Coral Reef Research Plan

Southeast Fisheries and Science Center

National Marine and Fisheries Service

FY 2001- FY 2005

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EXECUTIVE SUMMARY

This Research Plan guides the coral reef research efforts of NMFS' Southeast Fisheries and Science Center (SEFSC) for FY 2001 thru FY 2005, and will be updated every two years. Coral reefs of the southeastern U.S. are ancient, complex and biologically diverse marine ecosystems of great social, economic and ecological importance -- and they must be preserved, restored and protected. Unfortunately, as with coral reefs elsewhere in the world, southeastern U.S. coral reefs are increasingly threatened by factors including: coastal development, overfishing and overexploitation of marine resources, marine pollution, increased terrestrial runoff associated with agriculture; habitat degradation and destruction, invasive species, diseases, bleaching and global climate change.

Successful attempts to protect and restore coral reefs must be scientifically-based and founded on research of the highest caliber. In the southeastern U.S. there are three factors that clearly delineate the level of support and commitment that should be afforded scientific research: 1) the extent of important coral reefs in the southeast – regrettably "coral reef area" continues to be underestimated, for example, estimates do not include unmapped areas in the western Keys reef track and extensive low relief hard bottom reef habitats which occur on the east and west Florida Shelves and extend as far as North Carolina; 2) ecological stresses -- when compared to other coral reef areas in the U.S., many reef areas in the southeast region a) face more stress from human activities because of intense use from large concentrated coastal populations, b) coral diseases and algal competition are much more prevalent, c) coral bleaching is far more chronic, d) corals tend to be small, slow growing species that do not build reefs, e) the total species and genetic pool is much smaller resulting in less diversity and less resistance to pathogens and disease, and f) reefs appear to have greater difficulty recovering from disturbances.

SEFSC's coral reef research is conducted under a number of authorities: the Magnuson-Stevens Fishery Conservation and Management Act, as amended by the Sustainable Fisheries Act, the Endangered Species Act, and the Coral Reef Protection Executive Order (E.O.13089). SEFSC research also adheres to an *ecosystem approach* that recognizes that humans and their activities are an essential component of coral reef ecosystems. Research is additionally guided by a set of key principles including: research activities must provide critical knowledge to support NMFS' mission; SEFSC's coral reef research program must be comprehensive to meet the varied needs, interests, and priorities of NMFS clients; SEFSC must continue to build strong federal and non-federal research partnerships; and a continued commitment to sound-science, technological advances and innovation through continual improvements and research methodology development.

SEFSC's research program to better understand and support the effective management of coral reef ecosystems is organized into the following interdependent areas: Fishing impacts on coral reefs; Coral reef recovery and restoration; Marine protected areas; Coral reef mortality and degradation; Coral reef assessment--habitat, function and biodiversity; Coral reef species research; South Florida Restoration; Monitoring; and Socio-economic Research. It is estimated that the resources required to conduct necessary research in these key areas over the next five years is $25.4M.

SEFSC's guiding principles and research philosophy when combined with its research capabilities and commitment to world-class marine research, will ensure that SEFSC continues to generate the scientific knowledge and information necessary for resource managers to ensure the sustainable use, protection and recovery of coral reefs for the Nation's benefit.

INTRODUCTION

This Research Plan guides the coral reef research efforts of NMFS' Southeast Fisheries and Science Center (SEFSC) for FY 2001 thru FY 2005. Coral reefs are ancient, complex and biologically diverse marine ecosystems that are of significant social, economic and ecological importance. Coral reefs continue to be assailed by an array of factors: pollution, habitat degradation and destruction, over-exploitation, invasive species, diseases, bleaching and global climate change. The management of living marine resources, particularly commercial and recreational fisheries and protected resources, requires that 1) the impact of fishing activities on coral reefs and 2) the impact of coral reef declines on the status of fisheries and protected resources be scientifically understood. Addressing the well documented and current plight of coral reefs globally, as well as in the southeastern United States, demands that research be conducted within the framework of a "Plan" that provides a structured approach towards gaining the scientific knowledge to address the increasing declines in coral reef health. SEFSC's Research Plan builds on the expertise and capabilities of SEFSC and it's key research partners (*e.g.* academic institutions in the southeastern U.S.) and demonstrates SEFSC's commitment to sound science and providing information that will enable national and local resource managers to ensure the sustainable use, protection and recovery of coral reefs for the Nation's benefit.

This Coral Reef Research Plan provides an overview of the importance of coral reefs in the southeastern U.S. and identifies challenges and threats to these reefs. In addressing these threats, the implementation of research by SEFSC is discussed, by citing pertinent authorities, a set of guiding principles and the ecosystem approach to coral reef research adopted by SEFSC. Research efforts are organized into the following areas: fishing impacts; coral reef recovery and restoration; marine protected areas; coral reef mortality and degradation; assessment of coral reefs-habitat, function and biodiversity; coral reef species research; South Florida restoration; monitoring; and socio-economic research. For each research area, resource needs for FY 2001 thru FY 2005 are identified and core projects that currently constitute the main thrust of SEFSC's coral reef research efforts are briefly discussed.

THE IMPORTANCE OF CORAL REEFS IN THE SOUTHEASTERN U.S.

Coral reefs of the southeastern U.S are an invaluable coastal ecosystem to be preserved, restored and protected for a variety of important reasons, including the following:

Habitat Importance

- Coral reefs provide essential fish habitat for ecologically and economically important fisheries and support exceptional biological diversity and marine mammals and turtles. Additionally, coral reef support endangered and threatened species -- endangered and threatened sea turtles, especially hawksbill and green sea turtles use coral reefs as habitat along with the Nassau grouper, jewfish, speckled hind and Warsaw grouper (candidate species for the U.S. Endangered and Threatened Species List).

