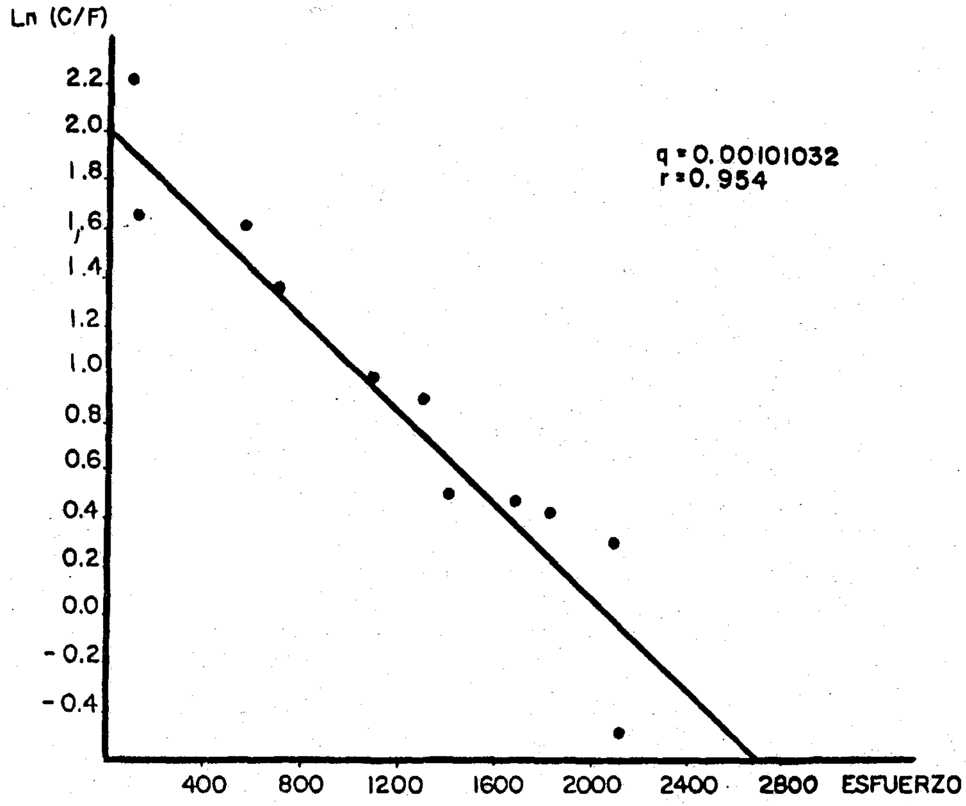


Figure 15. Relationship between the Catch Efficiency and the Fishing Effort

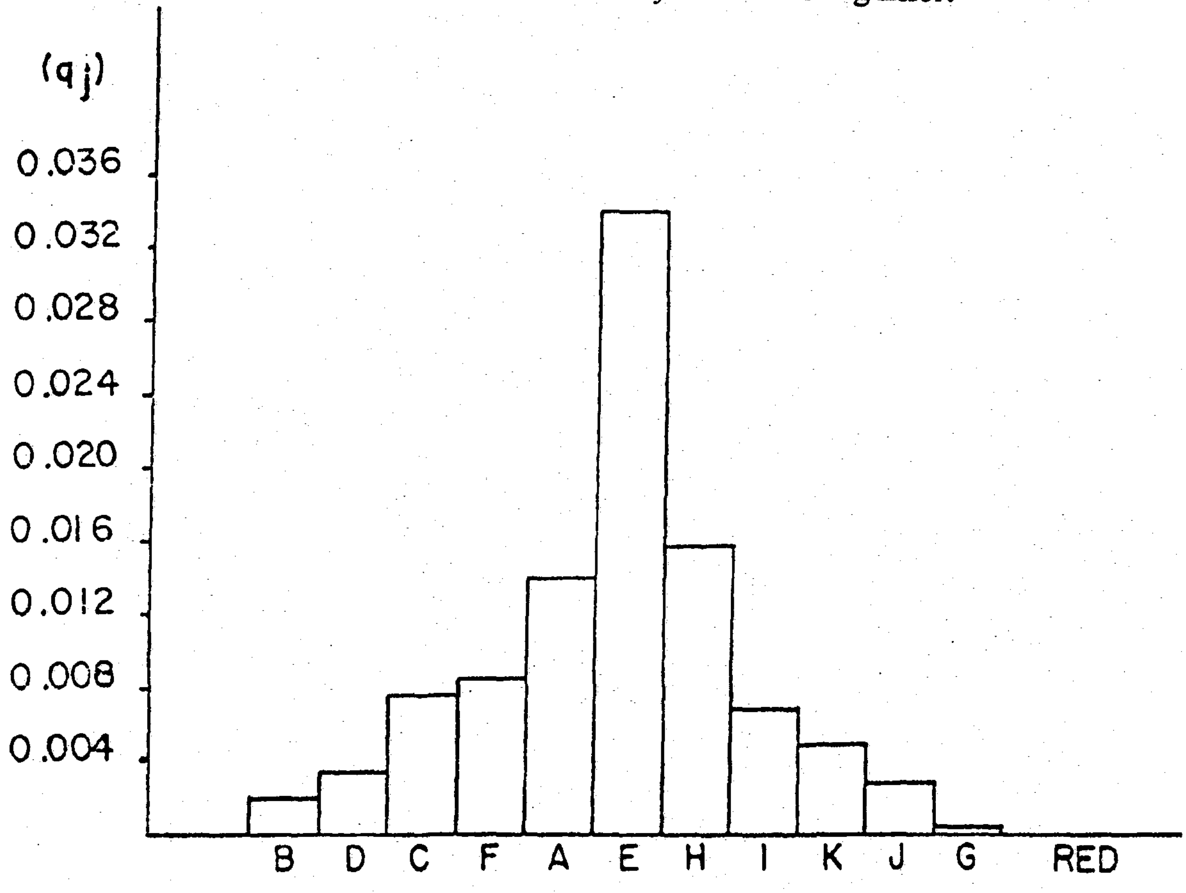


Figure 16. Catching Efficiency for the Gill Nets. De Lury's Method (1947)

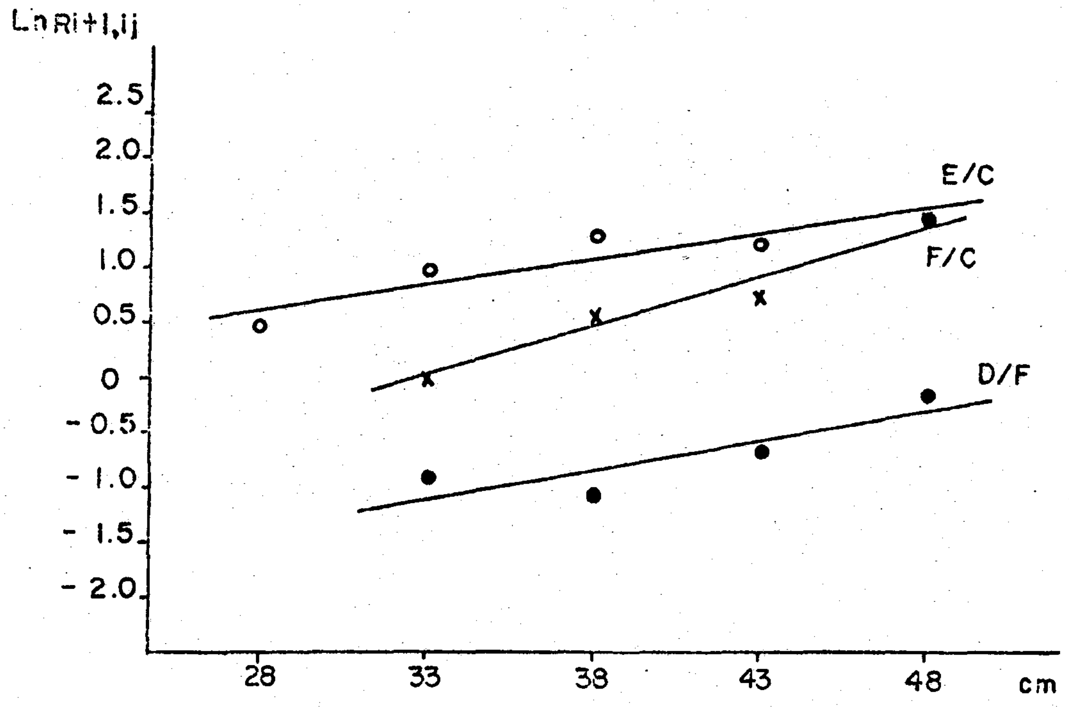


Figure 17. Relationship between Ln (Ri + I,ij) and the Sizes for the Chub (*Kyphosus incisor*)

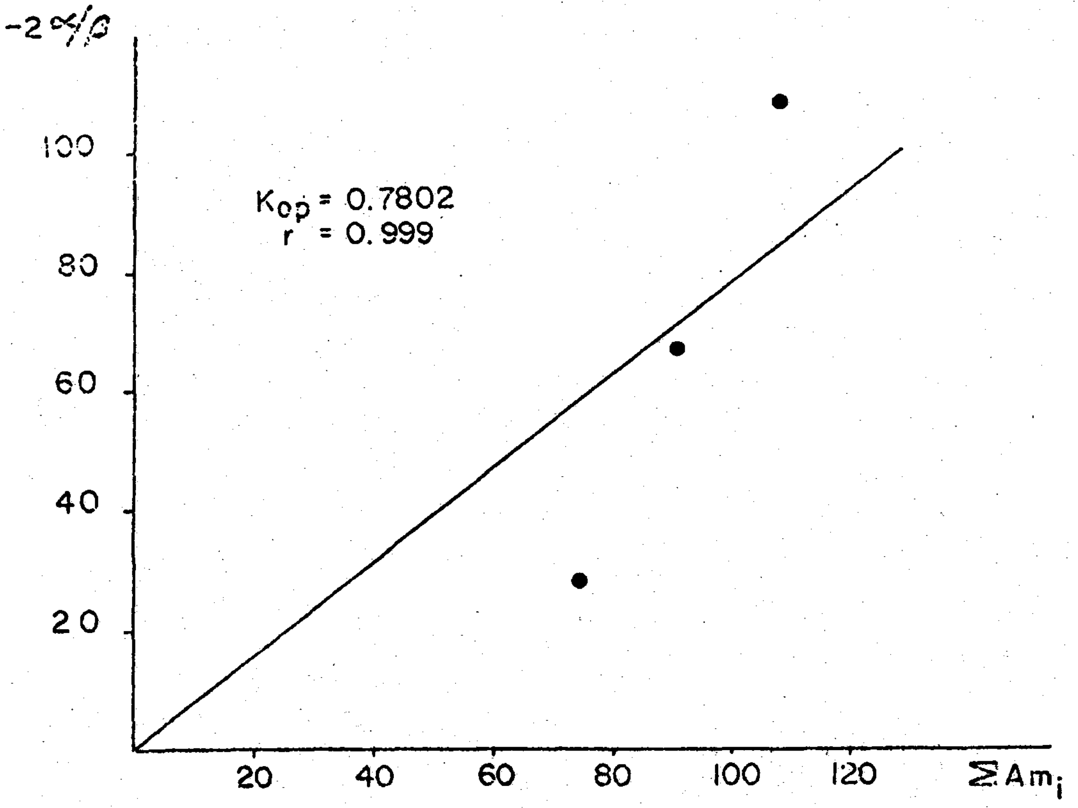


Figure 18. Relationship between Modal Lengths and Mesh's Working Area for Chub (*Kyphosus incisor*)

Table 3. Perimeters of Selectivity for Yellow Chub (*Kyphosus incisor*) in Function to the Mesh's Working Area.

Net	AM	α	β	ΣAMI	-2 α/β	LM CAL	δ²	δ
E	34.92	-0.6244	0.04473	74.75	27.92	27.24	85.85	9.27
C	39.83	-3.0343	0.09157	90.11	66.27	31.08	80.00	9.43
F	50.28	-2.8239	0.05207	107.65	108.47	39.23	106.2	10.3
D	57.37					44.76		

Table 4. Perimeters of Selectivity for Yellow Chub (*Kyphosus incisor*) in Function to the Mesh's Working Perimeter.

Net	PM	α	β	ΣPMI	-2 α/β	LM CAL	δ²	δ
E	22.00	-0.6244	0.04473	47.00	27.92	29.68	90.54	9.52
C	25.00	-3.0343	0.09157	51.40	66.27	33.73	20.64	4.54
F	26.40	-2.8239	0.05207	56.30	108.47	35.62	93.14	9.65
D	30.00					40.47		

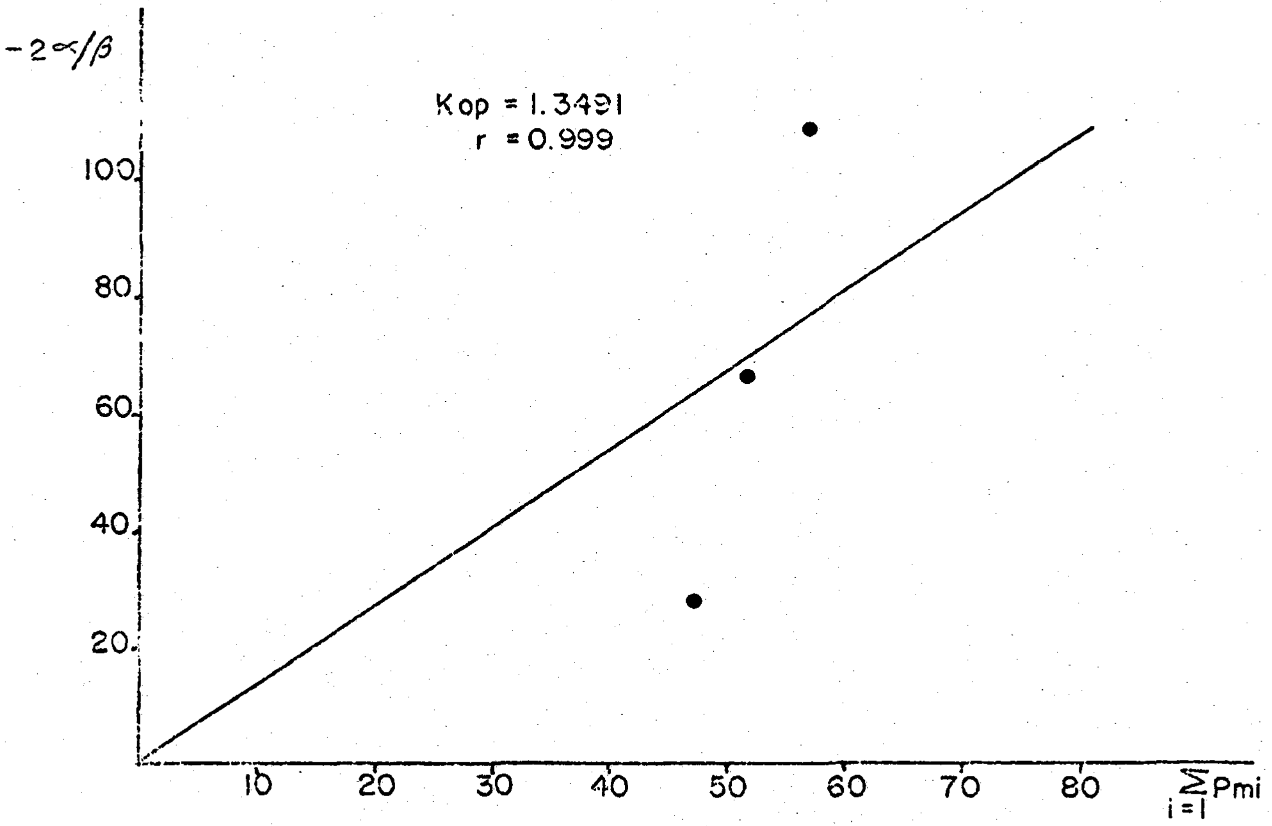


Figure 19. Relationship between the Modal Lengths and Mesh's Working Perimeter for Chub (*Kyphosus incisor*)

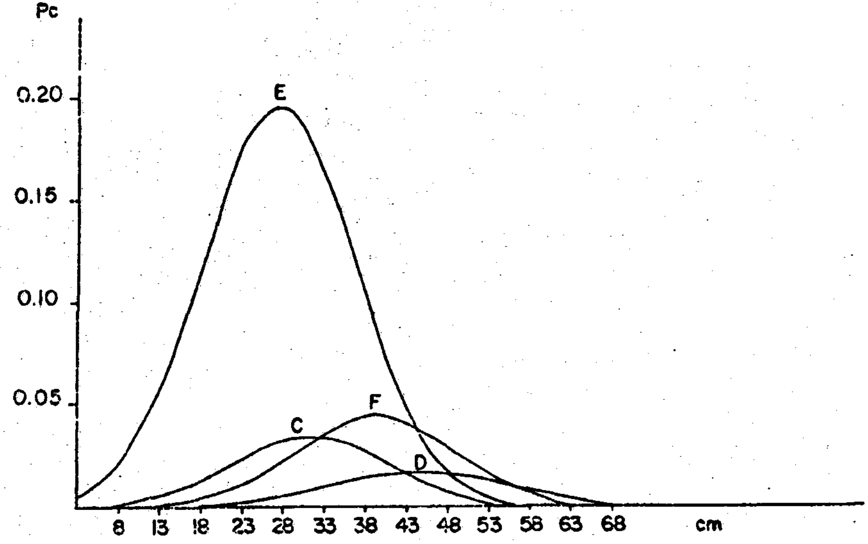


Figure 20. Selectivity Curves for Chub (*Kyphosus incisor*) Estimates in Function to the Mesh's Working Area and Fishing Power ($\delta_1 \neq \delta_2$)

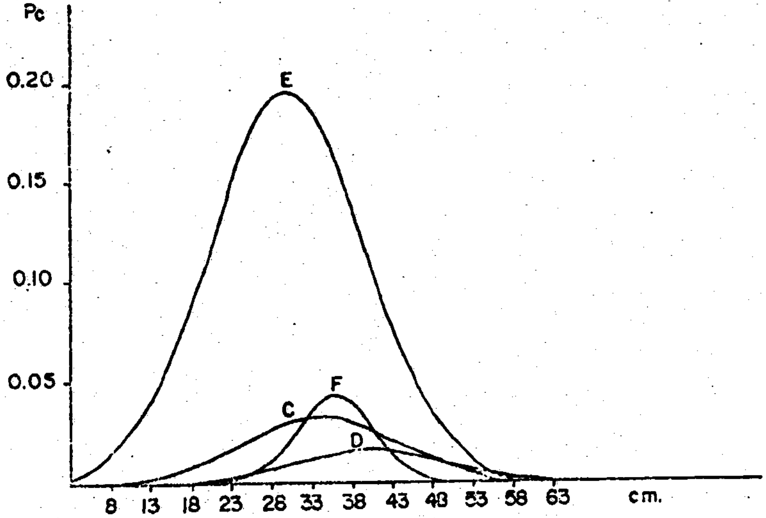


Figure 21. Selectivity Curves for Chub *(Kyphosus incisor)* Estimates in Function to the Mesh's Working Perimeter and Fishing Power ($\delta_1 \neq \delta_2$)

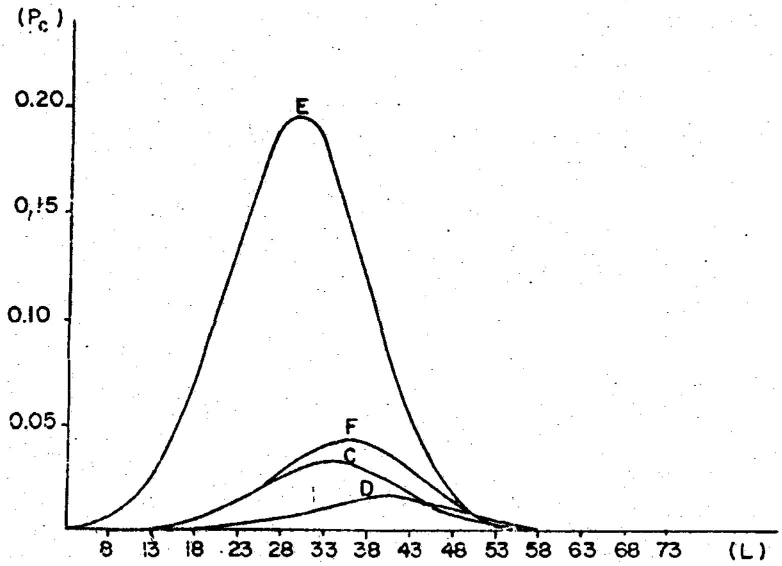


Figure 22. Selectivity Curves for Chub (*Kyphosus incisor*) Estimates in Function to the Mesh's Working Perimeter and Fishing Power ($\overline{\delta^2}$)

sum for the working areas of the meshes show a good fit for this range of mesh sizes 8.89 cm. (3.5") to 15.24 cm. (6.0"), independent of the hanging ratio used. In this case the optimum selectivity coefficient is 1.042; however, when we include nets with mesh sizes 17.78 cm. (7.0") in the linear regression analysis, we lose the proportionality between both variables (Table 7).

Finally, we found that the catch efficiency expressed in natural logarithm (No/h) drops proportionally when the working area of the mesh is increased. Figure 28 shows this linear relationship and we obtained a correlation coefficient (r) of 0.875. When we establish the relationship dependent on the working perimeter of the mesh (Pm), then our correlation coefficient (r) increases to 0.890 (Fig. 29).

Discussion

Hamley (1975) and Pope, et. al. (1975) revised the indirect methods used in fisheries biology to estimate selectivity curves and concluded that these methods are based on the supposition that all mesh sizes show the same degree of efficiency in the optimum sizes and that the width of the distribution for each curve remains constant.

Clarke and King (1986) show in their study on Atlantic herring (*Clupea harengus*) that it is not necessary to establish postulates on the differences in fish behavior to explain increases in the height and width of selectivity curves for a species as the size of the mesh is increased. They also indicate that their results support Pope et. al. (1975) in their conclusions in that it is not likely that these suppositions are trustworthy and that other methods should be used to fit gill net selectivity curves.

Based on this statement and taking into account the theoretical framework described in this study, we can observe that the results obtained are congruent and reflect consistently the catch and selectivity process of bottom gill nets used off the coast of Baja California Sur.

Apparently the physical parameters of the mesh, such as the area (Am) and the working perimeter (Pm) can be directly used in the model of normal distribution, substituting the size of the stretched mesh.

The modified normal model also takes into account the effect of the catch capacity of gill nets by incorporating the catchability coefficient (q).

Table 5. Comparison of the Coefficient of Variation for Modal Lengths.

Modal Length Net	LMOB	LMC/(AM)	LMC/(PM)
C	35.50	31.08	33.73
E	39.43	27.24	29.68
F	41.59	39.23	35.62
D	43.44	44.76	40.47
ΣX	159.96	142.31	139.5
$\overline{X}$	39.99	35.58	34.88
δ(n-1)	3.413	7.904	4.478
CV	0.0853	0.2221	0.1284

LMOB = Modal Length Observed
LMC/(AM) = Modal Length Calculated as a Function of the Working Area
LMC/(PM) = Modal Length Calculated as a Function of the Working Perimeter
CV = Coefficient of Variation

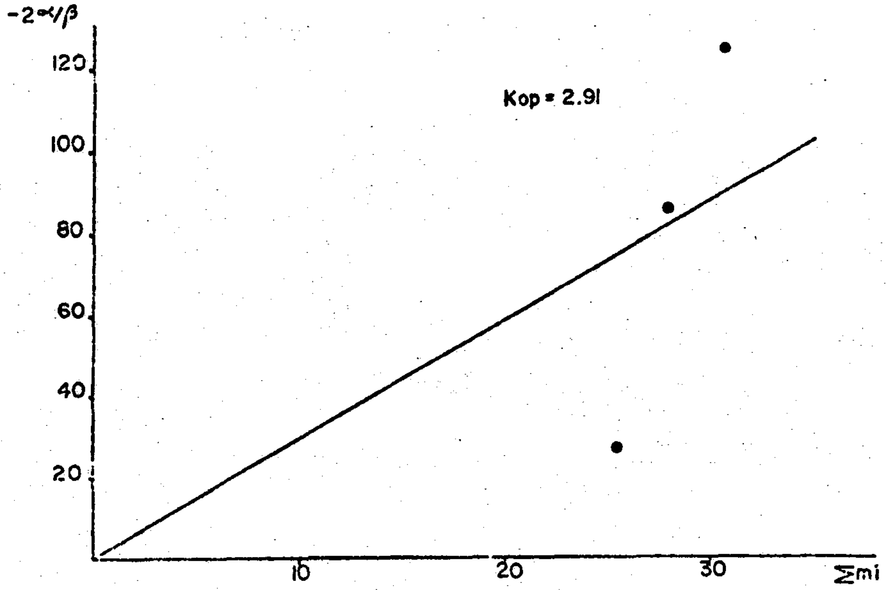


Figure 23. Relationship between the Modal Lengths and Mesh Sizes for Chub (*Kyphosus incisor*).

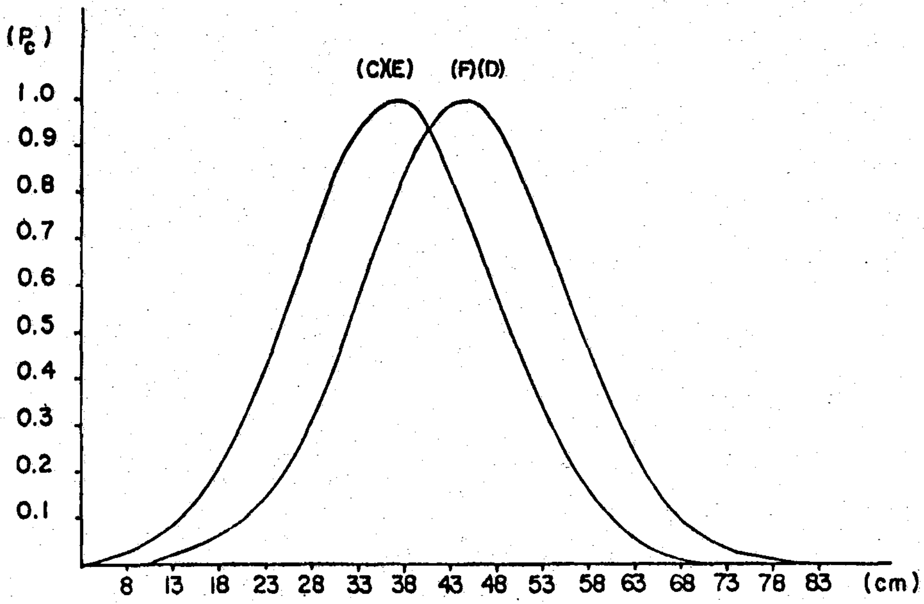


Figure 24. Selectivity Curves for Chub (*K. incisor*) Caught by the Gill Nets (C, D, E, F)

Table 6. Parameters of the Selectivity Curves for Chub (*K. incisor*), in Function of Stretched Mesh.

Perimeter / Net	α	β	$-2\,\alpha/\beta$	$\sum_{I=1}^{N} MI$	$\bar{L}CAL$	δ	R
C	0.5818	0.0435	26.75	25.40	36.96		0.915
E	-2.7125	0.06334	85.65	27.94	36.96	10.80	0.978
F	-3.220	0.05194	123.99	30.48	44.65		0.864
D					44.65		

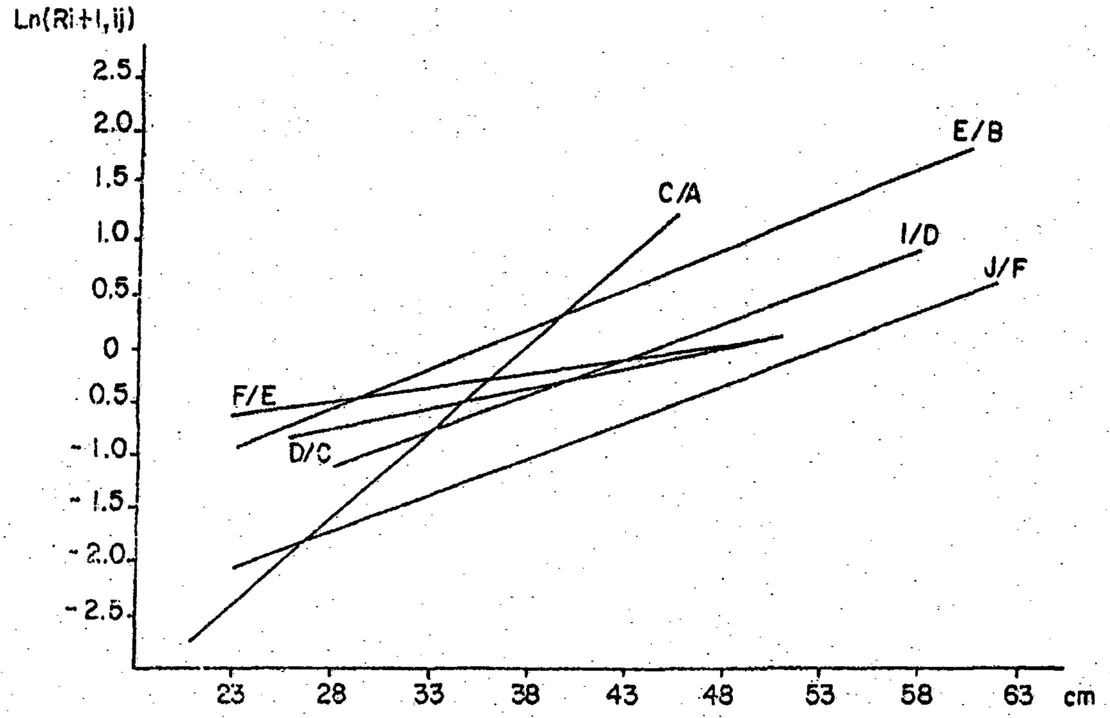


Figure 25. Relationship between Ln (Ri + I, ij) and Lengths of the Species.

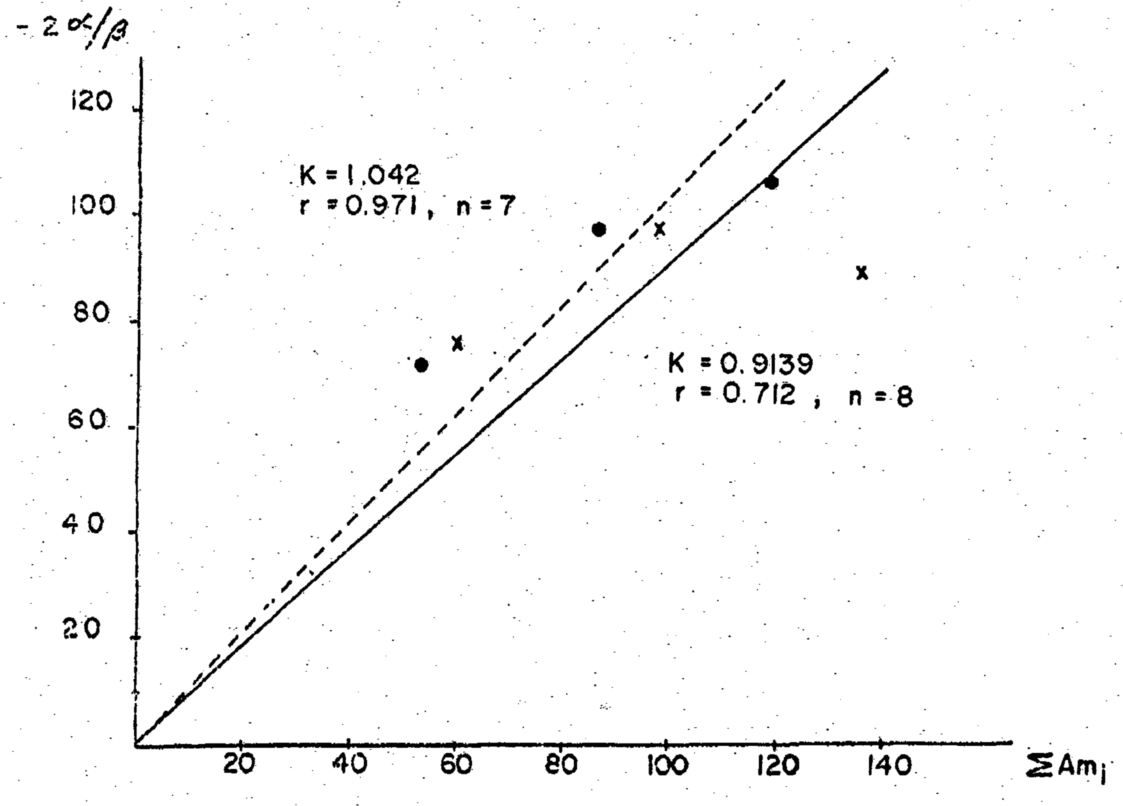


Figure 26. Relationship between the Modal Length and Mesh's Working Area.

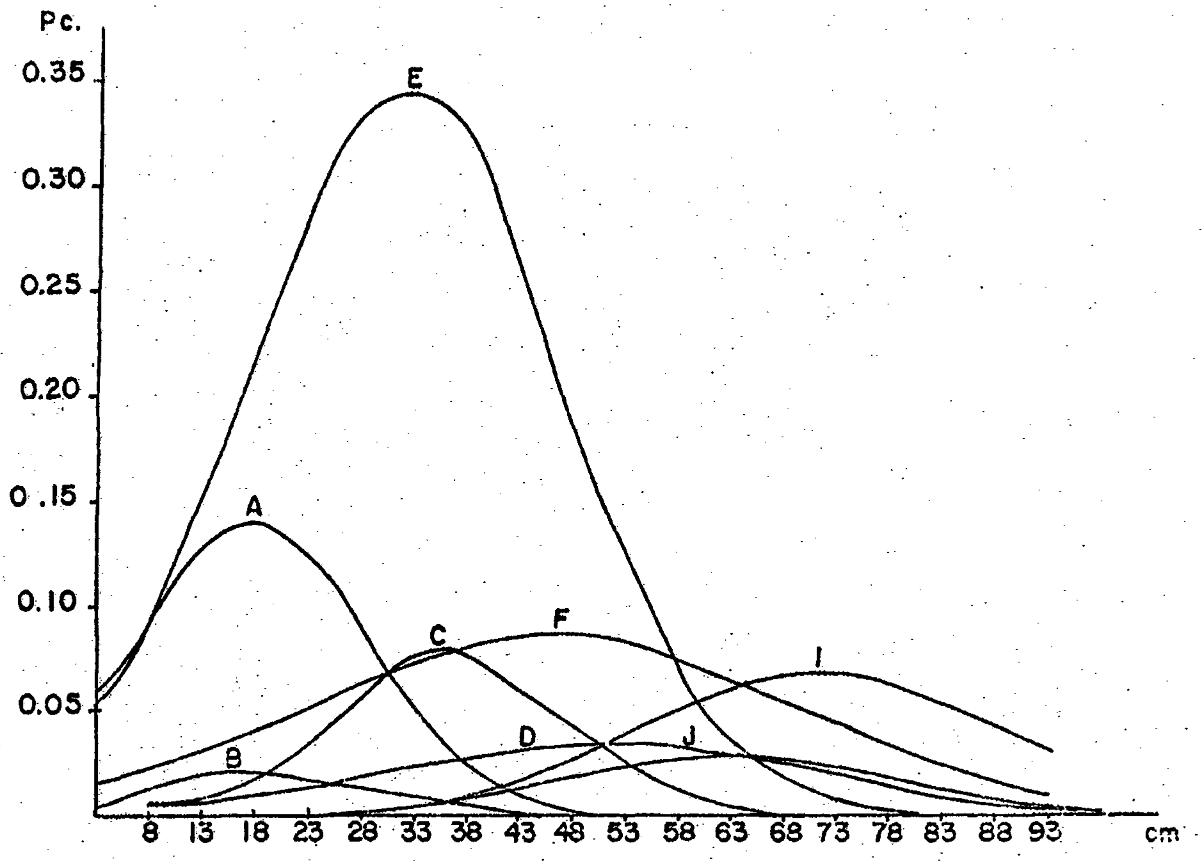


Figure 27. Selectivity Curves Estimates in Function to the Mesh's Working Area and Fishing Power

Table 7. Parameters of Selectivity for the Mixed Catches of the Gill Nets in Function to the Mesh's Working Area.

Net	AM	α	β	-2 α/β	ΣAM	LM CAL.	δ²	δ
A	19.52	-6.0951	0.16107	75.68	59.35	17.84	115.23	10.73
C	39.83	-1.7673	0.0363	97.37	97.20	36.40	441.60	21.01
D	57.37	-2.9452	0.0663	88.83	135.45	52.43	285.52	16.90
I	78.08					71.36		
B	17.11	-2.6447	0.0739	71.58	52.03	15.64	220.16	14.84
E	34.92	-1.2307	0.0253	97.29	85.20	31.91	554.94	23.56
F	50.28	-3.6545	0.0688	106.2	118.72	45.95	241.28	15.53
J	68.44					62.55		

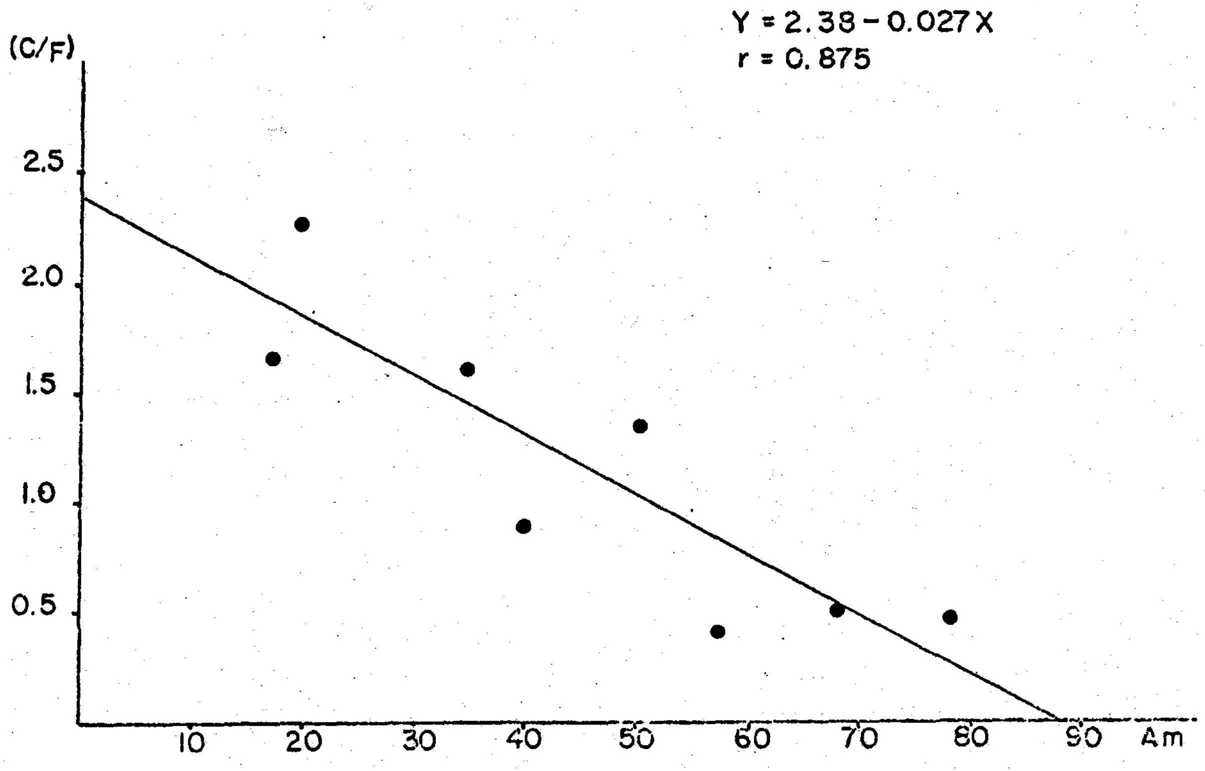


Figure 28. Relationship between the Catching Efficiency and the Mesh's Working Area.

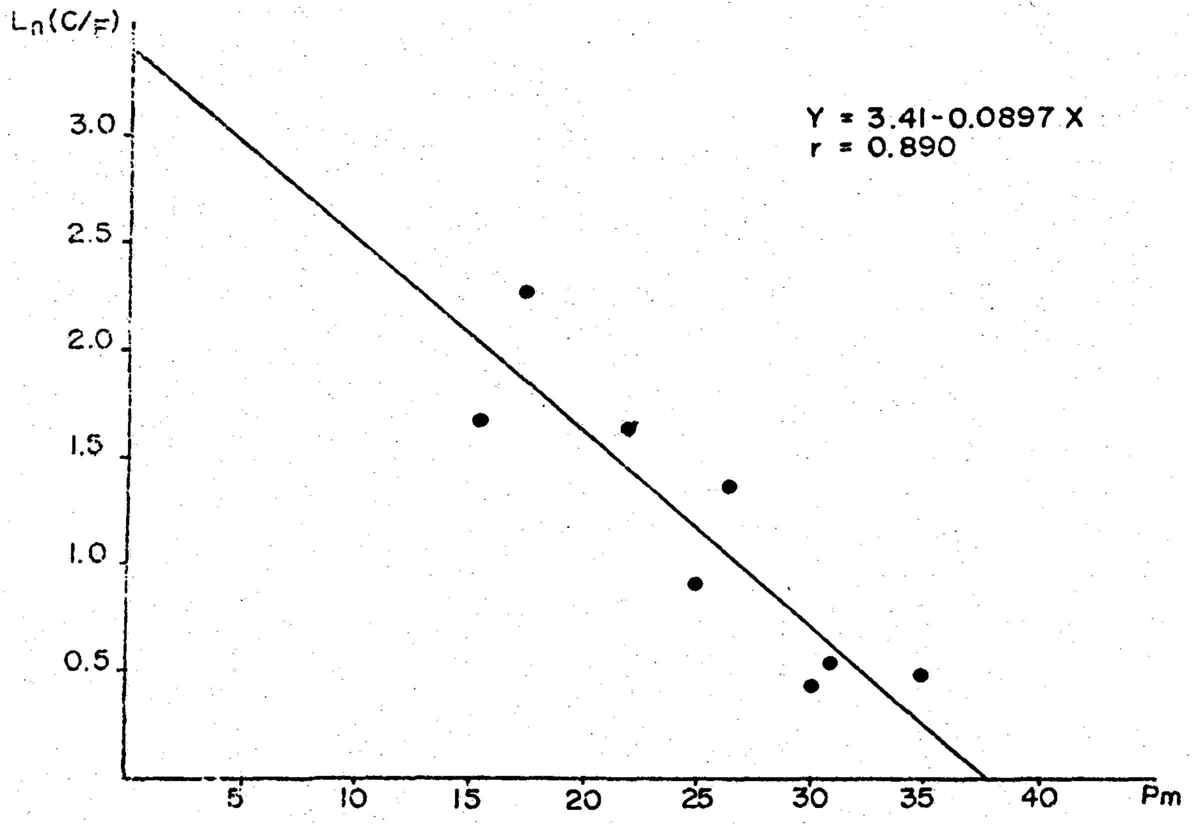


Figure 29. Relationship between the Catching Efficiency and Mesh's Working Perimeter

It is important to mention that the width of the selectivity curves produced by distribution variance requires a more in-depth statistical treatment to determine whether or not to use the average variance values or independent values estimated for each selectivity curve.

The origin of the variance in selectivity curves is worth an in-depth study, although in principle we can say that it directly depends on the catch process of each gill net.

The catch process determines the catch level efficiency for a range of sizes according to the species, and that level of efficiency depends on the optimum combination of the various physical parameters relative to the design of the net, such as material, color, and diameter of the twine, as well as the combined effect of the size of the mesh and the hanging ratio used in constructing the net.

All of this means that possible gill nets which are more selective for a certain fish length do not necessarily reach the highest level of catch efficiency.

Conclusions

The normal model for estimating selectivity curves for gill nets developed by Holt (1963) has been modified theoretically. The theoretical suppositions applied to the modified model are the following:

- Gill net selectivity for a given species depends on the selection factor (Kop) or the combined effect of the fish's shape and fish-mesh interaction coefficient.

- Increases in optimum modal lengths are proportional to the perimeter or to the working area of the mesh during the catch process.

- Gill net catch efficiency depends on the optimum combination of several parameters related to the design and construction of the net; such as the best selection of material, color and diameter of the twine, and the combined effect of the size of the mesh and the hanging ratio used.

- The shape of the selectivity curves depends on the one hand on the catch efficiency of each gill net, and on the other on the size selectivity process; that is, if the fish are snagged by their opercula or spines, or are trapped in the netting. These situations require specialized research that will allow us to clearly and with great precision and exactness, study the effects produced by the fish and those related to the gear during the catch process.

This method of analysis applied to the data obtained from the experimental fishing project carried out in the State of Baja California Sur meets the theoretical postulates outlined at the beginning, particularly since it sets the guidelines for explaining the interactions between the fish and the mesh during the catch process of bottom gill nets.

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USE OF VISUAL AND PASSIVE TECHNIQUES FOR SHELF-EDGE ASSESSMENT

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Introduction

Fishery independent enumeration of fish populations, as "assessment", is difficult at best, especially for the diverse species of the shelf-edge and live bottom habitats of the South Atlantic Bight region. To date, fishery biologists with limited budgets have been forced to settle for catch from a standardized unit of effort as an index of relative abundance and generate complementary life history information. Although comparison of indices may result in valuable information on trends in the abundance of a population, greater efforts should be placed on expansion of estimates of fish density to the regional population size. In this session, I will attempt to describe some of the techniques and rationale used by the South Carolina Wildlife and Marine Resources Monitoring, Assessment and Prediction program under contract and guidance of the NMFS Southeast Fishery Center. A brief summary of the major program objectives includes: 1) monitoring community structure, relative abundance and age structure of priority fish species/habitat types; 2) relating changes in each of the above to environmental factors and/or fishing activities; and 3) comparing results with results obtained from fishery dependent data analyses. The program expanded over 13 years primarily from a trawl survey of sand bottom groundfish to annual surveys of four to six habitat types (shallow coastal, sand bottom, live bottom, shelf-edge rocky outcrop, deep water rocky outcrop and deep water mud) each with different sampling techniques.

Past Research Efforts

Most of the reef fish of interest were in the low relief "live bottom" or moderate relief shelf-edge communities. Sampling was directed at index areas representing the few known areas of shelf and shelf-edge habitats large enough to allow deployment of all of the desired sampling gear. Sampling of both habitat types was similar and included:

1) Habitat confirmation via drift transects with Underwater Television (UWTV) (Fig. 1a).

2) Accumulative loran C plots of physical habitat limits.

3) Drift transects with UWTV (3 replicates).

4) Baited trap sets (2 types, many replicates).

5) Dawn and dusk hook and line (drift) fishing.

6) High rise trawls (3 replicates), where possible.

7) Water samples from Niskin bottle casts.

The number of "known" areas increased gradually with time and reconnaissance.

Several factors made the above sampling less than ideal. Sampling "index" stations allowed comparisons within and between index stations, but did not allow statistical expansion to regional populations. Although UWTV within the habitat is valuable for both habitat confirmation and fish counts, drift transects often do not cover the areas expected or at a desirable rate of speed. Most of the priority species do not trap well with the methods we used and great replication of

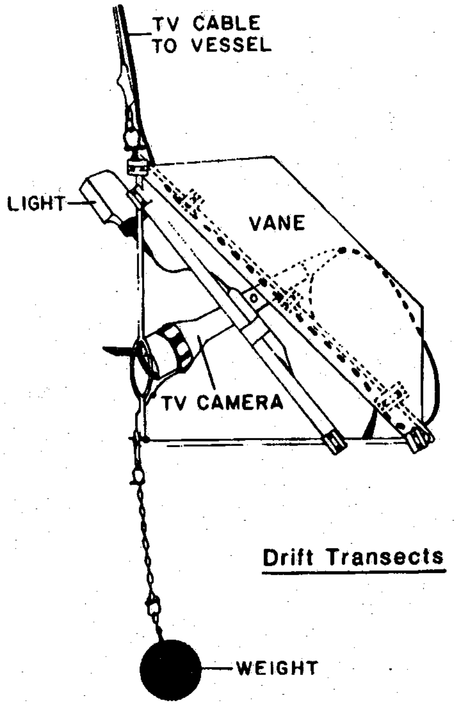

Figure 1a. Underwater Television

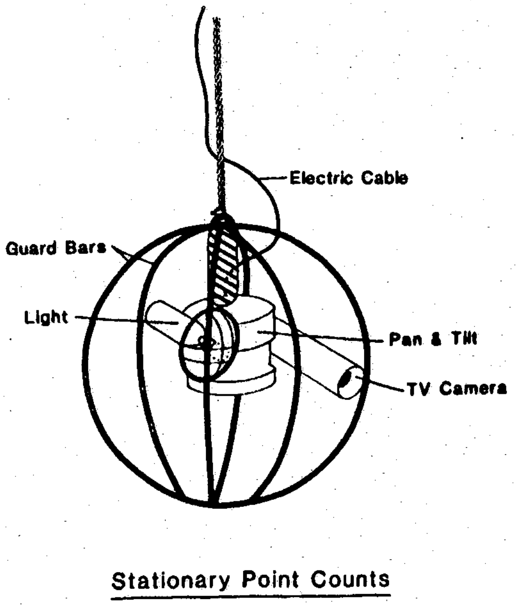

Figure 1b. Pan and Tilt System

trap sets takes large amounts of time. Hook and line fishing during limited periods of the day (dawn and dusk), although more productive, does not always fit into an efficient work schedule. If trawling is conducted without fairly detailed knowledge of the bottom topography, much time and money can be spent repeating and repairing trawls.

Damage to sessile invertebrates was an additional reason to reduce research trawling in sponge/coral (live bottom) habitats (Wenner 1983). And last but not least, despite popular demand, expansion of any program into surveys of numerous habitats each year at a set level of total effort, severely limits the effort in any one habitat type. "Priorities must be set."