- Coral reef habitat value has been estimated at $2,833 per $m^{2,}$ based on damage assessments used in Pennekamp Coral Reef State Park. Using this figure, the Florida Keys National Marine Sanctuary alone is worth $2.8 billion dollars based on it's 325 km^2 of coral reefs (Causey and Delaney, 2000). This figure does not include other reef areas of southern Florida in the Dry Tortugas National Park and Biscayne National Park. Reefs in the U.S. Virgin Islands and Puerto Rico are also worth billions of dollars. Puerto Rico, for example, reports 3,370 km^2 of coral reefs within 3 km of the coast (DNER 2000), second only to Hawaii. Also, most previous tabulations of corals have ignored low relief hard bottom reefs that extend from Texas around to North Carolina -- habitats that have corals and support productive fishery resources.

Biological Importance

- Coral reefs have the highest biological diversity in the marine environment and have been described as the "rain forests of the sea." No other habitat on Earth has such a high density of vertebrates as a coral reef. Reefs cover 0.2% of the ocean's area and yet they provide home to one-third of all marine fish species and tens of thousands of other species. The number and density of species using coral reefs is extremely high and much of the reef taxa have not been described or inventoried. Starck (1968) listed over 389 reef fish species from the Florida Keys alone. Additional species exist in the U.S. Virgin Islands and Puerto Rico.

Fisheries

- Florida's Monroe County, which includes the Florida Keys, has nearly all of the classically defined coral reefs in the continental U.S. and despite its small area, accounts for over a third of all commercial reef fish landings between Key West Florida and the Virginia -North Carolina border (Johnson and Hardy, 1999).

- In the 1990s, Monroe county accounted for about 20 million pounds of total commercial fishery landings, or nearly 20 percent of the statewide total for the 12 economically important species (Adams, 1992). The total 1990 commercial value was $64 million which generated economic activity of $90.4 million, earnings of $32.2 million and employment of 2,230 FTEs (Adams, 1992). The recreational fishery in the Florida Keys is estimated to provide an additional $500 million to the economy.

- Economically and culturally important fisheries of the U.S. Virgin Islands and Puerto Rico (specifically-- reef fish, conch, lobster and corals) are completely dependent on reef habitats.

- Spiny lobster, a reef associated species, supports important commercial and recreational fisheries in the southeast which had a recent ex-vessel commercial value in Florida of $30 million (DOC 1999).

- Pink shrimp, a major economically and ecologically important species, depends on coral reef associated rubble habitats for juvenile stages of their life cycle.

- On U.S. reefs, over 500 commercially valuable coral reef fishes and invertebrates are under federal management, including six candidate ESA species in the southeast, two of which are corals.

Land Building and Coastal Protection

- Coral reefs help to build land mass in tropical environments, provide beach sand and offer protection to coastlines from hurricanes, storm erosion and flooding by reducing wave action.

Tourism

- Globally, travel and tourism is growing at 10% per year and in 1997 represented approximately $5.5 trillion in total economic value, from which coral reefs are a major attraction (Hawkins 1998). Coral reefs are the major marine tourist attraction in the southeast: in the Florida Keys alone, coral reefs are credited with generating $1.2 billion in tourism revenue each year from 4 million annual visitors (English et. al, 1996).

Non-extractive Recreation

- Coral reefs are valuable for non-extractive recreational activities such as diving and snorkeling, photography and cultural enjoyment. These activities also contribute greatly to the economy.

Pharmaceuticals and Industrial Products

- Reefs provide valuable pharmaceuticals used to prevent and treat diseases such as cancer. Also, corals are being used for human bone replacement.

Public Education and Awareness of Marine Ecosystems

- Coral reefs with their clear, warm, shallow waters and high density of marine organisms, are ideal places for primary and secondary marine education about marine ecosystem structure and function. Few places, even on land, offer such ideal places for learning about species behavior and interactions. The benefits of coral reef management become readily apparent to visitors.

Research Laboratories

- Coral reefs because of their high level of ecological complexity, are ideal laboratories for pure and applied research on marine ecosystem structure and function – research with very important contributions to effective management and conservation.

THE STATE OF CORAL REEFS WORLDWIDE

The 1998 Reefs at Risk report (Bryant et al., 1998) estimated that 58% of the world's coral reefs are threatened by human activity, including coastal development, destructive and over-fishing practices, overexploitation of marine resources, marine pollution, and increased terrestrial runoff associated with agriculture and deforestation. These impacts are being exacerbated by natural events such as coral disease, crown-of thorns sea star outbreaks, and tropical storms and hurricanes (Global Coral Reef Monitoring Network, 1998). Additionally, corals are threatened globally by elevated sea water temperatures and increased CO2 concentrations due to greenhouse gas emissions. In 1998, this caused the most geographically extensive and severe coral reef bleaching event in recorded history occurred, with subsequent mortality affecting 70-80 % of all shallow-water corals on many Indo-Pacific reefs. Reef Check surveys conducted in 1997 and 1998 found that most reefs are severely overfished and most high value organisms such as grouper, lobster and giant clams are missing (Hodgson, 1999). It has been estimated that at least 1,200 marine species may have become extinct in the last few hundred years -- mostly unknown species that inhabit coral reefs (Malakoff 1995). Wilkinson (2000) estimated that the world has lost 11% of coral reefs and a further 16% are not fully functional. For a recent assessment of the status of U.S. coral reefs see NOAA's online State of the Coast Report.

CHALLENGES AND THREATS TO SOUTHEAST CORAL REEFS

SEFSC's Research Plan must reflect the challenges and threats facing Coral reefs in the southeastern United States. In addition to SEFSC's legislative mandates (*e.g.* MSFCMA/SFA/ESA/E.O.13089) and SEFSC's scientific expertise/capabilities (**See Appendix A**), there are three criteria that clearly delineate the level of support and commitment that should be afforded research in the SE: the extent of coral reefs in the southeastern U.S.; the general ecological characteristics and stresses faced by SE corals; and the specific threats and pressures being placed upon coral reefs of the southeast.

The Extent of Coral Reefs in the Southeastern U.S. Greatly Underestimated

- A common misperception is that 85% of all U.S. coral reefs occur in Hawaii while the Florida Keys, Puerto Rico and U.S. Virgin Islands combined, account for only 6%. Florida's estimates were based on classic definitions of "emergent coral reefs" which are limited to southern Florida and the Florida Keys, where reefs were thought to be well-documented. It did not include unmapped areas in the western Keys reef track and extensive low relief hard bottom reef habitats which occur on the east and west Florida Shelves and extend as far as North Carolina. The Florida's Oculina coral reefs, for example, were not included. Reefs in approximately 40% of the Florida Keys reef track (using classic definitions) have not been mapped, especially west of Key West. Additionally, the southeast also has extensive deep reef habitats (deeper than 20m) that have not been mapped. Because of a lack of detailed information on Hawaiian reefs, crude estimates (relying on total bottom area in depth ranges that potentially could have coral growth, especially in the NW Hawaiian islands, which accounts for 81% of Hawaii's reefs) were derived, that greatly exceeded actual coral cover because much of the substrate is probably unsuitable for coral growth and much of the hard bottom was probably lava flows without coral. Furthermore, lava with attached corals are not considered "coral reefs" by classic definitions. Thus, the importance of coral in the SE continues to be underestimated and Hawaii's inflated.

Ecological Stresses

- Coral reefs in the southeast region are subjected to greater stress than anywhere else in the U.S. Human impacts tend to be much greater because of intense use from large, concentrated, coastal human populations. Fishing and tourism activities are especially intense throughout the southeastern U.S. and Caribbean, particularly when compared to many remote reef areas of the Pacific.

- Land runoff and coastal pollution problems introduce sediments, pesticides, sewage, fertilizers, and heavy metals into coral habitats, particularly where large populations are centered close to reefs. Even the agricultural runoff from the Mississippi and iron rich dust and fungi spores from Africa have been implicated in coral stress.

- Vessel groundings, anchor damage, and tourism impacts are also more prevalent because of the high density of human activity in the southeast.

- Coral disease are much more prevalent in the Caribbean. Over ten coral diseases are believed to exist in the Caribbean -- pathogens have been positively identified for three of these diseases (Richardson 1998).

- Algal competition and overgrowth are considered much more important on western Atlantic coral reefs because of the loss of top predators and grazers such as Diadema.

- Coral bleaching is far more chronic in the Caribbean although acute episodes have occurred both in the Pacific and Caribbean. During a 1990 event, for example, approximately 65% of the *Millepora* corals died at Looe Key Reef.

- Invasive, and possibly exotic, algal species have smothered reefs off Palm Beach during sporadic outbreaks in the Florida Keys.

- Biogeographic differences in the species suite of corals in the Caribbean and Indo-Pacific basins mean that Caribbean reefs are less resilient to disturbance and degradation (Smith 1992). The Indo-Pacific has many species of fast-growing branching corals that recruit very successfully and are effective reef-builders that recover fairly well from disturbances. The Caribbean has only two such species, *Acropora palmata* and *Acropora cervicornis*, both of which have been named Candidate species under ESA, because of drastic regional declines. Coral species that recruit effectively in the Caribbean, unfortunately, are small species that do not build reefs effectively. Thus, even if ecological stresses in the two regions were similar, the threat to Caribbean reefs would be greater due to biogeographic differences in coral life histories and community structure.

- The total species pool in the Caribbean is much smaller than in the Pacific, furthermore, smaller total population sizes in the Caribbean means that there is less genetic diversity and hence, less resistance to pathogens and disease, than among larger populations, such as those found in the Pacific.

- Fluctuations in sea level appear to have had more historical impacts in the Caribbean than in the Pacific, because of factors such as developmental encroachment on coastal reef systems.

Specific Threats and Pressures:

- Specific anthropogenic threats to coral reefs in the southeast are fishing, excess nutrients, turbidity, pollution, and groundings and anchoring from boating (Ginsburg 1994; Rogers 1985; Department of Commerce,1996).

- Fishing can reduce fishery productivity and alter reef structure and function by: removing targeted organisms; killing unwanted organisms through bycatch mortality; and damaging habitat. The removal of top predators can disrupt the food web leading to excessive coral mortality from grazing organisms that have been released from predation controls (McClanahan and Muthiga, 1988). Detrimental fishing impacts have been well documented for reefs in Florida (Bohnsack et al. 1994; Ault et al. 1998), Virgin Islands (Jeffrey and Jennings, 1998) and other Caribbean reefs.

- Other fishing effects are also important: impacts of fishing gear on habitat are for the most part un-researched, and are a major concern (Hamilton et al., 2000); impacts of selective fishing practices on fish population genetics are strongly suspected of having detrimental impacts (PDT 1990, Bohnsack 1999) on the sustainability of reef structures and the population structure of reef fishes.

- The extent of overfishing in the southeastern U.S. (Table 1.), reflects the magnitude of fishing impact on coral reefs.

Jurisdiction	No. of Stocks Managed	Overfished	Not Overfished	Approaching Overfished	Unknown
SAFMC	86	15	0	0	71
GMFMC	61	4	6	2	49
CFMC	179	3	1	0	175
GMFMC/SAFMC	10	1	0	0	9
ASMFC	7	2	2	1	2
GSMFC	2	0	1	0	1
TOTAL	**345**	**25**	**10**	**3**	**307**

Table 1. Status of assessed species in the Southeastern US in 1999 (NMFS, 1999).

- Coastal development in Florida, Puerto Rico, and the U.S. Virgin Islands results in the loss of mangroves, increased vessel traffic, greater sediment runoff and nutrient loading in coastal waters, all of which severely stress coral reefs (Rogers et al., 2000). Puerto Rico, for example, has one of the highest human population densities in the world at 397/km^2.

- The almost complete loss of the sea urchin, *Diadema*, in the Caribbean in 1983 (Lessios 1988) greatly altered the grazing activity on coral reefs that resulted in shifts from coral to algal dominated reefs.

- Disruption of ecosystem structure and function has resulted in a lack of coral recruitment and reductions in survival of young corals. Major reef building corals have died extensively throughout the Caribbean over the last two decades (Hughes 1994, Jackson 1997; Rogers 2000). Coral cover for *Acropora palmata*, the major Caribbean reef building coral, dropped from 85% at Buck Island, US Virgin Islands to 5% in 1988 (Rogers 2000).