Several types of passive gear have produced such poor catch rates for species groups of interest in the South Atlantic Bight that we stopped sampling with the gear. Off bottom longlines (Kali poles = fish sticks) which fish well in other habitats, caught very few of the snapper/grouper complex in the shelf-edge habitats. Small species, such as grunts, may have debaited the large hooks (6/0 - 7/0) while not being caught, and/or the shallow water snappers and groupers may have been wary of short (8-12") leaders. Also, trap catches were poor for catching species of commercial/recreational interest. Small "minnow" traps, fished to sample juveniles of priority species, caught the local moray eels. You couldn't blame a juvenile for not entering a trap with a moray in it! Blackfish traps of fine (1/2" sq.) mesh, retained smaller fish, but only of the same species caught by commercial backfish traps. Fishing with modified Antillean (mini-S) traps, with two horse-neck funnels, and "Florida" traps, with a straight funnel, resulted in low catches of important species. Although our previous methods of fishing Florida traps have not been similar to Florida and Caribbean techniques (long sets with no bait; pers. comm., Mr Frank Lawlor, FL Sea Grant), our program is considering some of the following advice of an experienced local trap fisherman (Mr. Miles MacKaness, Charleston, SC):

1) Large entrance to circumference ratio, i.e. arrow trap.

2) Large single horse-neck funnel.

3) Bait spaced throughout interior.

4) Short soak time (45 min.).

5) Small buoys to decrease trap movement.

6) Wooden supports, if any, to decrease electrolysis.

7) Fish entrance into current.

8) Fish only new or "clean" traps.

9) Dawn and dusk best periods.

Additional trap designs will be tested in the near future in an attempt to obtain more adequate samples of several of the priority species. Also, more directed and efficient sampling of the patchy habitats should be possible by maintaining vessel position by anchoring or steaming into current rather than drifting.

Future Research Efforts

Some modification of the past sampling procedures has been initiated to increase the statistical validity of information for expansion from samples to regional fish populations. Yet, we would like to maintain some compatibility with our long-term data base by retaining some of the standardized gear/techniques. Sampling will be conducted throughout the region at randomly selected stations within habitat strata defined by the known limits of both live bottom and shelf-edge habitats combined. Miller and Richards (1980) suggested that priority species may move between these habitats seasonally. Additional efforts will be made to expand knowledge of habitat locations/limits by side scan sonar investigations, especially of the shelf-edge rocky outcrop areas. The total number of individual sites sampled during a given amount of sea time will be dramatically increased by a reduction in replication and sampling durations. Our proposed UWTV technique replaces time consuming transect counts (= continuum of point counts) with a single rapid point count via a pan and tilt system (Figure 1b), similar to diver methodology (Bohnsack and Bannerot 1986). Sampling of both habitats will be with identical techniques and will include:

1) Simultaneous habitat confirmation and visual point counts by UWTV (no station replicates).

2) Simultaneous trapping and hook and line fishing of reduced durations and reduced replicate sampling from a stationary vessel.

3) Rapid water measurements with CTD.

4) Single trawl sample, where possible.

Considerations

I have serious reservations about quantification of results from passive gears using chemical attractants. Baited gear, such as traps, long lines and hook and line have been traditionally used because they are relatively inexpensive, are effective in attracting/catching some species, and often produce results directly comparable to commercial or recreational methods. The assumption that fish of a given species always respond to a given stimulus (bait) in the same manner and, more importantly, that the distance of attraction is constant, are serious theoretical problems to the quantification of results. Shifts in directional attraction of a fish population to a bait source must be common in areas of tidally influenced currents. Calculations of adequate catchability coefficients defining fish responses to a given gear type should include an "average" of the natural range in environmental and behavioral situations. An additional problem in the interpretation of catch data from baited gear comes from a variable "fishing skill" factor, including correct gear placement and retrieval from a specific habitat type, which can greatly affect catch. Quality of bait may be another relative unknown.

Visual fish counts seem to have several advantages that baited traps and hooks do not. First, if you see a fish, it <u>was</u> there; unlike situations where a fish may not "take the bait" for some unknown behavioral or environmental reason. Second, if each counted fish is not caught, the research/ assessment effort does not compete with the fisherman by removal of the resource. Generally, visual fish counts, especially those of a priority species, are greater along a transect through a given habitat than the number of fish from trap catches in the same area would indicate. This has been true through many years of drift transects with UWTV and was particularly true for the visual counts made from a submersible during the summer of 1985. The exception may be in deep water where fish and crabs must forage over large distances and are very responsive to chemical (bait) stimuli (i.e. tilefish and golden crab). Further validation of visual techniques, quantification of attraction or avoidance responses, and comparisons with other assessment methods are needed.

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ASSESSMENT TECHNIQUES FOR REEF HABITATS ON THE SOUTHEAST UNITED STATES CONTINENTAL SHELF

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Reef fisheries off the southeast United States extend from Cape Hatteras, North Carolina to Key West, Florida, around the Gulf of Mexico to Mexico, and on shelf areas throughout the Caribbean. Types of reef habitat are numerous, the overall fauna is complex, and the intensity and kinds of fishing vary. Together, reef resources pose complex assessment problems. Assessment and monitoring of reef habitats are needed because there is substantial commercial and recreational harvest of reef fishes and management is required under the Magnuson Fishery Conservation and Management Act.

Of the major types of natural reef systems on the southeast United States continental shelf, probably most important to fisheries are the "hard bottom" reefs which are scattered at depths of 20-200m over the shelf from Cape Hatteras, North Carolina to Ft. Pierce, Florida, and throughout the Gulf of Mexico. Shelf width varies greatly by region: wide (to 160 km) off the Carolinas, Georgia, and the Gulf of Mexico to narrow off South Florida and much of the Caribbean. "Hard bottom" reefs usually are associated with outcropped sedimentary rocks. Relief ranges up to several meters, and the bottom is richly overgrown with macrobenthos (sponges, sea fans, soft and diminutive hard corals, etc.). A second reef type is the hermatypic coral reef (principally off South Florida), which for discussion of assessment we include with "hard bottom" reefs. The third category includes the deep shelf edge and shelf break reefs which occur in a narrow band from about 100-250m throughout the region (see Barans this volume).

Fishing practices vary little with region, but several gears are employed depending on the habitat and target species. Most of the commercial catch is from hook and line fishing with power reels. Bottom longlines on deep reefs take grouper and tilefish. Roller trawl gear and "high rise" trawls were occasionally used in the South Atlantic Bight north of Cape Canaveral. Their use was banned in the EEZ with approval of Amendment 1 of the Snapper-Grouper Fishery Management Plan in January 1989. Traps catch primarily black sea bass in the EEZ of the South Atlantic Bight and mixed reef species off Florida. Recreational catch with hook and line comes from private vessels, charter boats, and headboats (Huntsman 1976). There are about 90 active headboats in each the South Atlantic and Gulf of Mexico.

Background data on the history of exploitation of the South Atlantic shelf reef resources are sparse and difficult to interpret. North of Georgia, the commercial snapper-grouper fishery is modern and began in earnest in the 1970's, but early catch records did not identify species caught. Recreational reef fishing dates to the 1920's and had become substantial by the early 1960's but no records of catch exist. Thus, fishery-dependent data were not available for stock assessment and management purposes. Likewise fishery-independent data were lacking. Amounts of habitats, depth distribution, and abundance of various dominant reef fishes were not well known. Although "new rocks" or fishing sites are occasionally located, the system is highly exploited and many species are probably subjected to, at least, growth overfishing.

At the Beaufort Laboratory reef fish research efforts began in 1972 and were oriented toward describing life histories, especially growth, of South Atlantic and Gulf of Mexico reef species. Also, a headboat survey was initiated to develop long term data sets on catch and size distribution of reef fishes. Region wide sampling for size composition of commercially harvested reef fishes began in 1984 as the Trip Intercept Program (TIP). Our fishery-independent assessment efforts on reef fishes have concentrated on:

1) developing and testing methods for monitoring resources,

2) delineating and estimating the amount of available habitat,

3) defining fish community dominants and their biology, and

4) developing and testing methods for population estimation.

Mark-Recapture and Point Estimates of Fish Abundance

Early studies included tagging and SCUBA observation to ascertain fish movements and estimates of population size (Parker 1990). We tagged 4,150 reef fish off the Carolinas and Florida between 1972-75. Our laboratory retention studies (up to 6 months) revealed 75% loss rate for Floy (FT-2) dart tags applied to red porgy and no loss of Petersen disk tags in red porgy and spottail pinfish. Regrettably, about 75% of released fish in the field study carried dart tags. Tag returns (n=29) indicated little movement even after 2 years at large, and most recaptures were within 6 km of the release site. In 1975-77 we focused on a single reef off North Carolina to estimate local population size by mark-recapture procedures. Monthly point counts by divers allowed comparison of visual and indirect techniques. We tagged 2,736 fish (Petersen disk tags), representing 40 species and got 121 returns (4.4%). The recapture of several tagged black sea bass by hook and line as often as 3 times over this study period suggests high survival of released fish and good tag retention. Again, tagged fish moved little. Population estimates for black sea bass via Schnabel and Schumacher-Eschmeyer methods were identical. Estimates resulting from visual methods (SCUBA) varied considerably from tagging results. Water clarity and habitat heterogeneity both affected results profoundly. Visual estimates were 33 times greater than those of mark-recapture. We believe tagging gives a better measure of local reef abundance than visual counts as applied in this study for high density species such as black sea bass. Wenner et al. (1986) successfully used the Petersen mark-recapture technique for black sea bass population estimates at two patch reefs off South Carolina. Given that most reef species are far less abundant, we believe they may be more reliably censused by visual methods.

We conclude that for long term monitoring and assessment of most reef species tag-recapture, trap CPUE, hook and line CPUE, etc. do not provide efficient, reliable assessments even on a small scale (high density species, like black sea bass are the exception). Variability of trap, and hook and line catches was so great that surveys based on these methods are virtually impossible. The immense sample sizes required would greatly exceed even liberal budget prospects. We have since focused our fishery-independent studies of reef resources on visual estimation techniques.

Estimates of Reef Habitat

A first approximation of potential reef fish biomass, independent of catch-effort data, is possible by multiplying the amount of reef habitat (area) by the mean fish biomass per unit of reef area. In 1975 published estimates were not available for the amount of reef habitat and mean fish biomass in the South Atlantic Bight. Subsequently Parker et al. (1983) estimated the amount of reef area on the shelf between the 27-101m isobaths, Cape Hatteras, North Carolina to Cape Canaveral, Florida and between the 18-91m isobaths, Key West, Florida to the Mexican border. Since this procedure is a necessary first step toward assessing reef resources and is applicable to other shelf areas, highlights of that study follow.

The amount of reef habitat (rock, coral and sponge) was estimated from observations with a closed-circuit underwater television (CCUTV) system which was lowered from the OREGON II. Video monitoring and taping were conducted while the ship and camera system were drifting. An observer recorded the type of habitat seen during the initial view of a meter quadrat of the sea floor. The substrate was classified during the initial view of the sea floor, but up to 15 minutes of drift time were spent at some stations. The bottom was classified either as reef or non-reef at randomly selected stations within depth/area strata. If reef habitat, the station was further classified by relief less than or greater than 1 m. If non-reef, it was classified as vegetated or bare sand, sand/shell or mud. From the proportion of reef to non-reef points in the area sampled and from the known area of each stratum, the amount of reef was estimated.

Table 1. Estimates of percentage and area of reef habitat in South Atlantic (95% confidence limits in parentheses). Survey Strata (27-101 m depth). (from Parker et al. 1983)

		Cape Hatteras - Cape Fear	Cape Fear - Cape Canaveral
Area in Stratum (km²)		14,486	24,826
Area Reef Habitat (km²)	Total Reef	2.040 (1.027 - 3.500)	7.403 (4.608 - 10.745)
	>1m Relief	0.204 (12 - 1.91)	1.743 (504 - 4.208)
% Reef Habitat	Total Reef	14.1 (7.1 - 24.3)	29.8 (18.6 - 43.3)
	>1m Relief	1.4 (0.1 - 7.5)	7.0 (2.0 - 17.0)

Considerable reef habitat exists out to 100m depth in the South Atlantic Bight and Gulf of Mexico (over 57,000 km^2 or 22.8% of total area) but very little is over 1 m in relief (4,143 km^2 or 1.7% of total area). The remainder of the survey area was classified as sand/shell (about 50%), mud (25%) and vegetated (3.6%, includes SW Florida inshore areas). The shelf from Cape Hatteras to Cape Canaveral contains an estimated 9,443 km^2 of reef habitat (Table 1). Considerable variation in amount of reef existed among locations. Rock, coral, and sponge were patchy in all strata. Reef habitat occurred at 24% of the stations between Cape Hatteras and Cape Canaveral. This compares favorably with data of Miller and Richards (1979), who found reef fish at 18.9% of 5,300 trawl stations made during cruises by the R/V SILVER BAY. The similarity of these results suggests that trawling records might be useful for estimating the amount of reef habitat. The remaining deeper and unsurveyed area (101-183m) is small relative to the shallower, surveyed area, but it contains high relief habitat and probably contributes significantly to total reef fish biomass, particularly to that of deepwater groupers and golden tilefish.

For cataloging shelf bottom types and estimating the amount of reef habitat the straightforward, randomized procedure with an underwater TV worked well and produced credible results. Similar surveys should be undertaken for the 101-183 m shelf area to complete the habitat estimate. Technical difficulties with CCUTV such as sea state, turbidity, currents, and instrument reliability exist, but they often can be accommodated for habitat characterization studies.

Visual Surveys of Species Composition and Abundance

Photographic methods including TV or RUFUS allow a permanent record of extended observations on fish behavior and habitat association, but they are compromised by dim lighting, small depth of field (turbidity = visibility), narrow angle of view, difficulty in tracking target objects, and fish reaction to the gear. Surface deployed cameras requiring umbilical power have additional problems related to ship stability and control of camera view. Acoustic monitoring (Barans and Holliday 1983) has many of the same problems, in addition to validation of the technique.

We opted to use diver counts via submersible and SCUBA techniques for enumeration of fish. We have used submersibles on deep water reefs off North Carolina to:

(1) estimate standing stocks to supplement our yield estimates of reef fishes important to recreational and commercial fisheries

(2) examine the effect of submersibles on fish behavior

(3) estimate species composition and relative abundance, and

(4) observe behavior and habitat utilization on reefs below SCUBA depths (Parker and Ross 1986).

Using the JOHNSON SEA-LINK II (10 dives) and NEKTON GAMMA (7 dives) for a total dive time of about 23 hrs, we examined 13 reefs at depths of 23-152m in Onslow, Raleigh, and Long Bays, North Carolina. Transect distances and horizontal visibility were measured to relate numbers of fish to units of area. Surface support ships provided LORAN C measures of transect length and position. To measure visibility the JOHNSON SEA-LINK II, before each transect, would retreat from a secchi disk placed on the bottom until reaching fade-out distance. The submersible then followed a straight compass course across a reef while the forward observer recorded on tape and film the habitat type, fish behavior, species composition, and relative abundance of all species. From the starboard porthole, the aft observer simultaneously counted recreationally and commercially important fishes (Huntsman 1976) within his view, 90° to the transect path. Using horizontal visibility and distance traveled, a rectangular survey area was calculated. In previous SCUBA experiments Parker observed that fishes faded from view in the last quarter of a diver's secchi visibility range. Thus, for expansion of fish numbers the observation area was reduced by 25% to account for the reduced zone of fish detectability. When using the NEKTON GAMMA, a single observer had to perform all scientific operations and observations.

On two occasions observations from a submersible were matched with counts by a SCUBA team to determine:

(1) if submersibles altered behavior of reef fishes beyond that caused by SCUBA divers, and

(2) if estimates of abundance of important reef fishes from submersibles can be compared to those made by divers. In the first test divers counted fishes and observed fish behavior in a 360° area during passage of the JOHNSON SEA-LINK II at two locations along a 180m transect in 27-29m depth (Fig. 1). Lateral visibility yielded a 30m diameter field of view. Divers thus had a field of $707m^2$ for point counts and the submersible had a $450m^2$ rectangular survey area. Composition and abundance of reef fishes important in the recreational and commercial catches were determined. As the submersible cruised the transect, the aft observer counted fishes on the starboard side between buoys. On a second occasion point counts were done by SCUBA divers 15 min after passage of the submersible.

Comparing observations made by divers to those from submersibles, we learned that fish generally ignored both SCUBA divers and the

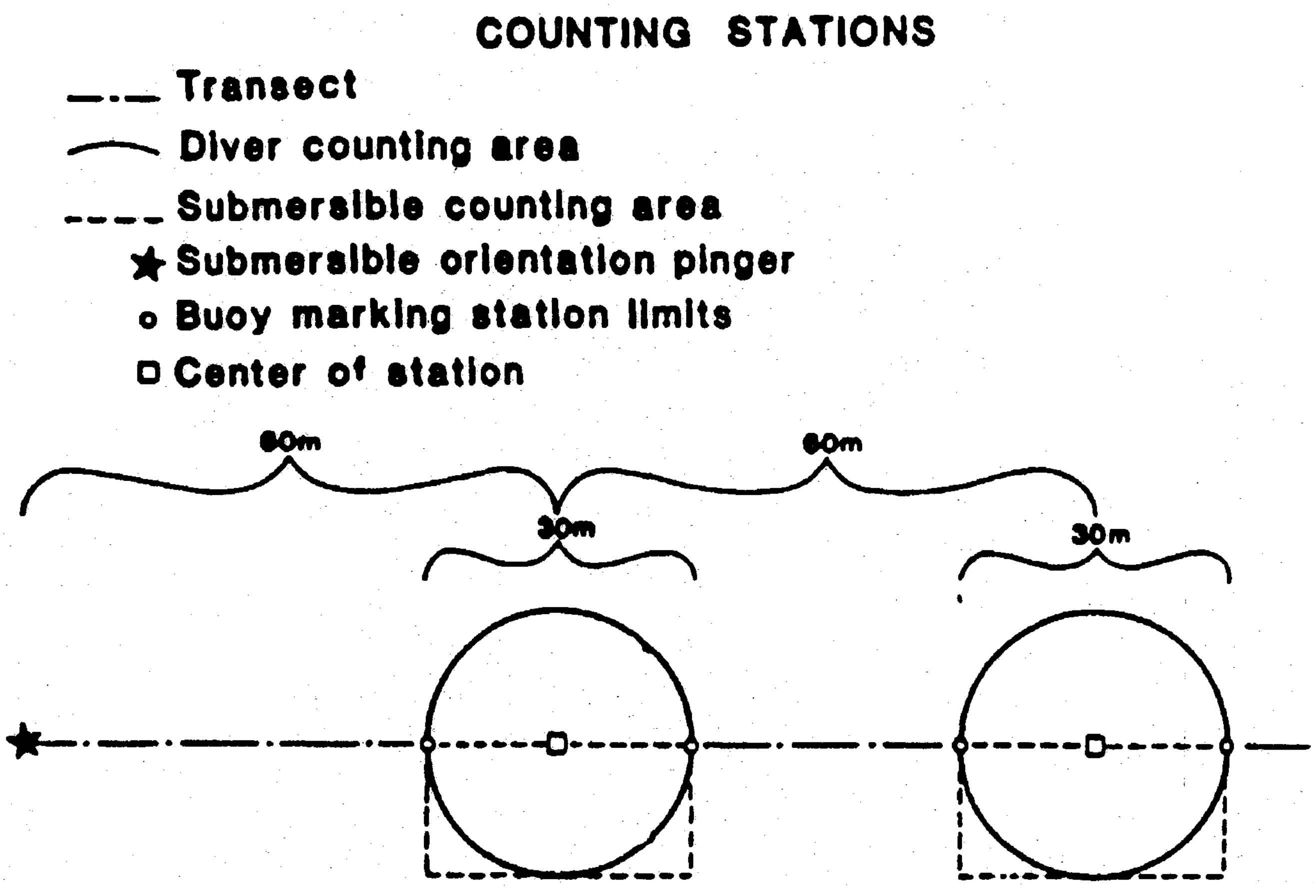

Figure 1. Schematic diagram of submersible and SCUBA diver fish counting. (Parker & Ross, 1986)

submersible. Fish counts of species important in the recreational and commercial fisheries were comparable when made simultaneously but when the submersible covered more area, more of the large, less abundant species were recorded. Conversely, the SCUBA team was more mobile in a small area and had a wider field of view, so it could better observe and identify small, cryptic species.

From transect data we derived biological and community features important for future designs of submersible and SCUBA surveys in the South Atlantic Bight. Some important species were widely distributed while others were more restricted to selected depth strata. Reef habitats (stations) contained significantly different numbers of species. The number of species and abundance were strongly correlated with vertical relief of the reef substrate in all depth strata and the mid-depths stratum (52-98m) contained the greatest number of species. The average number of recreationally and commercially important fish per hectare was 61 individuals over sand and 774 individuals over reef. Although only 7% of the fish counted occurred over sand bottom, up to 33% of the transect time was over sand habitat. Noteworthy also, were occasional sand covered ridges up to 20m high near reefs off the Carolinas. Some species previously thought to be tightly associated with reefs were actually seen rooting in sandy areas 10m or more away from the reef (red porgy, silk snapper, and snowy grouper).

The next steps in development of assessment procedures are unclear. We have been successful in counting/estimating selected species densities on reefs, but submersible and diver values need to be standardized. We need to measure the reliability of diver counts and how they vary among divers and as a function of the environment. Based on a field study at Looe Key, Florida, Witzig (personal communication)[1] examined many of the factors affecting the detection of objects underwater (size, coloration, number per area, habitat complexity, and physical characteristics of the water column). From this study he evaluated transect and point count methodologies used in estimating fish population abundance and determined the accuracy of visual estimates of population density. Quantification techniques for defining observer efficiency will allow calibration among divers, and in the future, transect surveys may be more comparable.

Conclusions

Our experiences reaffirm the belief that biologist can not effectively catch fish with unbiased gear or with uniform angler/hook efficiency. Hook and line, longline, traps, and trawl are fraught with application variability to such a degree that their use as long term monitoring techniques on shelf areas of the southeast United States is questionable. Chemicals and explosives are effective but generally unusable because they destroy habitat. Submersibles, TV, and SCUBA techniques offer proven ways to assess shelf habitat type, document species assemblages, and quantify abundance of dominant (important) resources. Each is useful over a selected depth range, and while equipment may be expensive on a daily basis, these visual estimates are probably less expensive than the more traditional hook and line, trap, and trawl approaches. Advances in SCUBA survey techniques such as in the "Bohnsack bounce" (see Bohnsack this volume) and Witzig's distance corrections lend even more credibility to their use as long term monitoring and assessment techniques.

We recommend that SEAMAP encourage completion of the TV survey for quantification of habitat in the 101-183m zone and that submersible techniques be used to complete the reef fish assessments needed to estimate yield potential in the South Atlantic Bight and Gulf of Mexico.

Footnote: John F. Witzig, NMFS, Fishery Statistics Division, 1335 East-West Highway 8313, Silver Spring, MD 20910. Ph.D. dissertation entitled Visual Assessment of Reeffish Communities, North Carolina State University, Zoology Department.

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POPULATION ESTIMATES OF COMMERCIALLY IMPORTANT REEF FISHES USING MARK/RECAPTURE AND VISUAL CENSUS TECHNIQUES ON THE FLORIDA MIDDLE GROUNDS

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A study to estimate populations of commercial reef fishes by mark/recapture techniques using traps and breakaway tag bottom longlines was conducted from September 9 to September 22, 1981 on an isolated reef area on the Florida Middle Grounds. A total of 629 individuals of 24 species were tagged and released with 21 individuals of 7 species recaptured. *Epinephelus morio* and *Haemulon aurolineatum* had the most recaptures with 9 and 4, respectively, with interval estimates of 464-1818 and 672-4914, adjusted for removals and trap deaths.

An underwater submersible was used to independently estimate reef fish populations from counts taken on strip transects and 10 minute point counts and to observe gear-related fish behavior. Transect estimates for *Mycteroperca phenax* were 3356 and 3800 from the bow and aft observer positions, respectively, and 463 and 507 for *E.morio*, which are similar to the mark/recapture estimate. Point counts are believed to overestimate the populations due to counting more individuals passing through the field of view than would actually be recorded during an instantaneous count for the given area.

Introduction

Effective reef fish fishery management is dependent upon the knowledge of accurate estimates of abundance of commercial species and knowledge of the impact of commercial fishing gears on reef fish populations. Present management policy is based on fishery dependent catch data obtained from commercial and recreational fishermen. These data are often unreliable (Gulf of Mexico Fishery Management Council 1980) and often estimates are made for species groups (e.g., snappers and/or groupers) instead of individual species. Other means of population estimation are required for greater reliability and specificity.

Fishery independent methods for estimating fish populations have been used for many years. Trawl surveys have been extensively used to assess fish populations (Powles and Barans 1980, Gutherz 1982); however, this method is not effective over high-relief substrate encountered in reef areas (Barans 1982).

Visual censuses using SCUBA have been employed to estimate population abundance of reef fishes (e.g. Brock 1954, Bardach 1959, Jones and Chase 1975, Sale and Douglas 1981). These methods, however, require extensive bottom time for adequate counts to be made and are therefore limited to relatively shallow waters to avoid lengthy decompression.

Underwater submersibles have been used recently to observe fishing gear (High 1980, Grimes et al. 1982) and to observe (Shipp and Hopkins 1978) and assess fish populations (Uzmann et al. 1977, Parker et al. 1986). Underwater habitats such as Tektite have also been employed for reef fish observations (Collette and Earle 1972), but, the cost of underwater habitats or submersibles may be prohibitive for regular use.

Trapping and tagging have been widely used to observe movements and migrations of reef fishes (Bardach 1958, Ingle et al. 1962, Springer and McErlean 1962, Topp 1963, Beaumariage 1969). However, the use of these methods in determining population size have, until recently (Parker et al. 1986, C. A. Wenner[1]), been limited to the freshwater environment.

To investigate the possibilities of utilizing mark/recapture procedures for estimating reef fish populations at moderate depths (25-35m) in the marine habitat, the present study employed breakaway-tag bottom longlines and fish traps to generate estimates of commercial reef species. A submersible was used to estimate these populations by means of visual, area-density estimates and to assess the validity of these procedures.

Methods and Materials

Study Site

The Florida Middle Grounds, located on the outer West Florida Shelf, is a living coral habitat approximately 120 nmi west of St. Petersburg in the eastern Gulf of Mexico (Fig. 1). The biology and geology are described by Smith et al. (1975), U.S. Department of the Interior, Bureau of Land Management (1981) and the authors cited in this study.

The study site was located at approximately 28° 34' N and 84° 18' W atop a pinnacle-like development, oriented along a northeast-southwest axis, surrounded by a barren sand bottom in 40 m of water. The sand bottom, depauperate of fishes and corals, isolated the study reef from neighboring reef areas by at least 0.6 km (Fig. 2), with occasional gorgonians surrounding the coral rubble and sand zone from 40m to approximately 35m. The rubble zone, or apron, ended abruptly at the bottom of a reef face, which consisted primarily

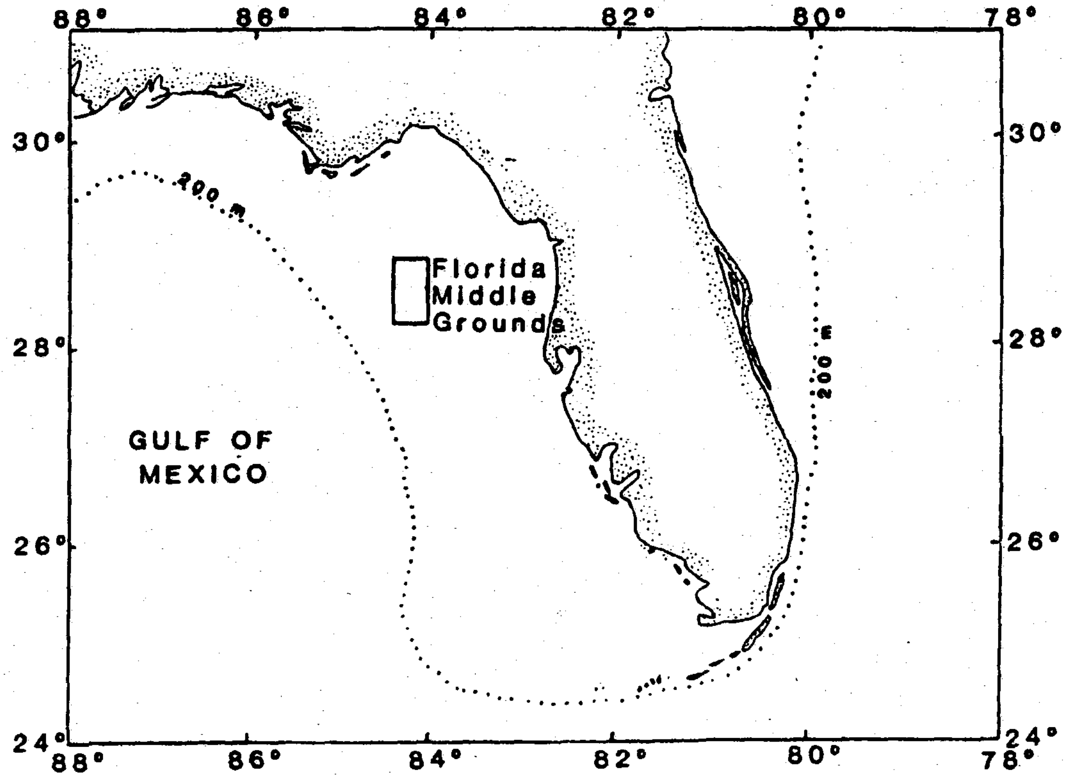

Figure 1. Eastern Gulf of Mexico showing Florida Middle Grounds (after Smith et al. 1975).

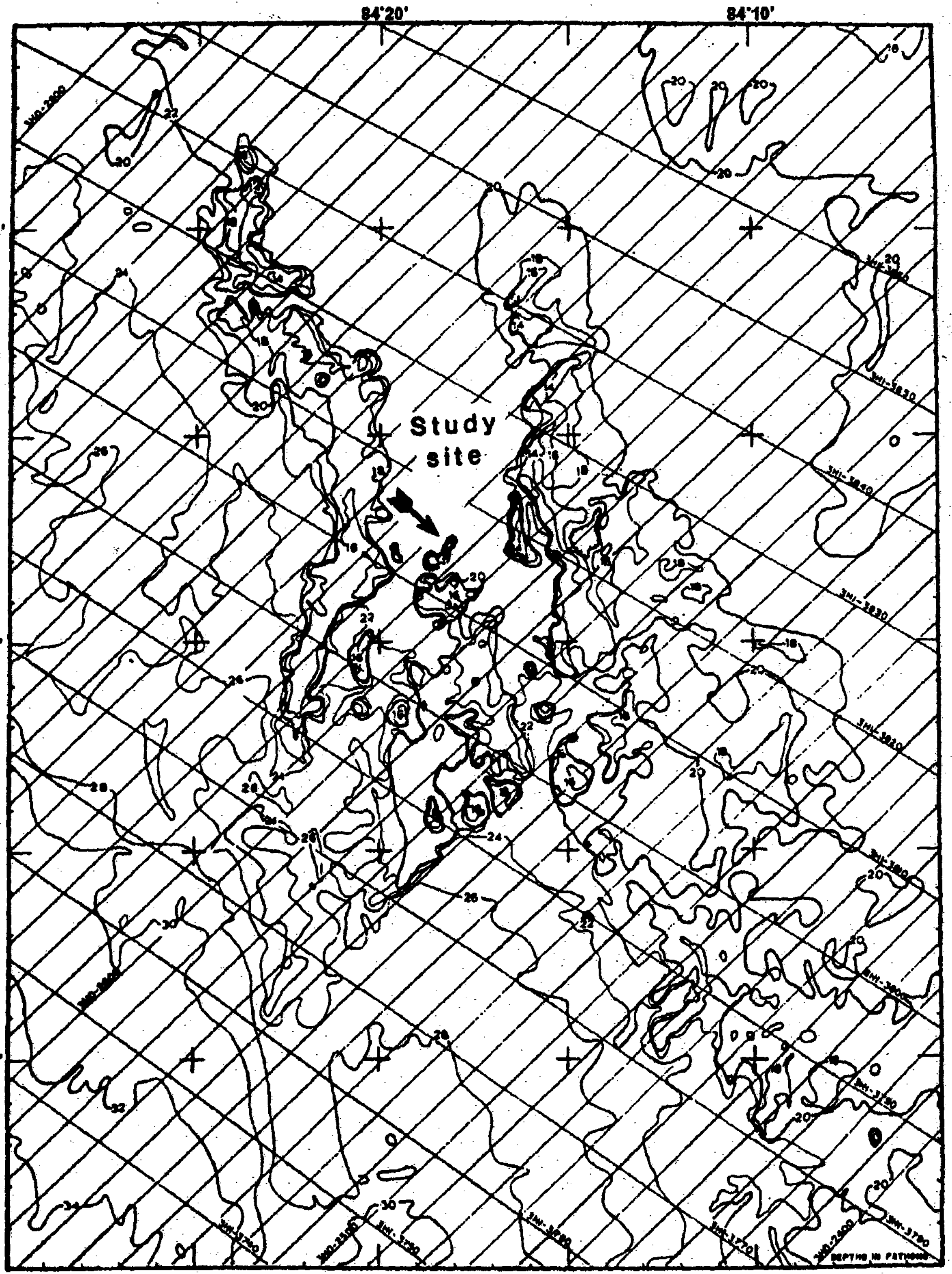

Figure 2. Bathymetry of Florida Middle Ground appended from Smith et al. 1975.

of the scleractinian, *Madracis decactis*, and the hydrozoan, *Millepora alcicornis*, with *Millepora* dominating the top of the reef face at approximately 30m. Proceeding reef-ward, *Millepora* and *Madracis* were replaced by *Porites* and *Dichocoenia* as the dominant hard corals on the gradually upward sloping reef flat. A similar zonation of corals is noted by Grimm and Hopkins (1977) on a nearby reef. Dense, irregularly spaced stands of gorgonians were also present, as were the sponges *Agelas dispar*, *Iricinia* sp., and *Speciospongia* sp. Sand patches of varying size, devoid of corals and sponges, were located in a seemingly random fashion, adding to the mosaic pattern of the reef flat. At 27 and 24m, two smaller reef faces of *Millepora* and *Madracis*, 2 to 3m in relief, were present, rising to the reef crest at approximately 22m. The benthic fauna of the reef crest appeared similar to that of the reef flat. Fish populations of the Florida Middle Grounds have been described by Clarke (1986) and Shipp et al. (1986).

The study reef was defined as the area within the boundaries of the deepest reef face at 35m. A total area of 0.5 km^2 was determined by planimetry from the outline obtained from a LORAN-C plotter, depth recorder, and an underwater video camera.

Field Methodology

The study area was located by underwater video camera with a pan and tilt mechanism, suspended over the side of the NOAA Ship OREGON II. While drifting over the area, a depth recorder and LORAN-C plotter were used to plot the boundaries of the reef area.

Two-hundred meter bottom longlines were deployed off the stern of the OREGON II. Longlines were weighted at each end and attached to a surface buoy. Approximately 100 No.7 circle hooks baited with frozen squid were placed on 5/16 inch nylon mainline at approximately 2m intervals. Fifty of the hooks were breakaway-tag hooks with an enumerated disc tag placed adjacent to the eye of the hook. These hooks were attached to a 4-lb test monofilament line, then to a standard 200-lb test monofilament leader. The remaining 50 hooks were attached directly to the leader. All leaders were fastened to the mainline by steel spring AK snaps with five sets of 10 breakaway-tag hooks and five sets of 10 standard hooks randomly placed along the mainline. The longlines were randomly set over the reef area for approximately 2 hrs soak time, after which they were hauled to the surface where the catch was identified and the presence or absence of the bait was recorded. The use of the longlines was discontinued after the first two days of the 11 day study period due to poor catch rate, high bait loss, and excessive fouling in the high relief substrate (see Discussion).

Hand-cranked commercial snapper reels with 3/32-in stainless-steel cable, with 3 hooks approximately 0.7 m apart on 200-lb test monofilament leader, were baited with cut frozen squid. These handlines were used irregularly throughout the study to attempt to deplete the populations and to aid in making recaptures.

Fish traps, approximately 60 x 90 x 76 cm, made of vinyl-coated 2.5 x 5.0 cm wire mesh, were baited with cut frozen fish. Each of the 42 trap sets were comprised of three to seven traps, spaced approximately 8 m apart on 5/16 in, single-buoyed nylon mainline. A square grid, equivalent to 0.9 nmi on each side, was divided into 64 quadrants of equal area, numbered and drawn on the plotted boundary of the study reef. Quadrants over the reef were randomly selected from a random numbers table, in which trap sets were set during the 11 day trapping period, from 9 September to 22 September 1981. During the first nine days, fish were tagged and released. Lengths, tag number, and trap deaths were recorded for each station. All recaptures were recorded and returned to the study area. During the final two days, all captures were removed to increase the probability of recaptures and to attempt to deplete the populations.

The tagging procedure involved raising the trap sets after 3 to 68 hrs on the bottom and emptying the contents into a 1900 l fiberglass holding tank divided into halves by an aluminum mesh partition. Fishes suffering from embolism were assisted in their recovery by puncturing the distended abdomens and protruding viscera with a syringe to allow escape of the expanded gases (Topp 1963). The fishes were then measured and place in the other half of the holding tank for observation. They were tagged through the epaxial muscle mass just ventral to the anterior portion of the first dorsal fin with numbered Petersen disc tags. Large individuals were tagged through the dorsal portion of the caudal peduncle or through the operculum. Only those not appearing disabled were released randomly over the study area; the remaining fishes were recorded and removed from the population.

The underwater submersible, JOHNSON-SEA-LINK I, and its support vessel, R/V JOHNSON, were used concurrently with the tagging experiment to make visual counts of reef fishes, to observe fishing gear in place on the reef, and record behavior (and numbers) of tagged fishes on the reef itself.

All counts were made by two observers, one located in the forward sphere seated next to the pilot, the other located in the aft diving chamber, viewing from the starboard port. The two observers alternated between the bow and aft positions with each dive to eliminate observer/position interactions in the counts (Shipp et al. 1986). A total of 13 dives was made from 14 September to 20 September 1981, five from which counts were made. The remaining dives were used to observe longlines, fish traps, and gear-related behavior. All dives and observations were recorded on video tape from an external camera mounted outside the forward sphere, equipped with floodlights. Two external 35 mm cameras, each synchronized with two underwater strobes, were located outside each observer position and controlled by either an adjustable intervalometer or by the observer.

The first visual census dive was used to establish the census procedure. Three strip transects, 457m (500 yd) in length, were made across the northeast to southwest axis of the reef. The fourth transect was a 229m (250 yd) continuation of the third transect. The second visual census dive was taken on a smaller nearby reef, approximately 1 km due east of the study area where three 91m (100 yd) transects were run with a 10 min point count at the beginning and end of each transect. The purpose of the dive at a nearby site was to determine if the study site selected was typical of the area. For the three remaining visual census dives, 183m (200 yd) strip transects with a 10 min point count at each end were considered optimal for the study reef. Only these three dives were used in generating population estimates. A transect and associated point counts of a dive made after dark were eliminated from the population estimates because of a profound faunal change.

The censuses were randomly situated, with the provision that the submersible remain over the reef area and not venture out over the apron or surrounding sand. No attempt was made to stratify the estimates due to the patchiness of the substrate and the limited amount of data.

Actual numbers of commercial species seen during both the transects and point counts were recorded. For the diminutive non-commercial species, actual counts were made only at the point counts, and abundance scores were used during the transects. The data for the diminutive species is reported by Shipp et al. (1986).

In addition to the tagging and visual censuses, tagging mortality was also investigated by using the catch of a single trap set used in the tagging program. The fishes were treated similarly as those used in the tagging program; however, instead of releasing the fishes, they were replaced in the traps and lowered to the bottom where they remained for

Table 1. Formulae used in estimating reef fish populations and their variance (from Ricker 1975).

METHOD	POPULATION ESTIMATE	VARIANCE
Schnabel	$N = \frac{(C_t M_t)}{R_t}$	$Var(\frac{1}{N}) = \frac{R}{(C_t M_t)^2}$
Modified Schnabel	$N = \frac{(C_t M_t)}{(R+1)}$	$Var(\frac{1}{N}) = \frac{(R+1)}{(C_t M_t)^2}$
Schumacher and Eschmeyer	$N = \frac{(C_t M_t^2)}{(M_t R_t)}$	$Var(\frac{1}{N}) = \frac{s^2}{(C_t M_t^2)}$

Where:

N = number of individuals present throughout study.

$R = R_t$ = total number of recaptures.

M_t = number of marked fish at large at the start of the t-th interval.

C_t = number of fish captured at time t.

$s = (R_t^2/ C_t) - [(R_t M_t)^2/ (C_t M_t^2)] / (m-1)$.

m = number of sampling intervals.

approximately 24 hrs. The traps were then raised and the condition of the fishes recorded.

Analysis of Data

Population estimates from the tagging portion of this study are computed by three iterative multiple census methods, the Schnabel (1938) method, Chapman's modification (1954) of the Schnabel method, and the Schumacher and Eschmeyer (1943) method. The equations for the estimates and their variance are given in Ricker (1975) and appear in Table 1. The confidence limits may be computed from the variance using a Student's t-distribution. For the Schnabel and modified Schnabel methods, Ricker (1975) gives a procedure to calculate the confidence interval using the Poisson distribution and recommends its use when the number of recaptures is small.

The effect of a hypothetical post-release mortality on the modified Schnabel population estimate for *E. morio* is calculated by subtracting 10, 20, and 50% of those marked and released from the number marked minus removals at each trap interval.

The negative binomial (NB) distribution was fit to each strip transect and point count using the maximum-likelihood estimate of the parameter k (Bliss and Fisher 1953). Each count was tested for goodness-of-fit by the chi-square test and the U or T tests of Anscombe (1950). Most estimates of standard error for the latter two tests were derived from graphs presented by Evans (1953) and Elliott (1977). The count data was then transformed as $y=\log(x+1)$. The mean and confidence intervals ($x=0.05$) were calculated for the transformed data, then back-transformed to the original scale and extrapolated to derive estimates for the total 0.5 km^2 area of the reef. The area of the strip transects and point counts used in the extrapolation were determined from the total angle of view from each observer position and an estimated 6.1 m (20 ft) effective visibility for all dives.

The log $(x+1)$ transformation was used instead of the more cumbersome transformation, $\sinh^{-1} (x+0.375/k-0.75)^{1/2}$, because the $\sinh^{-1}$ transformation is not defined

Table 2. List of species and number captured, tagged, released, and recaptured with traps, longline, and handlines. (continued over page)

GENUS	SPECIES	CAPTURED	TAGGED & RELEASED	RECAPTURED
Acanthuridae	*Acanthurus bahianus*	11	1	
	Acanthurus chirurgus	9	2	
Balistidae	*Aluterus schoepfi*	1		
	Balistes capriscus	57	34	2
	Monacanthus hispidis	17		
Batrachoididae	*Opsanus pardus*	12		
Carangidae	*Seriola dumerili*	5	1	
	Seriola rivoliana	1		
Chaetodontidae	*Chaetodon ocellatus*	36	11	
	Chaetodon sedentarius	8		
Congridae	*Hildebrandia flava*	1		
Ephippidae	*Chaetodipterus faber*	2	2	
Haemulidae	*Haemulon aurolineatum*	145	135	4
	Haemulon plumeri	17	12	3
Holocentridae	*Holocentrus ascensionis*	66	34	
Labridae		3	1	
Lutjanidae	*Lutjanus griseus*	2	1	
	Rhomboplites aurorubens	126	59	1
Muraenidae	*Gymnothorax moringa*	4		
	Gymnothorax sp.	10		
Ophichthidae	*Ophichthidae gomesi*	1		
Pomacanthidae	*Holacanthus bermudensis*	84	19	
Scaridae	*Sparisoma* sp.	1		
Sciaenidae	*Equetus acuminatus*	1		
	Equetus umbrosus	80		
Scorpaenidae	*Scorpaena* sp.	3	1	
Serranidae	*Centropristis ocyurua*	46	33	
	Diplectrum formosum	38	20	
	Epinephelus adscensionis	5		
	Epinephelus cruentatus	3	1	
	Epinephelus guttatus	7		
	Epinephelus morio	167	72	9
	Mycteroperca microlepis	2	1	
	Mycteroperca phenax	174	25	

GENUS	SPECIES	CAPTURED	TAGGED & RELEASED	RECAPTURED
Serranidae	*Paranthias furcifer*	2		
Sparidae	*Calamus* sp. (*nodosus*)	303	152	1
	Pagrus pagrus	45	11	1
Sphyraenidae	*Sphyraena barracuda*	2		
Synodontidae	*Synodus intermedius*	2		
Tetraodontidae	*Sphoeroides spengleri*	5	2	

for many of the values of k (k= 0.75) calculated in this study. Also, the log(x+1) transformation is near linear with the $\sinh^{-1}$ transformation, making it a good approximation at the values of k and x in this study (Green 1979).

Catch per unit effort estimates were calculated using the Leslie and Davis (1939) and DeLury (1947, 1951) regression methods as given by Ricker (1975).

Results

A total of 1504 individuals of 40 species were captured by all fishing methods employed (Table 2). Of these, 629 individuals of 24 species were tagged and released and 21 individuals of seven species were recaptured. The single recapture of *Pagrus* was recovered with a breakaway tag in its mouth from a bottom longline. The majority of fishes captured were taken in the traps. Species dominating the captures were *Calamus* sp. (*nodosus*), *M. phenax*, *E. morio*, *H. aurolineatum*, and *Rhomboplites aurorubens* with 303, 174, 167, 145, and 126 individuals, respectively.

The results of the mark/recapture experiment for the seven species of which recaptures were made are shown in Table 3. All captures and removals from the three gear types are included in the estimates. The most recaptures were obtained from *E. morio* and *H aurolineatum* with 9 and 4 recaptures, respectively, with percent recaptures of 12.5% and 3.0%.

The species observed during the visual censuses appear in Table 4. Results of the chi-square goodness-of-fit tests and the U and T test for departure from the negative binomial distribution indicate that the negative binomial was successfully fit to most of the data. Exceptions were the point counts of *B. capriscus, E. ascensionis, M. microlepis, H. aurolineatum*, and the bow point count of *E. cruentatus*. The first three species were each observed only once during the point counts, making the results of these tests and the respective population estimates (below) tenuous at best. *H. aurolineatum* were observed in schools (estimated at approximately 200 individuals) twice from the bow position and once from the aft position, with the remaining counts at or near zero. This schooling behavior makes the use of the negative binomial inappropriate for this species.

The bow point count of *E. cruentatus* was found not to fit the negative binomial by the U test. However, the departure was insignificant when using the chi-square test. The large positive value of the U test suggests that the distribution may be skewed farther to the right than is the negative binomial (Evans 1953); however, this would lend greater support for the log(x+1) transformation of this particular count so the estimates would not be greatly affected.

The estimates derived from the transects and point counts appear in Table 5. Different areas of view for the bow sphere and the aft diving chamber were used for the respective

Table 3. Calculated point and interval estimates of seven reef fish species from mark/recapture data taken with all gear types.

POINT AND INTERVAL ESTIMATES [1,2]			
Species	**Schnabel**	**Modified Schnabel**	**Schumacher and Eschemeyer**
Balistes capriscus	553	369	425
	153-5530	134-922	221-5256
Calamus sp. (*nodosus*)	31770	15885	27537
	3673-31770	4814-28882	11750-
Epinephelus morio	904	814	837
	476-2035	450-1628	534-1935
Haemulon aurolineatum	1960	1568	1880
	768-7838	700-3919	1001-15300
Haemulon plumieri	31	23	25
	11-155	9-58	12-215
Pagrus pagrus	342	171	867
	61-3420	51-311	98-
Rhomboplites aurorubens	4224	2112	3388
	754-42240	640-3840	1619-

[1] Point estimates are given above, interval estimates are given below.

[2] Interval estimates are calculated at $\alpha = 0.05$

Table 4. Species observed during strip transects and point counts. (continued over page)

GENUS	SPECIES	GENUS	SPECIES
Acanthuridae	*Acanthurus chirurgus*	Carangidae	*Caranx fusus*
	Haemulon coeruleus		*Decapterus punctatus*
Apogonidae	*Apogon pseudomaculatus*		*Elagatis bipinnulata*
	Phaeoptyx xenus		*Seriola dumerili*
Aulostomidae	*Aulostomus maculatus*		*S. rivoliana*
Balistidae	*Balistes capriscus*	Chaetodontidae	*Chaetodon ocellatus*
	Cantherhines pullus		*C. sedentarius*
Batrachoididae	*Opsanus pardus*	Clupeidae	*Sardinella anchovia*
Blenniidae	*Blennius marmoreus*	Diodontidae	*Chilomycterus schoepfi*
		Ephippidae	*Chaetodipterus faber*

GENUS	SPECIES
Gobiidae	*Coryphopterus glaucofraenum*
	Gobiosoma horsti
Haemulidae	*Haemulon aurolineatum*
Holocentridae	*Gobiosoma oceanops*
Labridae	*Bodianus rufus*
	Clepticus parrai
	Halichoeres bivittatus
	Lachnolaimus maximus
	Thalassoma bifasciatum
Lutjanidae	*Lutjanus griseus*
	Rhomboplites aurorubens
Mullidae	*Pseudupeneus maculatus*
Muraenidae	*Gymnothorax moringa*
Opistognathidae	*Opistognathus aurifrons*
Ostraciidae	*Acanthostracion quadricornis*
Pomacanthidae	*Holacanthus bermudensis*
	Pomacanthus arcuatus
	Centropyge argi
Pomacentridae	*Chromis enchrysurus*
	C. scotti
	Pomacentrus partitus
	P. variabilis
Priacanthidae	*Pristigenys alta*
Scaridae	*Nicholsina usta*
	Scarus croicensis
	Sparisoma aurofrenatum
Sciaenidae	*Equetus lanceolatus*
	E. umbrosus
Scombridae	*Scomberomorous* sp.
Serranidae	*Centropristis ocyurus*
	Epinephelus adscensionis
	E. cruentatus
	E. morio
	Hypoplecterus puella
	Liopropoma eukrines
	M. microlepis
	M. phenax
Serranidae	*Paranthias furcifer*
	Pikea mexicana
	Serranus phoebe
	S. tabacarius
Sparidae	*Calamus* sp. (*nodosus*)
	Pagrus pagrus
Synodontidae	*Synodus intermedius*
Tetraodontidae	*Canthigaster rostrata*
	Sphoeroides spengleri

estimates, so these are given separately. The area of a single transect is approximately 2134 m^2 and 1115 m^2 for the bow and aft positions, respectively. For the point counts, areas of 47 m^2 and 17 m^2 for the bow and aft via wing areas were used. Missing estimates for the 10 species indicate the absence of quantitative data and not necessarily the absence of individuals without regard to size class. Point count estimates in general tended to be at least an order of magnitude greater than did those derived from the strip transects for the same species. The point count estimates for *R. aurorubens* were calculated from the two night point counts. Note that the transect estimates for *E. morio* are quite similar to the mark/recapture estimates appearing in Table 3.