- Numerous new coral disease epidemics have occurred that have greatly damaged reefs including white-band disease (Aronson and Precht 2000a), and black-band disease (Antonius 1981). Widespread disease epidemics that have destroyed over 50% of the dominant coral reef building species throughout the Caribbean (Hughes 1994; Jackson 1997; Rogers 2000). Declines in the health of Caribbean coral reefs may be the result of increased exposure to pathogens and invasive foreign organisms brought into the Caribbean from shipping traffic (Bauer 1987).

- Fish disease outbreaks that resemble *Brooklynella* have caused widespread fish kills in the Caribbean in 1990, 1997, 1998 and 2000 (Causey and Delaney 2000).

- Human pressures combined with natural disturbances from hurricanes, storms, U/V exposure, and temperature changes can result in detrimental synergistic impacts on coral reefs (Knowlton 1992; Knowlton et al. 1990; Steneck 1994). Hurricane activity can be intense and repeated -- since 1979, eight damaging hurricanes have passed over the USVI (Rogers 2000). Extensive coral mortality in Florida has also been caused by warm and cold water stress (Porter et al., 1982). Dustan et al. (1999) reported 16.4% overall coral loss at nine sites between 1996 and 1998. Global warming, sea level rise, and increased ultra violet light exposure, possibly due to indirect human activities are also of concern (Hoegh-Guldberg, O. 1999).

RESEARCH IMPLEMENTATION

SEFSC's is committed to maintaining world-class marine research and expanding our abilities to generate scientific knowledge and information that will enable resource managers to ensure the sustainable use, protection and recovery of coral reefs for the Nation's benefit. SEFSC has a history of achieving coral reef research excellence (**see Appendix B**). SEFSC's coral reef research is conducted under legislative mandates, and is guided by principles and approaches that are currently being brought to bear on the priority research areas discussed below. The resource needs for the each research area for FY 2001 thru FY 2005 are also summarized below.

Applicable Authorities

SEFSC's coral reef research is conducted under the following authorities: *The Magnuson-Stevens Fishery Conservation and Management Act*, as amended by the *Sustainable Fisheries Act*, the *Endangered Species Act*, and the *Coral Reef Protection Executive Order* (13089) to preserve and protect the biodiversity, health, heritage, and ecological, social, and economic values of U.S. coral reef ecosystems and the marine environment.

Guiding Principles

In conducting coral reef research, SEFSC subscribes to the following principles:

1. Research activities must provide critical knowledge to support NMFS' mission.

2. SEFSC's coral reef research program must be comprehensive to meet the varied needs, interests, and priorities of its NMFS clients.

3. A strong commitment is needed to sound-science, technological advances and innovation through continual improvements and research methodology development.

4. SEFSC will continue to conduct quality research that is either not challenged or withstands such challenges.

5. Research must meet the standards of peer reviewers and peer-reviewed journals.

6. Research will be performed expeditiously, disseminated in a timely manner, and reported in appropriate formats for those in need of, or having interest in SEFSC's research findings.

7. SEFSC will continue to develop and establish strong scientific partnerships with other federal and non-federal research institutions

An Ecosystem Approach

Coral reef research conducted by SEFSC must rely on an *ecosystem approach*. This ecosystem-based approach recognizes that humans and their activities are an essential component of coral reef ecosystems and coral reef ecosystems include much more than the reef structure itself -- they encompass a wide range of inter-dependent biotic and abiotic features and processes. Gaining a better understanding of the complex connections and interactions of coral reef ecosystems is critical to understanding and predicting coral reef response to natural and anthropogenic stresses. Historically, coral reef research has been narrowly focused on small-scale processes on individual reefs. Coral reef issues have rarely been addressed on regional scales. For example, research has not paid sufficient attention to 1) the linkages between reefs and their associated ecosystems of mangroves and seagrasses, 2) long-term change in coral ecosystems and 3) relationships between coral reefs and remote fisheries.

Main Research Areas and Projects

SEFSC's research effort to better understand, monitor, and support the management of coral reef ecosystems is organized into the following nine areas: Fishing impacts on coral reefs; Coral reef recovery and restoration; Marine protected areas; Coral reef mortality and degradation; Coral reef assessment: habitat, function and biodiversity; Coral reef species research; South Florida Restoration; Monitoring; and Socio-economic research. These research areas, although discussed individually, are interdependent, particularly "monitoring" which is critical in all other research areas. The research activities discussed below constitute SEFSC's focus for FY 2001 thru FY 2005, and the resource needs identified do not include base funding .

Fishing Impacts on Coral Reefs

The impacts of fishing activities on coral reefs are not sufficiently understood, thereby limiting the effectiveness of efforts to prevent, mitigate or remedy fishing's adverse impacts. Key research areas include: impacts of selective fishing, genetic changes, cascade effects of removing top predators, and habitat damage of fishing gear. SEFSC plans to conduct research in the following areas:

Project: *Trophic cascade effects*. This research will test hypotheses involving the impact of removing top predators, as is often the case with fishing, and the impacts on benthic community structure of reefs.

Project: *Selective fishing impacts*. Determine the impacts of selective fishing practices on fish population genetics which ultimately determine the future health, resilience and genetic performance of important commercial and recreational species.

Project: *Selective fishing gear impacts on habitat*. Determine the impacts of fishing gears and practices on coral reef habitat. High priority fishing gears that potentially impact coral reefs include shrimp trawling; fish traps and pots, and hook-and-line fishing as identified in recent EFH SEFSC workshops (*e.g*. Hamilton, 2000).

Coral Reef Recovery and Restoration

The continued development of methods to enhance coral recovery, is a high priority to SEFSC, particularly because, in the southeastern U.S., in addition to having characteristically low growth rates, coral reefs are under intense anthropogenic and ecological pressure. For example, Coral disease and algal competition are prevalent in the Caribbean. The continued assessment of the effectiveness of restoration and recovery efforts is also necessary.

Project: *Coral reef restoration*. Evaluation of coral reef restoration structures at Elpis and Maitland grounding sites in FKNMS, and the determination of the characteristics and aspects of structure design that encourage in situ coral recruitment success.

Project: *Ecological restoration of coral reef habitats.* This project examines culturing and seeding of reef-building corals (including candidate sp. *Acropora palmata*) and sea urchins. In collaboration with academic colleagues at UNC-Wilmington and at Univ. of Miami, SEFSC is developing methods for collection, culture and settlement of broadcast-spawned coral larvae into reef restoration areas, and culture and re-introduction of the grazing sea urchin *Diadema antillarum*. Additionally, SEFSC will be pursuing collaboration with USGS and Biscayne National Park in developing coral nursery project for new and "rescued" coral colonies.

Project: *Effectiveness of restoration techniques.* This project monitors the effectiveness of coral reef restoration at the Fortuna Reef grounding site on Mona Island, Puerto Rico.

Project: *Evaluation and recovery monitoring of candidate species, Acropora palmata and A. cervicornis.* For the past 3 years, SEFSC has been monitoring *A.palmata* populations and their predatory snails, *Coralliophila abbreviata*, in the northern Florida Keys. This monitoring is ongoing and additional assessment of *A.cervicornis* recruit growth and survivorship throughout the Keys will be conducted. Genetic assessments of within-population clonal structure and between reef connectivity will also be undertaken.

Project: *Reef fish recovery***.** Evaluate the success of reef restoration efforts at Iselin grounding site at Looe Key Reef, by assessing reef fish community recovery.

Project: *Seagrass restoration***.** Analytical Comparison of natural and transplanted seagrass beds in the Gulf of Mexico to ensure the development of effective restoration techniques

Marine Protected Areas

Marine Protected Areas (MPAs) including areas protected from all fishing and other extractive activities, offer continued protection to reef biodiversity and ecosystem structure & function. There are increasing calls and scientific support for MPAs, however, much scientific work needs to be done to ensure the most effective and efficient use of MPAs. SEFSC's current focus is on characterizing the benefits and determining the most effective designs for MPAs.

Project: *No-Take Reserve impacts.* Assess the impacts of FKNMS SPAs and "ecological reserves" on reef fish populations inside and outside no-take protected areas. This is a cooperative research effort with the Marine Sanctuaries Division.

Project: *Coral reef benthic monitoring*. Level I no-take zones monitoring, of benthos in FKNMS -- Focus on assessing effects of no-take zones on algal abundance and herbivory.

Project: *Cape Canaveral No-take Reserve impacts.* Investigation of the effects of two no-take estuarine reserves at Cape Canaveral in the Merritt Island Wildlife Refuge on fish populations and surrounding fisheries.

Project: *Tortugas 2000.* An intensive effort directed at collecting baseline fish and habitat data from the Dry Tortugas National Park and the Florida Keys National Marine Sanctuary, in an effort to establish no-take marine reserves as part of the FKNMS Tortugas 2000 project.

Project: *Assessment of marine reserves.* Assessment of the following marine reserves: Hind Banks, U.S. Virgin Islands.; deep reefs of the West Florida Shelf (collaboration with Florida Statue University); gag closures on the western Florida shelf, Oculina Banks on the eastern Florida shelf, Tortugas Reserves, and Luis Pinna Reserve in Puerto Rico.

Project: *Aerial surveys.* In cooperation with the U.S. Coast Guard, aerial surveys of boat use patterns in southern Florida are being conducted to better understand how users relate to no-take zones. Sea turtle and marine mammal occurrence data will also be recorded.

Project: *Modeling the effectiveness of no-take reserves.* Development of a trophic model for Turromote Reef Platform (La Parguera, Puerto Rico) to predict changes following the closure of the area as a reserve.

Coral Reef Mortality/Degradation

Lack of scientific consensus is common regarding the roles and relative importance of nutrients, coastal modifications, chemical pollution, water quality and overfishing in impacting the health, structure and function of coral reefs. SEFSC is committed to understanding the critical factors that contribute to the decline of coral reefs, and is therefore, conducting research to determine the causes of coral mortality and habitat changes and investigate the symptoms of reef degradation.

Project: *Coral mortality*. Investigate the impacts of corallivorous snails on corals (including candidate *Acropora* spp.) in FKNMS.

Project*: Causal agents of coral reef decline.* The identification of causal agents of coral reef decline (singly and interactive), their relative importance, and possible mitigation. Agents include water quality, trophic disruption of reef communities from activities such as fishing, and natural disturbances such as climatic events (temperature extremes, storms), and coral disease.

Assessment of Coral Reefs: Habitat, Function and Biodiversity

To develop a comprehensive approach to reef management, it is important to conduct assessments of : 1) coral reef habitat (trends in distribution and quality, and biodiversity trends in abundance, species composition *etc*.) and 2) coral reef function (coral reef processes involving productivity, trophic dynamics and species interactions). Assessments will also include the status and recovery of protected and endangered marine species not addressed by turtle and marine mammal programs.

Project: *Expand fish and benthic habitat assessments***.** Expand fish and benthic habitat assessments developed in the Florida Keys to the Bahamas, U.S. Virgin Islands, Puerto Rico and live bottom habitats in the Gulf and Atlantic.

Project: *Reef and fishery research/monitoring at Navassa Island.* SEFSC personnel participated in a recent expedition (sponsored by the Center for Marine Conservation) to assess coral reef status at Navassa Island, a small, uninhabited US protectorate between Jamaica and Haiti. Results from this expedition suggest that, though artisan fishing by Haitians is ongoing, impacts to the reef fish assemblage and reef benthic community are minimal. Thus, Navassa may represent a unique opportunity to study ecological function of a largely unexploited, unimpacted Caribbean reef. There is currently no ongoing or planned monitoring or research program for Navassa Island reefs and fisheries.

Project: *Quantification of biodiversity status and functional role of cryptic reef fauna.* Cryptic reef invertebrates are extremely diverse and abundant. These animals make large and important contributions to reef function: probably as forage for larger vertebrate and invertebrate consumers (including those that are commercially important); and as agents of benthic/pelagic coupling and habitat modification. However, these components of the reef ecosystem remain largely uninvestigated.