Table 6 shows the results of the trap set used for the assessment of tagging mortality. The number captured refers to the total catch of the initial trapping, the number tagged are those individuals not appearing to be detrimentally affected by the first ascent and subsequent tagging. The number of survivors and the percent survival of those tagged are given in the third and fourth columns. It is noteworthy that the survivors underwent two ascents, unlike those tagged and released during normal tagging procedures.

Catch-effort models were used to compute population size for *E. morio* and *M. phenax*. The results are of little use because the

Table 5. Area-density estimates (using geometric means) extrapolated to the entire reef area of approximately 0.5 km^2, generated from visual counts from an underwater submersible. Estimates using arithmetic means are given in parentheses.

SPECIES	TRANSECT[1]		POINT COUNTS	
	Bow[2]	Aft	Bow	Aft
Balistes capriscus			440 -472-1433 (621)	
Calamus sp. (*nodosus*)			8191 2965-15441 (12422)	41919 20891-71838 (57598)
Epinephelus adscensionis			440 -472-1433 (621)	1198 -1284-3905 (1694)
Epinephelus cruentatus	408 172-783 (521)	58 -66-223 (100)	5702 1552-11270 (9316)	12347 3691-23302 (16941)
Epinephelus morio	463 202-879 (574)	507 46-1396 (1010)	6615 2159-12637 (9937)	16430 5466-30892 (23717)
Haemulon aurolineatum			9152 6104-12761 (249052)	17139 -2636-18759 (350671)
Lutjanus griseus	267 -48-1110 (1434)	96 -24-712 (505)	5315 -1097-16071 (34785)	3199 -1457-8649 (5082)
Mycteroperca microlepis				1198 -1284-3905 (1694)
Mycteroperca phenax	3356 1730-6326 (4406)	3800 854-13405 (10832)	48016 26536-81937 (70245)	175937 96197-306611 (255803)
Rhomboplites aurorubens			163997 -2271-3663747 (168934)	21069 -28734-5352920 (28799)

[1] Point estimates are given above, interval estimates ($\alpha = 0.05$) are given below.

[2] Two independent counts were taken by the two observers, one in the bow sphere, the other in the aft diving chamber of the submersible.

slop of the regression lines was not significantly different from zero (x=0.05), indicating that only small portions of the populations were removed during the study period.

Discussion

Mark/Recapture Estimates

Mark/recapture methods have been widely used to estimate small mammal populations and freshwater fish populations. In the marine environment, these methods have not been employed until recently on populations of *Centropristis ocyura* off the Carolina coast by R. O. Parker (unpublished data) and C. A. Wenner. A possible reason for the paucity of marine mark/recapture experiments is the lack of control over immigration and emigration to and from the population under study. Also, the responses and effects of tagging and trapping are virtually unknown for marine fishes, and serious violations of the underlying assumptions of these methods may result.

In this study, precautions were taken to avoid violation of assumptions, which are enumerated in many fishery and wildlife management texts (Seber 1973, Ricker 1975, Everhart and Youngs 1981). The assumptions for the mark/recapture methods used in this study area:

1) population closure,

2) random distribution of marked individual,

3) marks are not lost,

4) no mortality during the experiment, and

5) equal catchability of all individuals, marked and unmarked.

Ricker (1975) states immigration and emigration may be the one assumption that is most often violated. However, many coral reef fishes are highly territorial or remain within a specific home range for much of their adult lives (Bardach 1958). Several studies have been conducted to investigate reef fish movement. Springer and McErlean (1962) tagged 19 species, including *E. morio* and *H. plumieri*, and observed that most of the recaptures were from the same reef as the initial capture. The results of tagging studies reported by Ingle et al. (1962), Topp (1963), and Beaumariage (1969)

Table 6. Results of the mortality experiment conducted at approximately 30m.

Species	Captured	Marked	Survivors	% Survival
Acanthurus chirugus	2	2	2	100
Balistes capriscus	4	2	1	50
Calamus sp. (*nodosus*)	5	2	1	50
Epinephelus cruentatus	1	1	1	100
Epinephelus morio	6	4	4	100
Haemulon plumieri	6	5	5	100
Holacanthus bermudensis	1	1	1	100
Holacentrus ascensionis	6	6	6	100
Rhomboplites aurorubens	9	5	0	0

[1] Number captured in single trap set, 1st ascent.

[2] Number of "healthy" fish marked and replaced in traps.

[3] Number of survivors, 2nd ascent.

indicate that many of the commercial species (including *E. morio, H. plumieri, B. capriscus* and *P. pagrus*) remain within a restricted area with relatively few cases of movement from their respective capture locations. This was also found to be the case with *R. aurorubens* off the south Texas coast (Fable 1980).

The reef area in this study is separated from other neighboring reef areas by at least 0.6 km of barren sand bottom. Observations from the submersible during the day and the underwater video camera by night indicated that there was little, if any, activity of commercial species over the sand bottom. Nocturnal observations over the reef by both means indicate a general absence of commercial species.

The short duration of this study may also limit the number of recruits, immigrating to replace those permanently removed from the populations, and the number of emigrants (Yap and Furtado 1980, Pollock 1981). With the short study period plus the affinity of many species for their home range and the isolation of the study reef, it is believed that the populations under study were essentially closed.

The assumption of random mixing of marked fishes with unmarked fishes may be violated by their home range affinity, thus restricting random mixing. However, when sampling and marking are performed randomly over the population, then the estimates should not be biased (Ricker 1975) with respect to this assumption. Here, trap sets were placed in a random fashion over the reef area and marked fish were randomly released over the study area.

Petersen disc tags have been used in most of the tagging studies mentioned above. Springer and McErlean (1962) found that these tags are unsatisfactory for grouper and *H. plumieri*, having to replace tags several times within a few months. Topp (1963) recommended that disc tags be used only for short periods when direct observations are required. Grimes et al. (1982), however, had returns of *P. pagrus* and *R. aurorubens* marked with disc tags after more than 400 days at liberty. For the short duration of this experiment, the use of Petersen disc tags appears to be satisfactory. It was noted, however, that several individuals of *C. nodosus* and *B. capriscus* showed signs of potential tag loss from loose tags when recovered. This phenomenon may result in an upward bias in the estimates if tags were actually lost without notice.

Trap mortality was relatively common for most species taken in this study, resulting in removal of substantial numbers from the populations. It is believed that the primary cause of trap death is due to the rapid ascent and subsequent embolism of the fishes brought up from depths of 25-35m despite our efforts to aid their recovery. Topp (1963) mentioned similar problems with embolism in the offshore portion of his study, as does Grimes et al. (1982). Topp also observed a high mortality of fishes from predation as they recover from tagging on or near the surface and during their descent to the bottom. Our efforts to hold the fish until they appeared to recover from the trauma of tagging may have decreased this unknown, post-release mortality. The results in Table 6 support the hypothesis of a high survival rate of those fishes replaced in the traps, lowered to the bottom, and subjected to an additional ascent. The small sample sizes for the respective species and lack of controls preclude statistical analysis of these data. However, there is an indication that our methods may have increased the survival of released fishes. During the last submersible dive, nine tagged individuals were observed, including four *E. morio*, and one individual of *B. capriscus, H.bermudensis, A. chirugus, M. phenax*, and *C. faber*. None of these individuals appeared to be disabled or inconvenienced by the presence of the tag except *H. bermudensis*, which was swimming in a head up posture with weak rapid caudal fin movement. This was probably due to the trauma of recent handling. If a significant proportion of tagged fishes display this or a similar behavior, they may attract predators, increasing post-release mortality.

The "equal catchability" assumption is one of the more difficult assumptions to effectively test, especially with few recaptures. Otis et al. (1978) and Pollock (1981) discussed the shortcomings of various mark/recapture models to this assumption, including the Schnabel method (their Model M_t), stating that it is unlikely to be fulfilled in most wildlife populations and violation of this assumption may cause bias in the estimate.

They divide behavioral responses into two general types: trap response and heterogeneity. Trap response is the change in behavior of an individual toward the presence of a trap after that individual has been captured. It may become trap happy or tray shy resulting in either a negative or a positive bias, respectively. Heterogeneity, the alteration of equal capture probability as a result of age, sex, social structure, or other factors, causes a negative bias because sampling is limited to a subset of the total population. For instance, if larger individuals enter the traps first, they may actively or passively (by virtue of their size) exclude other conspecifics or other species. Sampling would, in effect, be limited to the population of these larger individuals.

From the capture history of recaptured individuals most recaptures did not occur until the last two trapping days, usually more than 48 h after release. Marked fishes were not observed from the submersible until the last dive, on the tenth day of the 12 days trapped, on which nine tagged individuals were recorded. This may be due to the need of a recovery period from tagging and handling after release and/or the unavailability of traps within a marked fish's home range (if this has not been disrupted by the fishes' temporary absence). Ricker (1975) suggested the use of different capture methods to help avoid these catchability problems. In this study, three different types of fishing gear were used. However, traps produced the greatest catch and were therefore used to a larger extent. It should be further noted, while the single recaptured *P. pagrus* was tagged by a breakaway-tag bottom longline and two recaptured *E. morio* were initially captured by standard bottom longlines, all recaptures were from traps. In any event, fish behavior in response to trapping is undoubtedly species-specific and warrants further investigation before the equal catchability assumption may be considered fulfilled.

Schumacher and Eschmeyer (1943) used a control chart to determine the number of trap days required to attain a specified level of precision for population estimates of bullheads. Figure 3 is a similarly derived control chart for *E. morio*. The abscissa refers to the station number of the trap sets, the left ordinate axis denotes the relative standard error of the population estimate in percent of the point estimate, and the right ordinate axis is the estimated number of individuals. The first point represents the first station at which a recapture was made. The next recapture was not made until station 35, where the lines decrease sharply. Each substantial decrease in both lines is due to one, three, two, and two recaptures at stations 35, 39, 43, and 44, respectively. Each decrease is progressively less, indicating reduced influence of additional recaptures on both the population estimate and its precision. After station 44, sampling continued without recaptures and a slight fluctuation is observed around 28.5% for the relative standard effort and increases from 760 to 837 for the population estimate. Using a t-distribution, it may be determined that the population estimate is within approximately 57% of the true abundance with a probability of 0.95, provided that the assumptions for this method are not seriously violated.

From this control chart, it is evident that only a few recaptures may result in very inaccurate estimates. For this reason, Ricker (1975) recommended only those species with four or more recaptures (i.e., *E. morio* and *H.*

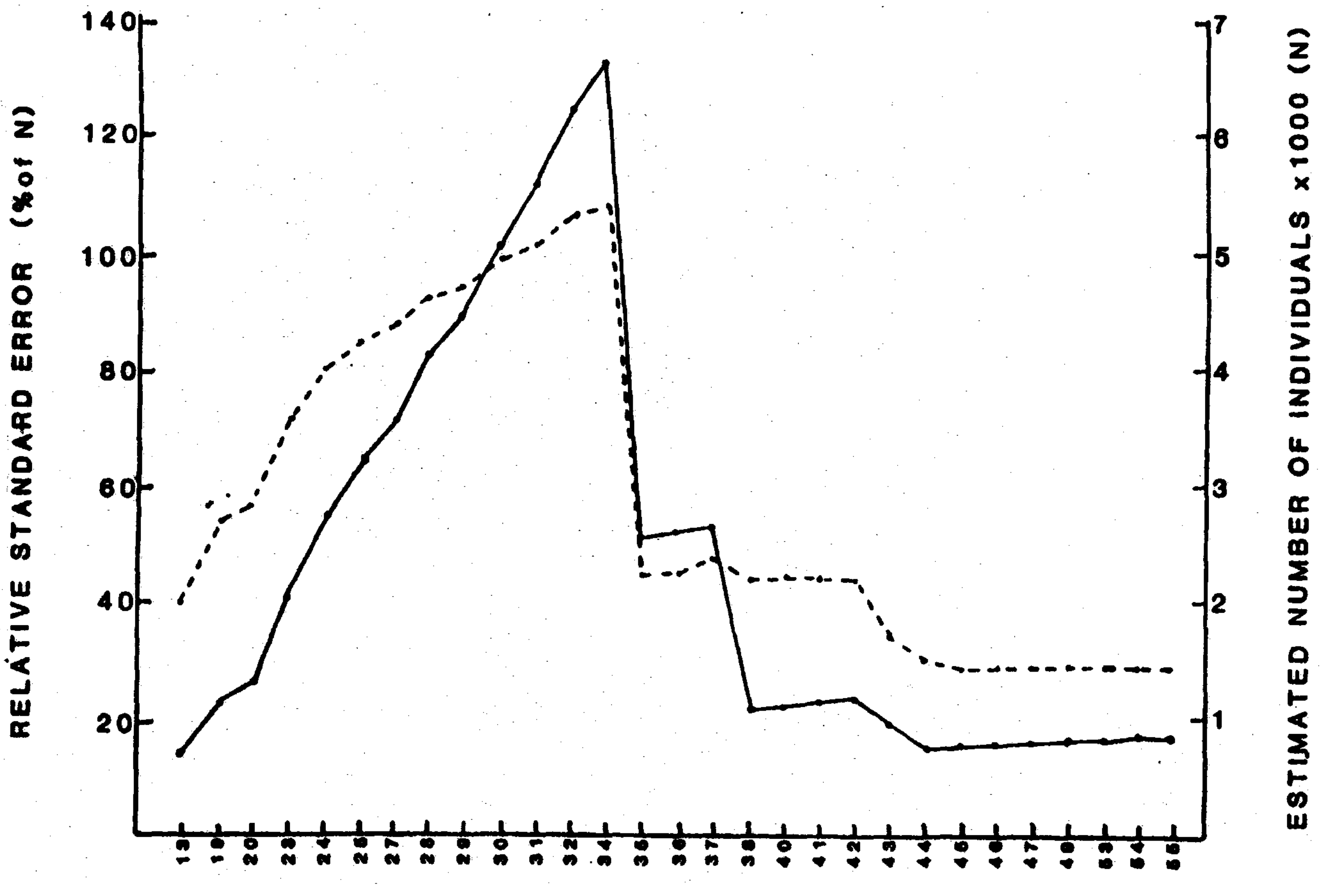

Figure 3. Cumulative relative standard error (---) and population estimates (—) of *Epinephelus morio* using the Schumacher and Eschmeyer procedure.

aurolineatum) be used. In fact, individuals of *H. aurolineatum* were only captured at 10 stations of which two produced recaptures, resulting in a wider confidence interval than for *E. morio*. The final relative standard error for *H. aurolineatum* is 38.8%, for which the true abundance is within 86.4% of the point estimate at a 95% confidence level.

DeLury (1958) discussed the differences between the Schnabel and the Schumacher and Eschmeyer estimates, stating the Schnabel estimate to be highly dependent on the randomness of the sampling. He suggested that the Schumacher and Eschmeyer regression model is preferable because, in practice, the necessary degree of randomness may be unattainable. Seber (1973) pointed out that the Schumacher and Eschmeyer model is heavily dependent upon the assumption of a constant population size. With the trap mortality and removals in this experiment, it appears the regression model may also be inappropriate, although it is evident that only a small percentage of the populations was removed. The modified Schnabel model, however, gives an almost unbiased estimate of N (Chapman 1952) when both the sample size (C_t) and the number of marked fishes at large (M_t) is small in relation to the total population (n) for each trapping interval (Seber 1973); i.e., C_t/N and M_t/N are less than 0.1. This is the case for both *E. morio* and *H. aurolineatum*. In addition, Overton (1965) gave an iterative procedure to adjust the Schnabel or the modified Schnabel method for known mortality, such as a trap death or removal. Here the adjustment is used in conjunction with the modified Schnabel estimate resulting in N = 855 with an interval estimate, using the Poisson distribution, from

464 to 1818 for *E. morio* and N = 1573 and the interval from 672 to 4914 for *H. aurolineatum*.

To correct for an unknown mortality, such as predation of released fish, multiply one minus the hypothetical percent mortality by the point estimate. This assumes constant post-release mortality of the released individuals throughout the study and is, in effect, reducing the number of marked fish at large, M_t, by the hypothetical mortality, thus reducing the point estimate similarly. Point estimates for *E. morio* following this procedure with 10, 20, and 50% post-release mortality, using the modified Schnabel estimate with Overton's adjustment for removals, are 770, 684, and 428, respectively.

Visual Estimates

Burnham et al. (1980) listed the assumptions concerning the behavior of the individuals counted and the properties of the sampling regime for strip transects (these assumptions may be applied to the point counts as well). They are:

1) individuals must be distributed randomly or the transects must be randomly placed with respect to the population structure;

2) individuals are not affected by the presence of the observer, not being either attracted or repulsed;

3) all individuals within the strip transect or point count are seen; and

4) individuals are counted only once.

It is likely that individuals are not, in fact, randomly distributed over the reef area. This is indicated by the wide confidence limits of the visual censuses (Table 5), a result of the large amount of variability of counts between samples. However, the transects were traversed over the reef area randomly to avoid serious violation of this assumption.

It was observed that individuals moved at right angles to the submersible's forward motion, especially those species such as *M. phenax* and *Lutjanus griseus*, which are usually seen swimming above the substrate. Schools of *Seriola dumerili* and *S. rivoliana* were noted to be attracted to the submersible many times during the dives, as were large schools of *Decapterus punctatus* and juvenile *H. aurolineatum*. Otherwise, most fish did not seem to be disturbed by the presence of the submersible. Similar findings are observed by Parker and Ross (1986).

Visual censuses, in general, tend to underestimate the number of species and number of individuals (Russell et al. 1978, Sale and Douglas 1981), especially cryptic species, which are nearly impossible to visually census (Russell 1977). In this study, the larger species were generally counted and most of the species censused are moderately mobile and thus easier to detect. *M. phenax*, *C. nodosus*, *L. griseus*, and *B. capriscus* tend to swim above the reef flat singly or in small groups (*B. capriscus* is usually found in pairs), while *E. adscensionis*, *E. morio*, and *E. cruentatus* are less mobile, swimming from one coral patch to another or remaining motionless, and are usually found singly near the reef faces.

The mobility of these species may also tend to cause overestimates of the populations, especially during the point counts. During drifts made with the underwater video camera, the pan and tilt mechanism was used to look behind the unit where small aggregations of *M. phenax* and *L. griseus* were observed to follow. This would not have a serious effect during the transects; however, we believe this may have positively biased the point counts significantly. All individuals passing through the field of view were counted during the entire 10 min, probably counting individuals more than once. The populations of the more diminutive species, such as the pomacentrids, several of the labrids, and smaller serranids are more appropriate for point count study due to their limited movement and small territories (Shipp et al. 1986). In addition, the relatively small sampling area viewed by the point counts may have also inflated these estimates.

The similarity of the mark/recapture and the strip transect estimates for *E.morio* may indicate that the various assumptions discussed above have not been seriously violated, at least for this species. The drastic difference between mark/recapture and point count estimates for *H. aurolineatum* may be due to individuals being counted more than once and the fact that all individuals were counted regardless of size. This is highly probable since this species surrounded the submersible in large schools of juveniles several times during the dives. The mark/recapture experiments only estimate the population of trapable individuals, neglecting the smaller individuals of which a great many of *H. aurolineatum* were seen. This may have also been the case for *R. aurorubens*, for which 34 juveniles were seen during the two night point counts, without any adults detected from any dive. For the remainder of the species, adults, similar in size to those trapped, were observed from the submersible.

The negative binomial distribution has previously been applied to samples of fish taken by gill nets (Moyle and Lound 1960) and otter trawls (Roessler 1965). C. S. Boland et al.[2] used the negative binomial to calculate confidence intervals for reef fish populations of the Flower Gardens off the Texas coast, obtained from strip transects, using an underwater video system. Results from the present study indicate that the negative binomial may be used to empirically describe visual census data of certain reef fish species. Inferences concerning actual distribution patterns would be premature from the data presented here. The sampling distribution may be affected by the size of the sampling unit (Elliott 1977), sampling stratification with respect to habitat type or population structure, or by periodic behavioral characteristics of a species (e.g., aggregations as a result of spawning). A more detailed study is required before questions of this nature can be addressed.

Comparisons of Sampling Methods

The ability of a particular sampling technique to effectively sample a community may be evaluated by the number of species sampled or by the number of species sampled per unit time. Table 7 lists the five methods used and criteria for comparing sampling efficiency. By these criteria the visual techniques are the most efficient methods used. But, to be more objective, each method should be examined individually.

The longlines were of little value over the reef area for several reasons. It was observed that the hooks tended to settle in small cracks and crevices in the reef, rendering the bait unaccessible to the larger fishes. This also resulted in snags when the longlines were recovered, increasing gear loss. Bait predation by small fishes and benthic invertebrates was a major cause of bait loss, cleaning the hooks

Table 7. Amount of time spent, number of samples, number of species sampled, and the number of species sampled per hour for each of the five methods used.

Method	Time (min)	Samples	Species	Species/Hour
Longlines	1235	8	9	0.44
Handlines	1845	16	11	0.36
Traps	42205	42	41	0.06
Point Counts	190	19	54	17.05
Transects	252	10	64	15.24

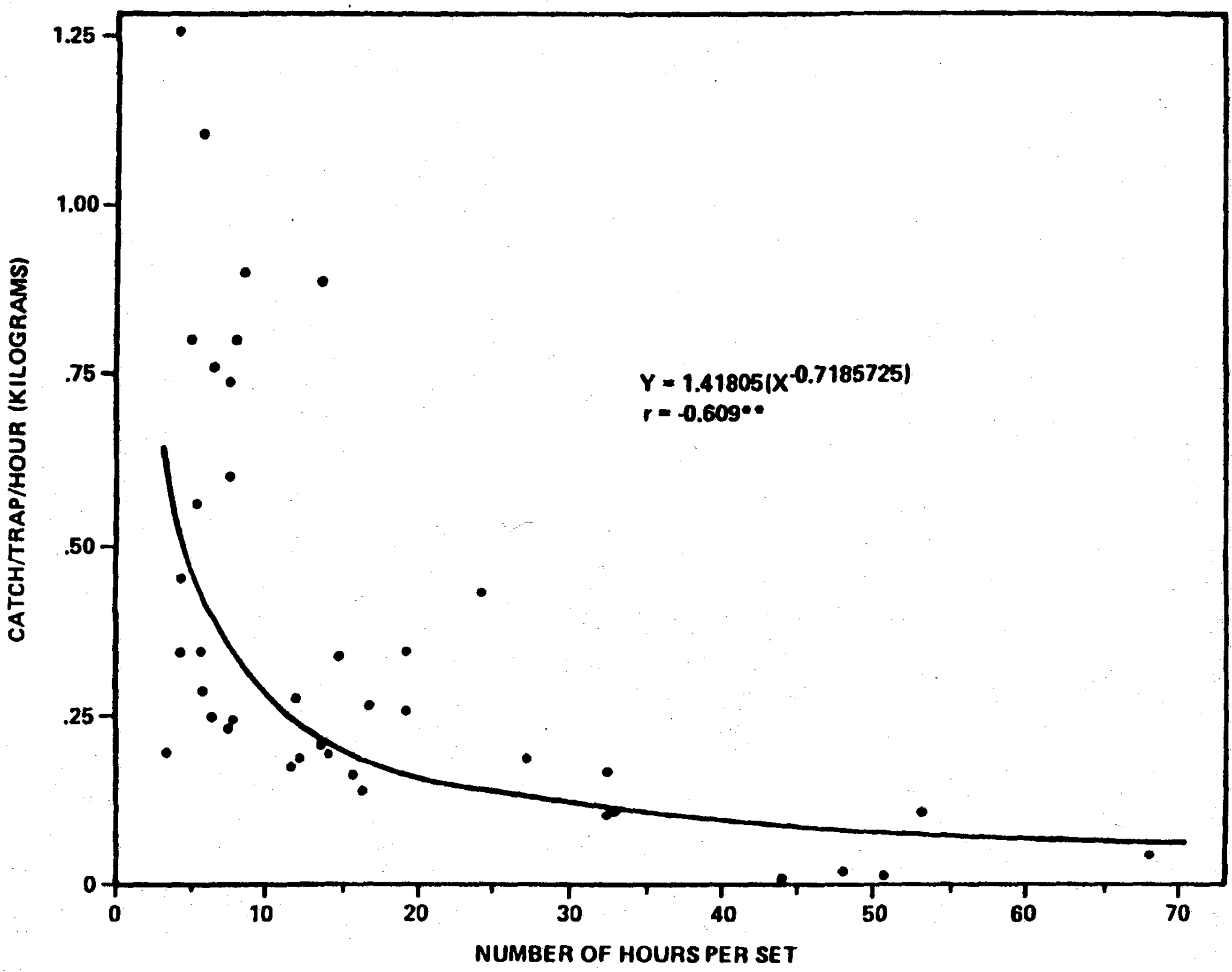

Figure 4. Catch of reef fish in kilograms per trap hour as a function of number of hours fished per set, Florida Middle Grounds.

within a matter of minutes. High (1980) and Grimes et al. (1982) also observed significant bait loss in deeper water (from 50 to 165 m and 119 m, respectively); however, bait loss was not as rapid as noted here. Buoying the mainline off the bottom may increase effectiveness in this habitat.

Handlines, according to the above criteria, produced fewer species per hour than did longlines. However, if the number of hooks for each method are considered, the efficiency of three to six triple hook handlines would far exceed the catch/effort of the 100 hook longlines.

Traps have the lowest number of species recorded per hour of any method used in this study. They require much less manpower than do longlines and handlines, however. Once they are set, traps may be left unattended until recovery, allowing time for other sampling activities. Longlines were recovered every 2 hrs, allowing enough time to bait and deploy another, while handlines require constant supervision. Usually four trap sets were out at one time, effectively reducing the amount of actual time used, thereby increasing efficiency.

Trap success decreased as fishing time increased. Significant negative correlation exists between catch and time fished (Fig. 4), indicating that traps are more productive during the first 5 to 10 h, a saturation level had been reached, the bait had been removed reducing the attractiveness of the trap, or a combination of these factors. This suggests that short trap sets would be more effective for sampling than fewer long sets within a given time frame, making short sets more productive for studies where large areas are to be covered rapidly.

The visual censuses were by far the most effective sampling techniques used. In addition to directly sampling a large number of species and individuals, submersibles have the advantage of allowing observation in changes in fish behavior in relation to other gear types and to the submersible itself, allowing these biases to be evaluated. They are not effective in turbid water (e.g., following a storm) or for the collection of specimens for other types of research (biomass, age estimates, etc.). Uzmann et al. (1977) and Parker and Ross (1986) discussed the advantages and shortcomings of submersibles for sampling reef fishes.

No one method is effective in sampling even the major components of the reef fish community. This is evidence by the fact that 126 adult *R. aurorubens* were captured in the traps, while only 34 juveniles were observed from the submersible. Only two adult *L. griseus* were captured in the traps, while several large schools were seen from the submersible. Only one *L. griseus* was taken with the handline, while neither was taken by longlines. These are important commercial species and without the combination of methods, one or the other would have been essentially undetected. Interestingly, *M. microlepis* was sighted on only a single occasion during a point count and trapped twice. This species is reported as one of the more abundant serranids on the Florida Middle Grounds at depths similar to those in this study (Smith et al. 1975, Smith 1976). The reasons for this discrepancy are unknown.

Catchability Coefficients

A major objective for the conduct of this work was to determine the impact of fishing activities on populations of commercial or recreational shallow water reef fishes on the Florida Middle Grounds. Insufficient data were obtained from bottom longline fishing to provide useful information, but substantial catches were made with traps for comparison with population estimates.

Estimates were derived for larger species found on the reef (Table 5), along with mark-recapture population estimates (Table 4). Despite a low tag return rate, because of the short duration of the study, population estimates from transects conducted on the JOHNSON SEA-LINK dives and mark/recapture population estimates were reasonably close for the 1/2 km^2 area. These two estimates were averaged to provide a mean population estimate for triggerfish, red grouper, porgy, and scamp. While without statistical significance, these combined estimates allow for general observations on the catchability of the commercially important reef species.

A total of 43 trap sets were made with three to six traps per set and for time periods of 3-68 hrs. The total sampling effort was 3,432 trap hours. A comparison of population estimates and catches of the four species indicated a capture rate of less than 1% for porgy (*Calamus* sp.) to approximately 16% for red grouper (Table 8). Catch per trap per hour was low for each of the four species, indicating a significant amount of effort would have been required to appreciably impact the populations.

Catchability coefficients (q, the percent of the population taken by one unit of effort) were calculated to determine the impact of a unit of effort (trap-hour) on each species (Table 8). The q for red grouper was an order of magnitude greater than for scamp, indicating that red grouper was by far the most vulnerable of the two groupers to traps. The value for porgy was low and may indicate that either they do not trap readily, or that they can escape from the trap. Some traps were observed from the submersible to contain porgy, but were empty when brought on the deck of the OREGON II, indicating escapement had taken place.

Table 8. Submersible and mark/recapture population estimates derived for four (4) species of reef fish on 0.5 km^2 Rum Reef, Florida Middle Grounds, and catchability coefficients (q) derived ffrom catch per trap hour.

SPECIES	POPULATION ESTIMATES			CATCH RATES			
	Sub	Mark/ Recapture	Mean	All Sets (N = 3432 trap hrs)			
				# trapped	% of pop.	#/trap/hr	q
Balistes capriscus	621 a	449 c	535	65	12.1	0.019	0.0036
Epinephelus morio	792 b	851 c	822	132	16.1	0.038	0.0046
Calamus sp.	35010d	25064 c	30037	284	0.9	0.083	0.0003
Mycteroperca phenax	7619b	e	7619	151	2.0	0.044	0.0006
				All Sets 6h (N = 218 trap hrs)			
Balistes capriscus				5	1.0	0.022	0.0041
Epinephelus morio				26	3.2	0.119	0.0145
Calamus sp.				71	0.2	0.326	0.0011
Mycteroperca phenax				29	0.4	0.133	0.0017

a = Row point count only.

b = Mean of bow and aft transect estimates.

c = From 3 estimation methods (Table 3).

d = Mean of bow and aft point estimates.

e = Not estimated.

Catch-per-unit of effort varied markedly with the number of hours a set was left in the water, as discussed in the section on comparisons of sampling methods (Fig. 4). Trap sets were categorized by time intervals to determine if there were significant differences in catch rates. The mean catch rates show substantial differences between time categories, although confidence intervals overlap considerably between adjacent intervals (Fig. 5).

Using catch per unit effort data from only the sets of shorter duration (3-6 hrs), the catch rates and estimates of catchability coefficients increased for three of the species by a factor of 3 (Table 8). The estimate for triggerfish did not increase appreciably, indicating that either the species can enter and leave the traps at will, or its behavioral pattern with respect to traps is different from the other species, or a substantial amount of error is associated with estimates derived form the small sample size and catch. The parallel threefold increase in q for red grouper, scamp, and porgy is encouraging, and indicates that the three species have similar behavior in relation to time of trap set, even though the catchability coefficients are quite different for each species.

This study provides initial, though rough, estimates of the impact of traps on some reef fish of commercial and recreational importance. It supports the findings of other workers that the "trapability" of each species varies, and that catchability coefficients for at least major species of reef fishes will have to be determined before traps can be used as an assessment tool. Some index of relative abundance for shallow reef areas can presently be developed using traps, but estimates for biomass and status of stocks will require a more precise knowledge of the efficiency of traps.

It is important to note that estimates of efficiency of traps and other gear can be determined only if estimates of population size are available. If gear efficiencies can be determined for small scale representative areas, rapid assessments of large reef areas can then be made with passive sampling gears, providing that the larger areas are similar to the representative areas in which population estimates and gear efficiencies were determined.

Barans (1982) and Gutherz (1982) discussed the problems of various gear types for assessing reef fish populations. The observations of these authors and the results of this study indicate that several methods should be used simultaneously to sufficiently sample a reef fish community. Careful consideration of the underlying assumptions of the methods used and the study design (refer to DeLury 1951, Ricker 1975, Otis et al. 1978, Pollock 1981) must be made to increase the reliability of the estimates.

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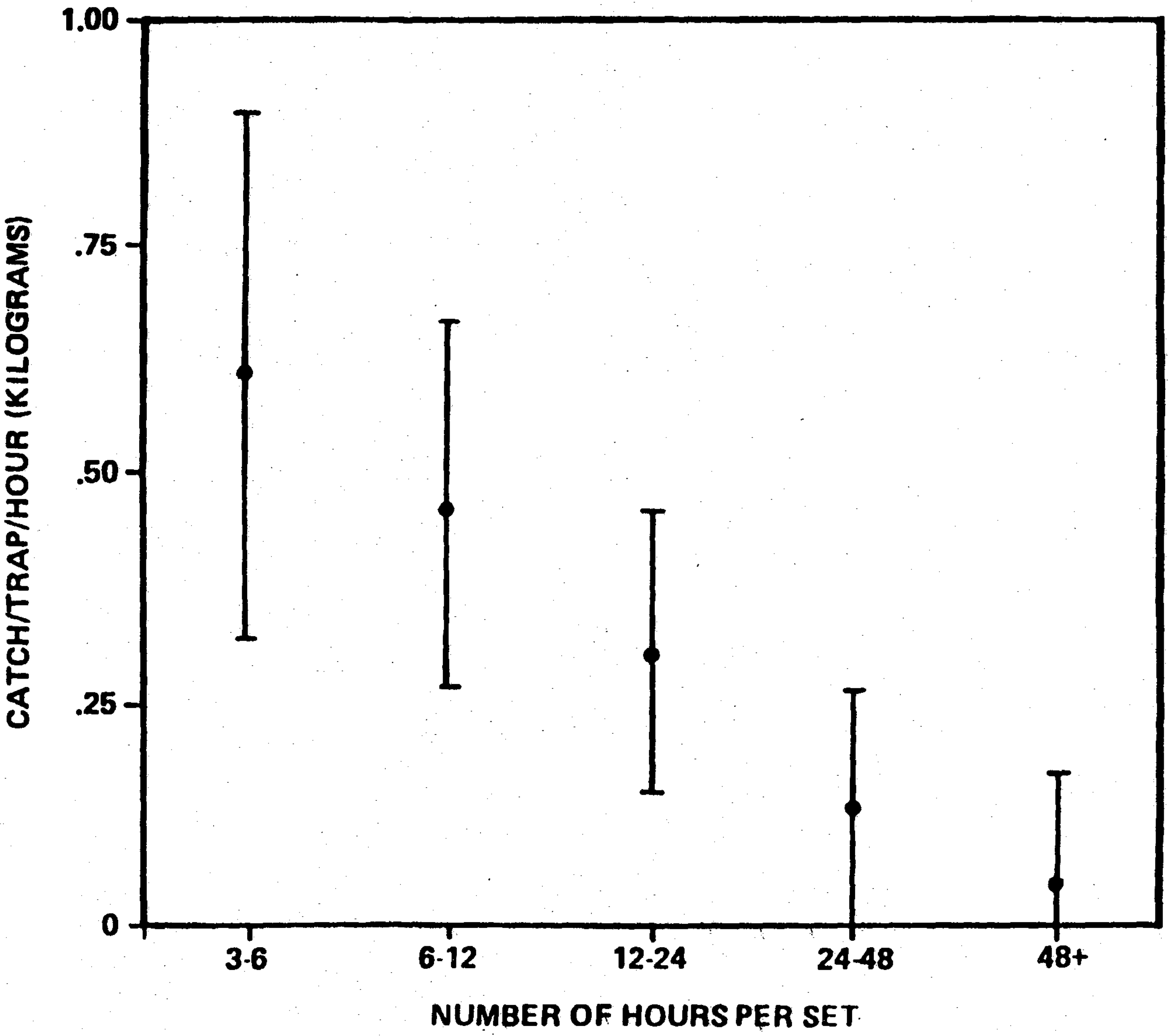

Figure 5. Catch of reef fish per trap per set in hours with 95% confidence intervals, Florida Middle Grounds.

submersible, and the crew of the NOAA Ship OREGON II for their long hours of hard work in gathering data for this study. In particular, we acknowledge the support of the NOAA Undersea Research Program Office, for funding support for submersible charter through the Harbor Branch Foundation.

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Text Footnotes

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BOTTOM LONGLINE EFFICIENCY, SELECTIVITY AND STANDING STOCK EVALUATION OF THE RED GROUPER (*EPINEPHELUS MORIO*) IN THE CAMPECHE BANK

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Introduction

The working framework defined in the bilateral agreement between Mexico and Cuba with regard to scientific and technological cooperation contemplates a series of cruises for exploratory and experimental fishing aimed at evaluating the distribution and abundance of the red grouper (*Epinephelus morio*) in the Yucatan Peninsula. During 1986 four seasonal cruises were carried out aboard Lambda-type Cuban vessels which operate with bottom longlines with the fishing techniques traditionally used by Cuban and Mexican fishermen. In this paper we present the results of the catch operation, emphasizing evaluation of technological aspects, in an effort to optimize the catch process for red grouper off the Yucatan Peninsula.

Objectives

Exploratory and experimental fishing activities were scheduled to meet the following objectives:

1) Determine the levels of operational efficiency and applied fishing effort during the catch process.

2) Evaluate the bottom longline catch efficiency according to the fishing grounds and season of the year.

3) Determine seasonal variations in relative red grouper abundance in the working zone.

4) Estimate the longline selectivity and evaluate seasonal variations in catch probability.

Area of Work

The work schedule for the research cruises covers the area of distribution of the resource in the Yucatan Continental Shelf (Fig 1). The area fished is located between parallels 21°41° North latitude and meridians 87°00° and 90°00° West longitude.

Gear and Materials

The cruises were aboard Cuban Lambda-type vessels which operate with 2 or 3 dories (grouper skiffs) 4.95m overall length, 1.75m wide, and 1.00m draft. They have a Yanmar inboard motor and carry 2 crew members, with a 36 hour endurance. Lambda vessels, which commercially fish red grouper, normally operate with 6 grouper dories and a 350 hook longline. The catch system is the one used by a typical bottom longliner from the Cuban commercial fleet. The technical characteristics of the longline can be found in Figure 2. The work onboard was carried out with the help of ichthiometers, a scale, and materials normally used in biological sampling. Some observations were carried out with the aid of the boat gear and instruments.

Methods

Sampling System

The survey cruises were planned around the geographical distribution of the red grouper (*Epinephelus morio*) over the Yucatan shelf, excluding areas where it was practically impossible to deploy this type of fishing gear due to rocky bottoms. We established a conventional stratum between 7-15 fathoms and another between 21-32 fathoms for our sampling stations. During the second cruise

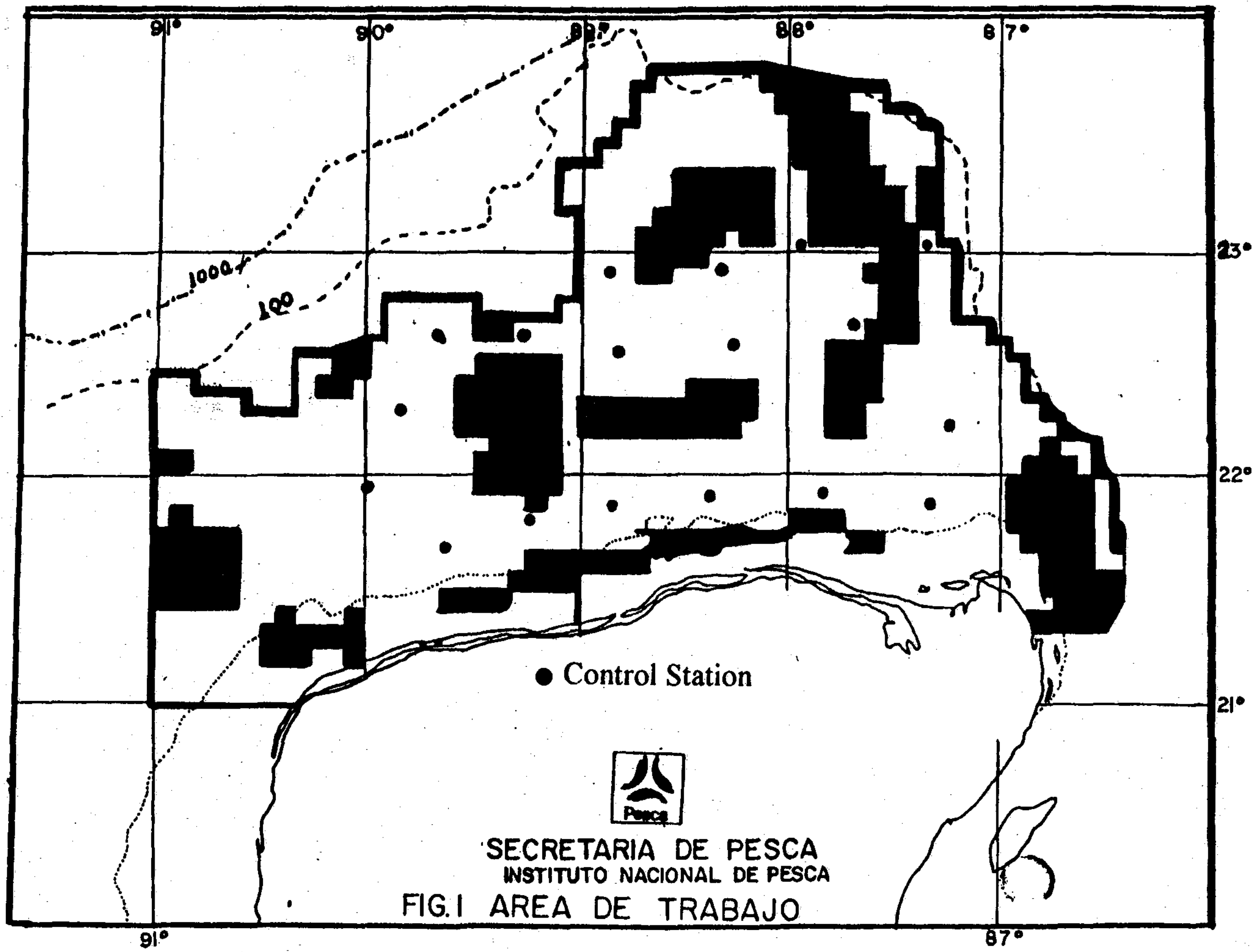

Figure 1. Area of Work

we considered a stratum between 40-50 fathoms in an effort to complement the information we already had; however, the results were not too satisfactory and the following cruises covered the two strata initially defined.

The geographical positions of the pre-established sampling stations were the same for the 4 cruises. At each station the catch was taken onboard dories according to the traditional fishing methods.

The set operation began at 6 a.m. and lasted for 10-15 minutes. The longline was not moved for 10-25 minutes, according to the fishermen's criteria. The hauling lasts between 50 and 70 minutes, depending on environmental conditions. During the operation, bait is put on the free hooks and replaced when it is no longer fresh. On a normal working day a maximum of 7 sets are made between 6 a.m. and 6 p.m. Normally set no. 4 lasts 30-45 minutes since that is when the fishermen eat aboard the mother ship.

The catch was weighed and sampled for biological purposes, emphasizing the fork length, total weight, gutted weight, sex, gonad maturity, fat content, and presence of parasites in the muscle tissue. From a technological point of view the samples were concerned with an analysis of the operational behavior of the bottom longline and the catch rates expressed in kilograms and number of individuals. At each control station oceanographical data such as surface and bottom temperature, salinity, height and direction of the waves, and fishing depth were measured.

Method of Analysis

Technical information compiled was processed separately for each cruise, paying special attention to seasonal abundance indexes (catch rates). The operational efficiency expressed in no. of hooks/station was directly related to fishing effort in order to determine different operating levels. Catch efficiency expressed as the proportion of individuals caught with respect to the total number of hooks deployed was considered to be the equivalent of CPUE and therefore was used as an index of relative abundance if the resource.

Estimation of density and standing stock was carried out according to the technical guidelines described by Alverson and Pereira (1969) and Yudovich and Baral (1968). Analytical treatment took into account the bottom longline as the sampling instrument of a commercially exploited stock. The working length of the longline was determined as the number of hooks, distance between the gangions, and the percentage of reduction during the fishing process. The working length of the longline was estimated considering that under fishing conditions its nominal length is approximately 20% shorter. Consequently, the average working length at each sampling station was calculated in the following manner:

$$L_T = D_R * (N + 1) * P_R$$

where:

L_T = working length of the longline

D_R = distance between the gangions

N = average number of hooks

P_R = percentage of reduction

The working area of the bottom longline was estimated according to the criteria established by Treschev (1975), which took into account that each gangion of the longline has its area of influence equivalent to a circle (Fig 3). Starting off from the catch efficiency values we applied the DeLury

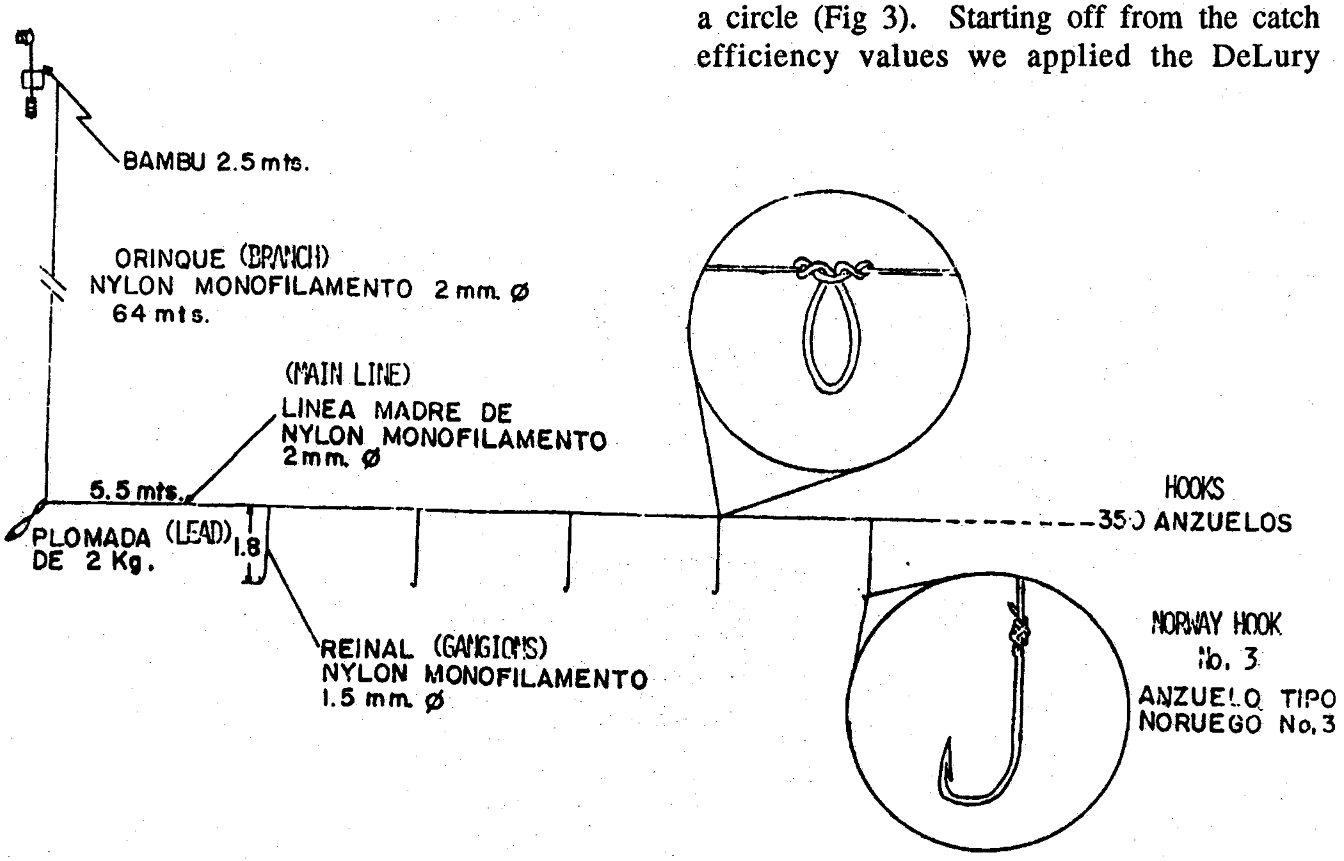

Figure 2. Technical Characteristics of the Bottom Longline

(1947) method described by Hamley (1972) to evaluate size selectivity for each fishing cruise, making a global estimate for 1986.

Results

Sampling Intensity and Catch Obtained

During the 4 fishing cruises some 462 control sets were made, averaging 115 sets per cruise. Sampling intensity, standardized at a grid of 225m^2, was variable for each stratum sampled and each cruise. On the average 2.93 control sets per grid or square were made. Table 1 indicates that stratum A, which comprises between 7 and 15 fathoms, was sampled with an average intensity of 5.61 sets per square, which is greater than the one applied to stratum B, found between 21 and 32 fathoms (1.91) sets per square. Station C was sampled with an intensity of 8.74 sets per square only during the second cruise.

The total catch obtained was 7607 kg, of which 5192 kg (68.3%) were represented by red grouper (*Epinephelus morio*). This catch is expressed in weight for 2604 specimens, which means the average weight of red groupers caught was approximately 2.0 kg. Seasonal variations in the weight of the individuals indicate an average value of 2.07 kg in winter (Feb.- Mar.), increasing to 2.52 kg at the beginning of summer (July), and dropping to 1.86 kg at the end of the season (Sept.- Oct.). During autumn (Nov.- Dec.) a minimum value of 1.70 kg was obtained.

Operational Efficiency and Fishing Effort

The catch process for red grouper uses a system of dories which operate independently of the mother ship and they provide the guidelines for establishing various indices of operating efficiency that can be used in a different manner to estimate the fishing effort applied to the fishery. The fishing unit is made up of the mother ship, the dories, the fishing gear, and the crew members. The operational index of efficiency is determined by the combined effect of the number of hooks on each longline, and the work capacity of the crew members. Consequently, a representative indicator of the operational efficiency is defined as the number of hooks used, per unit of time for each dory.

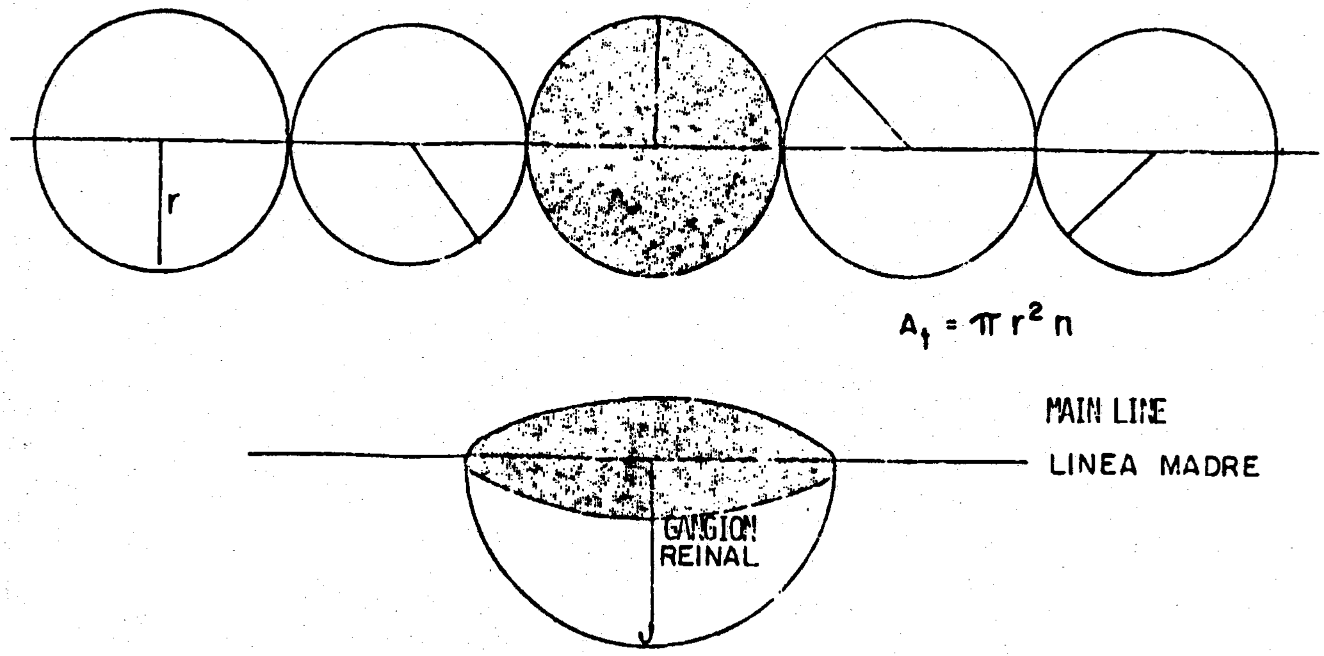

Figure 3. Geometry of the Longline during the Fishing Process

Table 1. Intensity of Sampling/Strata/Cruise.

CRUISE	STRATA DEPTH (B_Z)			
	A (7-15)	B (21-32)	C (40-50)	Yearly Average
1	7.93	3.96	--	5.44
2	5.00	0.85	8.74	2.17
3	4.50	2.10	--	2.62
4	3.90	1.60	--	2.09
Yearly Average	5.61	1.91	8.74	2.93

Table 2. Fishing Effort and Operational Efficiency.

STATION	CRUISE										
	1		2		3		4		TOTAL		N_{AZ}/LANCE
	Haul	Effort	Haul	Effort	Haul	Effort	Haul	Effort	Haul	Effort	
1	21	7294	8	2749	8	2704	6	2100	43	18847	345
2	21	6951	6	6449	7	2026	4	1376	38	12802	336
3	21	6741	5	1750	6	2027	6	2052	38	12750	330
4	12	3900	6	2097	5	1514	4	1390	27	8901	329
5	21	6797	6	2088	6	2025	6	2082	39	12992	333
6	21	6811	8	2799	6	2022	6	2064	41	13696	334
7	12	3127	-	-	4	1334	4	1378	20	5839	292
8	9	2770	7	2443	4	1349	4	1374	24	7936	330
9	21	6720	6	2051	4	1350	6	2082	37	12203	329
10	12	3832	6	2016	5	1668	6	2079	29	9595	330
11	-	-	6	2007	6	2021	4	1392	16	5420	338
12	6	1886	6	2209	6	2024	4	1392	22	7511	341
13	-	-	6	1882	8	2704	4	1392	18	5978	332
14	-	-	7	2294	6	2016	4	1362	17	5672	333
15	-	-	4	1333	6	2098	4	1382	14	4813	345
16	-	-	6	2097	6	2025	3	1013	15	5135	342
17	-	-	6	2061	4	1345	5	1679	15	5085	339
18	-	-	5	1746	4	1344	-	-	9	3090	343
	177	56829	105	36071	100	33596	80	27589	462	154085	333

N_{AZ}/LANCE = number of hooks/haul.

Table 2 indicates the operating capacity of the catch system for each season. We can see that during the first cruise a maximum number of 7294 hooks per station were used, while during the second, third and fourth cruises the maximum level of efficiency was only 2799, 2704, and 2100 hooks per station respectively.

Total fishing effort was 154189 hooks for 462 experimental fishing sets, with an overall average per cruise of 38548 hooks, using 333 hooks per set. During the first cruise 3 dories were used and for the other cruises only 2 dories were in operation. The level of efficiency for each dory/cruise was 18943, 18035, 16798, and 13794 hooks respectively.

The operational efficiency of the fishing unit also depends on how tired the crew is and on meteorological conditions in the fishing grounds. Therefore it is logical that at the beginning of each cruise the operational efficiency is greater, and gradually decreases by the end of the cruise. Also, when there is bad weather in the area operational efficiency is also reduced. In spite of this, and independently of bad weather, it is hard to maintain the same level of efficiency as at the beginning of the cruise. Figure 4 indicates the rate of decline in the operational efficiency as the number of stations sampled increases.

Catch Efficiency and Indices of Relative Abundance

In most of the studies carried out on commercial fisheries the indices of relative abundance are expressed in kilograms. This is because catch statistics from the red grouper fleet take into account the total weight unloaded without mentioning the number of

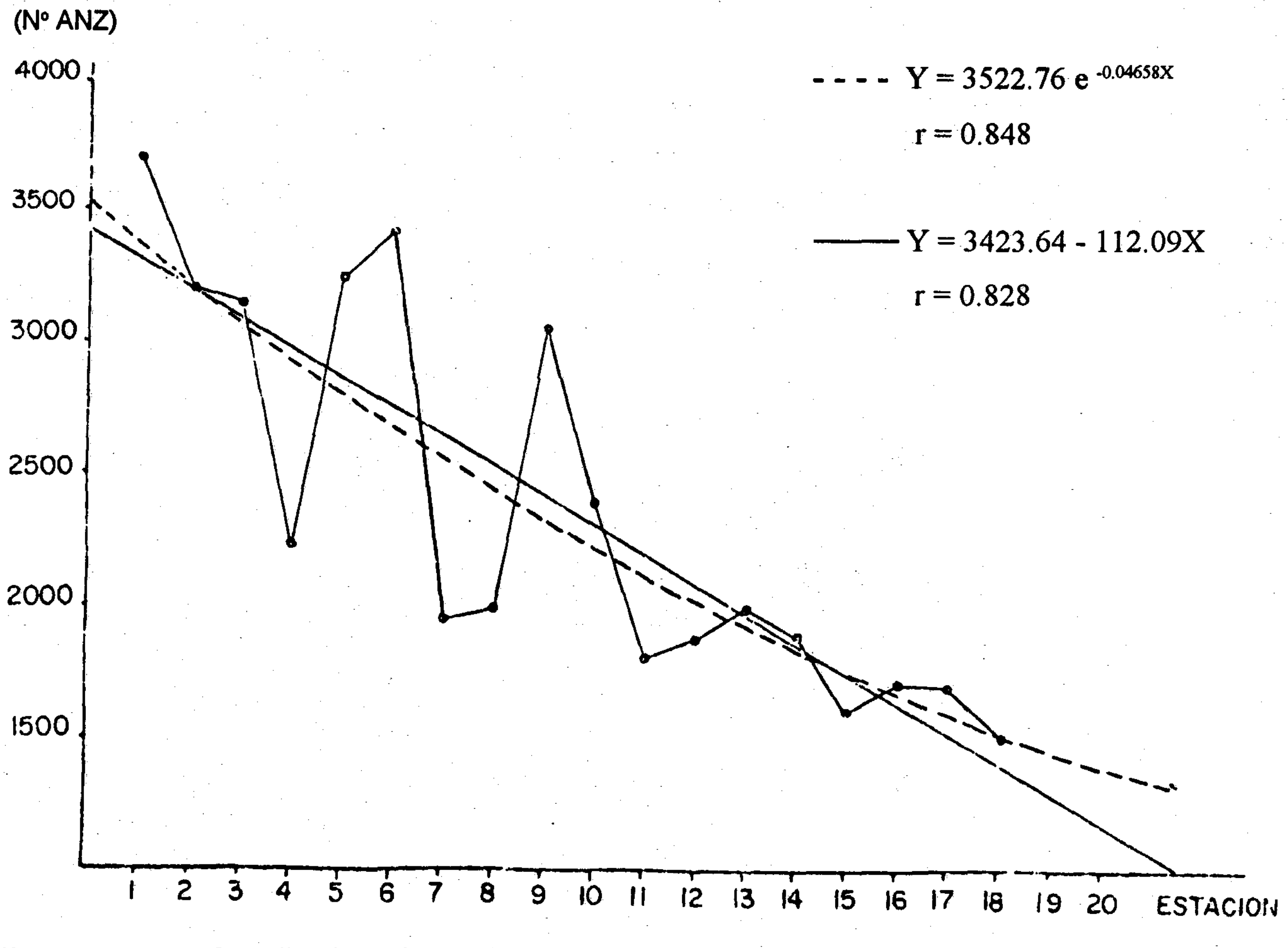

Figure 4. Rate of Declination of Operational Efficiency during the Fishing Process.

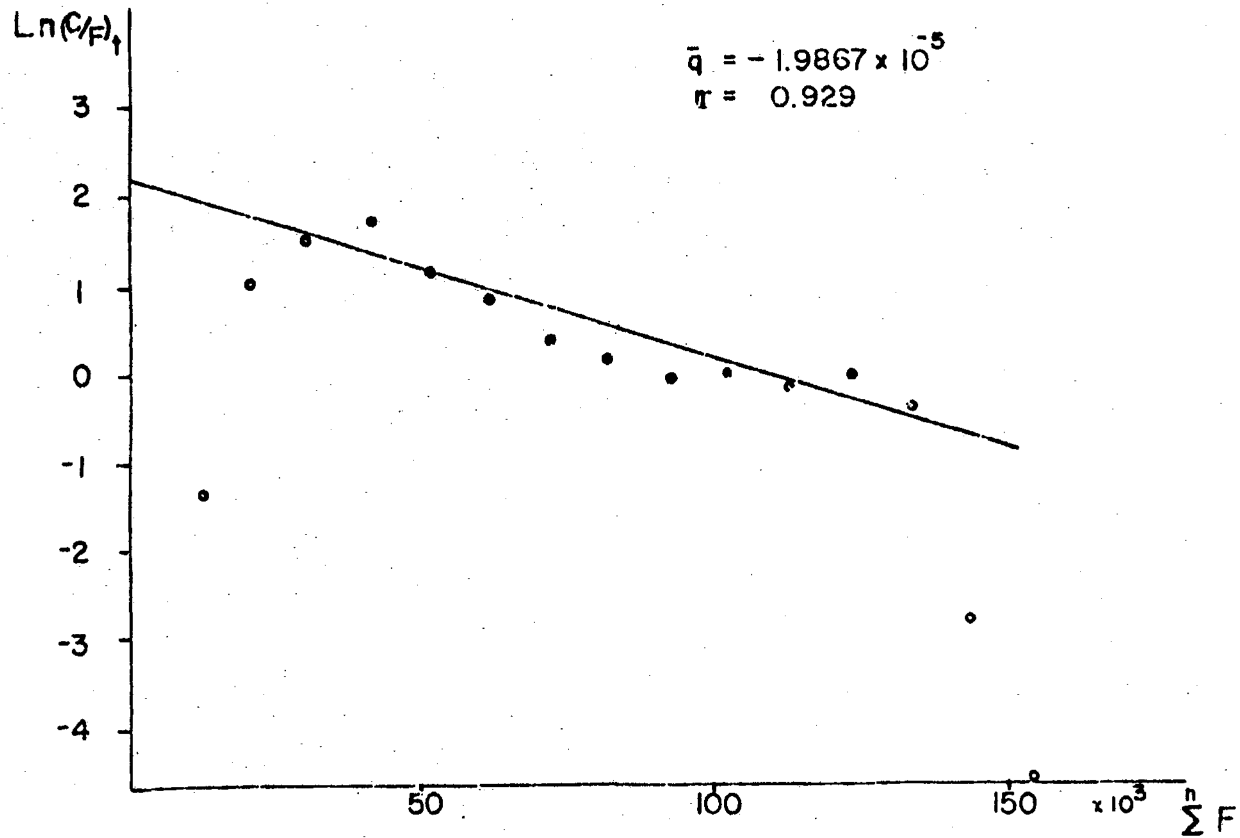

Figure 5. Relation between the Catching Efficiency and the Accumulated Fishing Effort.

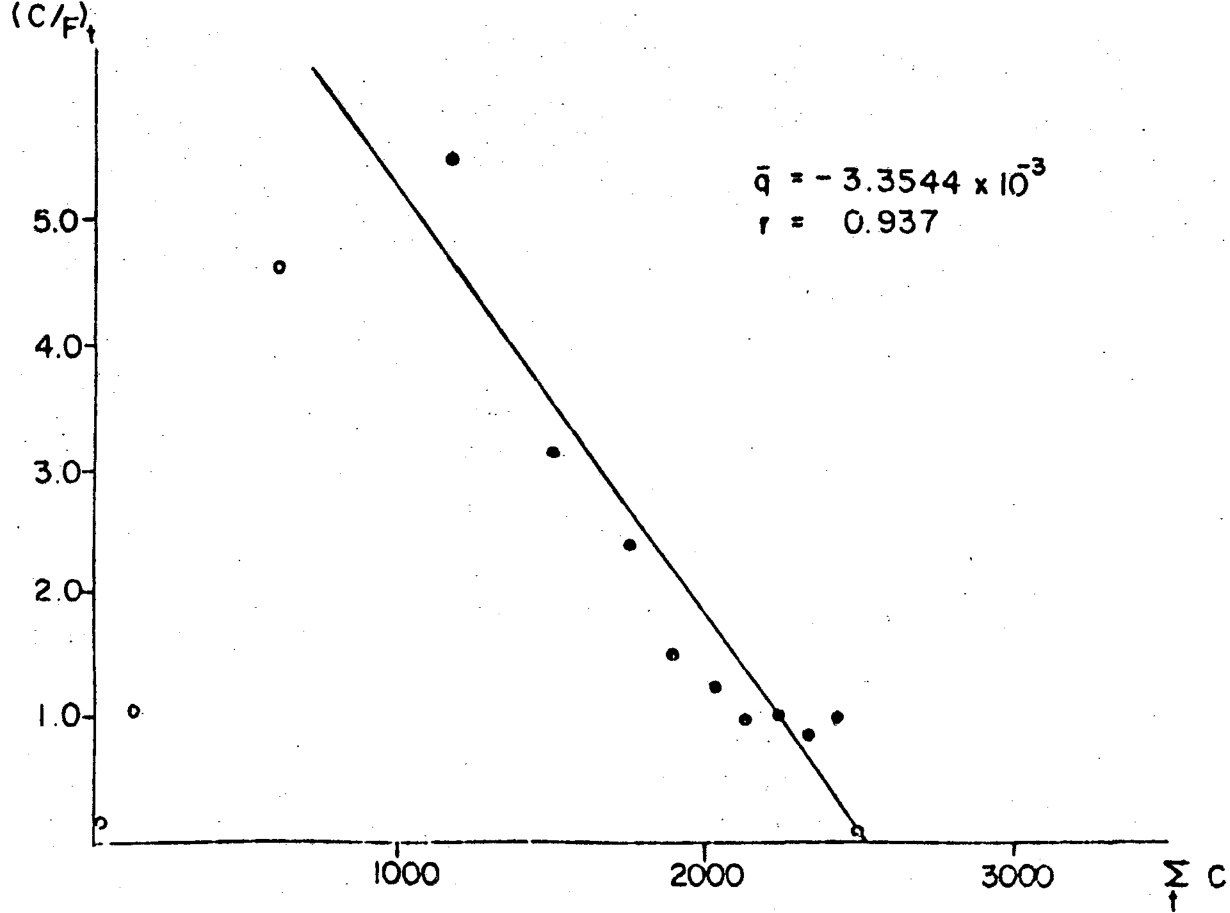

Figure 6. Relation between the Catching Efficiency and the Accumulated Catches.

Table 3. Catch, Fishing Effort and Catching Efficiency per Cruise.

Cruise	Depth	Total Capture	Grouper Catch		Fishing Effort	C.P.U.E	
	(BZ)	(Kg.)	(No.)	(Kg.)	(Hooks)	(No.)	(Kg.)
I(Feb-Mar)	7-32	3293.6	1123	2329.3	56,829	1.98	4.10
II(July)	7-50	1596.2	319	804.0	36,071	0.88	2.23
III(Sep-Oct)	7-32	1509.1	534	995.8	33,596	1.59	2.96
IV(Nov-Dec)	7-32	1208.4	627	1063.6	27,589	2.27	3.86
TOTAL		7607.3	2603	5192.7	154,085	1.69	3.38

individuals caught. In any case, whenever possible, especially in exploratory and experimental fishing studies, it is best to use both indicators so that it is possible to detect seasonal differences in the fish stocks and to also avoid bias in the abundance indices brought about by the resource's biological condition, which is seen in the individual's weight.

Table 3 indicates the overall results of catch efficiency for each fishing cruise. The best values are for the first and fourth cruises, with 1.98% and 2.27% respectively. These values are complemented by the indices expressed in weight, which were 4.10 kg/100 hooks and 3.86 kg/100 hooks, respectively.

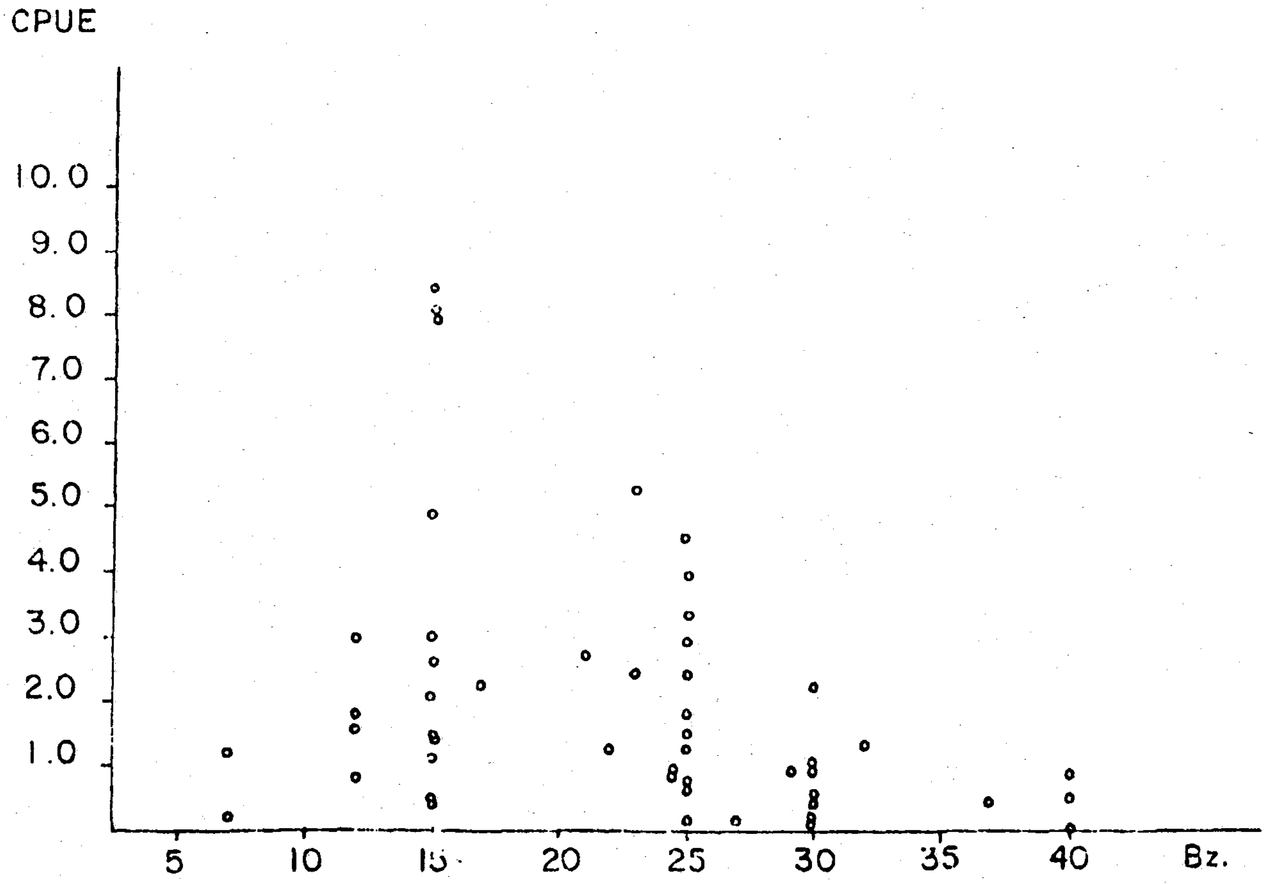

Figure 7. Stratification of the C. P. U. E. in Function of the Fishing Depth

Table 4. Estimation of Working Area and Catchability Coefficient for the Bottom Longline.

STATION	CRUISE			
	1	2	3	4
1	0.02258	0.0085	0.0084	0.0065
2	0.02153	0.0075	0.0063	0.0042
3	0.02090	0.0054	0.0063	0.0063
4	0.01209	0.0064	0.0047	0.0043
5	0.02104	0.0064	0.0063	0.0064
6	0.02108	0.0064	0.0063	0.0064
7	0.00968	-	0.0041	0.0042
8	0.00857	0.0075	0.0042	0.0042
9	0.02084	0.0063	0.0042	0.0064
10	0.01187	0.0062	0.0052	0.0064
11	-	0.0061	0.0063	0.0043
12	0.00584	0.0068	0.0063	0.0043
13	-	0.0058	0.0084	0.0043
14	-	0.0070	0.0062	0.0043
15	-	0.0041	0.0065	0.0043
16	-	0.0064	0.0063	0.0031
17	-	0.0063	0.0042	0.0053
18	-	0.0053	0.0042	-
Σa	0.17602	0.1084	0.1044	0.0852
$\bar{a}$	0.0160	0.0064	0.0058	0.0050
$q_{(E)}$	5.3491×10^{-3}	3.4798×10^{-3}	9.8580×10^{-3}	1.0441×10^{-2}
$q_{(C)}$	7.1489×10^{-3}	4.1243×10^{-3}	1.8432×10^{-2}	2.7329×10^{-2}

Figures 5 and 6 show the dependency of the catch per unit of effort with respect to the fishing effort applied and to the accumulated catch respectively. These relationships allow us to estimate the annual catch coefficient (q) of the bottom longline according to the criteria established by Hamley (1972). In addition to this, estimates of the catch coefficient were made for each cruise in an effort to evaluate seasonal variations.

Table 4 contains estimates of the longline's working area during the cruises and the estimates for the catch coefficient. Figure 7 shows the variation in catch efficiency depending on fishing depth. It can be observed that the highest values are found around 15 fathoms and gradually drop as depth increases.

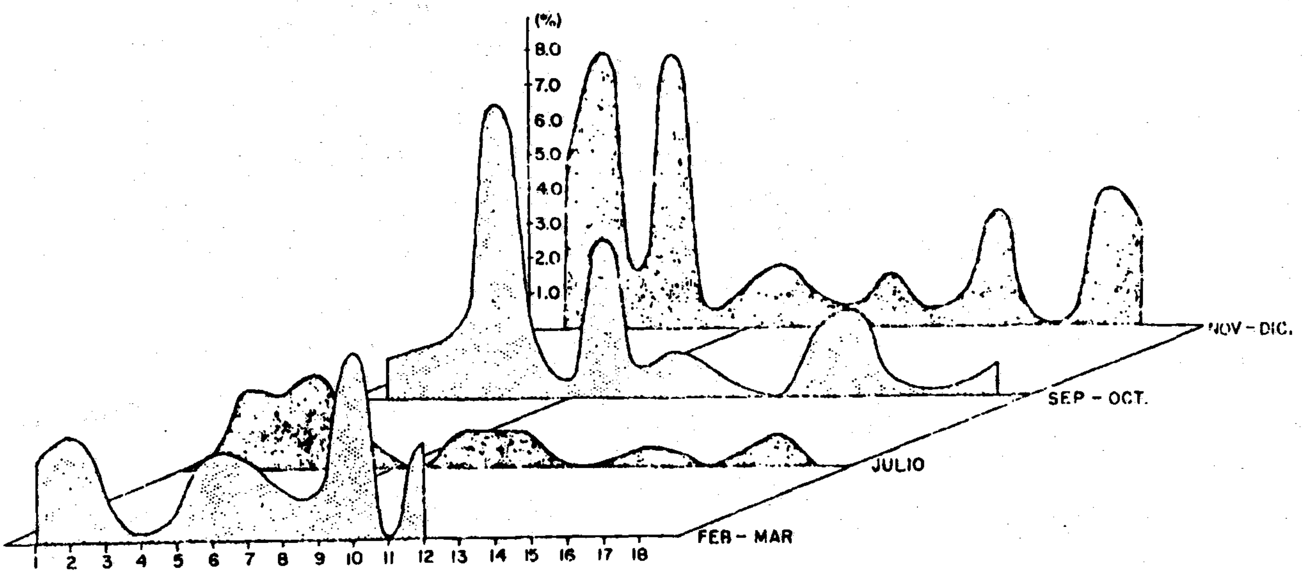

Figure 8. Seasonal Variation of the Relative Abundance of Grouper in the Yucatan Shelf 1986.

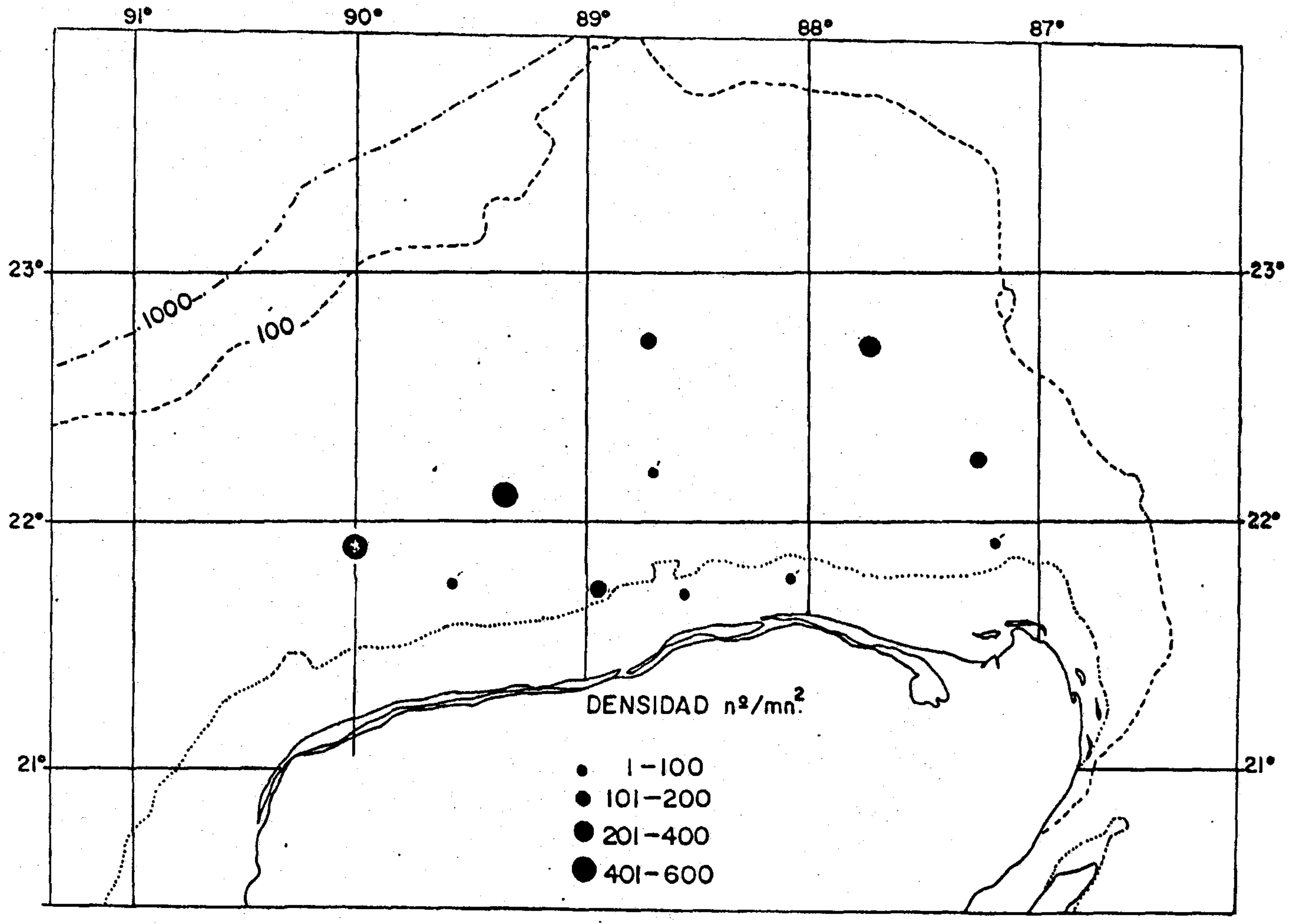

Figure 9. Densities of Grouper during the cruise LAMBDA/86/01.

The relative abundance of red grouper in the explored area indicates that the greatest concentrations are found at the station of 7-25 fathoms (Fig 8), and that there is also a clearly defined tendency for greater abundance at the end of summer and during autumn. There are concentrations of considerable importance in the strata at 30 fathoms, especially during autumn, although it is necessary to increase the sampling to confirm this fact during all seasons of the year.

During the February-March cruise the average value of density was 165 individuals/nm^2. During the summer cruise in July, the average density was 136 individuals/nm^2, with a dispersion coefficient of 0.9091 (Fig 10). By the end of the summer (Sept.- Oct.), average density increased to 324 individuals/nm^2, and the dispersion coefficient also increased to 1.2143 (Fig 11). The average density in autumn (Nov.- Dec.) was 526 individuals/nm^2, and the dispersion coefficient was kept high at a value of 1.0544 (Fig 12).

Bottom Longline Selectivity

Sizings carried out on each cruise indicate that for the winter period (Feb.-Mar.) the modal length was 35.7cm. At the beginning of summer (July) three groups with values of 30.4, 51.4, and 75.4cm (Fig 14) were well represented. By the end of summer

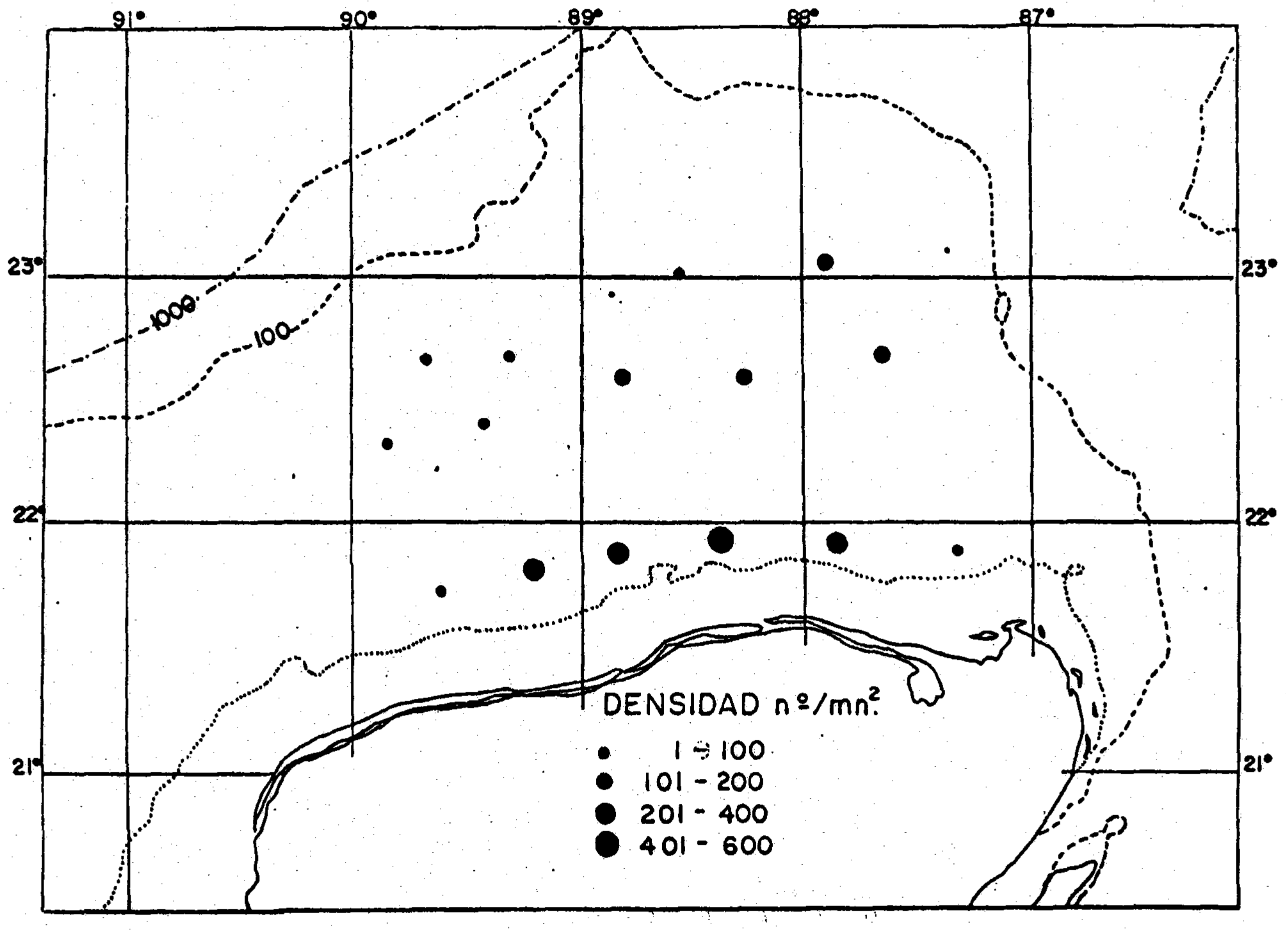

Figure 10. Densities of Grouper during the cruise LAMBDA/86/02.

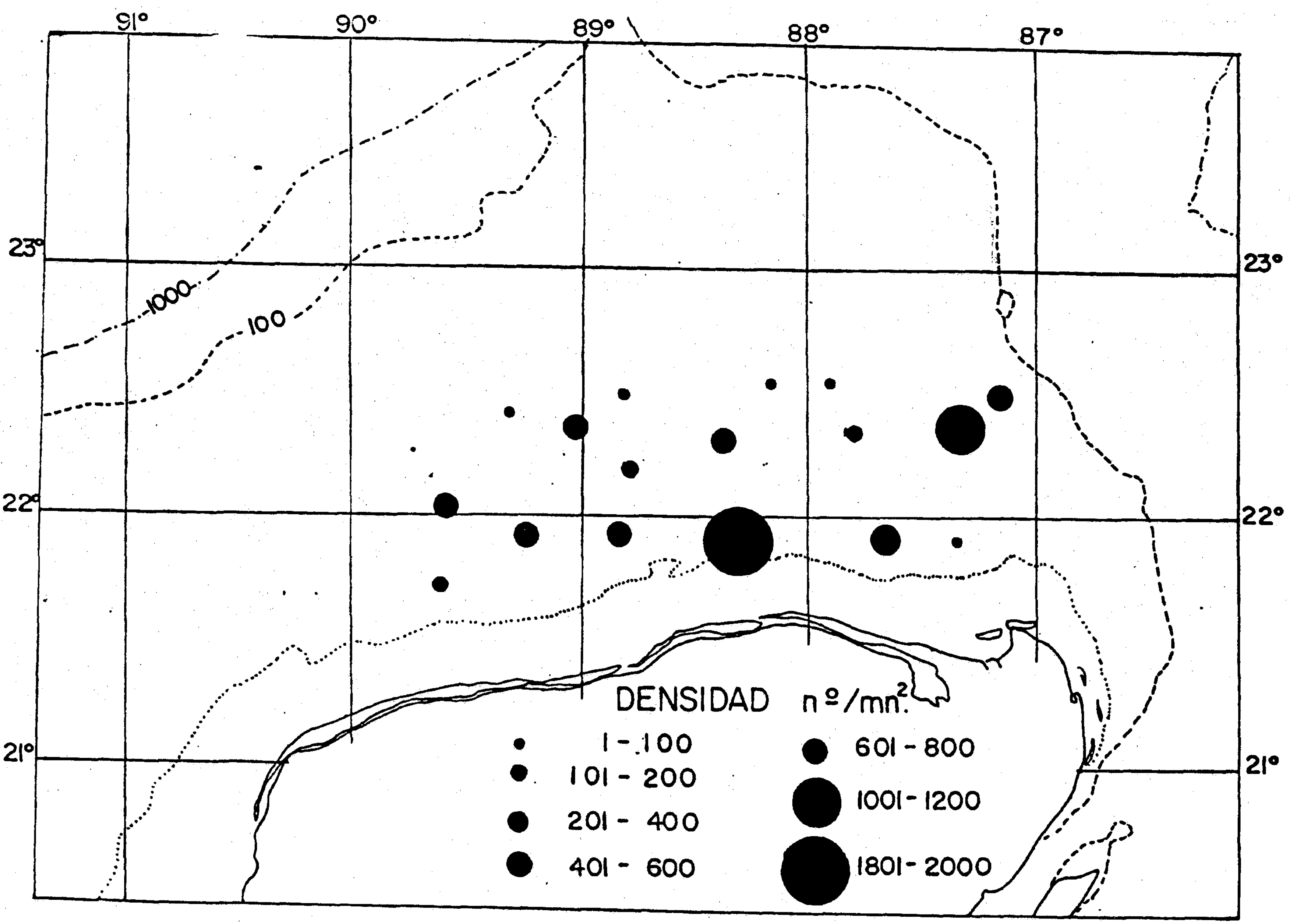

Figure 11. Densities of Grouper during the cruise LAMBDA/86/03.

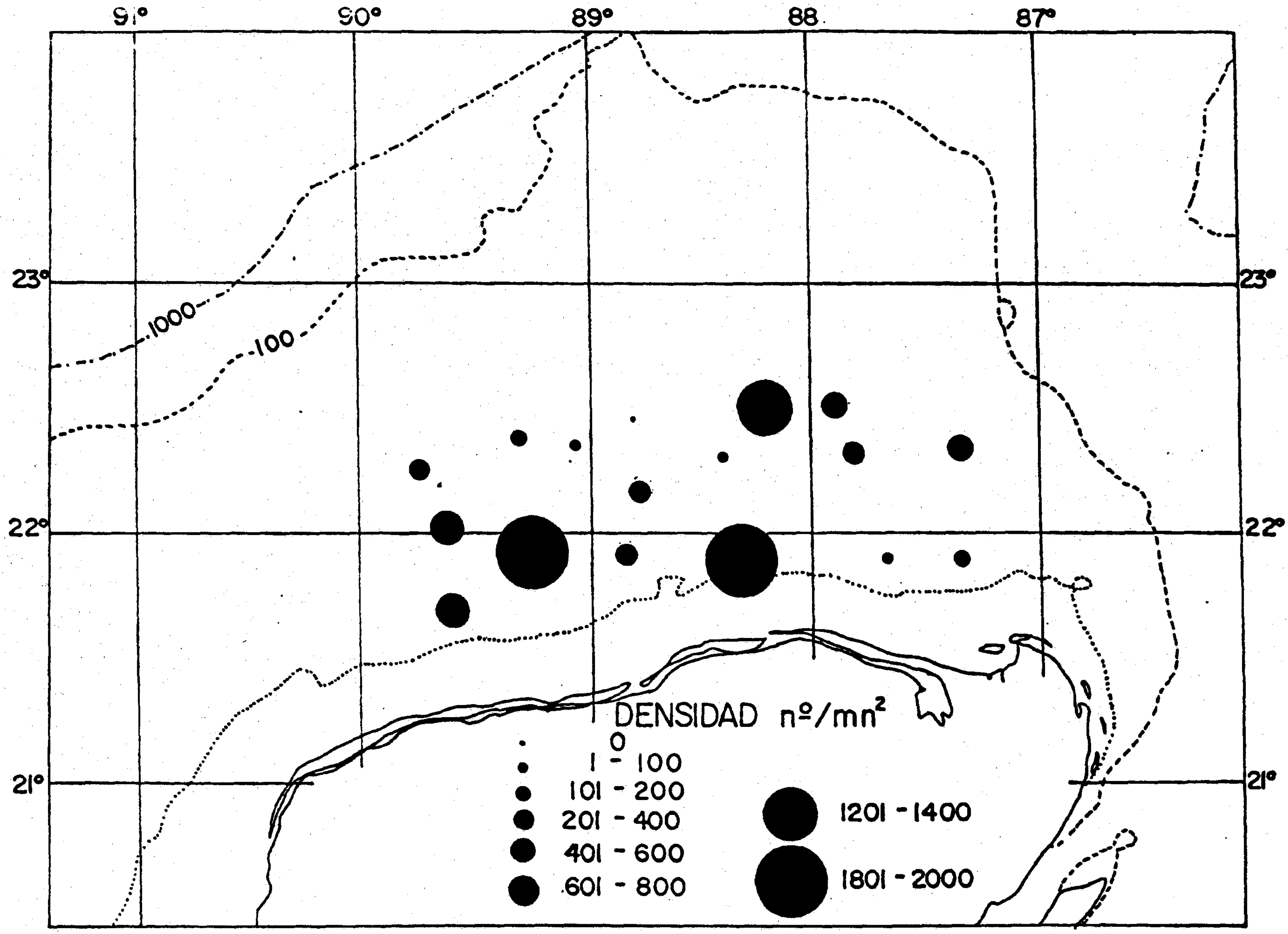

Figure 12. Densities of Grouper during the cruise LAMBDA/86/04.

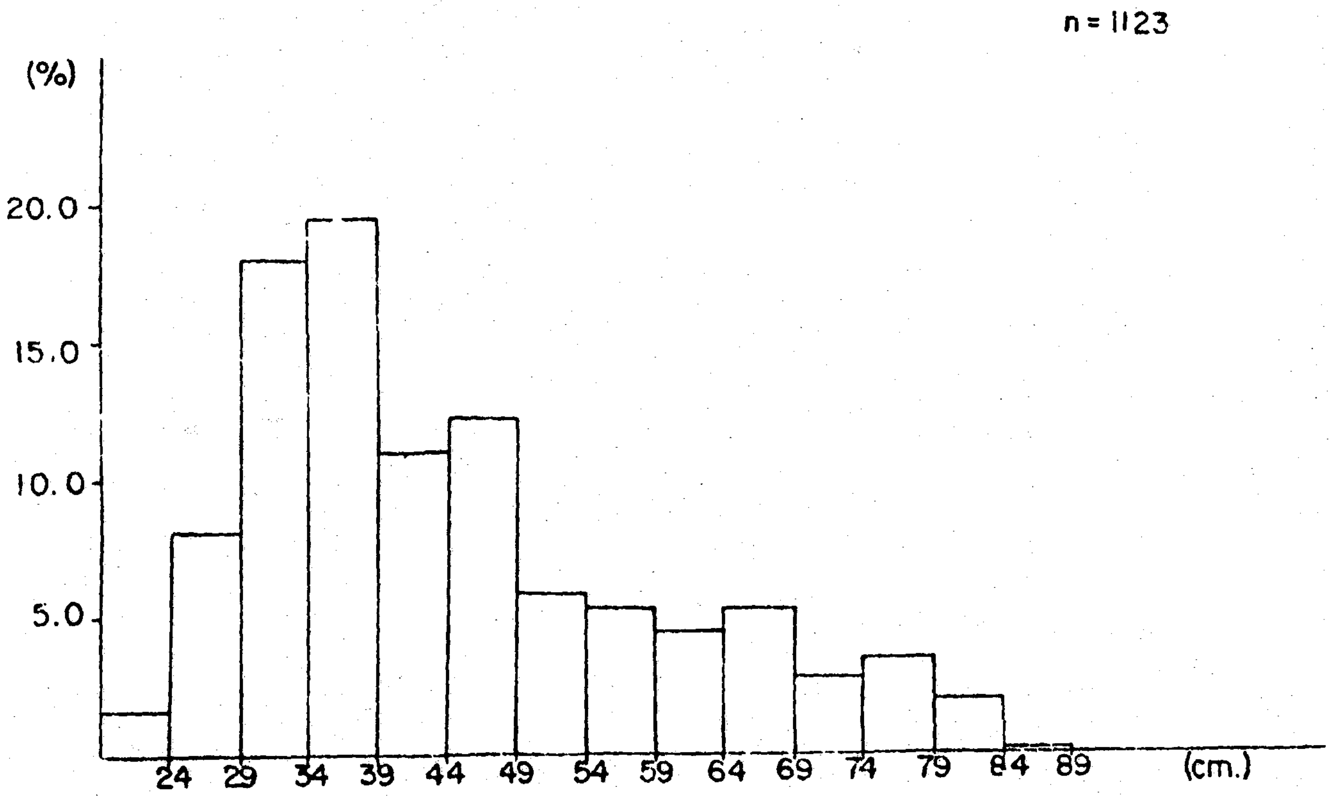

Figure 13. Size Frequency Distribution of Grouper, Cruise LAMBDA/86/01.

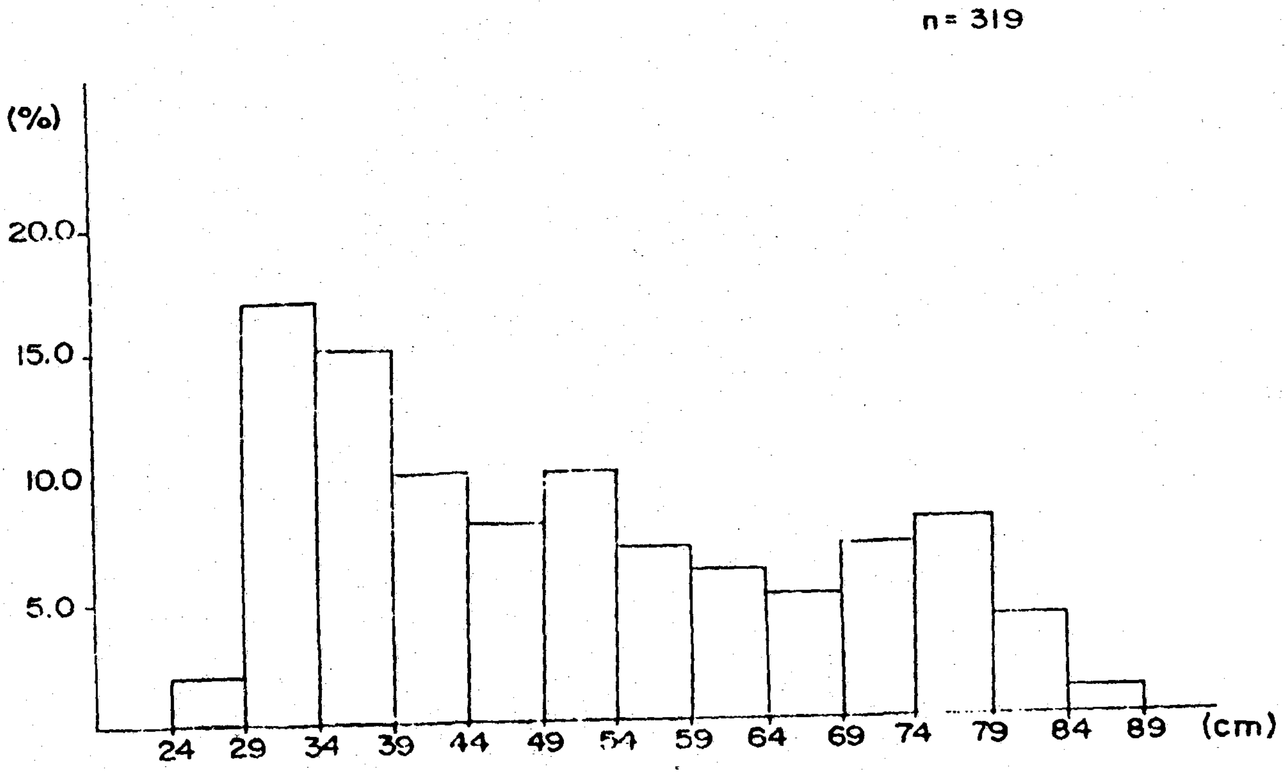

Figure 14. Size Frequency Distribution of Grouper, Cruise LAMBDA/86/02.

and during autumn, modal length was 35.5cm and 37.4cm respectively (Fig 15 and Fig 16). An overall analysis of the data coming from 2499 red grouper specimens that make up our whole sample can be found in Figure 17, where the modal length was 36.4cm. Red grouper were caught with a 22.8% level of efficiency.