Project: *Understand ecosystem structure and function.* Investigations will examine population dynamics and interactions between species, environmental factors, and habitat leading to a comprehensive theory of reef management. One focus will be to better assess reef quality in terms of trophic dynamics as well as assessing reef structure.

Coral Reef Species Research

Coral Reef species are essential components of "coral reef ecosystems." It is important to determine the health, life history, behavior and population characteristics of protected, ecologically and economically important coral reef species (including reef fishes, such as grouper, jewfish, Nassau grouper, corals, sponges, and algae).

Project: *Reef fish population changes -- Fishery independent visual point data recovery.* Seeks to capture historical data on reef fish abundance in the Tortugas for analysis.

Project: *Jewfish biology and management.* This research seeks to better understand the life history and ecology of jewfish: growth studies, habitat requirements, spawning and movement patters are being investigated for this protected candidate species.

Project: *Caribbean spiny lobster assessment.* Monitor spiny lobster fishery trends in Puerto Rico, Florida and the U.S. Virgin Islands.

Project: *Grouper distribution and spawning behavior.* This research seeks a greater understanding of the distribution and abundance of important predators along the Florida Keys Reef Tract. Black grouper, red grouper and gag are important fishery species that utilize the Keys' reef tract during their adult lives. Investigations include data collection on grouper habitat utilization and their spawning aggregation behavior.

South Florida Ecosystem Restoration

The South Florida Ecosystem Restoration Project will result in significant increases in freshwater flows to marine environments, thereby potentially impacting Florida's coral reef communities. Coral reefs are the ultimate downstream integrators of South Florida restoration efforts, and it is important to investigate the impacts of freshwater outflows from the Everglades on coral reefs and ensure that research results are incorporated in the formulation and implementation of restoration decisions.

Project: *Coastal impacts of South Florida Restoration efforts on LMRs*. The monitoring of reef fishes and assessing the potential impact of proposed freshwater releases into Florida Bay.

Project: *Larval reef fish recruitment into Florida Bay*. Measures, models, and predicts recruitment patterns of reef fish between adult reef habitat and Florida Bay.

Project: *Nursery habitat of reef fish species*: Florida Bay and the Ten Thousand Islands provide essential fish habitat for protected species such as jewfish and important fishery species such as gag grouper and gray snapper. Long term monitoring of the abundance of these key species will give us indications of the effects of upstream management changes on top-level predators in their nursery habitat.

Project: *Impact of freshwater flows on seagrass fauna*: Effects of increased freshwater delivery to Taylor Slough on fauna inhabiting seagrasses in receiving waters of Florida Bay.

Monitoring

Monitoring is a central aspect of SEFSC's coral reef research efforts and it is a vital component of all research areas. Monitoring includes: identifying critical factors such as bio-indicators or anthropogenic measures that should be monitored; assessing the status and trends in health of coral reefs and their components; and evaluating recovery and restoration efforts and the effectiveness of management plans. It is therefore important to collect baseline information to monitor and assess habitat and biological diversity and track the health and performance of coral reefs. However, a lack of standardized monitoring methods and protocols also makes it imperative to develop new technology and appropriate research methodologies. Listed below are criteria adopted by SEFSC in considering and selecting indicators for monitoring.

Project: *Stereo-video stock assessment***.** Develop new stereo video technology and computer software to collect accurate size and habitat data.

Project: *Global change assessment*. Global climate change through processes such as global warming is an important problem for coral reef management. The establishment of networks of no-take marine reserves in the SE offers a unique opportunity to monitor and assess global changes. Since local fishing effects are eliminated from reserves, the effects of global change are not confounded by human extractive activities. Therefore, the monitoring of reserves allow scientists to distinguish between natural and anthropogenic changes. This project will collect accurate population and habitat data that will lead to the development of models that can predict coral reef changes due to global warming.

SEFSC Criteria for Choosing Indicators of Coral Reef Health:

- *Indicators will characterize the current status and track or predict significant change in coral reef health.*
- *Indicators must be conceptually linked to the ecological function of concern (reef building capacity).*
- *Methods for measuring indicators must be technically feasible and appropriate for use in monitoring programs.*
- *Indicators must be able to distinguish extraneous factors from a true environmental signal or trends in ecological condition.*
- *Indicators must convey information on ecological condition that is meaningful to environmental decision-making.*
- *SEFSC is committed to developing evaluating and revising indicators.*

Socio-economic Research

Social and economic information is becoming increasingly important in coral reef conservation and management. This trend is consistent with the *ecosystem-based* research approach adopted by SEFSC: *human social and economic activities are indeed critical components of coral reef ecosystems*. In addition to the project discussed below, the importance given to socio-economic research by SEFSC is evidenced in publications such as "Consensus development and the use of marine reserves in the Florida Keys" (Bohnsack, 1997)

Project: *Collection of economic data from commercial trap fishers in the Caribbean*. Fish traps may contribute to habitat damage when placed or dragged over coral reefs. The collection and analysis of revenue and cost data on commercial trap fishing in Puerto Rico and the U.S. Virgin Island, will be used to inform critical regulatory decisions aimed at protecting coral reefs.