The annual estimate of catch coefficient q = 3.35435×10^{-3} does not show seasonal variation in the catch probability by the fishing gear, nor variations in the resource's abundance. This situation sets the guidelines for considering the possibility of overestimating the bottom longline's catch capacity. Figure 18 shows the selectivity curves estimated for each cruise. The shape and height of the curves are quite different according to the season of the year. Evidently, the estimated catch coefficient reflects the specific situation of the red grouper for each season. It is quite clear that the probability is greater for the end of the year cruises.

Standing Stock

Considering that the red grouper (*Epinephelus morio*) stock is subject to seasonal variations produced by the effect of diverse factors of a physical, chemical, and biological nature, we carried out estimates of standing stock on each cruise and later obtained an annual average value of 60324 tons. Table 5 contains the results and it can be seen that the estimates show a decreasing tendency throughout the year, reaching a

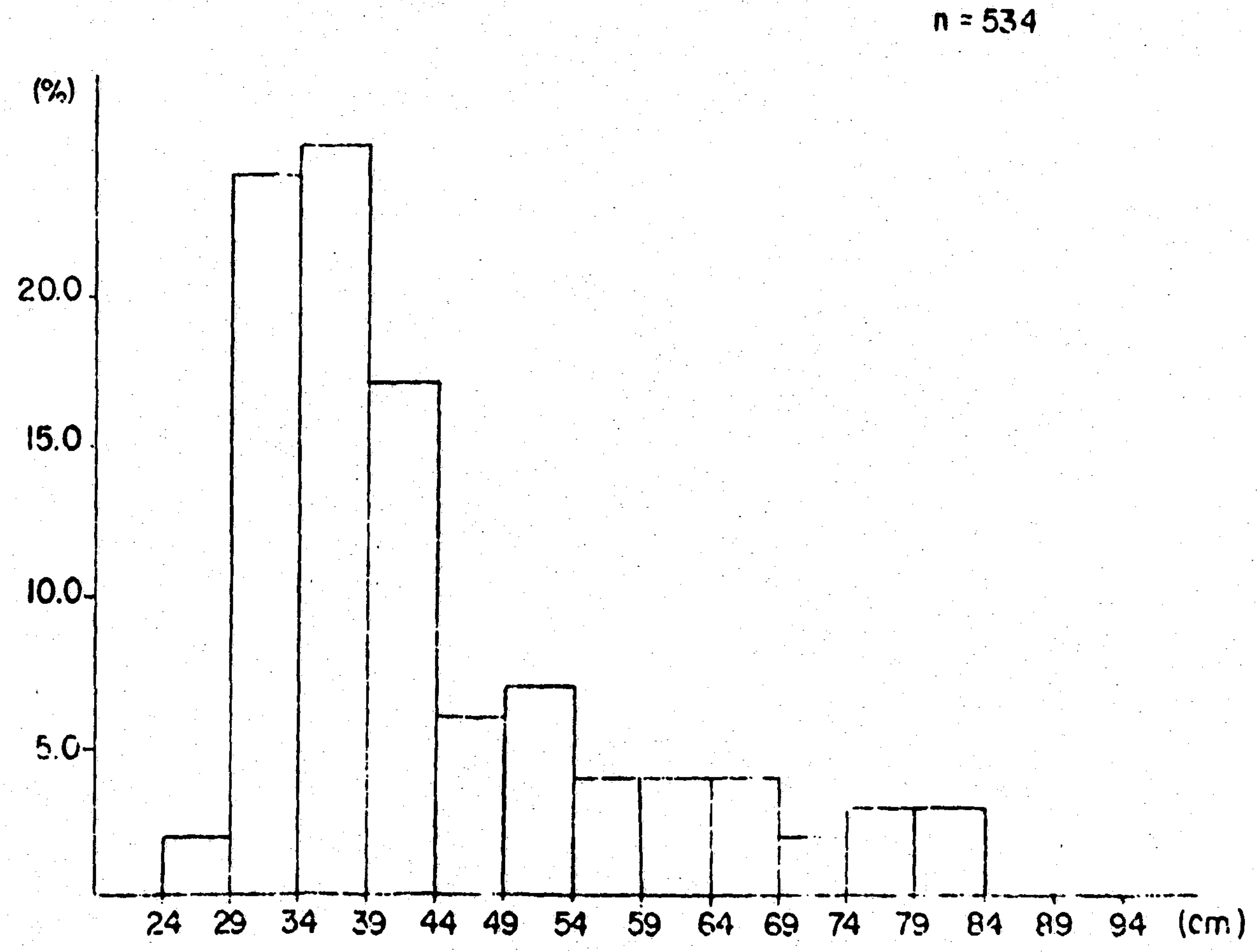

Figure 15. Size Frequency Distribution of Grouper, Cruise LAMBDA/86/03.

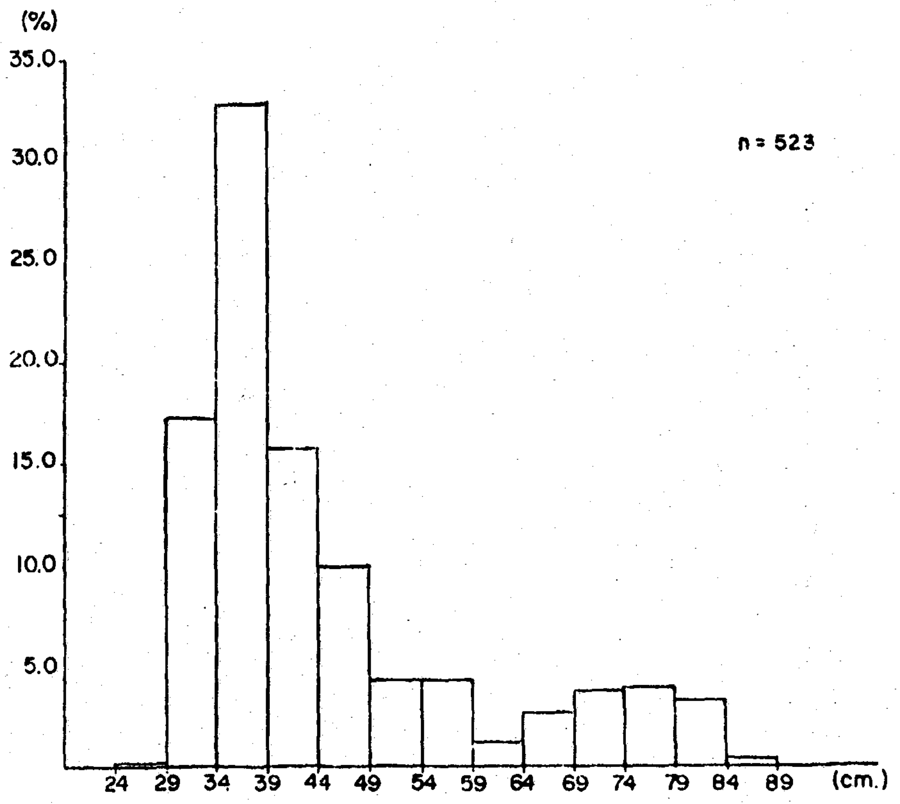

Figure 16. Size Frequency Distribution of Grouper, Cruise LAMBDA/86/04.

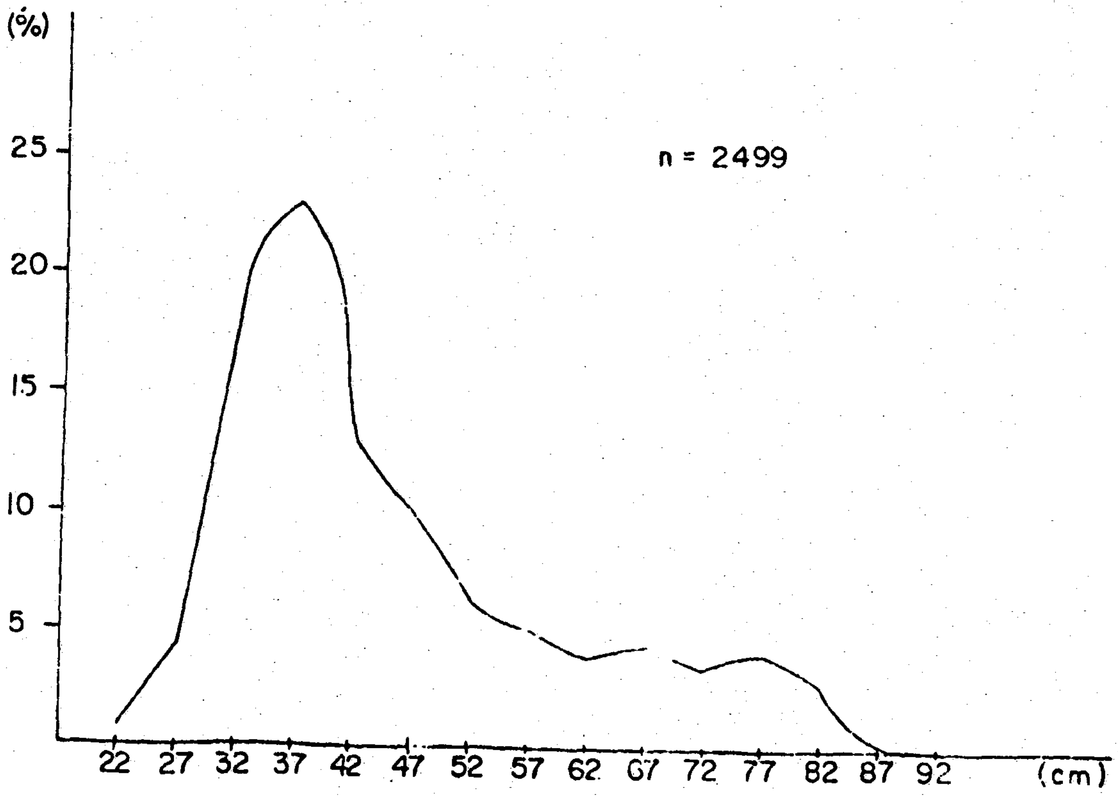

Figure 17. Global Size Frequency Distribution of Grouper (*Epinephelus morio*).

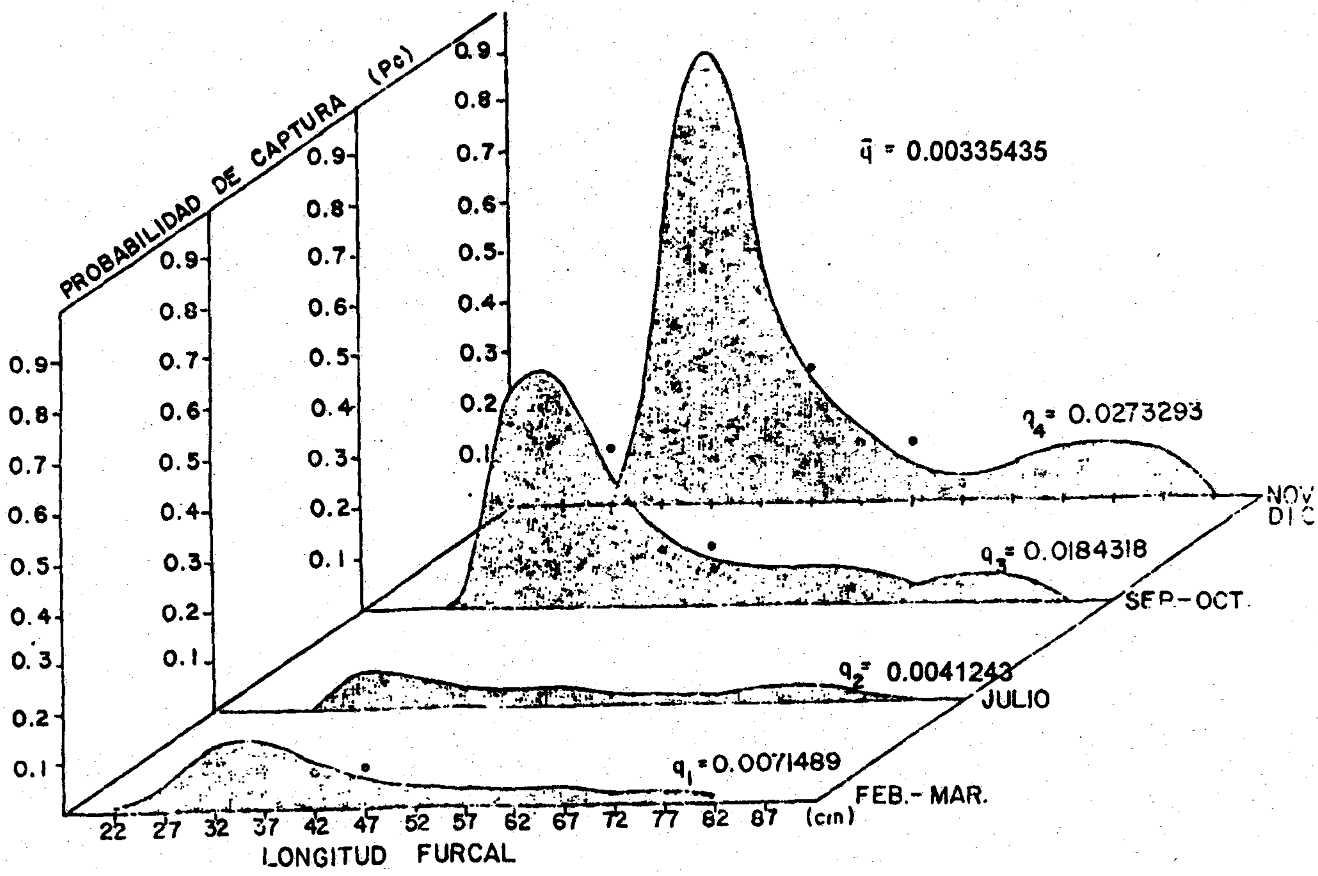

Figure 18. Seasonal Variations in the Selectivity of Bottom Longline for the Catch of Grouper (*Epinephelus morio*).

Table 5. Estimates of Standing Stock, Dispersion of Resource, Optimal Length, and Average Weight.

Cruise	**Standing Stock**		**Dispersion**	L_{OP}	P_M
	(N°)	**(TON)**	**Grade (Cv)**	**(cm)**	**(Kg)**
1	44,193,709	91,481.0	0.6655	35.7	2.07
2	32,426,267	81,714.0	0.9091	30.4	2.52
3	29,134,769	54,191.0	1.2143	35.5	1.86
4	8,182,702	13,911.0	1.0544	37.4	1.70
$\overline{X}$	28,484,362	60,324.0	0.6998	36.4	2.04

maximum value during winter. It is worth mentioning that the coefficient of variation (Cv) of the control catches show an inverse trend, that is, they tend to increase throughout the year from a value of 0.6655 in the winter, up to 1.2143 at the end of summer, and then drop to 1.0544 during autumn. Table 6 shows the confidence intervals for standing stock estimates, with confidence levels of 80.0 and 90.0%.

Table 6. Confidence Limits

Cruise	Standing Stock ($\overline{P}_{NJK}$)	
	β = 0.80	β = 0.90
1	44,193,709 ± 3406	44,193,709 ± 5309
2	32,426,267 ± 2772	32,426,267 ± 4295
3	29,134,769 ± 9642	29,134,769 ± 14895
4	8,182,702 ± 12742	8,182,702 ± 19738

This situation can perhaps be explained through the species' reproductive cycle, which suggests the hypothesis that the stock is grouped together during the winter for reproductive purposes and later disperses throughout the area to favor growth. The maximum sustainable yield can be estimated if we consider the criteria defined by Schaeffer (1954) or Gulland (1970). In any case it requires estimates of the instantaneous natural mortality (M), which we do not presently have.

Discussion

The results obtained during this study constitute a basis for making comparisons with results stemming from similar analyses. Analytical treatment of the compiled information uses methods developed by Hamley (1972) and Alverson and Pereira (1969), brought together in such a way that they satisfy the objectives set forth in the study.

An estimate of the catch coefficient is made by applying DeLury's (1947) two equations, accepting that the red grouper catches obtained from each cruise are independent events and that during each event the catch coefficient remains the same. Results indicate that the method of analysis shows a good fit and it is possible to select (q) values, whose correlation coefficient is the highest.

The evaluation of red grouper standing stock can be acceptable by applying Alverson and Pereira's (1969) model; however it is desirable to make other attempts to enrich the results and especially to strengthen the application of the direct evaluation method with the concentration coefficient (1-Cv) for red grouper throughout the year. In this sense we should mention that during the 1976-77 period Cuban researchers applied the method described by Yudovich and Baral (1968) to the information obtained during the joint Mexico/ Cuba research cruises off the Bank of Campeche.

At that time standing stock estimates did not consider the catch coefficient, since the method suggests applying a value of $q = 1.0$ as a first estimate. The same thing happens with the method described by Alverson and Pereira (1969). The results obtained varied between 5000 and 7100 tons for the July and October cruises in 1976 respectively, and between 7300 and 7600 tons for the July-August and December 1977 cruises. At present Cuban researchers refuse to use this evaluation method, probably because the standing stock estimates are so low, and also because such estimates are not congruent with those obtained by means of analytical methods.

The standing stock estimates obtained in this study are congruent with evaluations made by Sauskan and Oleachea (1974) and Buesa (1978), mentioned by Blanco et al. (1980). Klima (1976) calculated a standing stock of 76000 tons and a potential yield of 35000 tons, using the model of yield per recruit. However, he also points out the increase in the Mexican commercial fleet and that the yield per recruit could drop if fish mortality increases and age remains constant at first catch. On the other hand Valdez and Fuentes (1987) do not report standing stock estimates using analytical models that would allow us to make the necessary comparisons.

For all of the above reasons we suggest that these evaluation models of yield per recruit be applied, and that the corresponding populational parameters be updated.

Conclusions

The study of exploratory and experimental fishing carried out in 1986 during 4 seasonal cruises meets the objectives set forth at the onset of research. The methodology followed for the analysis was adapted to the characteristics of the information compiled, especially with regard to the estimation of the catch coefficient and its applications to the direct method of evaluation by Alverson and Pereira (1969).

There are seasonal variations in both longline catch capacities which are brought about by seasonal variations in the resource's abundance. This means that the selectivity curves of the bottom longlines show different levels of efficiency for optimum catch lengths.

Standing stock was estimated as a first approximation and is calculated at 60324 tons annually, reaching maximum values during the winter, and dropping off during summer and autumn. The degree of dispersion of the resource in the areas of distribution indicates that its behavior depends on its reproductive cycle, which takes place between 7 and 15 fathoms.

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POPULATION ESTIMATES OF DEEP-WATER FINFISH SPECIES BASED ON SUMERSIBLE OBSERVATIONS AND INTENSIVE FISHING EFFORTS OFF CHARLESTON, S. C.

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Studies to develop population estimates of deep-water reef fish based on visual observations from a submersible and on intensive fishing efforts were carried out in 1982 and 1983 in a 118 hectare site in 200 m of water, 148 km east of Charleston, South Carolina. Data from 7 submersible dives in 1982 and 6 dives in 1983 were used to develop population estimates on seven fish species in 5 different habitat types within the study area. Longline sets in 1982 (N=46) provided data adequate to generate population estimates for blueline tilefish and blackbelly rosefish. Population estimates could not be calculated for a third target species, snowy grouper, from the longline data. No longline derived estimates were developed in 1983, principally because of small sample size (N=30). Based on submersible studies, estimates of snowy grouper densities ranged from 2.6 to 15.5 individuals per hectare, with blueline tilefish estimates ranging from 0.5 to 1.4 per hectare. Based on regressions of CPUE on cumulative catch ($p=0.05$), blueline tilefish estimates ranged from 1.2 to 4.1 individuals per hectare and blackbelly rosefish estimates ranged from 8.1 to 96.0 individuals per hectare.

Introduction

Deep-water exploitable resources are easily and quickly overfished as removal of large specimens affects stock equilibrium. Accurate assessment methods which can provide sound management recommendations before stocks become overfished are imperative. The assessments should include indices of stock size, availability, rates of exploitation and recovery, and fishing techniques; and should also enable the fishery to maintain or enhance stock production and determine acceptable utilization rates to sustain optimum population levels.

Abundance of deep-water organisms is difficult to determine when reliance is placed entirely on indirect methods for collecting habitat, environmental, and faunistic data (Barans, 1982; Gutherz, 1982). Indices of abundances are generally extrapolated from catch rates of trawls, longlines, traps and hand lines. Information obtained is often incomplete or misleading and can result in erroneous conclusions regarding stock size and availability (Gutherz, 1982). Population information is restricted to those species caught and provides no information on ecological relationships including species interactions, behavior, habitat, or associated fauna.

Submersibles have been used extensively to observe marine fishes and invertebrates in an attempt to better understand ecological relationships, behavior, habitat preferences, and to compute population estimates (Able et al., 1982; Able et al., 1987; Anderson and Bullis, 1970; Barans et al., 1986; Grimes et al., 1986; Gutherz et al., 1983; Jones et al., 1989; Matlock et al., 1991; Parker and Ross, 1986; Ralson et al., 1986; Shipp and Hopkins, 1978; Uzmann et al., 1977; and van Hoek, 1982). Biological observations and habitat utilization can also be recorded and documented on video, audio and photographic records for later analysis when utilizing submersibles.

This paper documents results of studies conducted on the Charleston "Lumps" area near the edge of the continental shelf east of Charleston, South Carolina in August, 1982 and September 1983. National Marine Fisheries Service, South Carolina Department of Natural Resources, and Harbor Branch Foundation personnel conducted submersible survey and intensive bottom longline fishing activities to provide population estimates for snowy grouper (*Epinephelus niveatus*), blueline tilefish (*Caulolatilus microps*), and blackbelly rosefish (*Helicolenus dactylopterus*). Substantial information was also obtained on the Charleston "Lumps" habitat and on the abundance and distribution of other fish species within that habitat.

Materials and Methods

The South Carolina Department of Natural Resources, R/V OREGON, and the Harbor Branch Foundation, Inc. vessel R/V JOHNSON; along with the Harbor Branch

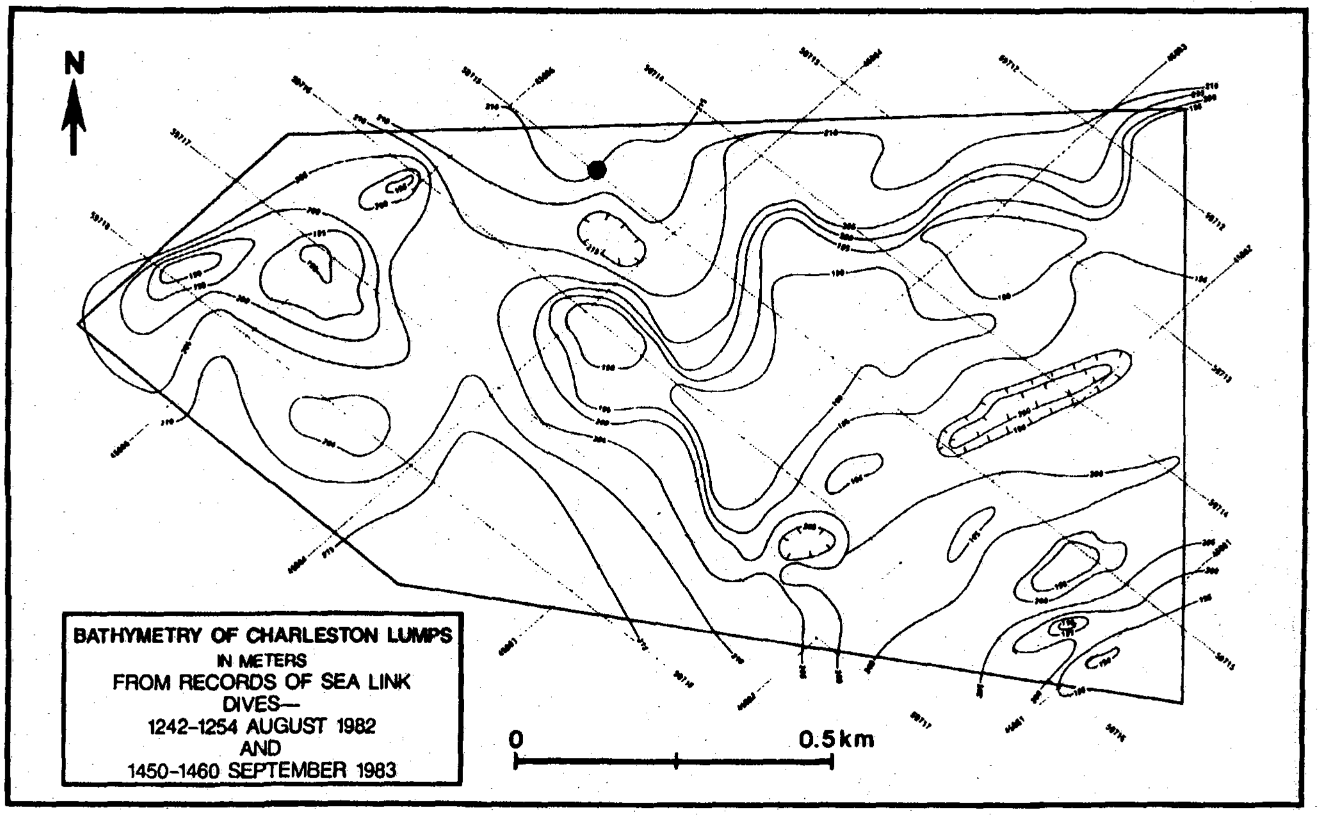

Figure 1. Bathymetric relief within the study area and around the topographic highs. Spot represents center of original search area (32° 43. 9' N; 78° 05. 9' W).

submersible JOHNSON SEA LINK were used during this survey. The submersible is a four-man, two compartment vessel. The forward acrylic sphere houses the pilot and an observer and the aft aluminum diving compartment carries a tender and second observer (Grimes et al., 1986 and Shipp et al.,1986). The R/V JOHNSON supported all submersible activities, and the R/V OREGON provided all fishing support.

Site Survey and Selection

Prior to the commencement of submersible activities, several days were spent searching for an appropriate isolated study site. Criteria for the study site included:

1) three or more target species caught per a 100 hook bottom longline set;

2) separate topographic highs which represented independent survey sites; and

3) an area small enough for the submersible to adequately sample within the budgeted time. A final study site was defined after completion of the acoustic and test fishing surveys (Fig 1). Key positions (coordinates) were stored in a Loran "C" plotter memory to ensure that the vessel remained within the defined sampling area and that dive tracks and longline sets could be plotted precisely. Habitat information obtained during submersible dives was utilized to construct a detailed chart of habitat type and distribution (Fig 2). An operational map of the site was continually upgraded until a final study site was defined with bathymetric and habitat data positioned on a Loran C grid (Fig 1 and 2). The study site was approximately 118.13 ha (0.4 square nm) in surface area and consisted of two discrete topographic highs. It was located about 148 km (80 nm) east of Charleston, South Carolina at 32° 44' N. Lat., 78° 06' W. Long. in 185 to 220 m depths.

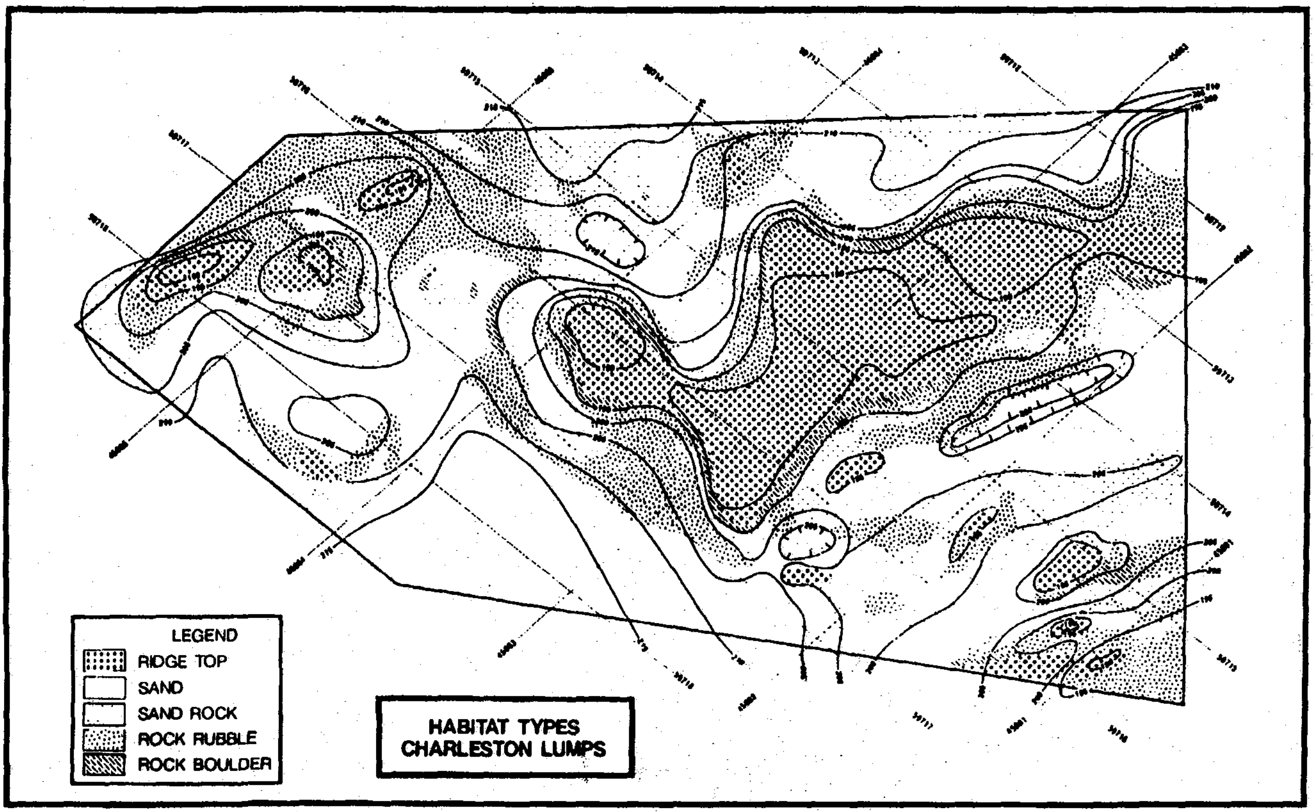

Figure 2. Diagrammatic presentation of habitats within the study area.

Submersible Survey

Survey methodology was initially established during a 1982 Florida "Middle Grounds" survey (Shipp et al., 1986 and Tyler et al., this proceedings) and was further refined to accommodate conditions encountered during this study. Species counts were obtained along all transects and at each point count location under standardized artificial lighting, with all fishes identified to the lowest taxon possible.

Survey procedures were as follows: The submersible moved to a randomly-selected starting point and settled onto the bottom. Three 1-minute point counts were made with the submersible stationary. Upon completion of the third point count, a course for the first 91.4 m (100 yd) transect was verbally received from the R/V JOHNSON. Transects consisted of a series of segments traversed at approximately 1 knot. Speed was variable (due to topography and current) but movement along each segment was continuous. Start positions and direction of submersible transects were randomly selected, but all transects did not follow the selected path due to currents and topography (Fig 3).

Upon completion of a segment, the submersible again settled onto the bottom and remained stationary while three additional 1-minute point counts were completed. A new course was then received from the surface vessel for the next segment. This procedure continued through all transect segments and point counts. Deviations from established procedures occurred when recording unusual biological activity or obtaining species verification.

While all segments were assumed to be equi-distant (91.4 m, 100 yards) the steep bottom topography played havoc with the submersible doppler navigation system and made this assumption questionable on certain segments. Over smooth bottom and gentle slopes, the doppler unit operated accurately but, on steep slopes doppler recorded distances were questionable and these distances were estimated by the submersible pilot.

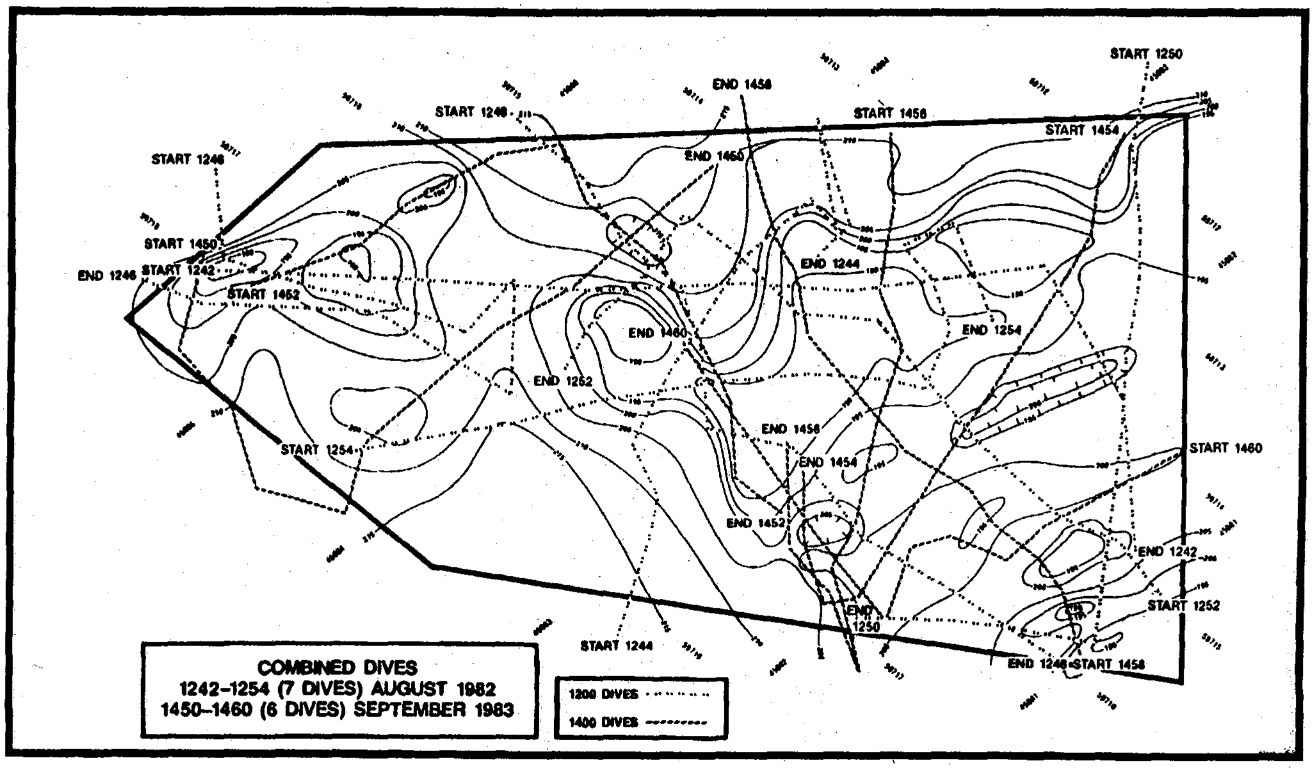

Figure 3. Transect coverage throughout study area in 1982 and 1983.

Audio recordings were made during the transect by each of two observers, one in the forward observation compartment and one in the aft diving compartment. Video tapes of select specimens and of the habitat were recorded from the forward position. Still photographs utilizing a 35 mm camera system with strobe lights were taken for habitat definition and species identification from both the forward and aft positions.

Information collected included species identification, number of individuals, habitat, time, depth, and distance traversed along the transect segment. Forward observers made counts and observations throughout the entire area viewed. The observer in the aft diving compartment generally counted only out of the starboard viewing port unless occluded.

Fishing

Upon completion of submersible activities, effort shifted to intensive fishing in an attempt to systematically reduce catch per unit effort, thereby allowing an estimate of the initial population within the study site to be computed. Unfortunately, severe weather substantially reduced submersible time and bottom longline fishing time in both years of the study.

Fishing gear and techniques including the use of bottom longlines and Kali poles has been described by Russell et al., 1988, and that reference should be consulted for an accurate description of the construction, handling and methodology of fishing bottom and offbottom longline gear. During the two year study, both bottom and off bottom longlines were randomly deployed throughout the study site. Set direction and habitat sampled were influenced by current and prevailing wind direction. For the 1982 portion of this study, 100-hook bottom longline sets of approximately 200 meters in length were alternated with sets of 40 Kali poles (6 hooks per pole) of equal groundline length. In 1983, the number of hooks per Kali pole was reduced to 5, and bottom longline sets were reduced to 50 hooks over 100 meters of groundline. All bottom longline and Kali pole activities were conducted during daylight hours.

In an attempt to reduce population numbers within the survey site, fishing was conducted over 12 days in 1982 (August 1-12) and 5 days in 1983 (September 9-13). Target species were snowy grouper, blueline tilefish, and blackbelly rosefish. Number and weight of each species caught by set was recorded and a catch per unit effort (CPUE) computed.

Analytical Procedures - Submersible

Analytical techniques used to evaluate submersible data included statistical comparisons between observers and their position in the submersible. Compared variables included: Species, numbers, and habitat type. Population sizes were estimated by computing a density (no/ha) value for each target species within each habitat and multiplying this density value by the estimated number of hectares per habitat type. Precise bottom area was unknown but was obviously larger than the surface area (118.13 ha), as bottom topography consisted of a series of irregular topographic highs and depressions.

The area viewed from the forward and aft compartments of the submersible, JOHNSON SEA LINK, was computed to be 0.287 and 0.156 ha respectively for each 91.4 m (100 yd) segment. Area viewed was computed using a viewing angle of 159 degrees for the forward and 120 degrees for the aft compartments and a visual distance of 14.6 m from each compartment. The 14.6 m visual distance was an estimate provided by the submersible pilot. Area viewed on a 91.4 m (100 yd) segment from the forward and aft compartments was computed using the formulas $[(28.24 \times d) + 280.19)]$ and $[(14.6 \times d + 224.15)]$, respectively.

(1) 28.24 and 14.6 represented the width of rectangles viewed during a segment in m;

(2) d represented the length of a segment in m;

(3) 280.19 and 224.15 represented the total area in square m viewed from the forward and aft compartments when the submersible was stationary.

Analysis of variance techniques were used to test for differences between observers, observer position and years. A multivariate paired t test, (Morrison, 1976; Tatsuoka, 1971; and Johnston and Wichern, 1981) was conducted to test if each observer viewed the same amount of each habitat. The computer packages Statistical Analysis Systems (SAS) and Statistical Package for Social Sciences (SPSS) were used for analysis of year, position, and observer differences.

Years were separated and treated independently for point counts, transect counts, and combined data. Mean density in terms of number per hectare and their associated confidence intervals were computed for each of the above factors for each of the two years.

Pooling of terms was employed whenever possible to simplify models and to construct mean densities and associated variances. Due to the high incidence of non-significance throughout the data set, pooling factors allowed the use of simplified models for further inferences; combining data from observer and position for density estimates improved the precision of those estimates.

Analytical Procedures - Fishing Data

Catch data were normalized to catch per 100 hooks per hour fished (CPUE) for the three species caught most frequently on bottom longlines (snowy grouper, blueline tilefish, and blackbelly rosefish). Population estimates were computed by regressing CPUE versus cumulative catch (Richer, 1975). Regression equations were tested for significance and the estimated x-intercept (i.e. estimated population size = N) was computed using:

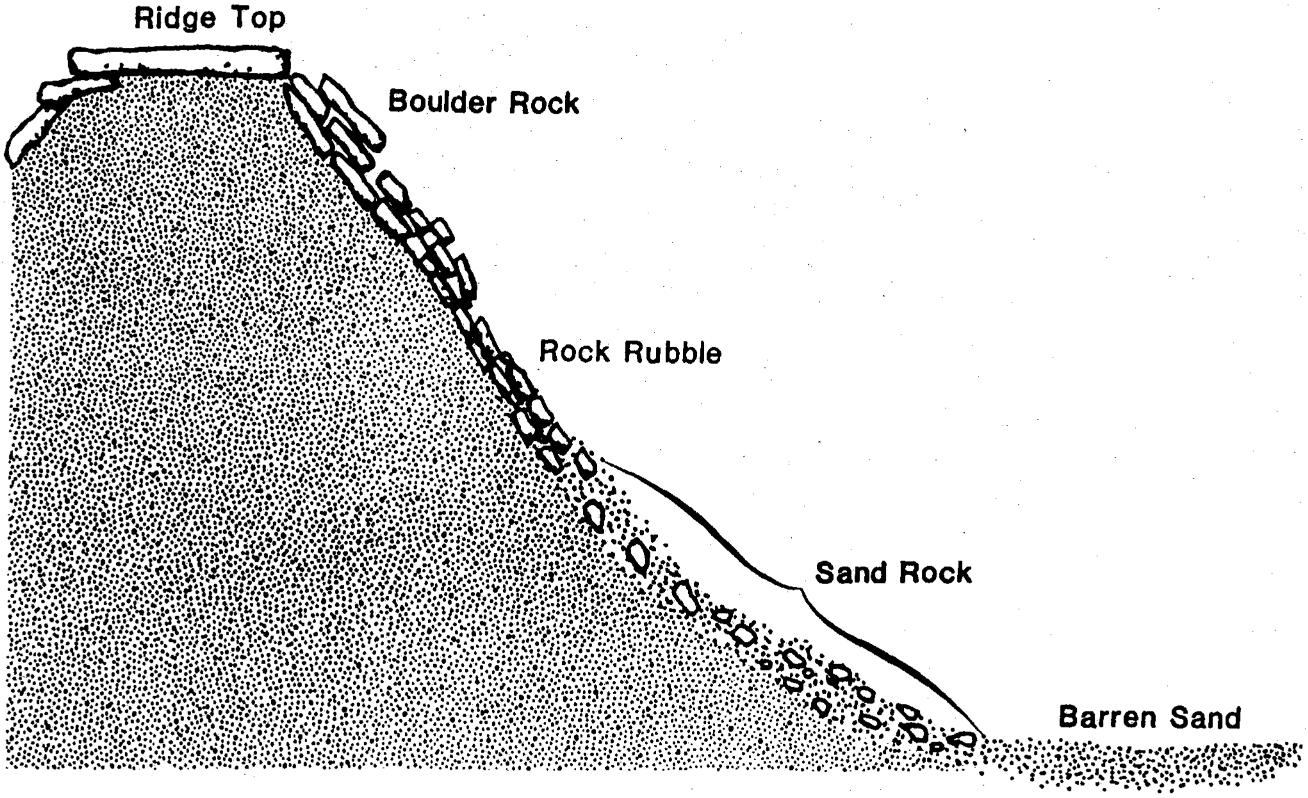

Figure 4. Diagrammatic presentation of habitats along slope from sand substrate to ridge top.

Table 1. Habitats sampled in the study area off Charleston, South Carolina using the Harbor Branch submersible during 1982 and 1983. Percent coverage by habitat and total number of hectares within each habitat are provided.

HABITAT	METERS 1982	METERS 1983	TOTAL	PERCENTAGE	HECTARES IN THE STUDY AREA
Sand	2,532	3,022	5,554	20.8	24.57
Sand Rock	4,144	5,059	9,203	34.5	40.75
Rock Rubble	2,455	2,726	5,181	19.4	22.92
Boulder Rock	2,072	645	2,717	10.2	12.05
Ridge Top	3,423	619	4,042	15.1	17.84
Total	14,626	12,071	26,697	100.0	118.13

N = - a/b where a = y intercept and b = slope.

Population estimates from this method were compared against those computed using visual sightings from the submersible.

Results

Physiography

The study area consisted of two major topographic highs (Fig 1). Throughout the general area many secondary topographic highs were noted with major ridges generally oriented in a northeast to southwest direction. These ridges consist of compressed foraminifera in a phosphorite matrix with a ledge and boulder appearance. The breakup and slippage of this material exposed a pedestal formation of foraminiferal ooze which had the appearance of sand or sand/rock-like material. Depending on the extent of the breakage, the compressed foraminifera had the appearances of rocks or boulders (pers. comm., Dr. Charles M. Hoskin, Harbor Branch Foundation, Inc., Ft. Pierce, Florida). This material separated the two major topographic highs within the study area. The series of ridge tops located in the southeast corner of the study area were believed to represent an adjacent topographic high. Foraminiferal ooze ("sand") was noted throughout the entire survey area, and at times formed large extensive dunes. Many steep slopes or terraces were noted, leading to major ridge tops (Fig 2). Terrain was reminiscent of mountainous regions in which valley floors, slopes of varying steepness, ridge splines, depressions, and extensive ridge tops (some mesa like) were present. Steepest slopes were generally noted along the northern portion of the study area but were not exclusive to that region (Figs 1 and 2). Slopes ranged from gentle to almost vertical walls (50°-60°) and were upwards of 20 m in height. The entire area consisted of five basic habitat types including: barren "sand" (composed of foraminiferal ooze), sand/rock, rock/rubble, boulder/rock, and ridge top (Fig 4). The dominant habitat within the study area was sand/rock. The combined barren sand and sand/rock habitat accounted for 45.6 % of the total area transected in 1982 and 66.9 % in 1983 (Table 1). Approaching topographic highs from deep water (215-220 m) the submersible traversed from areas of barren sand to ridge top plateaus (185-190 m).

The surface of the foraminiferal ooze can become mobile and cover exposed ledges which may have broken off the surface, giving it the appearance of shifting "sand". These barren habitats were depauperate and generally occupied by only a few invertebrates, and occasionally a few fish. The occurrence of anemones and pen shells in this ooze may represent areas recently covered or becoming exposed as these organisms require a hard substrate for anchorage. Frequently, the cover in these areas was only a thin veneer of sand.

Moving upslope, the amount of substrate and slope angle increased as habitat changed from barren sand to sand/rock (Fig 2 and 4). Slope increased significantly at the interface between sand/rock and rock/rubble. Faunal changes at the interface included an increase in finfish and invertebrates (sponges, encrusting organisms and hydroids). Along this interface an occasional grotto or large oblique burrow was observed. Continuing upslope, the angle becomes steeper, the rocks larger and more heavily encrusted with invertebrates. Phosphorite (boulder/rock) size was largest along the steepest portion of the slope. The boulder/rock habitat had the least surface area of the five defined habitats (Table 1 and Fig 4). The ridge top located above the boulder/rock habitat included a profusion of invertebrates, rocks of varying size, and interstitial sand. Boulder/rock areas appear to result from the breakage of the compressed foraminifera phosphorite matrix ledges which then moved down slope. Through time these boulders and rocks become smaller as they tumble farther down the slope, finally coming to rest in the sand/rock habitat (Fig 4).

Species

Thirty taxa were recognized during the two year study (Table 2). Taxa were identified to 22 species, 5 genera, 2 families of bony fishes and 1 shark. Twenty-six taxa of fish were recognized on transects and 20 on point counts. Seven species (snowy grouper; blueline tilefish; blackbelly rosefish; longspine scorpionfish, *Pontinus longispinis*; slime head; *Gephyroberyx darwini*; yellowfin bass, *Anthias nicholsi*; and *Laemonema barbatulum*) were observed often enough to allow an evaluation of their habitat preferences and distribution. The seven species represented 96.4 % of fish seen on point counts and 97.8 % seen on transects. Densities of these species and associated 95 percent confidence intervals are expressed as number per hectare (Fig 5 through 7).

Mean densities of the seven species expressed as number per hectare by year for all data combined are listed in Table 3. Densities by species and habitat for each of the two years are listed separately in Tables 4 and 5. Estimates were generally higher on transects than on point estimates. The habitat with the highest densities varied by species. The seven species were distributed throughout the entire survey area, with barren sand habitat having the lowest populations (Table 6), while four of the seven species had greatest densities in the sand/rock habitat.

Commercially important blueline tilefish (*Caulolatilus microps*) were the least frequently observed of the seven species, and had the lowest overall density (Table 4 and 5, and Fig 5). Although they were observed in all habitats, they were most often sighted on sand/rock and least frequently noted among boulder/rocks (Table 6 and Fig 6). Blueline tilefish utilized burrows and spaces between rocks as residence sites. They were observed sharing their residences with tilefish (*Lopholatilus chamaeleonticeps*) (once), and snowy grouper (several occasions). During the two year study a total of 77 blueline tilefish were observed (Table 2) indicating a small population within the study area. Bottom longlines caught 187 specimens, 145 in 1982 and 42 in 1983, suggesting a larger population than that indicated from submersible counts. Submersible estimates for the study site were 106 and 185 for 1982 and 1983, respectively (Table 6).

Table 2. Species and number of specimens observed during point and transect counts on 1982/83 dives off Charleston, South Carolina in 185 to 220 m; counts made from the Harbor Branch submersible.

SPECIES	POINT COUNTS		TRANSECTS	
	NUMBER OBSERVED	PERCENT OF TOTAL	NUMBER OBSERVED	PERCENT OF TOTAL
Anthias nicholsi	1,057	36.2	10,741	60.0
Helicolenus dactylopterus	576	19.7	2,399	13.4
Laemonema barbatulum	561	19.2	2,090	11.7
Pontinus longispinis	357	12.2	1,880	10.5
Epinephelus niveatus	195	6.7	243	1.4
Caulolatilus microps	37	1.3	40	0.2
Macrorhamphosus scolopax	34	1.2	131	0.7
Gephyroberyx darwini	31	1.1	101	0.6
Chlorophthalmus agassizi	24	0.8	44	0.2
Hemanthias vivanus	12	0.4	40	0.2
Plectranthias garrupellus	12	0.4	54	0.3
Jeboehlkia gladifer	5	0.2	44	0.2
Chaunax pictus	3	0.1	7	0.0
Urophycis floridana	2	0.1	6	0.0
Serranus sp.	4	0.1	12	0.1
Shark	2	0.1	-	-
Hyperoglyphe perciformis	2	0.1	-	-
Bothidae	3	0.1	14	0.1
Bembrops sp.	1	0.0	-	-
Mola mola	1	0.0	-	-
Synodus intermedius	-	-	9	0.1
Paranthias furcifer	-	-	11	0.1
Raja eglanteria	-	-	1	0.0
Synodus sp.	-	-	5	0.0
Xenolepidichthys dalgleishi	-	-	1	0.0
Lopholatilus chamaeleonticeps		-	3	0.0
Seriola dumerili	-	-	5	0.0
Decodon sp.	-	-	2	0.0
Gobiidae	-	-	7	0.0
Citharichthys sp.	-	-	1	0.0

Table 3. Mean number of individuals per hectare for selected species off Charleston, South Carolina in 185 to 220 m for point counts, transects and combined data. Counts made from the Harbor Branch submersible during 1982/1983.

SPECIES	POINT COUNTS		TRANSECTS		COMBINED	
	1982	1983	1982	1983	1982	1983
Laemonema barbatulum	19.8	21.8	31.3	26.0	27.4	23.3
Gephyroberyx darwini	3.2	1.7	2.1	2.2	2.5	2.0
Epinephelus niveatus	9.7	15.5	5.8	2.6	8.9	5.4
Anthias nicholsi	47.3	32.3	202.9	108.6	130.9	69.9
Caulolatilus microps	1.0	1.4	0.5	0.7	0.8	1.3
Helicolenus dactylopterus	29.2	15.3	35.7	27.0	31.2	22.1
Pontius longispinis	7.7	23.8	22.4	27.1	15.0	23.1

Yellowfin bass were observed on all habitats, but densities on barren sand were low (Fig 7 and Table 4 and 5). Sightings in the sand habitat occurred only around solitary rocks, not over the sand itself. Yellowfin bass were most frequently seen in high numbers on and around the boulder/rock habitat or at the crest of ridge tops. Often large numbers of schooling fish, thought to be yellowfin bass, were observed in the water column immediately above the rocky substrate, but identifications were not confirmed and counts were not recorded. Yellowfin bass represented the most numerous segment of the ichthyofaunal community found in the study site, with visual counts indicating populations of 15,186 in 1982 and 6,736 in 1983 (Table 6).

Gephyroberyx darwini were observed on all habitats, but the highest densities were noted on boulder/rock during both point and transect counts (Table 4 and 5, Fig 5). They were found within the interstitial spaces between rocks and boulders, along the interface between the boulder/rock and rock/rubble habitats, near the crest of the ridge top habitat, or at isolated rock sites within the sand habitat. *G. darwini* were not caught on bottom longlines, but submersible counts indicated a population of 252 in 1982 and 114 in 1983 within the 118 ha study site (Table 6).

Although blackbelly rosefish, longspine scorpionfish and *L. barbatulum*, were distributed throughout the study area, all three species were most commonly sighted over the sand/rock habitat (Fig 6). These three species had the highest overall densities (expect for yellowfin bass) in each habitat (Table 4 and 5). They occurred more frequently on the barren sand than other species and were primarily associated with scattered rocks and sand depressions (Table 4 and 5). Estimated population numbers were highest on sand/rock and lowest on sand or boulder/ rock (Table 6). Blackbelly rosefish and longspine scorpionfish were the most frequently caught specimens on bottom longlines. During the two year study, 1,393 specimens of blackbelly rosefish and longspine scorpionfish were captured on bottom longlines (952 in 1982 and 473 in 1983). Species identification between blackbelly rosefish and longspine scorpionfish from the submersible were initially difficult resulting in early misidentifications. This

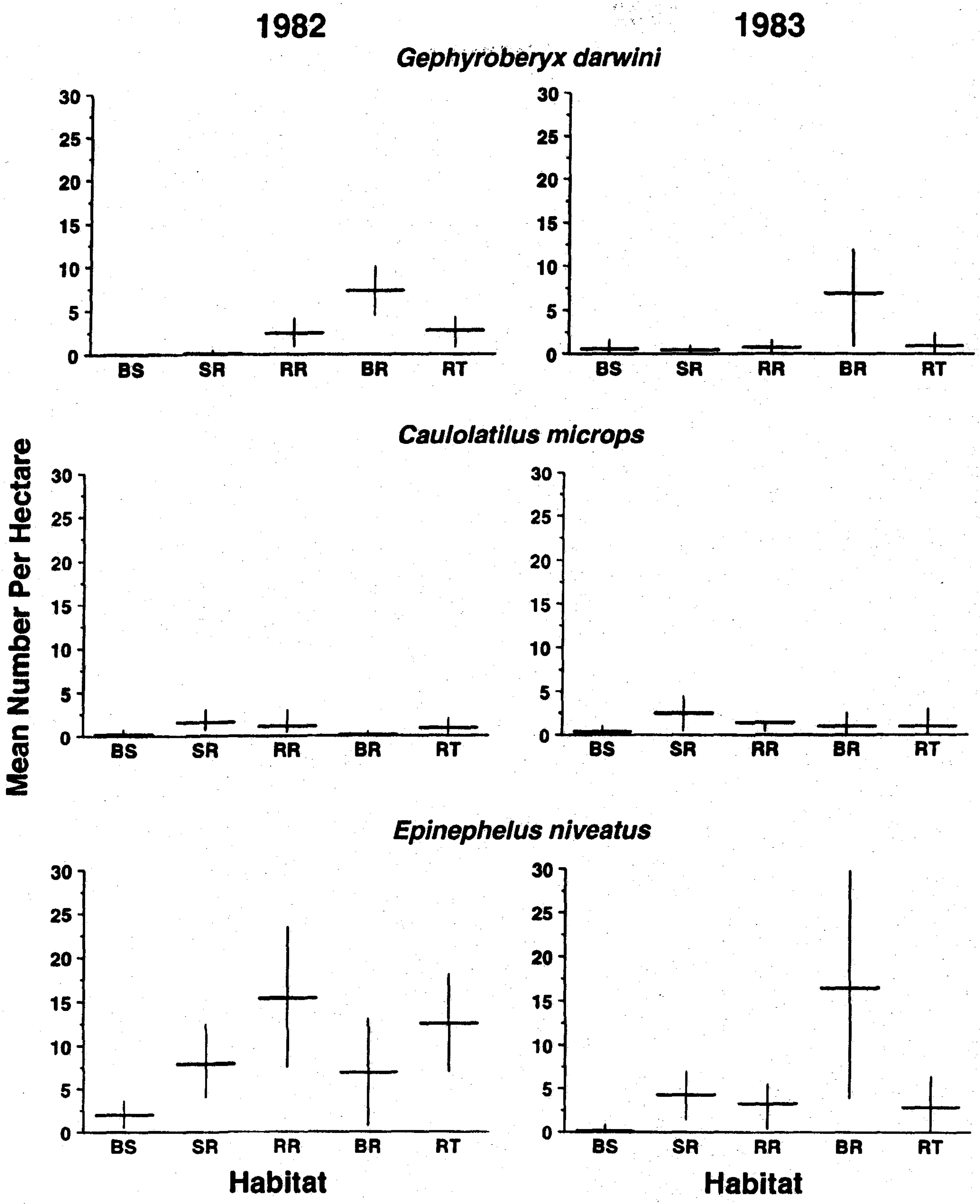

Figure 5. Mean number per hectare and associated 95 percent confidence interval by habitat for *G. darwini*, *C. microps*, and *E. niveatus* using combined data for 1982 and 1983 off Charleston, South Carolina. Counts made from the Harbor Branch submersible.

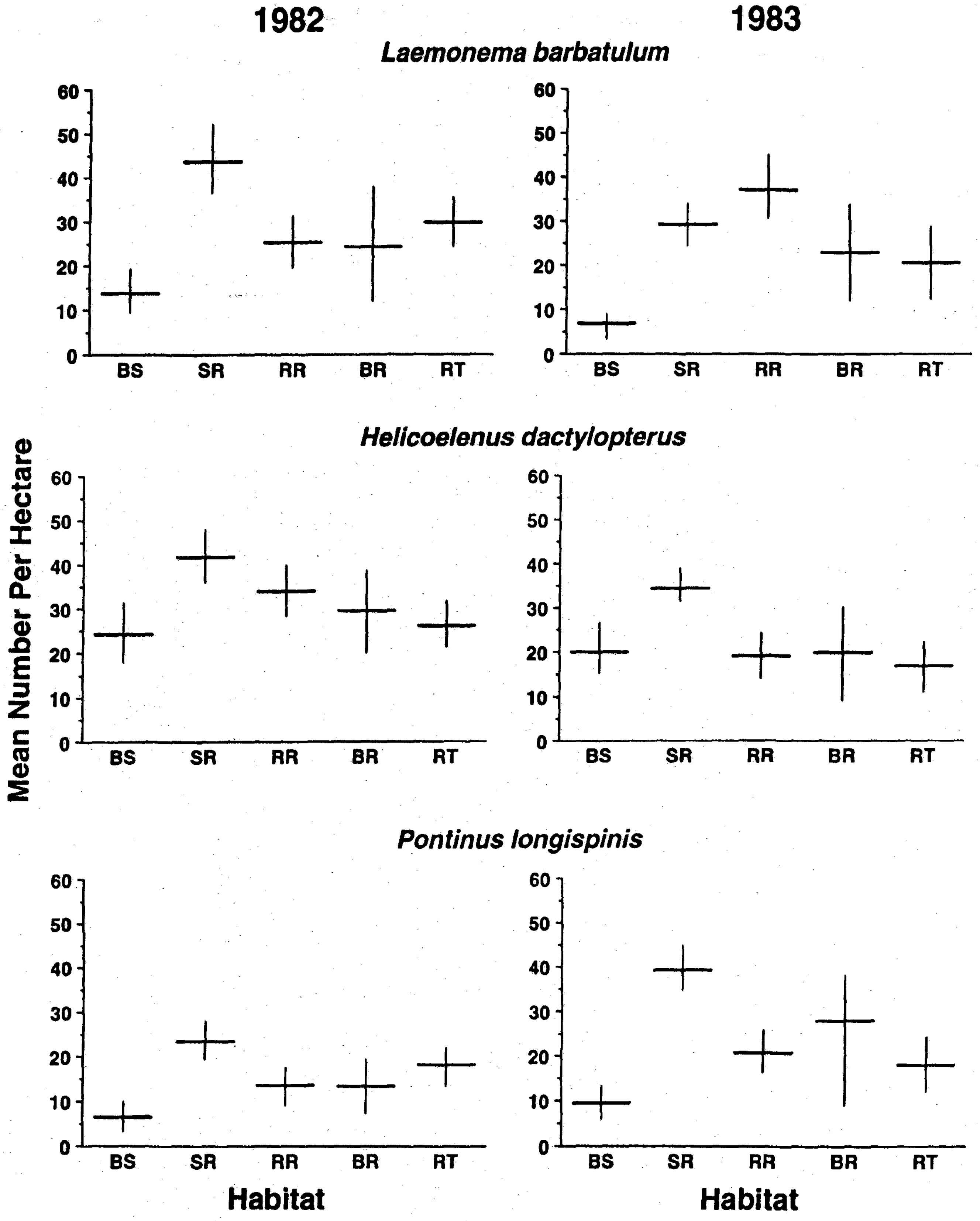

Figure 6. Mean number per hectare and associated 95 percent confidence interval by habitat for *P. longispinis*, *H. dactylopterus*, and *L. barbatulum* using combined data for 1982 and 1983 off Charleston, South Carolina. Counts made from the Harbor Branch submersible.

Table 4. Mean number per hectare by habitat based on counts made from the Harbor Branch submersible, in 1982 off Charleston, South Carolina in depths of 185 to 220 m (P = point counts, T = transect, C = combined, SA = sand, SR = sand rock, RR = rock rubble, BR = boulder rock, and RT = ridge top).

SPECIES	HABITAT AND HECTARES (ha)							
		20.44ha	33.43ha	19.85ha	16.77ha	27.64ha	Over	Over
		SA	SR	RR	BR	RT	All Mean	All SD
Laemonema barbatulum	P	10.2	45.5	19.0	0.0	24.5	19.8	17.1
	T	19.1	41.1	35.2	29.2	32.1	31.3	8.1
	C	13.8	43.6	25.3	24.3	29.8	27.4	10.8
Gephyroberyx darwini	P	0.0	0.5	3.1	8.9	3.4	3.2	3.5
	T	0.0	0.2	1.6	6.9	1.8	2.1	2.8
	C	0.0	0.1	2.5	7.3	2.8	2.5	3.0
Epinephelus niveatus	P	2.9	8.3	20.5	0.0	16.8	9.7	8.8
	T	0.6	7.4	7.4	8.3	5.2	5.8	3.1
	C	2.0	7.9	15.4	6.9	12.5	8.9	5.2
Anthias nicholsi	P	2.6	81.8	56.5	0.0	95.8	47.3	44.3
	T	3.7	63.4	178.0	276.7	492.8	202.9	193.2
	C	3.0	73.9	103.8	230.6	243.4	130.9	103.6
Caulolatilus microps	P	0.0	2.3	1.4	0.0	1.1	1.0	1.0
	T	0.5	0.7	0.8	0.1	0.5	0.5	0.3
	C	0.2	1.6	1.1	0.1	0.9	0.8	0.6
Helicolenus dactylopterus	P	18.4	37.4	32.2	35.7	22.1	29.2	8.4
	T	32.8	47.6	36.8	28.4	33.1	35.7	7.3
	C	24.3	41.8	34.0	29.6	26.1	31.2	5.7
Pontinus longispinis	P	1.2	15.0	9.7	0.0	12.7	7.7	6.8
	T	14.4	34.8	19.8	15.9	27.2	22.4	8.5
	C	6.6	23.5	13.6	13.3	18.1	15.0	6.3
Overall Habitat Mean	P	5.0	27.3	20.3	6.3	25.2	-	-
Overall Habitat SD	P	6.8	27.6	19.2	13.4	32.3	-	-
Overall Habitat Mean	T	10.2	27.9	39.9	52.2	84.7	-	-
Overall Habitat SD	T	12.5	25.2	62.7	99.6	180.5	-	-

Table 5. Mean number per hectare by habitat based on counts made from the Harbor Branch submersible, in 1983 off Charleston, South Carolina in depths of 185 to 220 m (P = point counts, T = transect, C = combined, SA = sand, SR = sand rock, RR = rock rubble, BR = boulder rock, and RT = ridge top).

SPECIES	HABITAT AND HECTARES (ha)							
		29.57ha	49.51ha	26.68ha	6.31ha	6.06ha	Over All Mean	Over All SD
		SA	SR	RR	BR	RT		
Laemonema barbatulum	P	5.0	23.6	34.4	23.8	22.3	21.8	10.6
	T	9.5	38.2	41.6	22.7	18.0	26.0	13.6
	C	6.9	29.2	37.1	22.9	20.6	23.3	11.2
Gephyroberyx darwini	P	0.9	0.4	0.3	6.0	0.9	1.7	2.4
	T	0.2	0.6	1.6	7.3	1.4	2.2	2.9
	C	0.6	0.5	0.8	7.0	1.0	2.0	2.8
Epinephelus niveatus	P	0.0	5.3	2.2	65.5	4.3	15.5	28.0
	T	0.2	2.6	5.2	4.3	0.8	2.6	2.2
	C	0.1	4.3	3.3	16.5	2.9	5.4	6.4
Anthias nicholsi	P	1.4	20.1	61.9	23.8	54.4	32.3	25.2
	T	7.2	91.7	212.8	125.5	105.9	108.6	73.7
	C	3.9	47.3	118.6	105.2	74.5	69.9	46.1
Caulolatilus microps	P	0.5	3.5	1.4	0.0	1.7	1.4	1.4
	T	0.3	0.7	1.4	1.2	0.0	0.7	0.6
	C	0.4	2.5	1.4	1.0	1.0	1.3	0.8
Helicolenus dactylopterus	P	10.6	30.5	16.2	0.0	19.3	15.3	11.2
	T	32.3	40.7	24.2	24.8	13.2	27.0	10.2
	C	20.1	34.4	19.2	19.9	16.9	22.1	7.0
Pontinus longispinis	P	5.9	33.0	16.0	47.6	16.6	23.8	16.5
	T	14.0	49.6	28.5	23.0	20.3	27.1	13.6
	C	9.5	39.3	20.7	27.9	18.0	23.1	11.2
Overall Habitat Mean	P	3.5	16.6	18.9	23.8	17.1	-	-
Overall Habitat SD	P	3.9	13.4	22.5	25.0	18.6	-	-
Overall Habitat Mean	T	9.1	32.0	45.0	29.8	22.8	-	-
Overall Habitat SD	T	11.6	33.7	75.5	43.3	37.6	-	-

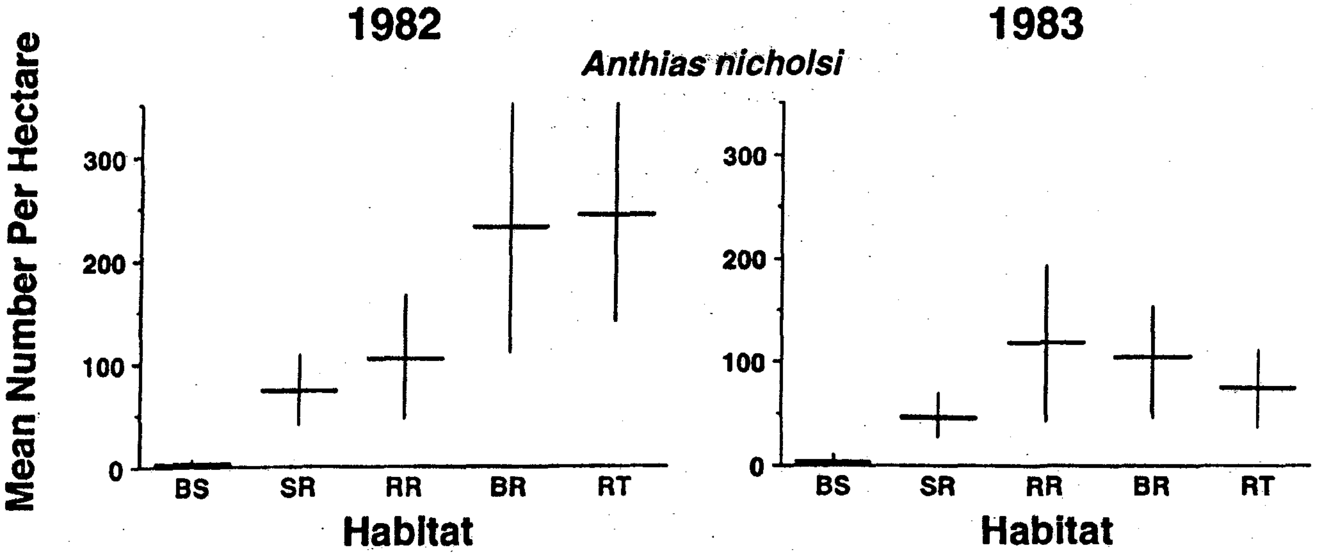

Figure 7. Mean number per hectare and associated 95 percent confidence interval by habitat for *A. nicholsi* using combined data for 1982 and 1983 off Charleston, South Carolina. Counts made from the Harbor Branch submersible.

difficulty was probably reflected in 1982 density estimates (Table 4 and 5). Submersible counts indicated a population of 5,700 in 1982 and 6,101 in 1983 for these two species combined (Table 6). *L. barbatulum* were not caught on longlines. However, submersible counts indicated a population of 3,474 in 1982 and 2,909 in 1983 (Table 6).

Snowy grouper were observed within each habitat, although densities were considerably lower over sand than at other habitats (Table 4 and 5, Fig 5). They were quite mobile and were most frequently seen actively swimming above the substrate rather than stationary on the bottom. Preferred habitat included areas in which rocks or boulders were present. Snowy grouper were observed actively pursuing blackbelly rosefish and longspine scorpionfish immediately above rocky substrates, but at no time was there success observed. They were most often observed on rock/rubble and boulder/rock habitats in close proximity to slope edges rather than on flat ridge tops. During the two-year study, 116 specimens were caught on bottom and offbottom longlines (90 in 1982 and 26 in 1983). They were caught more frequently on bottom longlines that off-bottom longlines (Table 7). Visual counts indicated a population of 1,073 in 1982 and 426 in 1983 (Table 6.)

Population Estimates from Fishing Activities

Catch rates for dominant species taken on the longlines are presented in Table 7. A significant negative correlation between catch per unit effort and cumulative catch was found in 1982 for 2 of the 3 species highly vulnerable to longline gear (Table 8). For these two, the blackbelly rosefish and blueline tilefish, 95 percent confidence interval estimates of population size were developed for comparison with submersible-derived estimates. Blueline tilefish density estimates ranged from 1.2 to 4.1 individuals per ha and blackbelly rosefish estimates ranged from 8.1 to 96.0 individuals per ha. No population ranges could be developed from 1983 intensive fishing data because the correlations between CPUE and cumulative catch were not significant. The number of longline sets in 1982 (46) was close to a pre-cruise target of 50, which was estimated necessary for a valid statistical comparison. The 1983 effort (30) was well short of the desired effort.

Table 6. Population number per habitat and year for combined data (point counts and transect). Estimates represent numbers within the study area off Charleston, South Carolina in 185 to 220 m. (SA = sand, SR = sand rock, RR = rock rubble, BR = boulder rock, and RT = ridge top).

SPECIES	Year	HABITAT					TOTAL OF ALL HABITATS
		SA	SR	RR	BR	RT	
Laemonema barbatulum	1982	282	1458	502	408	824	3,474
	1983	204	1446	990	144	125	2,909
Gephyroberyx darwini	1982	0	3	50	122	77	252
	1983	18	25	21	44	6	114
Epinephelus niveatus	1982	41	264	306	116	346	1,073
	1983	3	213	88	104	18	426
Anthias nicholsi	1982	61	2470	2060	3867	6728	15,186
	1983	115	2342	3164	664	451	6,736
Caulolatilus microps	1982	4	53	22	2	25	106
	1983	12	124	37	6	6	185
Helicolenus dactylopterus	1982	497	1397	675	496	721	3,786
	1983	594	1703	512	126	102	3,037
Pontinus longispinis	1982	135	786	270	223	500	1,914
	1983	281	1946	552	176	109	3,064

Table 7. Catch rates, expressed as number per 100 hooks per hour for three species off Charleston, South Carolina in 1982 and 1983. Catches were made off the South Carolina Wildlife and Marine Resources Ship R/V OREGON. BL = bottom longline, OB = off-bottom longline.

SPECIES	CATCH FROM BOTTOM AND OFF-BOTTOM LONGLINES			
	1982		1983	
	BL	OB	BL	OB
Epinephelus niveatus	0.089	0.025	0.034	0.014
Caulolatilus microps	0.089	0.066	0.076	0.021
Helicolenus dactylopterus	0.759	0.343	0.427	0.343
Total	0.938	0.434	0.583	0.379

Discussion

Results from the separate submersible studies in 1982 and 1983 were reasonably consistent (Table 6). Differences in species population estimates between the two years are not extreme, and standard deviations are generally lower than the means, infrequently the case in open ocean studies which attempt systematic quantification of mobile species (Table 4 and 5). Some differences between visual population estimates for each species by year resulted from the use of two calculation techniques. Population estimates for individual habitat types from habitat specific fish densities were summed (Table 6), or an overall population estimate was calculated from the mean of fish densities from all habitats and the area of the study site (Table 9). Also, a number of factors influenced the development of both visual and intensive fishing population estimates.

Visual population estimates may be subjected to attraction or avoidance biases, effect of changing visibility on observer counts due to water clarity, and effects of submersible lights on finfish, particularly below depths of even modest light penetration. During submersible dives, verification of species identification was through video closeups. During this process, specimens being video taped generally appeared mesmerized, and held position, although the submersible approached to within a few feet. Snowy grouper appeared to be attracted to the submersible lights and their numbers are probably overestimated. Other species, such as *Anthias* would move into crevices or away from the light field as the submersible approached (Barans et al., 1986). Species that flee to the periphery of the light and are less available for counting will be underestimated.

The mode of submersible operation is also important in estimating the true numbers of fishes present. Tyler et al. (this Proceedings) reported that larger, mobile fishes such as snappers and groupers were overestimated by point counts because of their attraction to the submersible when it was stopped. Transect counts provided lower population estimates than did point counts for the two larger species, snowy grouper and blueline tilefish, in both 1982 and 1983 surveys (Table 9). Conversely, species that tended to hide from the bright submersible lights, such as *Anthias*, were probably underestimated by replicated point counts and were seen more frequently on transects. Cryptic or burrowing species, such as the blueline tilefish, were probably underestimated by either mode.

Population estimates derived from intensive longline fishing overlapped submersible estimates only for blackbelly rosefish, one of two species for which estimates were tabulated in 1982. Major problems in generating population estimates for additional species in 1982 and all species in 1983 were the limited number of sets due to heavy weather in both years, and high variability induced by using two different longline gear types. Population estimates based on removal through intensive fishing require that no immigration or emigration occurs to or from the study area. This was an open area in which both blueline tilefish and grouper were observed actively swimming. Intensive fishing should have been conducted quickly, therefore, reducing potential variability.

Matlock et al (1991) succeeded in developing population estimates by intensive benthic longlining in 300 meters off of Texas for Golden tilefish, cuban dogfish (*Squalus cubensis*), Southern hake (*Urophycis floridana*), and Gulf hake (*U. cirrata*). As in this study, their population estimates derived from submersible transects exceeded estimates derived from intensive fishing activities, although population size ranges overlapped for golden tilefish off Texas using the two methodologies.

Matlock et al (1991) reported "average" population sizes of 446, 134, or 81 (5.3, 1.6 or 1.0/ha) for golden tilefish, based on methodology used, in a study area of approximately 84 ha. They also reported submersible derived estimates of 150 (3.7/ha) yellowedge grouper (*Epinephelus flavolimbatus*) in an area of approximately 41 ha. Those population and density estimates are in the same general range as those generated for this study of 307-1,831 (2.6-15.5/ha) for snowy grouper (Table 3 and 9), and 59-165 (0.5-1.4/ha) for blueline tilefish (Table 3 and 9) within 118 ha. Though both the Texas and South Carolina surveys used similar methodologies, direct habitat observations of the two sites indicated that at the South Carolina site, the current was stronger (bringing in more food), the amount of rocky substrate was greater, (for invertebrate attachment and cryptic species), and abundance of water-sifting invertebrates and planktivorous fishes was much higher than at the Texas site. Consequently, the South Carolina site should support a greater biomass of apex carnivores such as the snowy grouper. An aparent increase in the population of blueline tilefish at the South Carolina site that was probably fished commercially between years suggests possible difficulty with the visual sampling methodology. This may have been related to the high percentage of transects in the sand habitat in 1983.

Table 8. Results of DeLury CPUE regressions for estimation of population size (N), probability (p), and upper and lower population estimates at the 95 percent confidence level for *Epinephelus niveatus*, *Caulolatilus microps*, and *Helicolenus dactylopterus* from 1982 (46 sets) and 1983 (30 sets) from intensive fishing on the Charleston lumps study site.

	SPECIES	N	P	Pop. Range 95% C.I.	Submersible Estimate (Table 6)
1982	*Epinephelus niveatus*	181.5	0.2423	-	1,073
	Caulolatilus microps	178.0	0.0022*	145-478	106
	Helicolenus dactylopterus	1,984.0	0.0225*	952 - 11324	3,786
1983	*Epinephelus niveatus*	214.0	0.9258	-	426
	Caulolatilus microps	266.0	0.9165	-	185
	Helicolenus dactylopterus	1,148.0	0.2270	-	3,037

* Statistically significant

Table 9. Population estimates based on mean number for all habitats combined times total number of hectares (118.13) within the survey site located off Charleston, South Carolina. Data obtained during 1982/1983 dives on the Harbor Branch submersible.

SPECIES	1982			1983		
	TRANSECT	POINT COUNTS	COMBINED	TRANSECT	POINT COUNTS	COMBINED
L. barbatulum	3,697	2,339	3,237	3,071	2,575	2,752
G. darwini	548	378	295	260	201	236
E. niveatus	685	1,146	1,051	307	1,831	638
A. nicholsi	23,968	5,587	15,463	12,828	3,815	8,257
C. microps	59	118	95	83	165	154
H. dactylopterus	4,217	3,449	3,685	3,189	1,807	2,611
P. longispinis	2,646	910	1,772	3,201	2,811	3,792

At a small unexploited site in Onslow Bay, North Carolina, Epperly and Dodrill (1995) reported an exploitable biomass of snowy grouper of approximately 11 kg/m^2. At 8.4 kg per fish, (their initial mean weight for snowy grouper) that translates to 1.3/m^2 or 13,000 fish per hectare, approximately 3,000 times the density estimated for deep-water groupers off of Texas and South Carolina. We assume that the 46 m x 56 m site, located in 194 m, was a concentration area for snowy grouper, and that the cumulative 25 t (over 90 % snowy grouper) taken had recruited into the site over the 10-month study. However, Parker and Ross (1986) estimated concentrations of nearly 8,000 snowy grouper per ha at a separate site. Dodrill et al (1993) felt that, "Small areas are not likely to support such biomass even seasonally if the fish were restricted to feeding on or above hard bottom, unless feeding was restricted because of spawning or other activity".

Despite difficulties encountered during this study in determining precise species densities and population estimates of deep-water fish stocks, progress was make in terms of development, evaluation, and application of viable techniques. The development of population estimates for blueline tilefish and blackbelly rosefish from intensive longline fishing allowed catchability coefficients to be derived for the two species of 0.01 (1 %) and 0.005 (0.5 %) respectively. These coefficients represent the percentage of the populations of these species that would be taken by a 200 m groundline bottom longline from within the 118 ha study site. Verification of such data and development of gear efficiency estimates for other deep-reef species should allow eventual quantification of numbers and/or biomass per unit area.

We feel that research should continue to compare multiple estimation methods for each deep-water population/community addressed. In addition, the collection of associated environmental factors with population estimates would assist biologists in determining those factors that affect population size and density, providing the information necessary if management agencies are to effectively prevent the overexploitation of long-lived, slow-growing, deep-water resources.

Acknowledgments

We wish to thank the crews of the Harbor Branch Inc. R/V JOHNSON and the JOHNSON SEA-LINK, and the South Carolina Department of Natural Resources R/V OREGON for their excellent support of the diving and fishing operations during this study. Support for submersible activities was provided by the NOAA Undersea Research Program Office. Special thanks are also extended to Gilmore Pellegrin, Keith Mullin, Scott Nichols and Robert Shipp for the manuscript review and their many helpful suggestions for its improvement. We thank Velda Harris and Beth Reeves for typing assistance.

Note: This manuscript was in a rough draft stage at the time of the senior author's death in 1991. Because of the value of the information contained in this paper, we felt that publication was appropriate, and are responsible for any shortcomings perceived by the reader (WRN and CAB).

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DEEPWATER ASSESSMENT TECHNIQUES FOR INVERTEBRATE RESOURCES

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Introduction

The most important group of deepwater invertebrates are the crustaceans, particularly shrimps, crabs, and lobsters. Interest in these deepwater resources is prompted by the high market value of crustaceans in general. While a number of mollusks, such as octopuses and gastropods (e.g. Ito and Tachizawa 1981) are caught using passive gear, they are not presently significant resources in deep waters. Thus, concern here will be limited to the crustacean resources. The dominant groups of interest are the caridean shrimps, and crabs, particularly of the genus *Geryon*. Of potential importance are lobsters, especially nephropsid lobsters, and possibly giant isopods, *Bathynomus giganteus*, either for meat or as biological specimens.

There are a number of methodologies available to assess resources, but present discussion will be confined to just two: traps and visual census, the latter including photography, video recording, and direct observation via submersible. Various acoustic techniques (e.g. fish finders or side-sonar) may become valuable tools in the future, but further refinements and studies are required before these can be used routinely for assessing invertebrate resources.

Unique Characteristics in Assessing Deepwater Invertebrates

The use of traps and visual census for assessing deepwater invertebrates is fairly straightforward and similar in application to the assessment of shallow water fishes and invertebrates. However, there are a number of differences that must be accounted for, and these arise because of the depths fished and the species present. Relative to shallow water, species in deeper water will be characterized by lower abundance, lower diversity, and often by small size (e.g. shrimps).

Deepwater invertebrate resources are generally found between 200 m and 1000 m, that is, on continental and insular slopes, or submerged seamounts. Because of the depths involved, gear displacement and manipulation can only be controlled, at best, to a moderate degree, and sometimes not at all. This will have obvious consequences on the use of various gears and efforts to calibrate their effectiveness.

Low species diversity is generally advantageous. Often the resource will be characterized by a single group, e.g. shrimps, or even a single species. As such, any assessment technique used can be refined and specialized toward that group. This is particularly important in assessing trap function. Traps are influenced by a number of behavioral actions, including demand and suitability as shelter, competition, predation, and conspecific attraction. Fewer species make it easier to understand how an assessment technique works and consequently how it can be improved.

On the other hand, low species abundance is disadvantageous. Sufficient numbers of individuals must be sampled for statistical purposes. Thus, if abundance is low, sampling must either be more intensive, (i.e. more units must be employed) or sampling must be highly repetitive, or the gear used must be capable of surveying a large area. This latter point, in the case of traps, means that traps should be designed to maximize the effective area fished.

Small invertebrates, like shrimps, because of their size, are difficult to observe and identify by visual means. This obviously limits the usefulness of visual techniques in these cases. On the other hand, visual assessment of deepwater invertebrates is generally simpler because individuals are slow moving and closely associated with the bottom. Thus, avoidance or attraction are minimized, and the census need deal with two dimensions only.

Advantages and Disadvantages of Assessment Techniques

The advantages and disadvantages of traps and visual techniques are summarized in Table 1. In general traps are simple to use and retain specimens for further analysis, but they are highly selective, both in what they catch (species composition) and in how much they catch (abundance, size-selectivity). As a generalization, as light levels decrease with depth, it can be expected that with increasing depth the role of providing shelter becomes a less significant factor in affecting trap catch. Thus, traps primarily fish only those species that are attracted to bait. This would make traps unsuitable for quantitatively sampling, for example, penaeid shrimps. To be truly quantitative traps require calibration. This can be an involved process and is usually specific to a particular trap design fished in a particular manner.

Visual techniques in deep waters are limited by their generally great expense and limited coverage, both in area and in species. Obviously individuals must be large and nonburrowing. However, much information can be obtained on both the organisms and their habitat.

Because visual and trapping techniques are both selective, but differ in what they sample, better results can be obtained when both techniques are used together. In particular, visual techniques can be extremely useful in trap calibration studies.

Assessment Techniques

Visual Census

The use of visual census techniques is straightforward. Censuses can be conducted using still photography, video or movie cameras, and by making direct observations from submersibles. In all cases the statistical treatment of data is similar, following the basic principals of line or strip transects (but see Gazey 1983). These have been reviewed, in general, by Yapp (1956), Skellam (1958),

Table 1. Advantages and disadvantages of deepwater invertebrate passive assessment techniques.

Advantages	Disadvantages
TRAPS	
Inexpensive	Very selective (species attracted to bait)
Easy to deploy and recover	Must be calibrated (abundance, selectivity)
Can sample burrowing species	
Can sample small species	
Retains specimens for identification and study	
Can be employed over rough bottom	
VISUAL CENSUS	
Can sample non-trappable species	Expensive
Generally non-selective for epifauna	Limited to larger epifauna
Can be employed over rough bottom	Limited areal coverage
Can obtain habitat & behavioral information	No specimens retained

Eberhardt (1978), Gates (1979), and Quinn and Gallucci (1980), and for marine resource surveys by Patil et al. (1979).

The major design criteria is the area to be sampled. In still photography this is the area/photograph; in direct observation or filmed transects it is a function of the width of the transect. The area chosen is always a compromise between maximizing the area covered and the ability to discriminate (Miller 1975). The latter is a function of the degree of illumination and distance from the object of interest, itself a function of size. Thus, the smaller the individuals of interest, the smaller the area will have to be. Obviously there are limits, and very small species (e.g. shrimps) will be difficult to quantitatively assess using visual techniques, although this too has been attempted (e.g. Bergstrom et al. 1987). Individuals at the edge of the field of view will be further away and may be more difficult to see and identify. As such, the area photographed must either be small enough for all individuals to have an equal probability of being accurately detected, or the probability of detection with distance from the center of the photograph must be calibrated. Invertebrates are often patchily distributed, and this must be accounted for when determining area to be sampled and distribution of sampling stations.

Still photography can be used to estimate density, obtain size-frequency data, and to get general habitat information. Cameras can be repetitively lowered to the bottom, or mounted on towed sleds, remote-operated vehicles (ROV's), or submersibles. Photographs are subsequently analyzed individually. A typical survey results in thousands of photographs. However, only a portion of these are usually suitable for analysis, and, of these a large number will be empty due to low individual densities. Although this significantly reduces the work load, considerable time and effort must still be spent in analysis.

The use of vertically mounted cameras for assessment is presented by Miller (1975) and has been subsequently used to assess populations of *Geryon* crabs (e.g. Melville-Smith 1983, 1985). Area photographed (A) is a simple function of the height of the camera off bottom (H) and can be calculated from the following formula (Melville-Smith 1983):

$$\text{Log}\ (A) = \text{Log}\ (a) + b\ \text{Log}\ (H)$$

The parameters a and b will depend upon the particular camera system used and can be calculated by photographing a measured grid at known distances. Calibration can be done in shallow waters, but should not be done on land because of the differing optical properties of air and water. Miller (1975) took photographs of 3.4 sq.m., per photograph, while Melville-Smith (1985) sampled as much as 7.3 sq.m., per photograph. He was able to do this by suspending his lights below the camera to maintain illumination while increasing height above the bottom.

For cameras mounted at an angle the determination of area photographed is more complex. This has been addressed by Patil et al. (1979), who should be consulted for further details. Wigley et al. (1975) used an angle mounted camera on a sled to survey *Geryon* and lobster (*Homarus americanus*).

Size-frequency information can be obtained from photographs, but linear measures are not uniform and depend upon distance from the camera. Thus, size measurements must be calibrated. Again, this is simplest to do for vertically mounted cameras. In either case, a measured grid can be photographed and used to calibrate sizes taken from photographs (Miller 1975). Three-dimensional, and hence size information, can be obtained by using stereographic photography. This is more complex and time consuming, but much of the analysis can now be computerized. Details of stereophotography are given in Boyce (1964), Cullen et al. (1965), Van Sciver (1972), Dill et al. (1981), and Klimley and Brown (1983) and elsewhere.

Direct observation and filmed transects are similar in their approach, and as above, they can be used to estimate density and obtain size-frequency and habitat information. Density estimates from submersibles and ROV's must account for, or control variations in height off bottom and altitude (see Caddy 1976). Filmed transects can be made from sleds, ROV's and submersibles, and have the advantage of having a permanent record for further analysis. This is extremely useful for purposes of verifying identifications. However, filmed transects are more severely limited with respect to aerial coverage. Transect studies should be coupled with detailed studies of the associated fauna. Taking detailed observations or film records of selected individuals is almost prerequiste for species identification, since specimens generally cannot be collected. The ability of modern video camera systems with telephoto-zoom lenses to make close-up observations is particularly advantageous.

Direct or filmed observations also have the advantage of being able to make continuous recordings over time as well as space, so additional information can be gained on species behavior and habitat characteristics. This capability makes these techniques extremely valuable in assessing the function of, and calibrating other techniques such as traps. In fact, due to the high cost involved with visual techniques, particularly the use of submersibles, they are most useful when they can be applied in limited studies to calibrate and confirm observations obtained with other, more widely applicable gear (e.g. see section on traps below).

As with still photography, size-frequency information can be obtained by measuring individuals recorded on film or video and converting these to true dimensions using a previously recorded calibration grid. Records taken from ROV's and submersibles must account for the possibility of variations in height above the bottom. Again, stereophotographic techniques are also applicable. Less precise, but useable estimates of size can be made by trained observers following techniques worked out for diver run surveys of fishes (e.g. Bell et al. 1985). With advances in technology more sophisticated methods are becoming available. For example, the submersible JOHNSON SEA-LINK is equipped with two lasers that project parallel beams a know distance apart. These can be projected at any object to provide an immediate reference standard for size estimation.

Traps

Traps have been used to survey a number of deepwater invertebrates. Good examples of shrimp surveys are given by Struhsaker and Aasted (1974) and Gooding (1984), who detail various aspects of the methodology, as does Wilder (1979). Melville-Smith (1986) and Wenner and Ulrich (1986) document the use of traps to survey *Geryon* crabs.

Traps are inexpensive and easy to use (Fig. 1). Traps themselves can be made out of almost any material, but reinforcing rod surrounded by wire mesh is most typical. Various shapes and sizes can be used (Fig. 2) depending upon one's objectives and available resources (see below). Traps can be set singly or with several along a trap line. Closely spaced traps should be set, if possible, at right angles to the bottom current to avoid interference. Lines to surface buoys can be of thin polypropylene (ca. 0.25 in.) which is cheap, buoyant, sufficient to handle several moderately sized traps and reduces the amount of current drag on the line. In areas of moderate to strong currents an anchor weight between the traps and the buoy line will help prevent the traps from being dragged along the bottom. A swivel placed at the base of the buoy line is helpful. Trapping can be conducted from any boat large enough (ca. 7m in length) to carry traps and be equipped with a winch or pot hauler.

For assessment purposes trap catch can be used either as an estimate of relative abundance or of absolute abundance. Estimation of relative abundance need only assume catchability remains constant. However, relative density estimates are only valuable in indicating change in abundance over time or between different areas. Trap catch can be used as such, but this seems useful only when the commercial potential of the resource has been established, either by obviously large, and hence valuable trap catches, or by other assessment techniques. If the potential of the resource is to be assessed, then trap catch must be converted to a measure of absolute abundance.

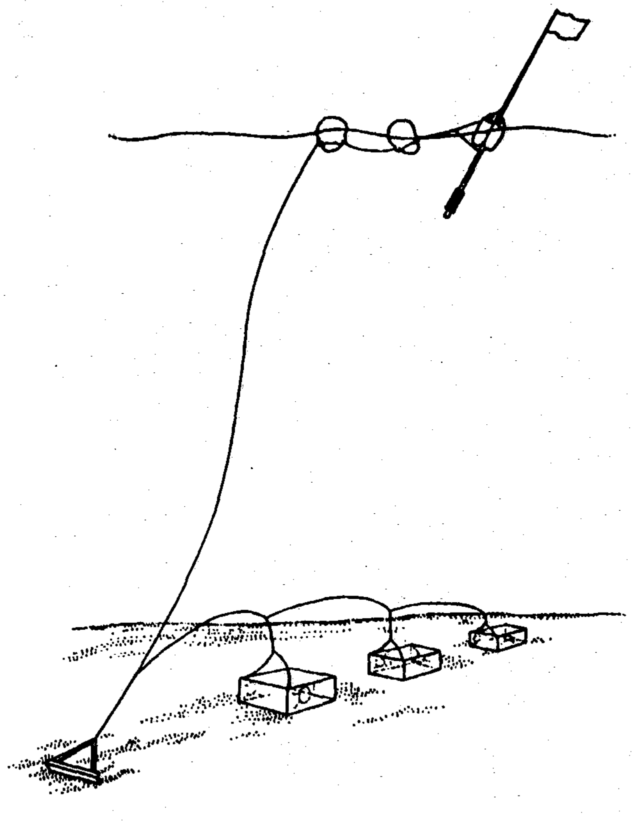

Figure 1. Example of a simple arrangement for deploying deepwater traps (redrawn from King 1981).

To convert trap catch to absolute abundance it is necessary to determine the effective area fished (EAF), as opposed to the area influenced. The area influenced by a trap is the area in which bait can be detected and responded to. Because of the effects of currents this area can be irregularly shaped, with distances from the trap being greater downstream. EAF is strictly defined as follows (Miller 1975):

$$\text{EAF (sq.m./trap)} = \frac{\text{Catch(\#/trap)}}{\text{Density(\#/sq.m.)}}$$

Thus, the calculation of EAF assumes that all individuals have a probability of capture equal to one inside the EAF, and equal to zero outside the EAF. It is the EAF times the number of traps hauled that determines the total area surveyed. Since sample variances are reduced with increasing aerial coverage, one wants to maximize the area surveyed for a given amount of effort. As such it is also desirable to maximize the EAF's by modifying trap design and use (see below). Typical EAF's in deepwater invertebrate surveys reported in the literature vary from circles of radii 30m (Wenner and Ulrich 1986) to 120m (Melville-Smith 1986) for *Geryon* crabs, and 45m for *Heterocarpus* shrimp (Ralston 1986).

In addition, if more detailed information is desired, particularly size-frequency data, then trap selectivity must be accounted for, i.e. in how biased a manner does a trap catch individuals with respect to their size or sex. Traps are typically highly selective.

Factors Affecting Trap Performance

The magnitude of the trap catch, the size distribution sampled, and trap selectivity depend on a variety of factors: funnel size, shape and placement, trap shape and volume, mesh size, soak time, bait, light, behavioral cycles, inter- and intraspecific interactions. These factors should be manipulated to maximize catch and decrease selectivity of the target species or species group as much as

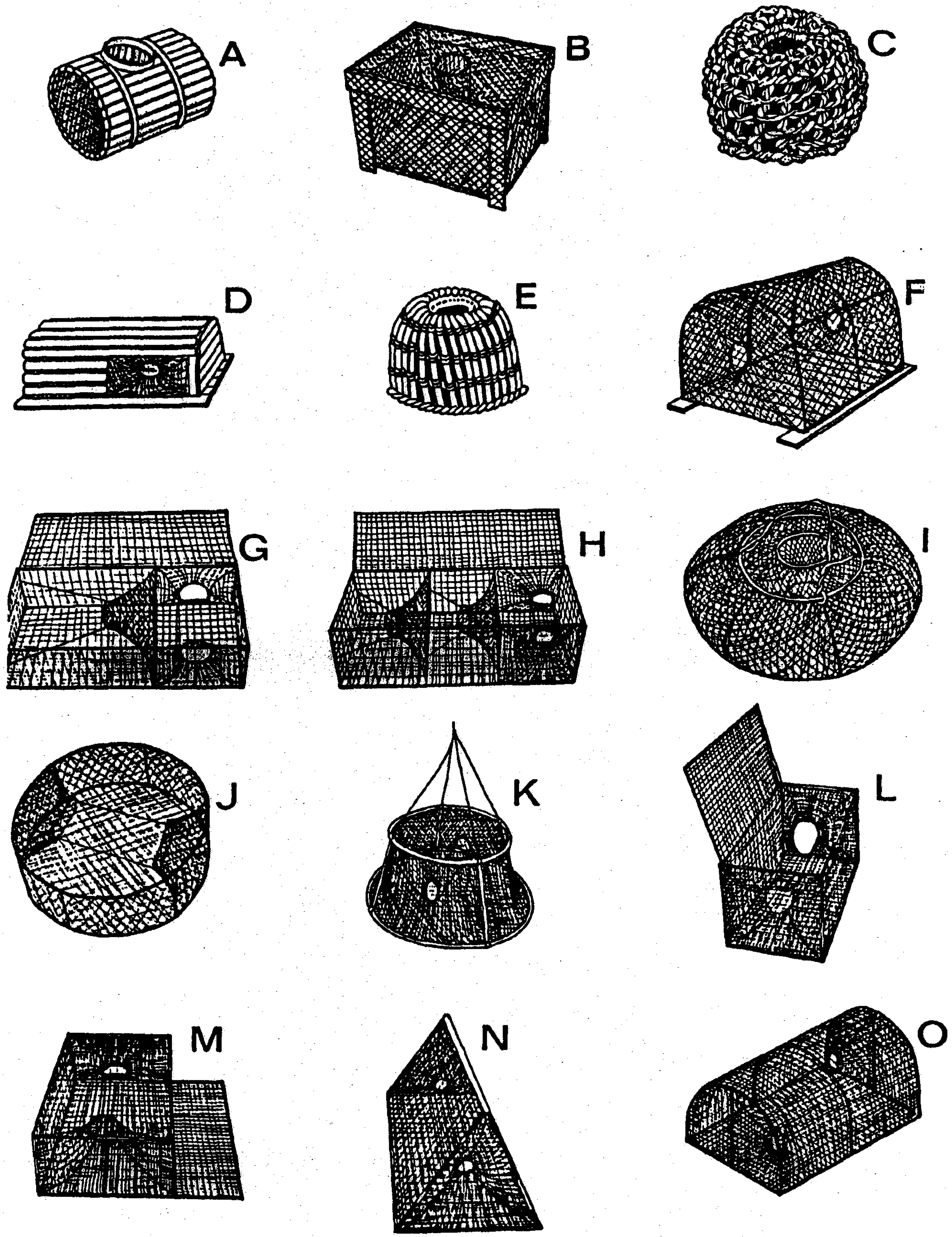

Figure 2. Examples of various designs of traps previously used or tested for sampling crustaceans. A-H: designs used for lobsters, G-K: designs used for shrimps. Sources: A-F: Cobb and Phillips (1980), G: Richards et al. (1983), H: Haefner and Musick (1974), I-J: Miller (1978), K-N: Struhsaker and Aasted (1974).

possible. This will not only increase the EAF, but also provide more individuals for size-frequency and other biological analyses. Traps are very specific; designs that work for one species may be inappropriate for another. Because of this, the effects of these factors will be reviewed. Slight modifications can greatly affect catch. Thus, once a final design and methodology are determined they should not be altered. In the end, it is better to have an inefficient, but known sampling gear, than two or more improved versions of unknown efficiency.

Variations in mesh size seem to affect catch in a predictable manner. This has been studied in particular by Koike (Koike and Ugura 1977, Koike and Ishidova 1978) for shrimps and crabs; Krause and Thomas (1975) did similar work with American lobster. In general, the larger the mesh size the smaller the catch. Selection curves for traps are similar in shape to those of trawls (e.g. Gulland 1983), although small meshes occasionally showed decreased catches of very large individuals (Fig. 3). This may be due to intraspecific interactions (see below). Melville-Smith was able to calibrate the EAF's of traps of different mesh size by simply using a constant conversion factor.