Summary of Resource Needs

Research Area	Resource Needs ($)					
	FY 01	**FY 02**	**FY 03**	**FY 04**	**FY 05**	**Total**
Fishing Impacts on Coral Reefs	250K	200K	300K	300K	400K	**1,450K**
Coral Reef Recovery and Restoration	350K	300K	400K	400K	400K	**1,850K**
Marine Protected Areas	1,000K	1,300K	1,400K	1,400K	1,600K	**6,700K**
Coral Reef Mortality/Degradation	500K	400K	400K	400K	500K	**2,200K**
Assessments of Coral Reefs	500K	600K	800K	800K	900K	**3,600K**
Coral Reef Species Research	700K	600K	700K	700K	800K	**3,500K**
South Florida Ecosystem Restoration	200K	200K	400K	400K	600K	**1,800K**
Monitoring	500K	400K	600K	600K	800K	**2,900K**
Socio-economic Research	250K	250K	250K	300K	300K	**1,350K**
Total	**4,250K**	**4,250K**	**5,250K**	**5,250K**	**6,250K**	**25,350K**

Table 2. Summary of Coral Reef Research Resource Needs (FY 2001 – FY 2005)

Appendix A -- SEFSC's Research Capabilities

The SEFSC is ideally located with easy access to much of the Caribbean with access to major marine libraries and possesses extensive computer and analytical assets. The staff has considerable coral reef experience. The SEFSC has close cooperation with the Florida Keys National Marine Sanctuary, several National Parks, the National Undersea Research Center (Aquarius site, Key Largo), the Caribbean Marine Research Center (Bahamas) and several academic institutions with coral reef research capabilities, including the University of Miami's Rosenstiel School for Marine and Atmospheric Science and NCORE; National Institute Coral Reef Institue, NCRI) at Nova Southeastern University, Florida State University, the University of Puerto Rico, and the University of the Virgin Islands.

SEFSC Staff Capabilities:

- Dr. James Bohnsack, Coral reef ecology and reef resource management. Expertise in artificial reefs, marine reserves, reef fish ecology, population dynamics, stock assessment, and experimental ecology.
- Dr. Anne Marie Eklund, artificial reefs, experimental ecology, reef fish biology, spawning behavior and ecology, jewfish recovery, habitat assessment.
- Dr. Margaret Miller, Coral reef and benthic ecology, experimental ecology, habitat assessment, algal-coral interactions, nutrients, coral reef assessments, reef restoration.
- Dr. William Richards, larval fish biology, ecology, and distribution.
- Dr. Joan Browder, South Florida Ecology, ecological modeling.
- Dr. John Lamkin, larval fish ecology and distribution.
- Stephania Bolden (graduate student/employee) Nassau grouper recovery and behavior
- David McClellan, database management, data collection, field biology.
- Douglas Harper, computer operations, field biology, data collection.
- Jack Javech, illustration, field biology, data collection.
- Jose Rivera (contractor) - Puerto Rico research coordination, side scan sonar, habitat assessment & surveys.
- R.L. Hill (reef fish ecology, reef fish fisheries, habitat dynamics and restoration, ecological modeling)
- J.G. Ditty (larval fish taxonomy and ecology and fish habitat and nursery requirements)
- P.F. Sheridan (seagrass and mangrove habitats, benthic ecology, community structure and function, coastal habitat restoration, predator-prey relations, temporal and spatial distributions of fishes and invertebrates)
- A. Hamilton (fishing effects on EFH)
- J. Lyczkowski-Shultz (larval fish distributions)
- Robert Allman (Early life history, recruitment, age and growth)
- John Brusher (Age, growth and reproduction)
- Dr. John Carlson (Shark biology and assessment)
- Alan Collins (Reproduction of reef fishes)
- Dr. Enric Cortes (Shark population biology and assessment)
- Andrew David (Reef fish recruitment dynamics)
- Douglas DeVries (Age, growth, reproduction and fishery dynamics, shape analysis)
- Nancy Evou (Age and growth of reef fish)
- Dr. Gary Fitzhugh (Ecology and life history of reef fishes and flounders)
- Linda Lombardi (Age and growth of reef fishes and sharks)
- Joe Mikulas (Age and growth of reef fish)
- Chris Palmer (Age, growth and reproduction)
- **Sustainable fisheries Branch** has a large staff that specializes in stock assessment and modeling.

Selected Partners:

- Dr. Jerry Ault, Dr. Steve Smith, Dr. Jaingang Luo, and Dr. Geoff Meester, University of Miami, coral reef fish and habitat assessment. They specialize in multispecies stock assessments and modeling.
- Dr. Steven Miller, University of North Carolina at Wilmington, coral reef habitat assessment.
- Dr. Alina Szmant, University of North Carolina at Wilmington, coral biology and nutrient dynamics of coral reefs.
- Dr. Jim Colvocoresses, Florida Fish and Wildlife Conservation Commission, habit and fish assessment.
- Dr. Richard Appeledoorn, University of Puerto Rico, conch, spiny lobster, and reef fish assessments in Puerto Rico.
- Dr. Christopher Koenig, Florida State University, grouper biology and ecology and reef fish habitat assessment.
- Dr. Mark Hixon, reef fish predation dynamics.
- Dr. Bob Cowen, University of Miami, reef fish larval fish biology and ecology.
- Dr. James Beets, Jacksonville University, red hind and reef fish assessments in USVI.
- Dr. Caroline Rogers, USGS - Jacksonville, coral reef monitoring and research.
- Ms. Ginger Garrison , Virgin Island National Park, coral reef research.
- Richard Curry, Biscayne National Park, coral reef and water quality research.
- Dr. Felicia Coleman, Florida State University, grouper biology and ecology and reef fish habitat assessment.
- Dr. Craig Dahlgren, Caribbean Marine Research Center, Bahamas, reef fish management and biology.
- Dr. John McManus, University of Miami, Director, National Center for Caribbean Coral Reef Research.

Appendix B - Recent SEFSC Publications Arranged by Coral Reef Research Areas

Fishing Impacts on Coral Reefs:

- Harper, D.E., J.A. Bohnsack and B. Lockwood. (in press) Recreational Fisheries in Biscayne National Park, Florida, 1976-1991. Mar. Fish. Rev.
- Bohnsack, J.A. 2000. A comparison of the short term impacts of no-take marine reserves and minimum size limits. Bull. Mar. Sci. 66: 615-650.
- Bohnsack, J.A., D.E. Harper and D.B. McClellan. 1994. Fisheries trends from Monroe County, Florida. Bull. Mar. Sci. 54:982-1018.
- Bohnsack, J.A. 1999. Artificial Reef Research Overview. Pages 53-59 *in* W. Horn, ed. Florida Artificial Reef Summit '98. Florida Department of Environmental Protection and Palm Beach County Department of Environmental Resources Management. Tallahassee, FL.
- Harper, D.E., J.A. Bohnsack, and D.B. McClellan. 1994. Investigation of bycatch from the wire-trap fishery in federal waters off southern Florida. Proc. Gulf Carib. Fish. Inst. 43: 3-25.
- Bohnsack, J.A. 1993. The impacts of fishing on coral reefs. Pages 201-207 in R.N. Ginsburg (compiler), Proceedings of the Colloquium on Global Aspects of Coral Reefs: Health, Hazards, and History. University of Miami, Coral Gables, Florida. June 10-11, 1993. 420 p.
- Parker, R.O., Jr., 1998. Changes in a North Carolina reef fish community after 15 years of intense fishing: Global warming implications. Trans. Am. Fish. Soc. 127: 908-920.