The characteristics of the funnel (entrance) are one of the most important factors affecting catch and selectivity. Narrow openings will restrict larger individuals from entering (Fig. 4) (Koike and Ugura 1977, Koike and Ishidoya 1978, personal observation). If one is interested in small shrimp species, openings could be reduced in size to avoid bycatch of, for example, giant isopods, but small openings seem to be attractive to hagfish (personal observation,

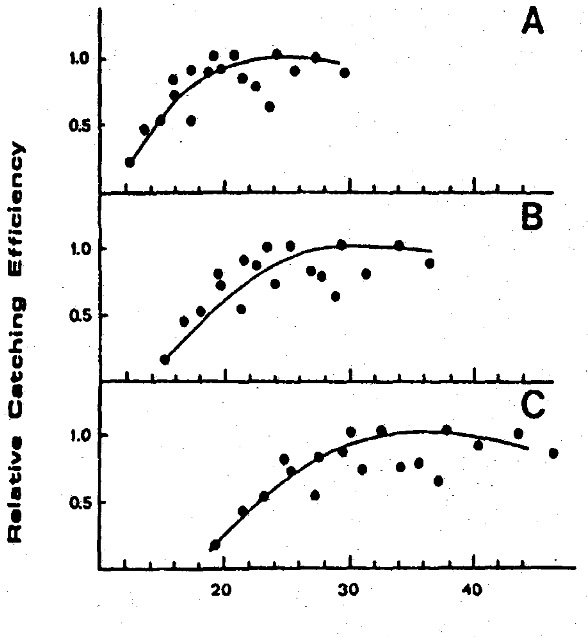

Figure 3. Example of selectivity versus mesh size: selection curves for Pandalus borealis for mesh sizes of (A) 19mm, (B) 23.4mm, and (C) 30.3 mm (redrawn from Koike and Ogura 1977).

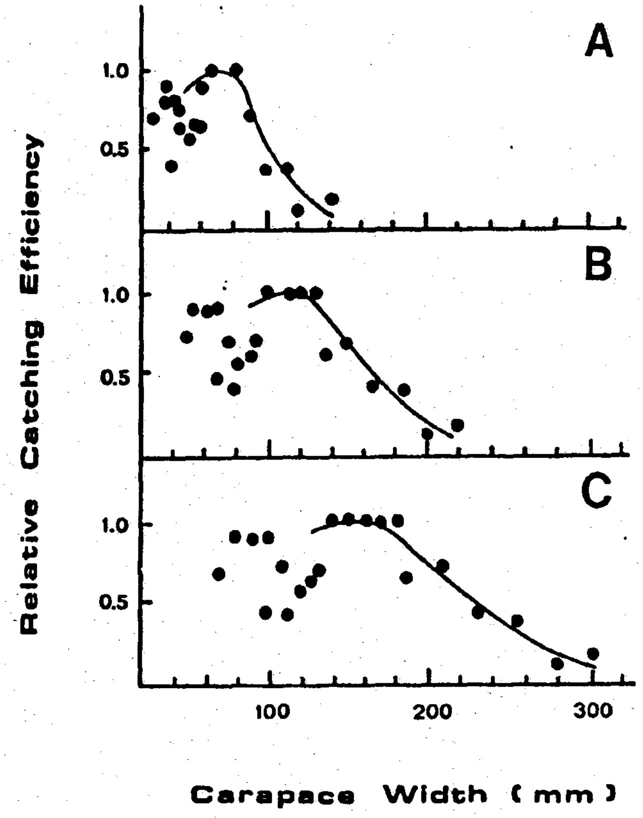

Figure 4. Example of selectivity versus entrance width: selection curves for *Chioneoectes japonica* for entrance widths of (A) 300mm, (B) 500mm, and (C) 700mm (redrawn from Koike and Ogura 1977).

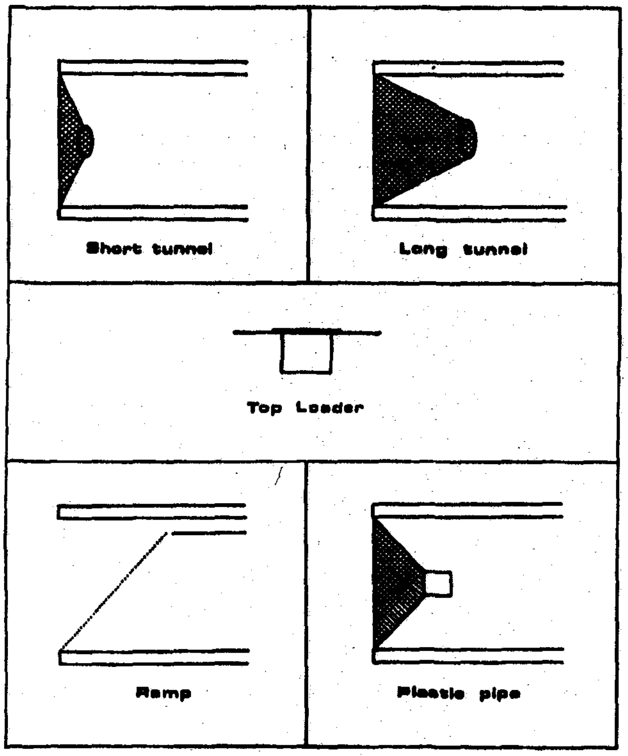

Figure 5. Funnel designs for shrimp traps tested by Kessler (1969).

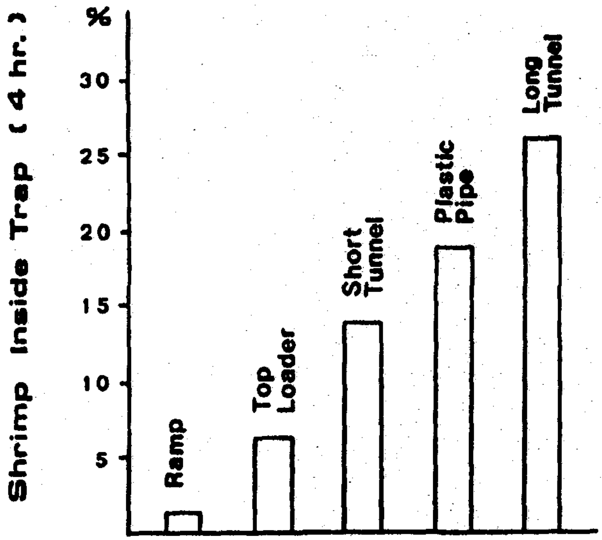

Figure 6. Shrimp trap efficiency based on ease of entry for funnel designs shown in Figure 5 (redrawn from Kessler 1969).

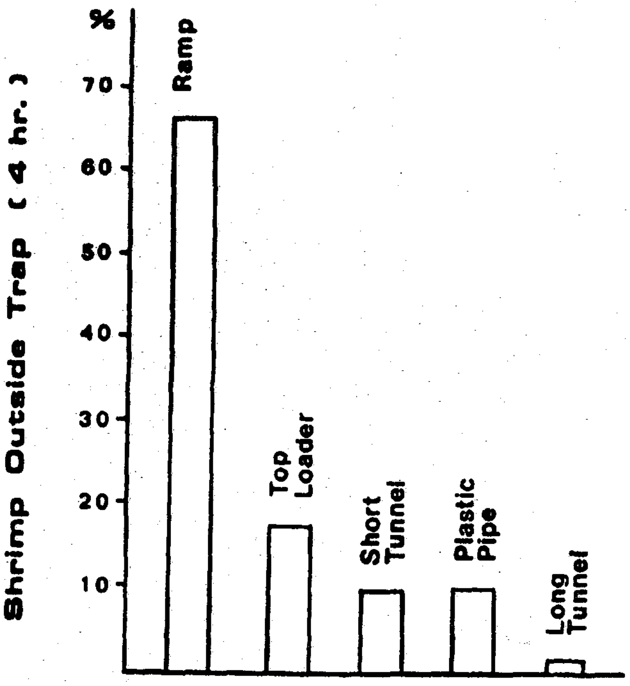

Figure 7. Shrimp trap efficiency based on ease of escape for funnel designs shown in Figure 5 (redrawn from Kessler 1969).

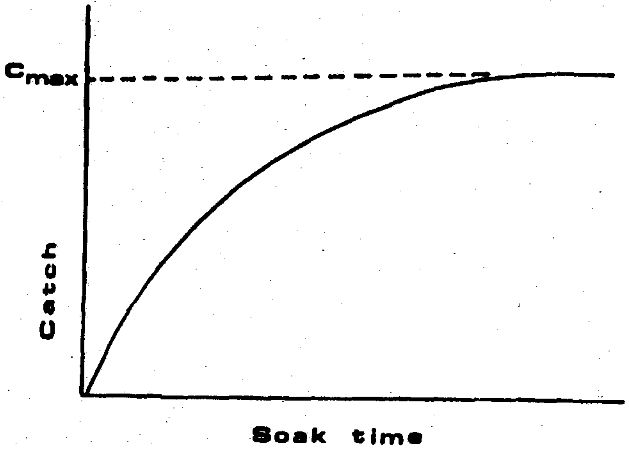

Figure 8. Hypothetical relationship between catch and soak time. The trap is saturated when no further increase in catch (C^{max}) is observed.

Wenner and Ulrich 1986) which can foul bait and traps with mucus, consume bait, drive away shrimp and otherwise reduce the catch. Kessler (1969) compared the effectiveness of several different types of openings for catching pandalid shrimp (Fig. 5). He found an inverse relationship between ease of capture and ease of escapement (Figs. 6, 7). Thus, the easier it was to get in, the harder it was to get out. They found a long tapered funnel worked best.

The location of openings is critical and species dependent. The shrimp species studied by Koike and Ishidoya (1978) preferred not to leave the bottom, and catches decreased with increasing height of the opening. In contrast, Kessler (1969) observed shrimps to be willing to climb traps to get to openings. Miller (1980), studying crabs, found raised openings to be advantageous because they placed incoming crabs above ones inside, thereby reducing the effect of intimidating displays by the latter. Wenner and Ulrich (1986) used two types of traps, one with a top funnel, the other with a side funnel, to survey crabs. The top funnel trap differentially caught more *Geryon* relative to *Cancer borialls*, but differentially caught smaller individuals. In the side funnel trap these relationships were reversed. All evidence seems to indicate that catch is maximized when the bait odor trail leads individuals to the entrance. Crabs showed limited searching away from areas of concentrated odor, and if the entrance was not located after a short period they would either loose interest or be chased away by other crabs (Miller 1978). Butler (1963) suggested using traps covered with burlap except at the entrances. Supposedly, this still allows the bait scent to diffuse out of the trap but creates a concentration gradient with a maximum at the openings. Struhsaker and Aasted (1974) found covered traps to be 2.5 to 10 times more effective than noncovered ones.

Traps have been designed in a wide variety of shapes: circular, square, rectangular, "tent" shaped (Fig. 2). The effects of shape are not clearly understood, but some designs are clearly better than others, e.g. Struhsaker and Aasted (1974), Brown and King (1979). Often, trap design is more a function of local tradition or ease of on deck storage.

Trap catches increase over time, but do so at a decreasing rate so that a maximum is asymptotically reached (Fig. 8). At this point a trap is said to be saturated. Saturation effects have been noted for shrimps (Inoue et al. 1977), crabs (Miller 1978, Somerton and Merritt 1986) and lobsters (Austin 1977). Thus, catches of differing soak times need to be calibrated before they can be compared. Austin (1977) modeled soak time effects with the following equation relating catch (C) to soak time (S):

$$C = a\ S^{(1-b)}$$

The parameters a and b are determined by regressing Log (catch) against Log (soak time) for a number of catches hauled at different times from areas of similar density. Somerton and Merritt (1966) developed an equation for standardizing catch rates (CT) of variable soak time (t) to that of a one day soak time (C1):

$$\frac{C1 = e^{-a} - e^{-b}}{Ct = e^{-at} - e^{-bt}}$$

The parameters a and b are fitted via nonlinear regression using data collected as above.

Increasing trap volume generally results in increased catch. Since trap volume has no affect on the area influenced by the trap, increased catches must result from larger traps increasing the probability of entry and retention. This seems to be due to behavioral interactions inside the trap. Miller (1978) reported that at saturation crabs on the inside would intimidate others from entering. Increasing trap volume increased not only the catch, but also the density (Miller 1979, 1980). For shrimps, Inoue et al. (1977) thought catch was limited by territorial behavior inside the trap.

Bait affects trap catch in two ways: by influencing the area influenced by the trap, and by increasing density within the trap. The area influenced by the trap is a function of the quantity of scent released and its rate of dispersion. Generally it has been found that oily or bloody fishes, e.g. scombrids or clupeiforms, make good bait as they contain an abundance of substances that are easily released (Struhsaker and Aasted 1974, Brown and King 1979). Shrimps are considered better than squid (Struhsaker and Aasted 1974), while shark meat is considered to be poor (personal observation). Odor release seems to be a function of surface area for diffusion. Thus, chopped bait releases its scent faster than whole bait. However, the desired rate of release is also a function of soak time. Struhsaker and Aasted (1974) found greater catches with coarse-chopped bait than with fine-chopped bait. This may have resulted from finely chopped bait attracting organisms too rapidly such that bait supply was exhausted long before recovery, giving trapped organisms ample opportunity to escape or turn to cannibalism. Personal observations on deep-set longlines showed that shrimps and isopods were differentially attracted to pieces of bait that were already being eaten by other individuals. The action of these early arrivers in cutting up the whole bait and enhancing scent release was obviously important in attracting others. If bait is to be held in containers, ones with mesh openings are recommended over ones with small perforations (Brown and King 1979, Miller 1979). This allows for a greater surface area for scent release, and lets smaller organisms actively feed on the bait, thereby exposing new material for diffusion. At the same time it prevents larger individuals from consuming all the bait prior to recovery.

Miller (1978) observed crabs to have no interest in traps without bait. Conversely, Inoue et al. (1977) found shrimps to enter unbaited traps, due to some thigmotaxic response. However, traps without bait would not attract shrimps to the trap in the first place. Increased amounts of bait were shown to increase saturation densities (Miller 1980, Sainte-Marie 1986), possibly by reducing intraspecific conflicts. Sainte-Marie (1986) observed changes in selectivity as well, with more large individuals caught, as bait quantity increased.

Light is thought to have little affect on trap catches of deepwater invertebrates (Struhsaker and Aasted 1974). In tank studies, penaeid shrimps have been observed to enter traps in response to light, but this may have been an attempt to escape light, and would not be a factor at depth.

Activity cycles will affect traps catches. Evidence indicates most invertebrates are more active at night, and overnight trap soaks should yield higher catches (Bjordal 1986, Kessler 1969, Sainte-Marie 1986).

Inter- and intraspecific interactions affecting trap performance have been noticed by several investigators. Miller (1978, 1980) found that if crabs did not quickly enter the trap they would engage in intraspecific aggression, resulting in some crabs being chased away. Bjordal (1986) observed aggressive interactions where large lobsters (*Nephrops*) would chase off small ones. Aggressive interactions also occur inside the trap. Miller (1978, 1980) found crabs in traps to intimidate others trying to enter. This effect was reduced if bait was plentiful or if trap design was altered (see above). With shrimp, cannibalism inside the trap can be a problem. Struhsaker and Aasted (1974) felt between 1% and 15% of the catch was lost due to cannibalism, with small individuals attacking larger ones, particularly gravid females. Again, this effect became more pronounced if bait became limiting. Richards et al. (1983) studied interspecific interactions between lobsters (*Homarus*) and Cancer crabs. One species of crab tended to avoid entering traps occupied by lobsters, the other entered in reduced numbers. An example of possible interactions between shrimps and hagfish was mentioned previously. Traps in deep water also attract larger predators, such as sharks, that are capable of driving away or consuming invertebrates which do not quickly enter traps. In one case, a trap set in over 700 m was visited by two *Hexanchus* sharks, 2.5m and

5m in length respectively, within a period of 10 minutes. The smaller shark was observed to thrash at or near the trap, driving off surrounding organisms (Nelson and Appeldoorn 1985). One interesting phenomenon is that large species (e.g. giant isopods versus shrimps, personal observation) and larger individuals within a species (Sainte-Marie 1986, Bjordal 1986) tend to have greater rates of movement. Thus, of individuals attracted from long distances, a greater proportion should be large, and these would therefore be selectively caught.

Determination of Effective Area Fished

There are a number of ways proposed to determine EAF. Most of these rely on independently determining density, and then calculating EAF from Equation 1 above. Once determined, EAF is assumed to be constant. In shallow water catchability for some species has been found to vary, affected by factors such as season, and/or molting cycle for crustaceans. In deep water this may or may not occur to the same degree since seasonal cycles and cues are progressively dampened with depth. Variations in catchability can be accounted for and corrected given sufficient study (e.g. Morrissy and Caputi 1981).

If the species of interest is large, visual census methods are particularly useful in estimating density for trap calibration. Density estimates are made as discussed above. Since trap calibration does not require an extensive aerial survey the expenses involved with deepwater visual assessment are kept to a minimum. Miller (1975) and Melville-Smith (1986) used still photography to estimate density prior to trapping. Visual transects from a submersible have been used to estimate isopod density for comparison to trap catches (unpublished data).

Tagging methods can be used to estimate density if net emigration and immigration does not occur (see Seber 1982 for a general review). However, tag returns are typically very low. In a novel approach, Brethes et al. (1985) released tagged crabs known distances from traps in order to calculate the probability of capture versus distance. This was a linear relationship, and integration of the function yielded an EAF equal to a circle of radius one-half the maximum distance traveled. However, this calculation requires the assumption that the probability of capture, once reaching the trap is equal to one, which is not the case. Thus, EAF is overestimated.

Fishing success methods (e.g. DeLury or Leslie methods, see Ricker 1975) have been used to estimate population size in gastropods (Ito and Tashizawa 1981) and shrimps (Ralston 1986) in conjunction with trapping. This method has the advantage of being quick, since fishing must be done over a short time period, and its calculations are simple. However, the area fished must be assumed to be closed, i.e. no net immigration or emigration, and catchability is assumed to remain constant with decreasing abundance. Ralston (1986), for example, used the Leslie method, where catch per unit effort is regressed against cumulative catch. The resulting slope is equal to the catchability coefficient (g), which is defined as the proportion of the population removed with one unit of effort. The Y-intercept is population size. Knowing the total area fished, one can calculate density, and hence EAF. Ralston was able to do this conducting his experiments on a naturally isolated platform.

Eggers et al. (1972) proposed a way to estimate EAF based on detecting competition between nearby traps. A plot of catch/trap versus spacing between traps should rise to an asymptote as spacing increases. The point at which the maximum is reached represents the minimum distance traps can be apart before they start interfering with one another, i.e. their EAF's overlap. Thus, the EAF is a circle with a radius of one-half this distance.

However, this method does have problems in application. It must assume that the area influenced by a trap is indeed a circle, which is not the case. Observations (Miller 1978, Wilson and Smith 1984, Bjordal 1986) indicate that organisms approach bait preferentially from down current. Thus, the area influenced by a trap is elongated downstream, and the minimal distance will therefore vary depending upon the orientation of traps to the current. True EAF, however, should be constant. The method also assumes that distances between traps can be accurately determined. In practice, in deep water this is difficult to do. Traps tend to drift on descent and may move substantially once on the bottom if not securely anchored (Nelson and Appeldoorn 1985, Wenner and Ulrich 1986), and bottom currents may differ from surface ones.

Statistical Considerations

A final note should be given with respect to the distribution of sampling effort. As with any survey, conventional techniques for statistical sampling can be applied (Cochran 1977, Raj 1968). With deepwater invertebrates, care should be given to adequately sampling the entire depth range of the species of interest. Most species assessed are not uniformly distributed with respect to either size or sex. This is particularly important to note if unbiased size-frequency samples and sex ratios are desired. For example, Wigley et al. (1975) and Wenner and Ulrich (1986) found female *Geryon* to be differentially distributed in deeper waters. Struhsaker and Aasted (1974) and King (1981) found length-frequency distributions of shrimps to vary with depth, with smaller individuals occurring preferentially at the shallowest and deepest depths. Since these species were protandrous hermaphrodites, sex distribution was similarly biased.

Monitoring and Assessment

The use of passive sampling methods for monitoring and assessment, while not without difficulties, is necessary. In many areas (e.g. steep or rocky bottoms), or for particular species (e.g. burrowers) passive methods are the only options available. For monitoring purposes assumptions can be less strenuous, and less detailed information will be required. Often the primary concern here is changes in relative abundance or size/age structure over time. Assessment, on the other hand, implies an attempt to estimate potential productivity or response to fishing pressure. Absolute estimates of density and unbiased or bias controlled size/age structure are desired, and these require a more rigorously applied methodology. The question of productivity, versus standing stock, is particularly important with respect to deepwater resources. Because of the apparent distance between these resources and the base of the food chain, one would have to be conservative and assume a low rate of productivity until evidence to the contrary is gathered.

The principal problem in using passive methods is the choice of gear. No method is clearly preferable. Choice will depend upon the question being asked and species of interest, and will be subject to financial and logistical constraints. Because all methods are selective, better results can be achieved when a combination of methods is employed, both for survey and calibration purposes.

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PELAGIC LONGLINING AS A SAMPLING TOOL FOR BIOLOGICAL MONITORING AND RESOURCE ASSESSMENT

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Introduction

Pelagic longlining has had a long and erratic history in United States waters. Many refinements have been made in the 30 years it has been in use and pelagic longlining may serve as a sampling tool in the future.

Longlining in the Gulf region began with the exploratory work of the OREGON I under the direction of Dr. Harvey Bullis in the early 1950's. Led by the U.S. Fish and Wildlife Service, these exploratory cruises were conducted throughout the Gulf of Mexico and Caribbean. The fishermen used crude hand-deployed longline gear. Longline gear consisted of coiled manila ropes, glass floats, and large steel hooks, all of which were stored in large pails. Lines were tied together to provide from 3 to 5 miles of longline. The catch of these exploratory efforts varied by location, season, and species. Catch per unit of effort (CPUE) for yellowfin tuna, for example, ranged from 2 to 12 fish per 100 hooks during these cruises. Large concentrations of yellowfin tuna were identified off the mouth of the Mississippi River and into the Caribbean. Sampling efforts ended in 1955.

During the early 1960's the Japanese fleet entered waters off the U.S.. By 1963, the U.S. government, through the Bureau of Commercial Fisheries, in cooperation with the Japanese fishing fleet, had developed a data collection and reporting program called the Japanese Quarterly Statistical Report. Data collection continued through the creation of the National Marine Fisheries Service (NMFS), and sampling ended in 1981 when the Japanese abandoned the fishery. Data were reported by the Japanese in quarterly reports and contained location, species (number of individuals), and number of hooks set in 5° by 5° (Latitude-Longitude) squares.

Some analysis of this large data set has been conducted by NMFS. In general the data have been difficult to analyze because of the changes in gear practices and target species during the data collection period. CPUE and total annual landings of yellowfin tuna by the Japanese in the Gulf of Mexico were highly variable from year to year (Fig. 1). There was, however, a distinct decline in both CPUE and Landings during the last ten years of the Japanese tenure in the Gulf of Mexico. Combined data of all 18 years, show that for yellowfin tuna CPUE was greatest during the spring and early summer.

During the last five years of the Japanese efforts in the Gulf of Mexico, there was a growing concern over billfish and shark bycatch. This concern developed concomitant with the Fisheries Management and Conservation Act of 1976, which declared a 200 mile Fishery Conservation Zone for the United States. From this, a foreign fisheries observer program was developed by NMFS and operated out of Pascagoula, Mississippi. This effort lasted four years and consisted of federal observers traveling onboard Japanese vessels to record various data available from the fishing efforts of the Japanese. During this time, observers recorded information on approximately 1,000 sets that were made between 1978 and 1981 in the Gulf and South Atlantic regions.

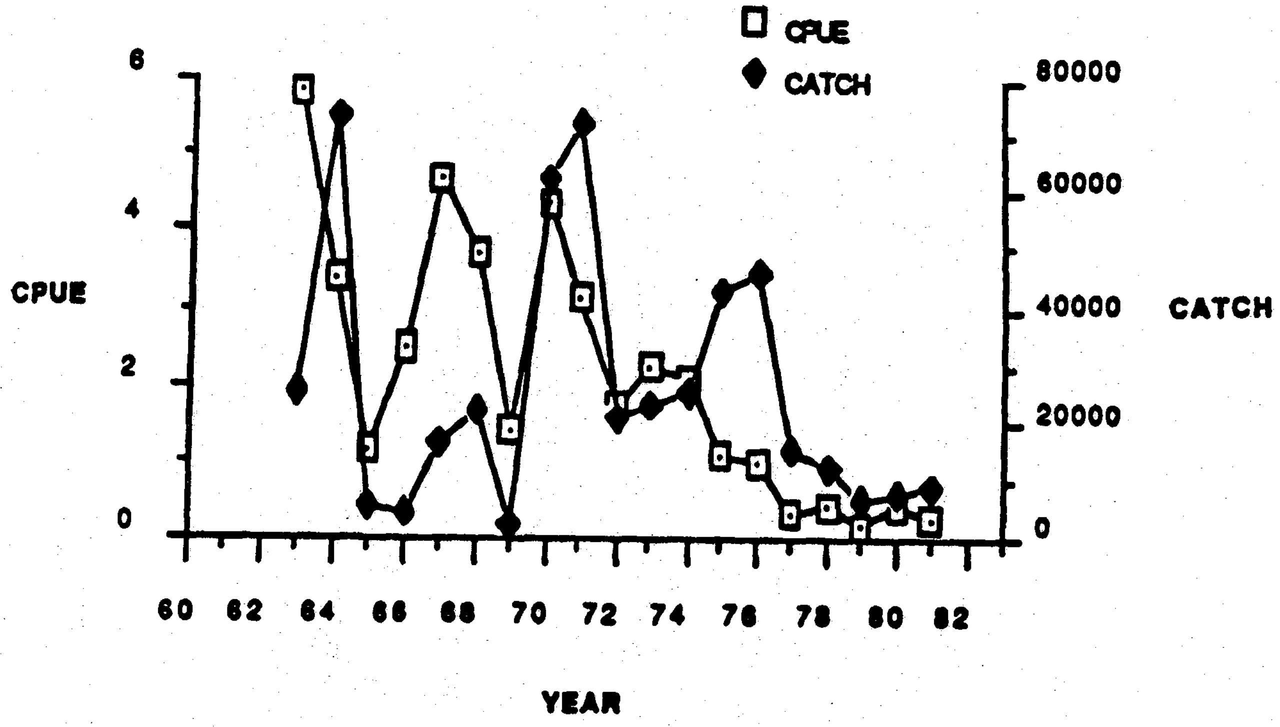


Figure 1. Total landings and catch per unit of effort reported by the Japenese for yellowfin tuna landed in the northern Gulf of Mexico from 1960 - 1981. (NMFS)

Three sources of data were collected from the Japanese fishing effort: observer data, reporting data required of the Japanese by the U.S. Government, and a Coast Guard report that notified the U.S. Coast Guard when the Japanese entered U.S. waters. These data sources were analyzed and compared by Thompson (1982) and Reese (1983). Both studies concluded that the Japanese were not always accurately reporting time and location, and they were under-reporting billfish catches. These findings have led to questions concerning the validity of the Japanese data available through the required reporting program.

The Japanese abandoned the fishery in 1981 and U.S. concerns over nontargeted and targeted resources quieted down. During recent years however, concerns over pelagic resources have resurfaced. Adams (1987) summarized yellowfin tuna landings for the East Coast and the Gulf of Mexico. These data indicated that landings had increased during the prior five years. Louisiana landings, increased from 35 pounds in 1984, to 200,000 pounds in 1985, to 2 million pounds in 1986, exemplify the significant increase in landings in both the Gulf and South Atlantic regions. The reports are rapidly renewing historic concerns over billfish, and the Fisheries Management Councils are under increasing pressure to (a) regulate the tuna fishing in U.S. waters and to (b) reduce, and eventually eliminate, billfish bycatch.

Several questions emerged when examining the historic yellowfin and tuna data:

- Based on Japanese reported data, what factor(s) led to the apparent decline in the number of tuna landed and catch-per-unit of effort between 1970 and 1981?

- Had overfishing occurred or had there been a change in the migratory pattern of yellowfin tuna?

- Was there evidence of poor year class strength?

- Had yellowfin tuna landings by the domestic fleet in the Gulf of Mexico and South Atlantic Region increased significantly between 1981 and 1986? What other pressures were being exerted on Gulf of Mexico stocks for Cuban and Mexican (East Coast along Gulf Mexico) landings, (estimated to be 800 tons in 1986)?

- Were other foreign vessels active in the fishery?

- What is billfish bycatch and mortality associated with tuna longlining?

Based on these questions, the National Marine Fisheries Service is considering the development of a monitoring and assessment program for pelagic fish populations. In developing this program, NMFS must decide whether to continue to monitor landing data and continue the observer program, or initiate its own longline sampling program. To answer these and other questions, examination of the U.S. observer program data was conducted to determine whether the data set might provide a dependable source of collected information with a sufficient sample size to provide insight into the effort required to initiate such a program.

Methods

To develop this monitoring program we set out to examine whether the data set could be used to design a statistically valid sampling program. Pertinent variables studied were:

1. The number of sets required to estimate CPUE in a given year and effect of :

    a. CPUE on sample size,

    b. month of effort on sample size,

    c. bait on CPUE,

    d. location on CPUE,

    e. boat or captain on CPUE.

2. The number of sets required to approximate the size frequency distribution of a population.

3. The length of longline required to estimate the two above parameters.

Two statistical tests were used to determine the number of sets that would be required to estimate some of the parameters. The two tests are briefly described below.

1. A running average was used to determine the number of sets required to come within a 95% confidence interval of CPUE. The mean, and a 95% confidence interval about the mean, was calculated for the entire sample for a given year. Random samples were selected from the same population, and a running mean was recalculated by increasing the sample size by one for each iteration.

2. A trumpet diagram was used in a similar fashion. The mean and variance were calculated for one of the variables for a given year. The mean was then recalculated by increasing the sample size by one for each interaction, and the confidence of that interaction was plotted as percentages of the mean against "N". A rule of thumb was that when the curve begins to level out, there is little value in increasing sample size.

As in all statistical analyses, assumptions and qualifications are critical and are as follows.

a. the analyses were intended as an overview, and much more refinement is needed,

b. the means for the observer data were assumed to approximate the real population mean,

c. the distributions of all data were assumed to be normal.

Results

Tuna CPUE data from 1978 were analyzed using both statistical approaches. A plot of the running mean for yellowfin tuna data (all sets) against N indicated that 30 to 40 sets would approximate the mean (Fig. 2A). A trumpet diagram of the same data set also shows that 40 and 50 sets would provide a

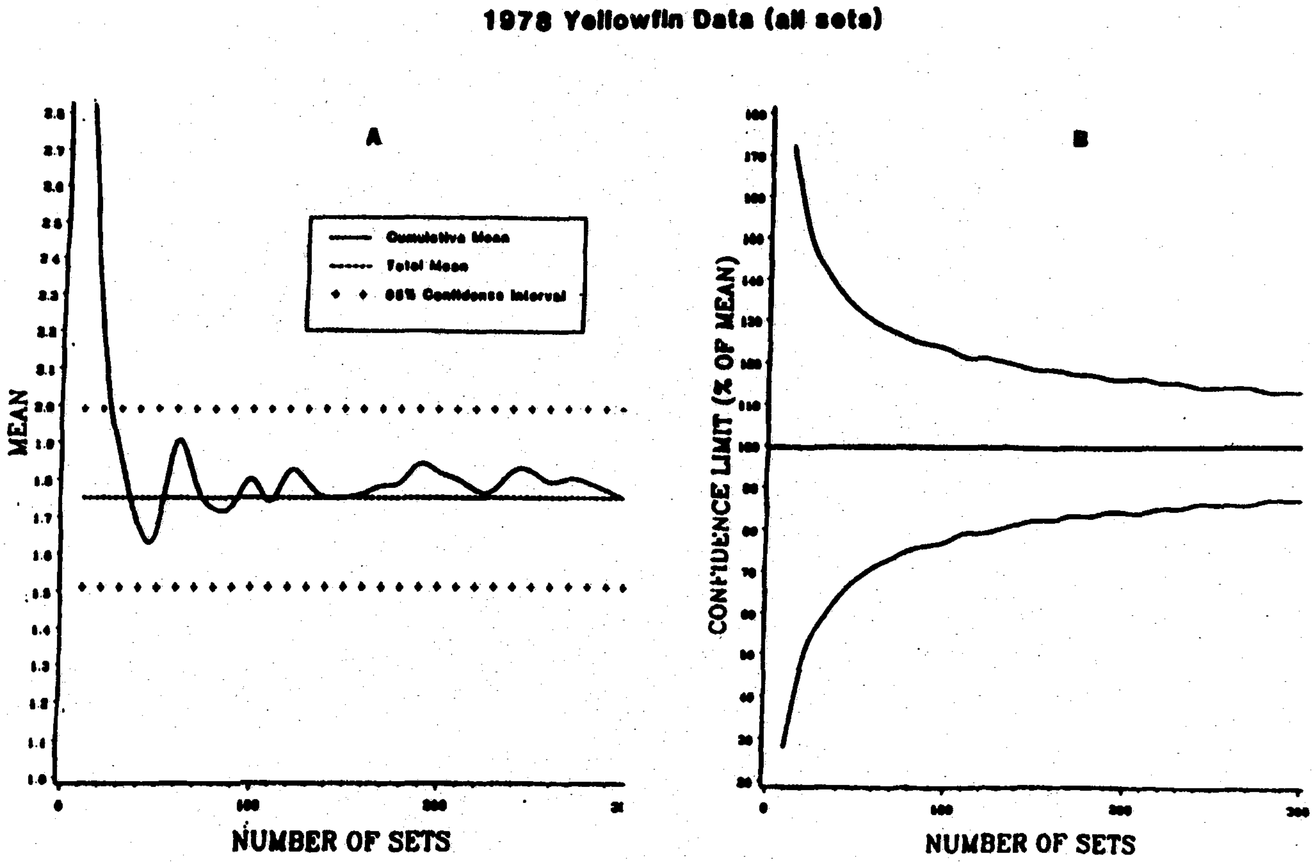


Figure 2. NMFS 1978 observer data for yellowfin tuna (all sets) showing A) random cumulative mean method, and B) trumpet diagram method for estimating adequate sample size.

satisfactory sample size (Fig. 2B). Many of the sets recorded during 1978 targeted specific species (i.e., bluefin, yellowfin, bigeye). CPUE increased for those sets that targeted yellowfin tuna. When yellowfin tuna were the target species, the number of sets required to approximate the mean fell to 20 to 30 using the two statistical approaches (Fig. 3A and 3B). In 1979, CPUE dropped for both nontarget and target sets for yellowfin tuna. A decrease in CPUE increased the number of samples required to approximate the mean. The yellowfin tuna were used for most analyses.

Running average and trumpet diagrams of 1979 data are shown in Figures 4A and 4B. These analyses were also run on bluefin tuna, yellowfin tuna 1978 (Fig. 5A and 5B) which suggested that 20 to 30 sets were required to estimate sample mean. The same analyses on blue marlin data from 1978 indicated that approximately 30 to 40 sets would be required to approximate the mean CPUE reported by the observers. The CPUE's of target sets versus all sets for specific species (bluefin, yellowfin and blue marlin) were compared (Table 1). The most significant effect on CPUE occurred when yellowfin were the target species. The CPUE of bluefin tuna remained low and did not change. In 1979 there was a drop in CPUE of yellowfin tuna, but a relative increase in CPUE of yellowfin tuna occurred when they were the target species.

The length frequency distributions for the various species were also examined using a random subsample of 1978 data consisting of 80 sets and 40 (Fig. 6). Also shown in the

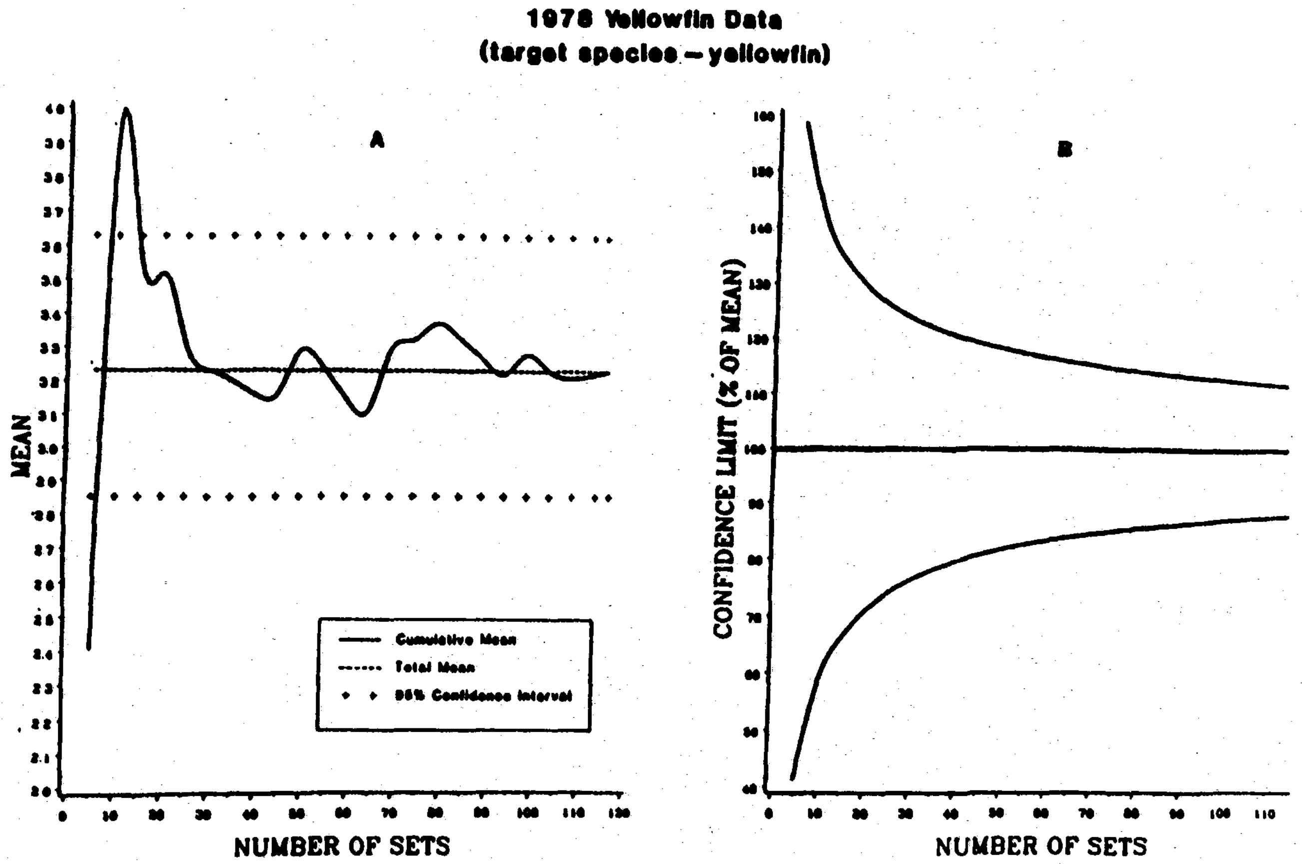
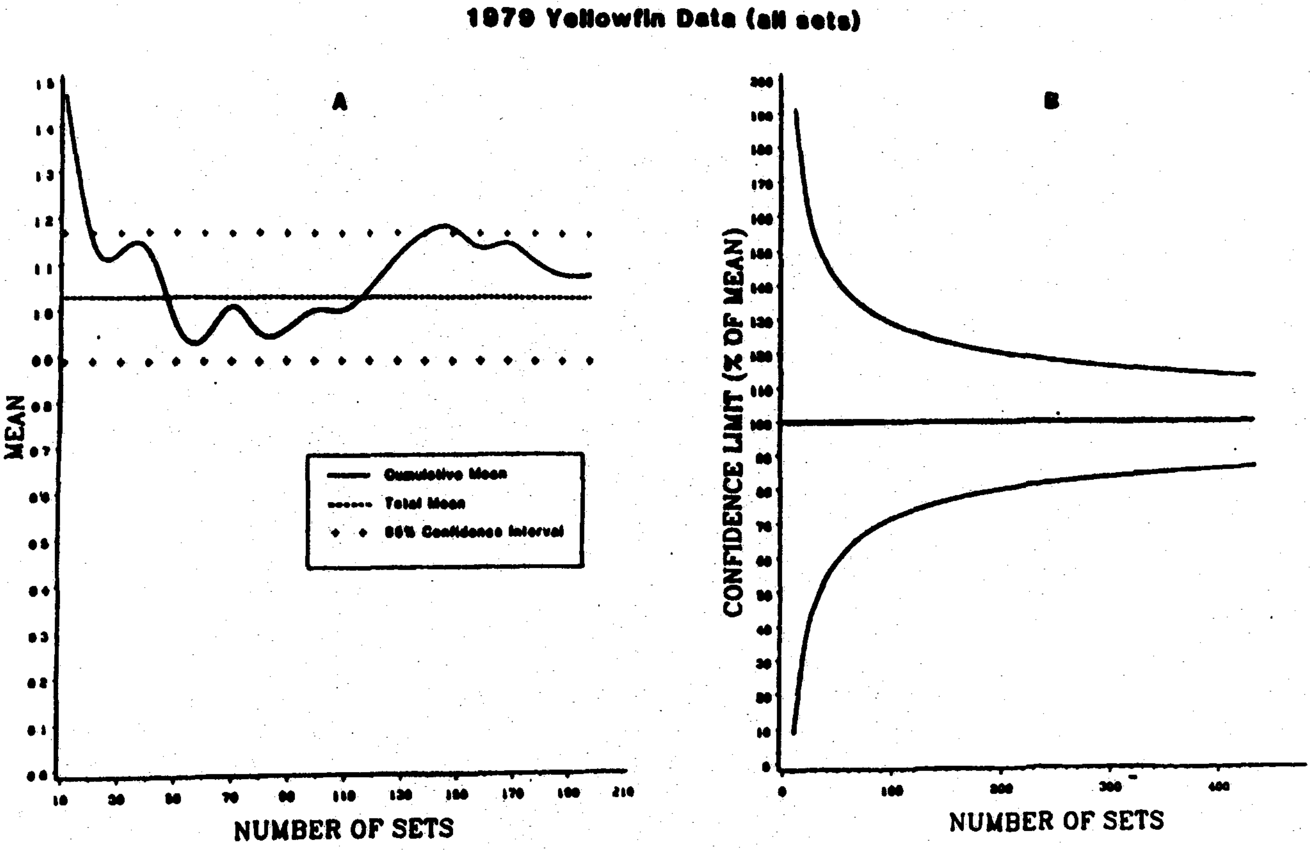


Figure 3. NMFS 1978 observer data for yellowfin tuna (target species = yellowfin) showing A) random cumulative mean method, and B) trumpet diagram method for estimating adequate sample size.

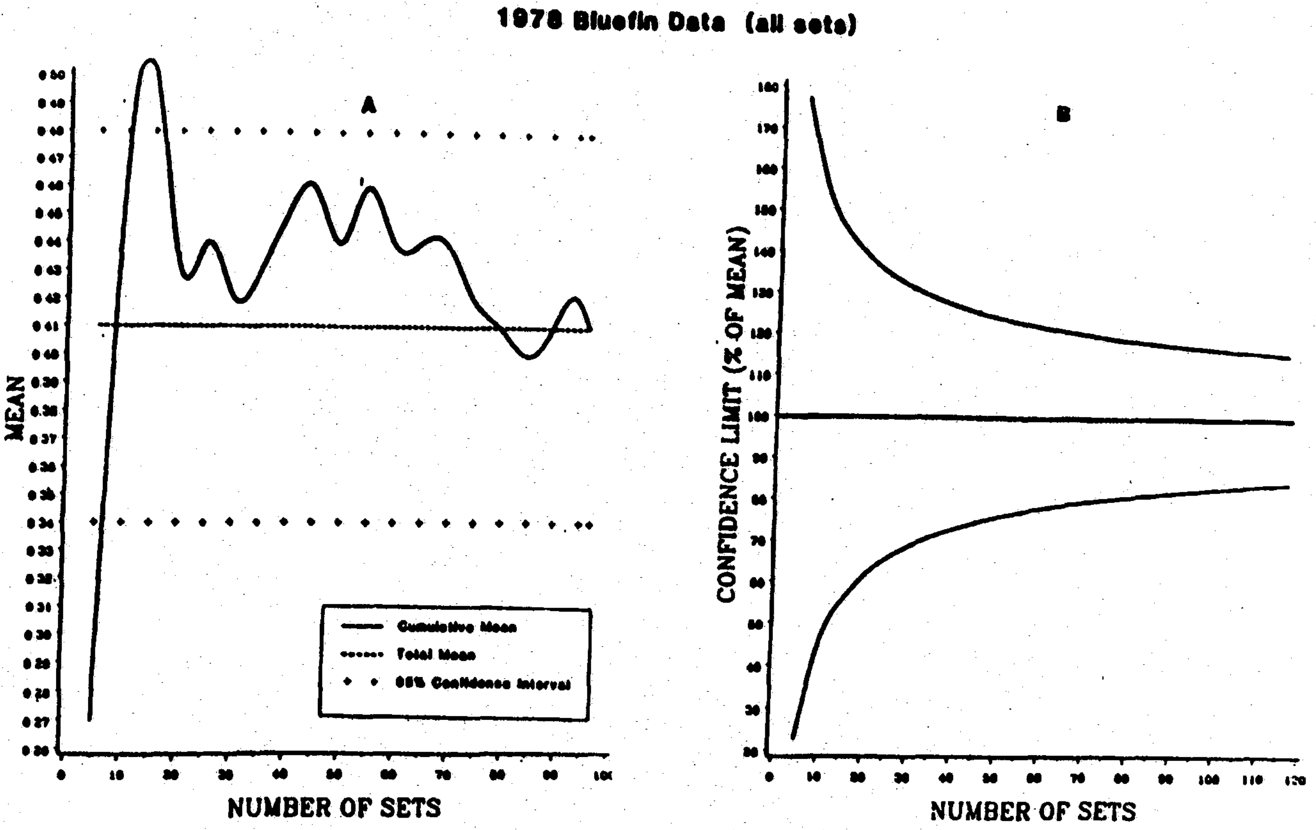
figure are length frequency modes, which may indicate year classes. Based on these data, between 40 and 80 sets would be required to approximate the length frequency distribution observed for the total population sampled in 1978.

NMFS also expressed interest in the number of hooks or line length that would be required to monitor both CPUE or length frequency distribution of a given species of fish. The relationship of CPUE to the number of hooks in 1978 was plotted (Fig. 7) using yellowfin data. It was difficult to draw any conclusions from this graph because of scatter and a concentration of fishing effort around a high number of hooks. There was a general trend toward an increase in CPUE with an increase in the number of hooks, and no saturation point was evident. However, these data should be broken out by date, target species, gangion length, and time of year before making any conclusions.

The effect of type of bait on CPUE for 1978 yellowfin tuna landings was examined. There was a statistically significant difference between squid, mackerel, and saury (Tukey's T-test). CPUE was lowest when squid was used and highest when mackerel was used. Mackerel was statistically more effective than saury, and saury was statistically more effective than squid. The effect on CPUE by these types of bait on CPUE should be examined.



1979 Yellowfin Data (all sets)



1978 Bluefin Data (all sets)

Figure 4. NMFS 1979 observer data for yellowfin tuna (all sets), and **Figure 5.** NMFS 1978 observer data for bluefin tuna (all sets) showing A) random cumulative mean method, and B) trumpet diagram method for estimating adequate sample size.

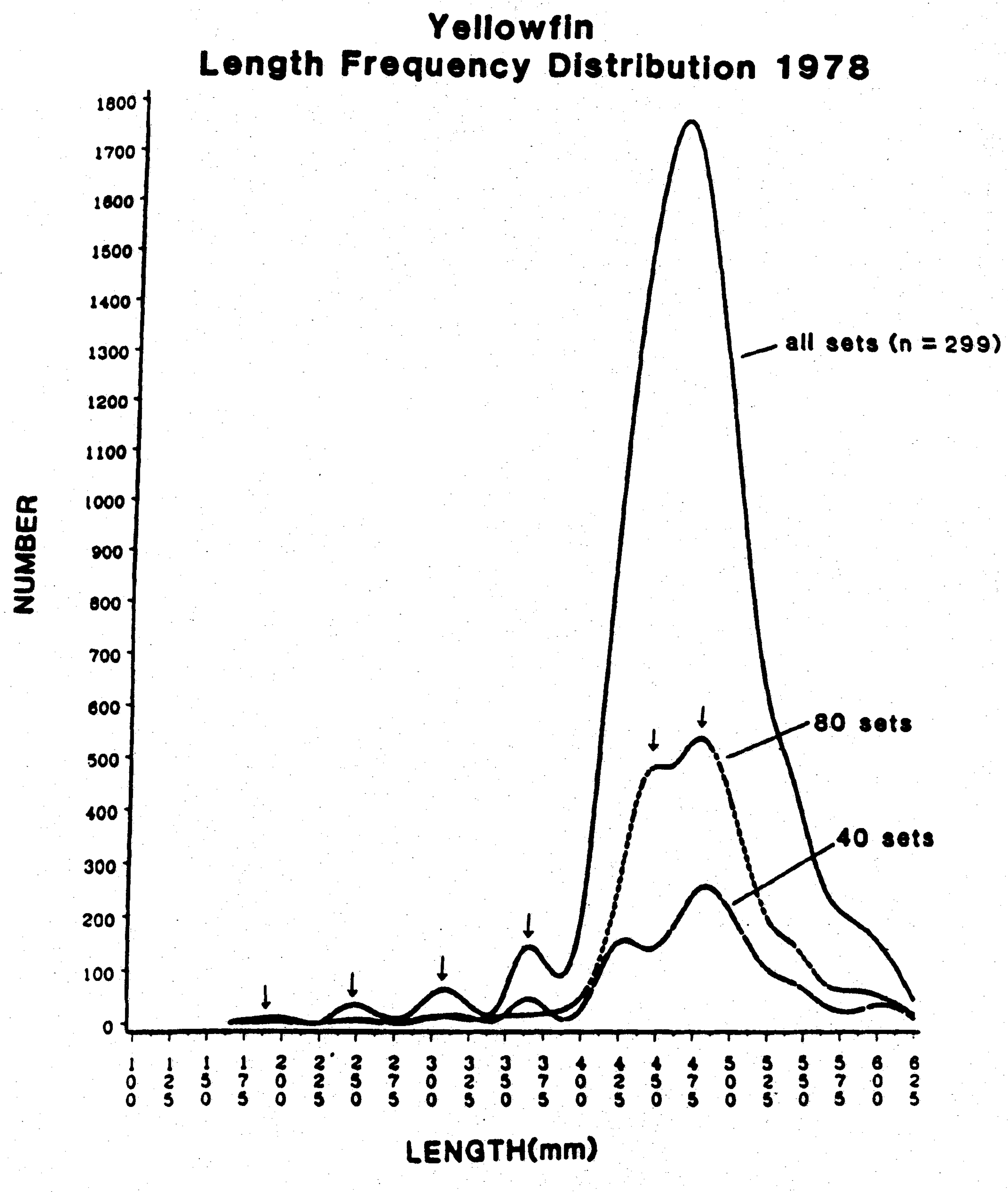


Figure 6. NMFS 1978 observer data for yellowfin tuna showing length frequency distribution for all sets, 80 randomly selected sets, and 40 randomly sets. Possible year-classes are indicated by arrows.

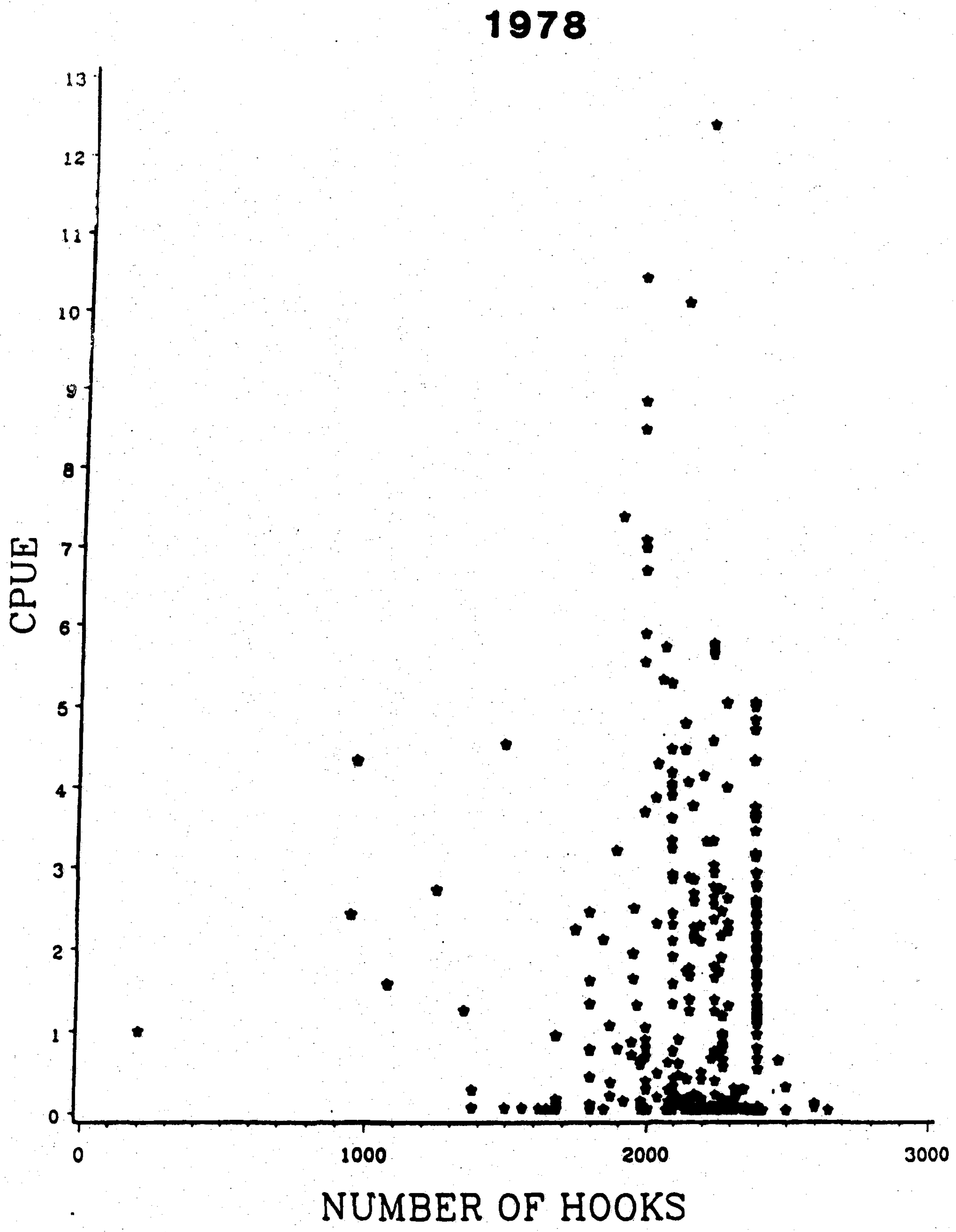


Figure 7. NMFS 1978 observer data for yellowfin tuna comparing catch per unit of effort to total number of hooks per set.

Comparing the CPUE's of different months demonstrated that blue marlin CPUE was highest during August and September in both 1978 and 1979. In addition, blue marlin catch was the highest when yellowfin tuna were the target species. Examining CPUE (trumpet diagram) within a single month when yellowfin catch rates were highest, showed that 10 to 15 sets would approximate the mean CPUE during that particular month.

Conclusions

Obviously, there are still many questions that must be asked. In designing a sampling effort for NMFS, a stratified random sampling design or weighted analysis should be considered because the effort of yellowfin tuna fishing is highest during the spring/summer months. The effort required to monitor changes in CPUE should also be evaluated. The question of how many samples would be required to measure a change in CPUE should be asked. The effect of other variables such as amount of bait, time of year, gangion length, captain's experience, area covered by drift, water temperature, or other environmental influences on CPUE should be examined.

Acknowledgments

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ENCOUNTERED DATA, STATISTICAL ECOLOGY, ENVIRONMENTAL RISK ANALYSIS, AND WEIGHTED DISTRIBUTIONS

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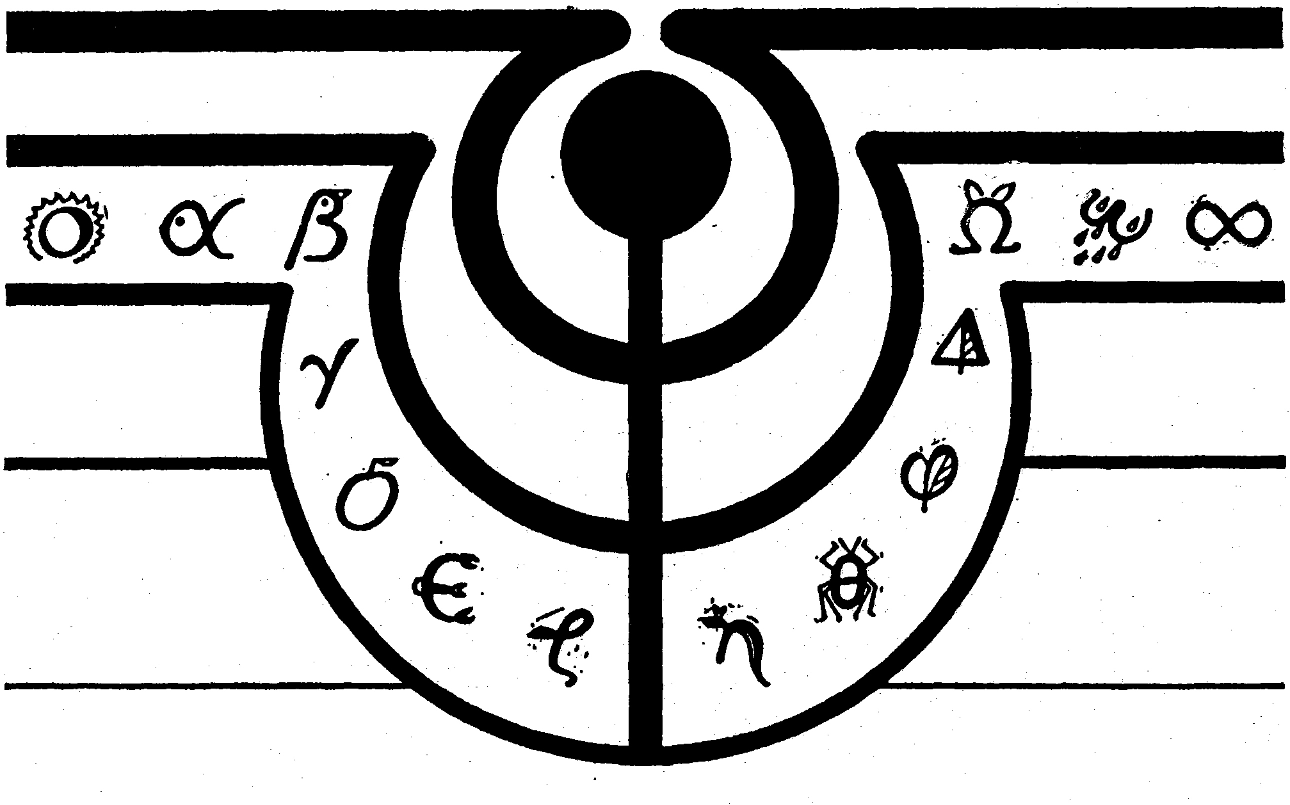
Out of necessity, many worthwhile studies lack a sampling frame for populations under study. Observational mechanisms become procedures of unknown and unequal probability sampling without a sampling frame for reasons of selection bias implicit in differential prospects of observing and recording.

There are situations where the recorded observations cannot be considered a random sample from the original population. This may be due to a variety of reasons peculiar to the substantive field of study responsible for the adopted protocols of observation making and recording. The unavoidable non-representativeness may occur because of non-observability of some events, a damage caused to an original observation resulting in a reduced value, or an adoption of a sampling procedure giving unequal chances to the units in the original. Or, it may be that the data sets are in the nature of historic data bases assembled from diverse sources of literature.

IMPROVING THE QUANTIFICATION AND COMMUNICATION OF MAN'S IMPACT ON THE ENVIRONMENT AND OF THE ENVIRONMENT ON THE MAN: MIMIC THE METHODOLOGICAL INTUITION AND THE SUBSTANTIVE INTUITION AT THE SAME TIME. INTEGRATIVE EXCELLENCE WITH INDIVIDUAL INTEGRITY IN THIS AGE OF INFORMATION FOR WHICH STATISTICS IS A KEY TECHNOLOGY



The statistical analysis and interpretation of these kinds of observational studies and encountered data raise a variety of conceptual and methodological problems before the questions involving representativeness of the sample and robustness of inferences about the true populations may be satisfactorily answered.

Weighted distributions and weighted methods arise in the context of data gathering, modeling, inferences, and computing. Topics covered may include, but are not limited to the following:

(a) The space age and stone age syndrome of data gathering and analysis in modern ecological and environmental work. The challenge of breaking into the cycle of no information, new information, and non-information while having to deal with soft data, hard looks and prudent decisions involving errors of the 'third' and the 'fourth' kind in addition to the first and the second.

(b) Mathematical and statistical concepts and methods for the modeling of univariate weight functions for encountering and selection bias.

(c) Multivariate results with applications to Bayesian inference and to sampling protocols and their effects on multivariate relations and parameters.

(d) Extraneous variation, overdispersion, double exponential family, and a generalized linear model.

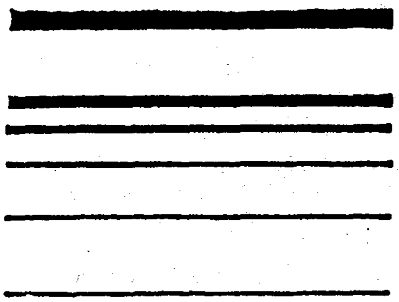
(e) Clinical investigations and length biased sampling in biomedical research; efficacy of early screening of disease, organ transplantation, and intervention.

(f) Resource utilization and management surveys; size biased sampling, ascertainment studies, and transect sampling in statistical ecology.

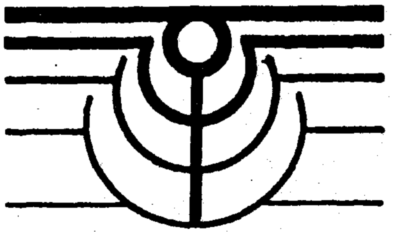
(g) Combining data and risk analysis, crystal cube for coastal and estuarine degradation, extrapolation involving errors in variables, multiple time series categorical regressions to partition fish mortality, and population dynamics subject to harvesting and recruitment distributions in fisheries.

(h) Role and need of general methodology and forum for statistical ecology and environmental statistics in statistical, ecological, and environmental societies.

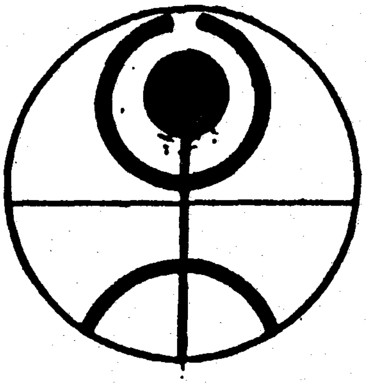
Design Development



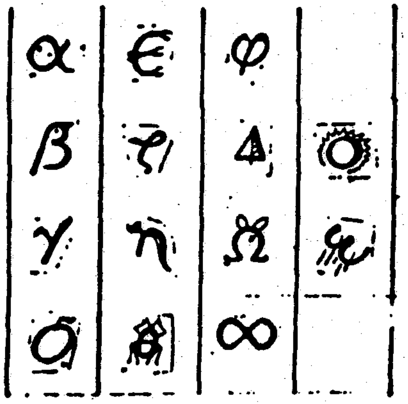
1. Cosmic atmospherical environment



2. The evolution of the earth



3. Man and his dominations on the earth



4. Illustrations of the species developed from the Greek numerical characters from Alpha to Omega and to infinity with Sun, Moon, Air, Clouds and Rain.

SYMBOL DESIGN

FOR "CENTER FOR STATISTIC ECOLOGY AND ENVIRONMENTAL STATISTICS"

Symbol Design depicts the evolution of the global situation from the cosmic order with species and man becomming an inseparable part of the total global and cosmic environmental situation.

Design Concept is Original. It has received national award at an annual competition of industrial design in India.

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NEW TECHNIQUES IN PASSIVE GEAR ASSESSMENT OF DEEP-WATER FISHES

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Introduction

Walter and I would like to thank Dr. Hernandez Avila, Ms. Bane and both the Sea Grant and SEAMAP staffs for inviting us to share our opinions on stock assessment at this Passive Gear workshop. We both have reputations for radical ideas, so you can fasten your seat belts. Although I have serious reservations about interpretations of data from baited gears, as previously expressed, I believe that some combinations of passive techniques do have great potential for incorporation into the development of a long-term sampling program for assessing reef fish populations.

In the future, successful population assessment will be achieved through a combination of imagination, firm knowledge of critical aspects of fish behavior, and application of some sophisticated electronic techniques. The use of "high-tech" passive methods in strategic areas that are determined by the natural movement patterns of a fish population could result in more rapid, more cost-effective and more accurate stock assessments than could be obtained by traditional passive methods. The location and timing of passive gear sampling might be optimized by taking advantage of fish behavior in terms of seasonal population shifts (Hayse 1987), spawning aggregations (Shapiro 1987) or foraging excursions (Collette and Talbot 1972). Obtaining information to understand specific reef fish movements and behaviors is within our research capabilities. Passive techniques rich in potential range from monitoring with remote underwater TV (Helfman 1986) to analyses of sound production by Sciaenid (Mok and Gilmore 1983) and bowhead whale (Cummings and Holliday 1985) populations.

Cross-Shelf Weir Example.

My suggestion for an ideal passive assessment technique for monitoring abundance of snapper and grouper species is the combination of a cross-shelf weir with electronic enumeration gear. In principle, only minor modification of the cross-slope weir method would be required to encompass deep-water reef fish. Directing animal and fish movements is nothing new on a small scale; ecologists use drift fences to monitor snakes, lizards and turtles, while fishermen use cross-stream weirs for salmon, and net-leads into pound nets for striped bass. Why not something larger (Fig. 1)? Now, think of the possibilities of a large part of any population moving past a given point within a limited time period, say, two to four weeks. Stationary monitoring sites could be established where needed, either temporarily or permanently, to observe, count and/or measure passing animals.

It might even work for some reef fish, if two assumptions were met. First, fish of the snapper/grouper complex would have to make some movement at least once a year (feeding, spawning, temperature avoidance, etc.). This appears contrary to some information from tagging studies (Grimes, Manooch et al. 1982), but is suggested by the disappearance of many species from nearshore reefs in winter (Hayse 1987) and by some trawl information (Miller and Richards 1980).

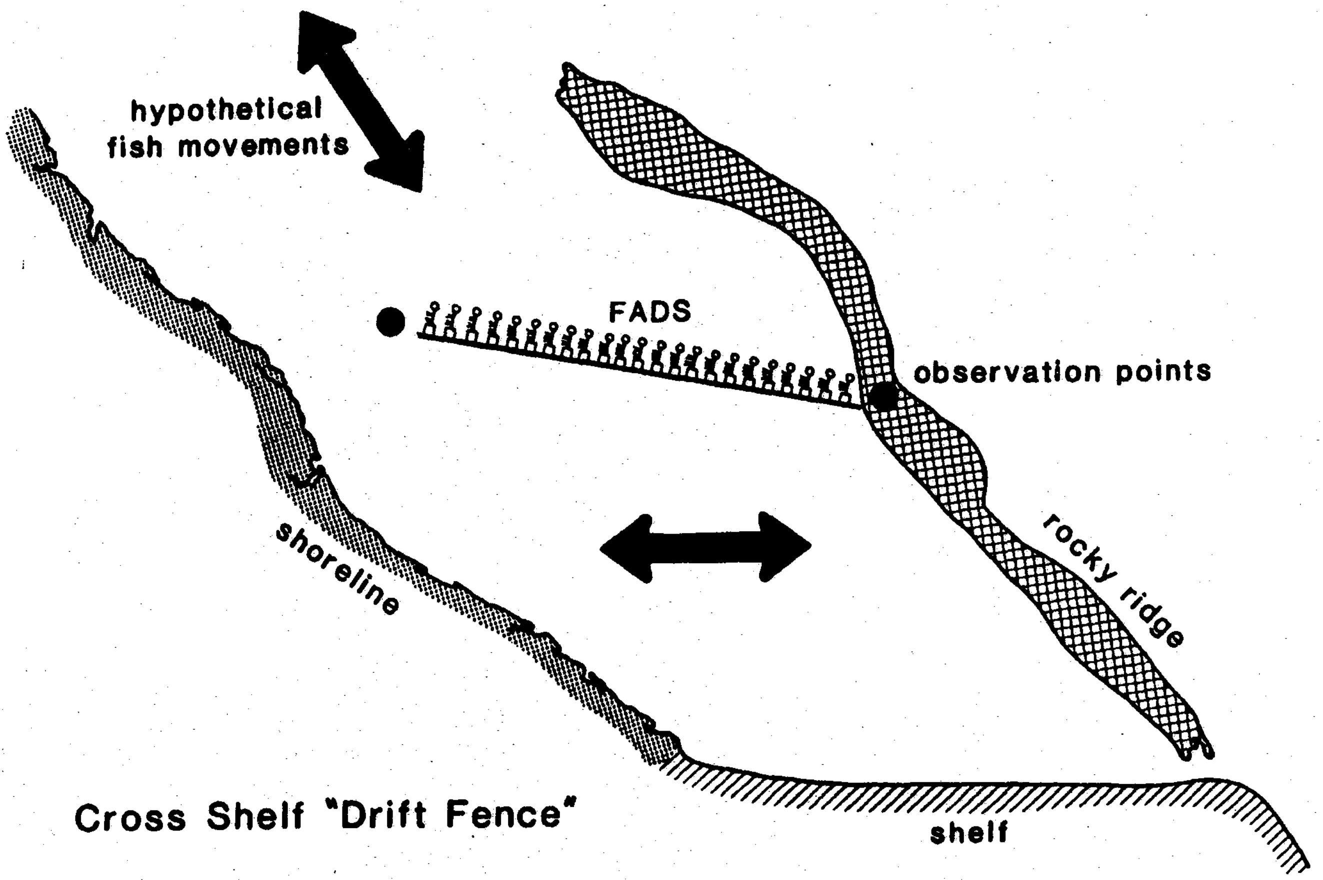

Figure 1. Cross-Shelf Weir

The second assumption is that fish attracted to a single or group of fish attraction devices (FADs) would move along a series of correctly spaced structures. Building a wall across the shelf would be expensive, if it were permanent and solid, or even if it were temporary and of bubbles (Smith 1964). Mel Bell of the South Carolina Marine Resources Division has developed inexpensive FADs which have successfully attracted pelagic and benthic species (Roundtree 1987). The total material cost was well under $1.00 each. Expanding briefly on this idea, FADs (fence posts) could be placed every 7-8 m (human visibility = 12-20 m) across the shelf at an angle great enough to promote fish following the line rather than crossing it. This spacing would require 125 FADs/km, or about 8000/ 64 km, at about $1.00 each. The total cost is a considerable investment, but in perspective, represents less than the cost of four sea-days on some research vessels, and less than one day on many others.

Now that the fish, hypothetically, are moving past a single point near the end of the FAD weir, how would they be counted? A biologist surveying salmon at a weir gate might make counts visually by using UWTV, or electronically by using an acoustic array. Both of these methods have great potential. Reef fishes were visually counted with remote UWTV many years ago (Smith and Tyler 1972), although the distance between camera and monitor was relatively short. Since then, UWTV has advanced greatly with development of reduced cable size, ROV's (Busby 1987), and remote satellite transmission. Lengths of individual fish can be accurately estimated with a parallel-beam laser system mounted on the TV camera, so that two fixed-distance reference points project onto anything viewed. Interestingly, few administrators or biologists seem to be interested in funding or developing a remote visual station. Acoustic counting systems could be incorporated to extend the range of fish intercept. Fisheries consultant firms specializing in acoustics/electronics have reliable systems presently available which may be adaptable to such an assessment need (Carlson 1982).

Other specialized systems exist, such as acoustic dopler current profilers (ADCP's), which are presently used by the National Ocean Survey to monitor current velocity in major estuarine systems and upgrade current forecasting models. High-resolution side-scann and sector-scann sonars are used by the U.S. Navy to locate relatively small objects in the water column and may have direct application in enumeration of fish. A combination of visual and acoustic sensors may produce the best assessment data (Fig. 2).

I am not suggesting that the cross-shelf weir technique is the ideal passive assessment method; it may not even work! The example was developed to demonstrate an application of high-tech passive methods to an advantageous behavioral situation, for the purpose of population assessment. Deep-water grouper, like snowy and yellowedge, might be best enumerated by a submersible during spawning aggregations, if we knew more about the time and location of spawning.

Why High-Tech?

I feel that we must increase assessment efficiency with technology. The traditional beach seine/hook-and-line assessments are labor-intensive and they have not produced many valuable quantitative population estimates. The Regional Fishery Management Councils are increasingly demanding better estimates in real time. Those of you responsible for conducting marine research are aware of increasing costs such as vessel time and manpower, but future problems with insurance/liability and over-time should mushroom. Many of these increasing costs may necessitate reducing at-sea manpower through increased efficiency. It will take some money up-front to develop the necessary

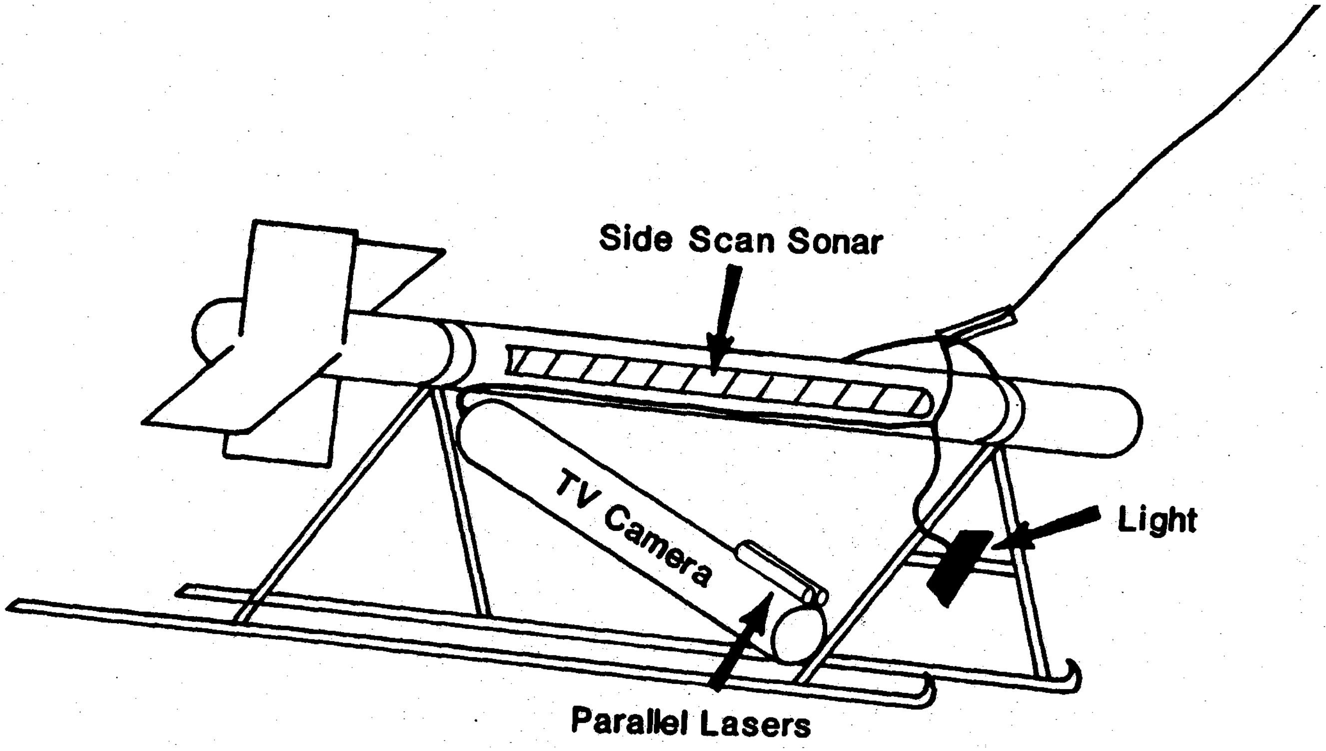

Figure 2. Visual and Acoustic Sensors combined.

technology or apply the techniques already used in other fields/industries. The need for fisheries professionals to be "open and creative" in the application of remote technology to population assessment and fisheries management has, similarly, been expressed by Thorne (1988).

It seems to me that other oceanographers, and some geologists, have for years been getting away with demands for state-of-the-art hardware to conduct their research. I think that often biologists (the "good guys") are used to backing down and compromising for the meager monies available. Maybe it is time for biologists to get their heads and money together and do one good assessment study with good equipment, producing good results with multiple applications, rather than conducting many poorly-funded studies with beach seines.

Retraining biologist-level personnel to operate UWTV's, ROV's, sidescan sonars and acoustic dopler arrays will require much thought and "due consideration" by the "old guard" administrators -- the same ones who thought word processing would not replace typewriters. If fishery-independent population assessment is going to survive, we are going to have to retrain. I do not believe biologists should necessarily understand the physics of underwater electronics or fiberoptics, but they should be able to apply modern electronic tools to get the job done more rapidly and more accurately.

I have several suggestions for those interested in application of expensive electronics equipment to fisheries investigations on a limited budget. They are:

1) Start making contacts with researchers using similar gear or techniques (maybe on a smaller scale).

2) Establish your interest and respectability.

3) Retrain yourself and/or your staff.

4) Gain experience by short-term rental, or by borrowing equipment.

5) Assure that replacement/repair costs are covered by budget or insurance.

6) Interest a large group in purchase and time-sharing of hardware; much of the gear that presently exists in the hands of the oil industry, Navy or agencies/foundations promoting marine research is not fully utilized within an annual cycle.

Fish Behavior: A Key Factor

Understanding the response of a population of fish to changes in their environment (physical and biological), or to a sampling method, can be a key factor in calibrating passive assessment techniques and, ultimately, correctly interpreting the results. Beyond efficient application of information on fish movements to sampling techniques, the immediate behavioral responses of fish to a given bait, the presence of a camera or a propagated sound can influence the effectiveness of gear type. Fishery biologists have been estimating catchability coefficients for many years, and often, gear effectiveness is a variable and elusive characteristic, quantification of which requires catch comparisons between techniques and/or direct observations of the gear/fish interactions. Although important behavioral information can be learned from analysis of temporal and spatial differences in catch, fish responses can be easily documented visually and interpreted from observations made with UWTV, ROV's, or from submersibles.

Assessment in the Real World

Now that we've indulged Charlie's vivid imagination, let's look at what is feasible, reasonable and, most importantly, might possibly be accomplished for deepwater resource assessment. The Gulf, South Atlantic, and Caribbean Fishery Management Councils are faced with the difficult task of managing fisheries over huge shelf and slope areas that are little surveyed and even less assessed. Frequently, commercial fisheries expanded, peak, and decline before long-term assessment studies can even be implemented. It's a standard rule of thumb that the number of biologists working on a resource is inversely proportional to the landings. Target commercial species such as golden tilefish, yellowedge grouper, snowy grouper, and misty grouper are slow growing, requiring 10-30 years to reach 10 kg-20 kg adult size, may require 6-15 years to reach sexual maturity, and are highly susceptible to baited fishing gears in the relatively depauperate deeper waters of the Gulf of Mexico, Atlantic off the southeastern US, and the Caribbean. Stocks of these species are easily decimated and slow to rebuild (we aren't aware of any that have rebuilt), probably never to the virgin condition exploited by southeastern bottom longline and trap fisheries over the past 20 years.

The history of fisheries independent assessment of demersal species is largely one of trawling. Many of the shelf-edge and slope commercial fishers are either mud-bottom burrowers, or live in rocky habitat, precluding the use of even roller-rigged type trawls. In the early 1980's, the Natural Marine Fisheries Services' Mississippi Laboratories initiated a series of studies over the continental shelf (>30 m, or beyond effective SCUBA range) and slope (to 600 m) to assess stocks of deepwater commercial species using various passive techniques. Objectives of these studies were to:

1. Conduct systematic cruises in the Gulf, southeastern U.S. waters, and Caribbean to determine catch-per-unit effort (CPUE) for deepwater fishes with passive fishing gears.

2. Develop time-series information on CPUE to determine trends in abundance and size structure.

3. Determine efficiency of passive sampling gears to convert CPUE data to estimates of total number and biomass.

This last item is of particular importance because the size of shelf and slope area precludes complete coverage with fishing gears, and because estimates of total number and/or biomass are necessary for the Councils to develop allowable catch levels for commercial and recreational fisheries. The general approach taken for non-trawl benthic fish was to:

1. Quantify habitat type and area. The total amount (area) of habitat by type should be quantified by first conducting visual surveys with submersibles, ROV's or over the side TV where feasible. These initial "sightings" would be used to develop descriptions of the topography, physiography, and fauna associated with each habitat type. These surveys would be limited in area, and coordinated with acoustic or side-scan sonar studies to provide ground truth to broader survey techniques. Broad-scale acoustic or side-scan sonar surveys over shelf and slope areas would then provide, with tight confidence intervals, total estimates of habitat by type, as well as, specific locations of habitat by type.

2. Evaluate sampling gears and determine efficiency. A variety of finfish sampling methodologies such as mark-recapture (with break-away tags), bottom longlines, off-bottom longlines, traps, drop lines, TV and submersible surveys should be tried to provide comparable estimates of population size within small, isolated, study sites. The objective of these site-specific studies would be to develop catchability coefficients for sampling gears. Multiple methods should be used to verify results. The catchabiltiy coefficient referred to here in the percentage of a particular species, captured by a specific unit of gear, in a limited, will-defined study site, as opposed to the classical definition of "q" as being the percentage of the total population of a species taken by a standard unit of effort.

3. Survey index areas within habitat type. The patchy distribution of deep-water habitat and varying productivity within habitat types requires subsampling on a stratified random basis with passive assessment gears to get a "true" range of estimates of population size. The critical

component of any study done for assessment purposes is the use of standardized gear and techniques. Direct comparisons between areas can be made only if gear and techniques are standardized. Time-series CPUE data are only useful if gear and techniques are standardized. Time-series or area comparison studies are a waste of money without standardized gear and techniques. The random selection of sites within habitat types, and a knowledge of the efficiency of gear by species, provide the basis for wide-area assessments.

4. Extrapolate to total areas. Once total area by habitat type is known from acoustic ar side-scan sonar surveys and density of fish is known at stratified, randomly selected within-habitat sites, estimates of total number or biomass by species are then straightforward to compute. This would, of course, only provide a one-time assessment. If reasonably effective management regulations are in place, random, rapid habitat-specific surveys conducted every 3-5 years would probably be adequate to follow trends in stock status. A preponderance of outer shelf and slope habitat falls into two general categories, rocky, occupied by deep water "reef" fishes, and broad flat areas of mud-sand mixture, occupied by burrowers where bottom consistency allows.

Approach for Softbottom or Low Profile Areas

Standard acoustic (echo sounder) equipment is not effective for determining "active habitat" for deep-water burrowers or fishes associated with low-profile reef areas. Large areas of the Gulf of Mexico form 175 m to over 400 m in depth and the south Atlantic area from 60 m to 300 m provide a suitable mixture of mud/sand to allow burrows to be maintained by golden tilefish and yellowedge grouper. Populations of galatheid crabs and other invertebrates occupy these and secondary, associated burrows, forming a forage base for these commercial fishes. There are also considerable expanses off of the Florida west coast from 100 m to 300 m, of very low profile (<1 m), widely spaced, calcareous protrusion areas frequented by yellowedge grouper. These areas are visible on a side-scan sonar, and easily missed on standard echosounders. Habitat assessments over broad areas can be done rapidly with side-scan sonar which can cover a track line of up to 100 m in width at substantial towed speeds.

Burrow areas can also be identified with side-scan sonar as was done by Able, et.al. (1987), for areas of golden tilefish concentration off of the U.S. mid-Atlantic states. Although they could not effectively count burrows or determine "fresh"from old burrow areas, they could determine areas of heave burrowing, and could rapidly map areas of suitable golden tilefish habitat. A series of one to two cruises per year, conducted over several years, should be adequate to quantity all softbottom or low profile areas on the U.S. shelf and slope. These would quantify physical characteristics only, and would be one-time surveys. Randomly selected passive gear (bottom longline) surveys should be conducted concurrently to provide estimates, with variance, of species number and biomass. Actively fishing multiple areas also provides samples for monitoring long-term changes in age structure, sex ratio, and fecundity. Index areas should be selected and revisited on a three to five year schedule to track changes in abundance over time.

An evaluation of assessment methodologies were carried out in 1984 on golden tilefish and yellowedge grouper grounds south of Galveston, Texas, utilizing the research submersible JOHNSON SEA-LINK and the FRS OREGON II. The study, reported by Matlock, et.al. (1991), concluded for golden tilefish population estimates that "longline estimates were probably more accurate [than submersible population estimates, (authors)] because errors in area estimation and double counting were evident in submersible data." They also reported that the "effective" fishing power of the bottom longlines used in their study was to remove a number of fishes from the population that, "... is equal to the length of the longline x a width of 12 m x fish density." Assuming that this is a valid relationship and can be re-confirmed through additional studies, it provides a basis for the conversion of CPUE data to estimates of species abundance.

Approach for High Profile Rock or Reef Areas

Unlike mud bottom areas, rock or reef sites on the outer shelf edge and slope are easily identifiable with modern acoustic survey equipment. Initial visual surveys for ground truth and habitat definition would require substantial vessel time, but could be accomplished with over-the-side TV, as done by the South Carolina Wildlife and Marine Resources Department on shallower continental shelf reef areas, or with limited ROV or submersible surveys at shelf edge and slope sites. Larger-area surveys to map habitat type could take the form of rapid acoustic-only surveys, as have been conducted by the NMFS Beaufort Laboratory, with total reef habitat estimated. Each subsequent acoustic survey would better define habitat area by type and reduce variance associated with the estimate. As with side-scan sonar on mud/sand areas, these surveys could be conducted over several years until southeastern deepwater high profile areas are mapped. These would be one-time only surveys, with substantial initial costs, but would not have to be repeated, and subsequent efforts could be totally expended on biological assessments.

Like soft-bottom studies, gear efficiencies would be determined through multiple techniques such as mark-recapture (in situ tagging only), submersible survey, or intensive fishing (DeLury-types regression). Once catchabiltiy coefficients are developed, deep reef fish assessment is accomplished by randomly sampling multiple within-habitat sites, and multiplying (with variance) by total habitat area. Periodic sampling to determine long-term trends can be done by randomly selecting a variety of sites every three to five years or by revisiting representative index areas periodically.

Studies to evaluate population estimation methods were carried out on the Charleston Lumps area in August, 1982, and September, 1983. (Gutherz, et.al. this proceedings). The studies were not as successful as the Texas deep-water assessment activities, but estimates of populations of several deep reef species were developed based on data from submersible surveys and intensive longline fishing. Wide variances resulted from a lack of adequate sampling intensity, especially in 1983, but submersible population estimates were generally much larger that those derived from intensive fishing. Data from the study were used to compare efficiency and operation of various fishing gears (Russell et.al., 1988).

Can Such Approaches Really Work ?

The ultimate test of any methodology is it's application in predicting results in untested situations. A broad-scale deep-water submersible and fishing survey was conducted along the island slope around Puerto Rico and the U.S. Virgin Islands in October, 1985, providing an opportunity to test findings make in U.S. deep-water assessment studies. Densities of deep-water groupers and snappers around Puerto Rico and the U.S. Virgin Islands were estimated from submersible transects and point counts by depth category (300-1,500 ft.), and habitat type. Bases on the effective fishing power of bottom longlines determined during the Texas golden tilefish and yellowedge grouper assessment methodology study (length of longline x 12 m x fish density), catch rates of 4.4 commercial snappers and 0.3 commercial groupers (4.7 m total commercial fish) per 200 m groundline bottom longline set were projected. Actual fishing operations were conducted at each of 13 submersible survey sites (176 total longline sets) with average catch/set being 3.5 commercial snappers and 0.3 commercial groupers (3.8 total commercial fish per set). These results are either a successful transfer of technology from deep- water studies off of Texas to the Caribbean, or came from the great random number generator in the sky, never to be duplicated.

Reef Fish Assessment Odds and Ends

Attempting to develop methods to "quantify nature" over the years has led to a variety of failures and a few successes. Generally, assessment studies end up being "inconclusive", even after years of work. After expending great amounts of efforts, sea time, and dollars, it seems worthwhile to comment on a few things about reef fish assessment that were learned the hard way.

* Shallow reef areas are much more complicated to study than deep reefs. Longlines seldom work on shallow reefs because of excessive tangling and a high density of small bait stealers. Traps or deep lines work well for sampling larger commercial and recreational species, but species-specific catchability coefficients must be developed, especially for traps.

* Deep-water traps appear effective for deep-water shrimp off of Hawaii or Puerto Rico, or for large crabs in the Berring Sea. Deep-water fish trap sets have been consistently unproductive (except for hagfish) in the Gulf of Mexico, Atlantic off of the Southeastern U.S., and in the Caribbean.

* Deep-water in-situ tagging for mark-recapture studies sounds like a good idea, but doesn't work very well. Breakaway tag studies in 200 m off Charleston resulted in few returns from circle hooks in lips, and lots of tag returns from various places along the alimentary canal. One blueline tilefish stomach contained 6 tags. Efforts to clip the gangion on hooked groupers with shears from a submersible were also unsuccessful (the fish wouldn't hold still).

* Fishery independent sampling of highly mobile, schooling reef fishes such as red snapper and amberjack may simply be unrealistic. Few "reef" fishes occupy different habitats at different life stages that leave them vulnerable to systematic sampling. Red snapper is an exception, with trawl-caught indices of juvenile abundance dating back to 1972. Assessing populations of adult pelagic reef species is much cheaper and more easily done by sampling recreational fisheries as has the NMFS Beaufort Laboratory since 1972, or sampling commercial fishing vessels at the dock.

* Keeping it simple is important in conducting at-sea assessment studies. Bad weather, gear problems, uncooperative fish or fisherman will always consume large portions of available time. Plan for overkill of cruise objectives. It is difficult to get too much data.

* Large area studies and ultimate complete habitat coverage generally require large chunks of sea time. Offshore, shelf-edge and slope studies require large, very expensive vessels. Some offshore resources may simply not be worth the expense of trying to accomplish "total biomass" assessments. Monitoring landings or periodically sampling "index" areas for CPUE trends may be adequate to determine resource trends.

* Each study brings some new information to light. Perseverance in fishery-independent assessment is necessary to slowly add to the knowledge of deep reef areas that are so difficult to study. Or, to quote A.M. Sullivan: "Depth of ocean is still the sullen foe of men who pry the damp, oppressive black. The breath of light illumes times bivouac and adds a trifle to the mite they know."

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SUMMARY OF NEEDS AND AVAILABLE TECHNIQUES

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Introduction

For almost a day and a half, we have heard about the use of passive gear for resource assessment. The speakers have been some of the world's experts in this field. This is an area where not much is known, and quite frankly many fishery biologists do not believe passive gears have much potential for assessment. Indeed, I probably would have included myself with the cynics, although now I am not so sure.

It is very appropriate that SEAMAP sponsored this workshop as each element of the program has passive gear identified for resource assessment. While the goals of SEAMAP are wide ranging, the overall goal is focused, being the collection of standardized data for long term data bases. Standardization in this context includes calibrated data. While this may at first seem relatively straightforward, the concept becomes less clear when one considers that data being collected today will have little significance unless combined with data collected with standardized sampling methods over a five to ten year period. This means that investigators concerned with long term data, and especially investigators in SEAMAP, must have the best possible information available about survey techniques when initiating a new survey activity. And, it does not hurt to have a crystal ball when making decisions about what sampling gear and tactics to use.

The goals of this workshop are to assess the status of passive sampling techniques, determine if standardization of these techniques is possible, and then to look ahead to determine future needs. Toward these ends, a number of different sampling protocols have been presented and discussed, including bottom traps, bottom longlines, pelagic longlines, entanglement gear, handlines, and visual methods. My role is to attempt to summarize the presentations and discussions, and if possible to identify any unifying principles.

SUMMARIES

Initial Selection

The workshop began appropriately with Dr. Robert Miller's paper on passive gear applications for stock assessment. Here he stressed the need to select the best possible sampling technique at the outset of a survey program and then stay with it. Investigators should avoid changing gear, but instead focus on understanding the sampling method. This same concept was emphasized by several other speakers, but qualified to some extent. Drs. James Bohnsack and Walter Nelson, for example, showed how the selectivity of some sampling gear could limit catches to a few species, thereby misrepresenting the ecosystem being surveyed. In these instances, one might have to change sampling protocols or face the problem of continuing to build a data base that does not yield a meaningful representation of the fishery. Cross calibration, of course, is always possible, but not when forced to contend with samples from a method so selective that except for a few species nothing else is caught.

The need to obtain data on all species sampled was strongly emphasized by Dr. Miller. This necessity was amplified by Dr.

Joseph Kimmel when he showed how target species had changed in the Puerto Rico trap fisheries, such that species with little to no economic value a few years ago were now desired animals. Had only the initial target species been sampled, a trap based survey program would have had limited value. Besides the need to consider all species caught, Dr. Charles Barans discussed the difficulty of handling some types of sampling gear, and how problems with gear handling and application could significantly influence the outcome of a survey program.

Overall, it was readily apparent that the initial selection of sampling gear and methods should be of paramount concern to anyone establishing a monitoring program. This selection should minimize gear selectivity and ensure ease of handling. Once the selection is made the investigators should try to stay with the chosen method, conduct studies to understand limitations of the method, and obtain as much data as possible from the samples to maximize the usefulness of the method over time.

Bottom Traps

The sampling technology associated with bottom traps appeared further advanced than many may have realized. Traps were shown to provide an inexpensive method of sampling relatively large areas by Dr. Miller. Results appeared to be repeatable and useful for a broad range of management and research applications. However, traps also were shown to be highly selective, and this selectivity could vary by season, area, trap type, bait (type and amount), sex and stage of sexual maturity, and the animal first entering the trap. Dr. Bohnsack discussed the effect of mesh size in the trap, and Dr. Richard Appeldoorn showed how the size and type of trap funnel could significantly influence catches.

Drs. Miller and Nelson provided information which showed that bottom traps could provide consistent results, but that these results were often highly selective toward a few species. Thus, a major consideration with using traps as an assessment tool was in the initial selection of the trap design and in how the trap would be used, including handling and deployment procedures. This selection could have far reaching effects to the point that if not done correctly, and the correct procedure is not always known, the usefulness of the results could be greatly impaired.

Bottom Longlines

Similar to traps, bottom longlines were shown to provide relatively inexpensive coverage of large area. However, also similar to traps, and perhaps even more so, bottom longlines are highly selective. This selectivity appeared to be both species and size specific (i.e. selective toward the larger species and age classes). Two types of bottom longlines were discussed: standard (Dr. Nelson and Jose Manuel Grande Vidal) and off bottom or the so-called Kali poles (Dr. Barans). Bottom longlines appeared to have greatest sampling potential for deeper water areas and where bottom relief was fairly smooth (Drs. Nelson and John Merriner). They were not considered to be a particularly good tool for shallow reef areas. While Kali poles have been touted as an excellent method for sampling rough bottom areas, none of the papers supported this assertion.

The results presented by Dr. Nelson covering submersible assisted gear studies were surprisingly consistent showing that longline samples could be representative of a portion of the fish stocks (tilefish and grouper). Catchability coefficients were developed, which based on the limited results to date, appear to be repeatable. However, these coefficients were influenced by the type of gear used, deployment procedures, soak times, bait, area, and season. The area and season aspects of selectivity also were apply portrayed by Jose Manuel Grande Vidal in his review of a standardized bottom longline survey.

The general impression from discussions of bottom longline sampling methods was that this technique is not as advanced or well understood as methods relying on traps, but that bottom longlines have good potential for certain targeted species. Rough bottoms are not good areas for this technique nor should it be considered for small species.

Pelagic Longlines

Only one paper was presented on pelagic longlines as an assessment tool. Dr. Charles Wilson used data from NMFS observer coverage of the Japanese tuna longline fleet in the Gulf of Mexico to examine potentials of longline sampling for monitoring changes in tuna and billfish abundance (selected species). Of major significance was a discussion in his paper on how a major change in fishing tactics may have influenced the usefulness of commercial CPUE data for resource assessment. Fishery-independent data, on the other hand, would not have been affected showing how important survey data can be for monitoring the status of stocks.

Pelagic longlines appear to have some potential for assessment applications. However, their selectivity is not well understood and the cost of using this technique is probably fairly high. Selectivity appeared to be influenced by bait, how the gear was rigged and deployed (e.g. depth of set), and possibly soak time. Also, the thought of making 20 to 60 sets of 50 to 70 miles of longline gear to gain a representative sample is a deterrent in itself. Except for certain specific applications, this probably is not a technique that will experience broadscale application, at least in the near future mainly because of cost.

Entanglement Gear (Gill and Trammel Nets)

Gill and trammel nets are common sampling tools used at one time or another by most fishery biologists. Mr. Jose Manuel Grande Vidal provided an engineer's perspective of how the geometry of gill nets affects selectivity, considering mesh sizes and empirical catch data. His approach warrants more attention in this country.

Entanglement nets are used by virtually all state fishery management agencies, including Puerto Rico. However, while individual state agencies seem to use standardized sampling protocols, Ms. Karen Jo Foote in her summary of state and Federal passive gear activities showed that there was little to no standardization between agencies in using the gear. For example, some agencies appear to rely on a strictly passive approach when using entanglement gear; others combine the passive approach with one involving active encirclement of fish concentrations, and still others use boats to chase fish into the nets. Apparently, each set of circumstances dictate the design and tactics to be used in applying entanglement nets to fishery assessment.

A worthwhile effort would be a study of the history behind and rationale for how entanglement gear is used across the southeast region. Indeed, this study would be a precursor to any attempt to standardize data from entanglement gear. The paper by Ms. Foote is a step in this direction.

Statistical Implications

Data from any sampling procedure are useless until converted into information through statistical analysis. As Dr. G. P. Patil noted in his discussion of statistical considerations in fishery-independent assessment, however, without good data even the best statistical tool will not produce worthwhile information. A good understanding of statistics and sampling theory is essential for laying out effective sampling and monitoring programs, but the overwhelming need is to thoroughly understand the biases and errors associated with the sampling tools and protocols being used.

UNIFYING PRINCIPLES

Even though unifying principles for passive gear applications were not as obvious as some would like, a number of apparent tenets did emerge from the presentations and discussions. Most notable of these was the sharing of considerable sampling selectivity by all the passive gears. This selectivity seemed to change in accordance with a host of factors, many of which did not appear to be well understood. A major consideration for a passive gear sampling program, thus would have to be the need to conduct concurrent research to try to identify and quantify selectivity aspects of the gear and tactics being used.

Careful selection of sampling gear and procedures for a monitoring program was shown to be of paramount importance. This selection should be made based on an understanding of the need to keep gear and procedures standardized and constant over time. All aspects of the sampling protocol have to be standardized even to the quantity and type of bait used. And finally, comprehensive and complete data records need to be maintained for passive gear sampling events, including data on nontarget species.

APPENDIX 1

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