Coral Reef Recovery and Restoration:

- Miller, M.W. (In review). Using 'natural' reef ecology in artificial reef research: advancing artificial reef goals through attention to ecological processes. ICES Journ. Mar. Sci.
- Miller, M.W. (In press) Corallivorous snail removal: evaluation of impact on *Acropora palmata*. Coral Reefs
- Miller, M.W and J. Barimo (In press) Assessment of juvenile coral populations at two reef restoration sites in the Florida Keys National Marine Sanctuary: Indicators of success? Bull. Mar. Sci.
- Miller M.W. (in review). The importance of evaluation, experimentation, and ecological process in advancing reef restoration success. (for submission to Proceedings of the 9th International Coral Reef Symposium).
- Bohnsack, J.A., A.M. Eklund, and A.M. Szmant. 1997. Artificial reef research: Is there more than the attraction-production issue? Fisheries 22(4): 14-16.
- Bohnsack, J.A. 1996. Maintenance and recovery of fishery productivity. Chapter 11 in Tropical Reef Fisheries. N.V.C. Polunin and C.M. Roberts (eds). Chapman & Hall.
- Bohnsack, J.A. and J.S. Ault. 1996. Management strategies to conserve marine biodiversity. Oceanography 9: 73-82.
- Bohnsack, J.A. 1992. Reef resource habitat protection: The forgotten factor. R.H. Stroud (ed). Stemming the tide of coastal fish habitat loss. Mar. Rec. Fish. 14: 117-129.

Marine Protected Areas:

- Bohnsack, J., M.P. Crosby, and K.S. Geenen. 2000. Access management options. Pages 59-77 *in* Crosby, M.P., K.S. Geenen, and R. Bohne (eds.) Alternative management strategies for marine and coastal protected areas: A reference manual for their development and assessment. U.S. Man and the Biosphere Program, Washington, D.C. 168 p.

- Murray, S.N., R.F. Ambrose, J.A. Bohnsack, L.W. Botsford, M.H. Carr, G.E. Davis, P.K. Dayton, D. Gotshall, D.R. Gunderson, M.A. Hixon, J. Lubchenco, M. Mangel, A. MacCall, D.A. McArdle, J.C. Ogden, J. Roughgarden, R.M. Starr, M.J. Tegner, and M.M. Yoklavich. 1999. No-take reserve networks: protection for fishery populations and marine ecosystems. Fisheries 24(11):11-25.
- Johnson, D.R. , N.A. Funicelli, and J.A. Bohnsack. 1999. The effectiveness of an existing estuarine no-take fish sanctuary within the Kennedy Space Center, Florida. North American Journal of Fisheries Management 19(2): 436-453.
- Bohnsack, J.A. 1999. Incorporating no-take marine reserves into precautionary management and stock assessment. Pages 8-16 in V.R. Restrepo, ed. Providing scientific advice to implement the precautionary approach under the Magnuson-Stevens Fishery Conservation and Management Act. NOAA Tech. Memo NMFS-F/SPO-40.
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- Vásquez-Yeomans, L. y W. J. Richards. 1999. Variación estacional del ictioplancton de la Bahía de la Ascensión, Reserva de la Biosfera de Sian Ka'an (1990-1994). Rev. Biol. Trop., 47 (Supl. 1): 197-207.
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- Fogarty, M.J., J.A. Bohnsack, and P.K. Dayton. (in press). Marine reserves and resource management. Chapter 134. C. Sheppard (ed.). Seas at the Millinnium: An environmental evaluation. Pergamon, Elsevier Science., N.Y.
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- Appeldoorn, R.S., C.W. Recksiek, R.L. Hill, F.E. Pagán, and G.D. Dennis. (1996). Marine protected areas and reef fish movements: The role of habitat in controlling ontogenetic migrations. Proc 8th Intl Coral Reef Symp.
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- Hill, R.L. (1998). Using knowledge of microhabitat selection to maximize recruitment to marine fishery reserves. Proc Gulf Carib Fish Inst. 50: 417-426
- Hill, R.L. and J.R. García-Sais. (in press). Techniques and assessment of baseline conditions for identifying community changes associated with the Marine Fisheries Reserve in La Parguera, PR. Proc Gulf Carib Fish Inst. 47:

Coral Reef Mortality and Degradation:

- Miller M.W., E. Weil, A.M. Szmant (2000) Coral recruitment as a structuring factor for reef benthic communities in Biscayne National Park, USA. Coral Reefs 19:115-123.
- Miller M.W., M.E. Hay, S.L. Miller, D. Malone, E. Sotka, and A.M. Szmant. (1999) A new method for manipulating nutrients on coral reefs: effects of nutrients vs. herbivory on reef algae. Limnology & Oceanogr. 44:1847-1861.

Assessment of Coral Reef Habitat, Biodiversity, and Function:

- Miller M.W., A. Falace. (2000) Evaluation methods for trophic resource factors: nutrients, primary productivity and associated assemblages. Pages 95-126 *in* Seaman W (ed.) Artificial reef evaluation with application to natural marine habitats. CRC Press, Boca Raton, FL.
- Sluka R.D. and M.W. Miller. (In revision) Herbivorous fish assemblages and herbivory rates across habitats in Laamu Atoll, Republic of Maldives. Coral Reefs
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Coral Reef Species Research:

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