NOAA Technical Memorandum NMFS-SEFSC-487

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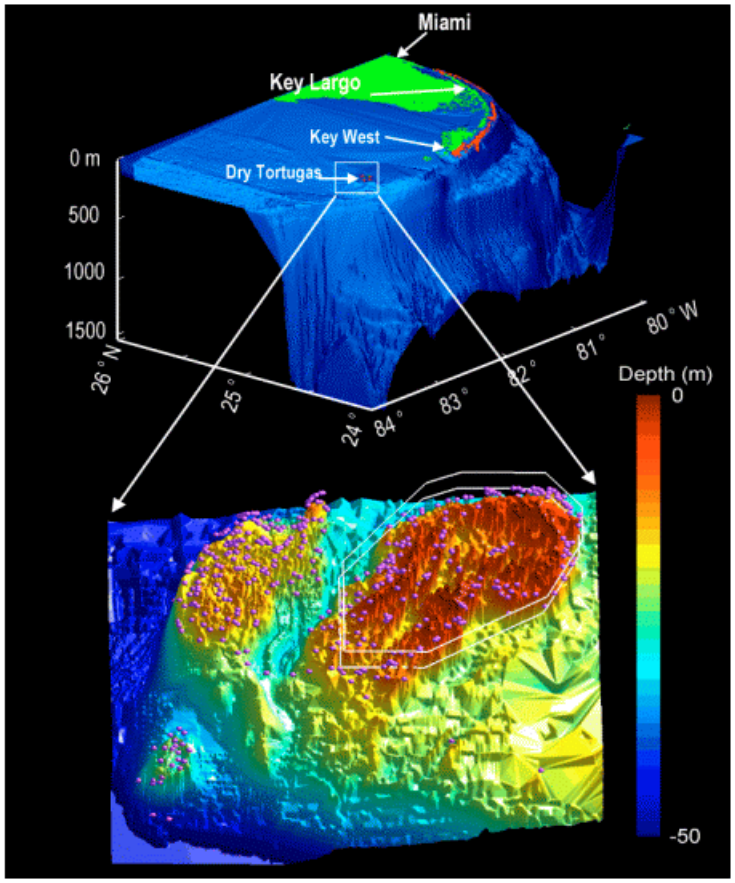

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Science Center
75 Virginia Beach Drive
Miami, Florida 33149

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August 2002

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This report should be cited as follows:

Ault, J. S., S. G. Smith, G. A. Meester, J. Luo, J. A. Bohnsack, S. L. Miller. 2002. Baseline Multispecies Coral Reef Fish Stock Assessment for Dry Tortugas. NOAA Technical Memorandum NMFS-SEFSC-487. 117 pp.

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August 2002

Executive Summary

The Tortugas region, sometimes called "Florida's Yellowstone", is located west of the Florida Keys on the southwestern Florida shelf. It includes an island archipelago in Dry Tortugas National Park; and, Tortugas Bank, Riley's Hump, and Rebecca-Isaac Shoals in the Florida Keys National Marine Sanctuary. The Marquesas lie to the east and extend to Key West. The Tortugas region is a unique tropical marine environment of national significance, renown for its productive coral reef ecosystem, diverse fisheries resources, broad fishing opportunities, and spectacular scenic beauty. The Tortugas play a critical role in regional ecosystem function and dynamics, supporting economically-important fisheries for reef fish, kingfish, mackerels, pink shrimp and spiny lobster. Because of its upstream position in the Florida Current, the Tortugas region is widely considered a principal spawning ground that repopulates waters and supports fishery production throughout the Florida Keys and south Florida, where oceanographic variability influences reef fish population recruitment.

Despite its remoteness from urban development, the Dry Tortugas are considered a fragile marine frontier potentially threatened by overfishing and habitat degradation from trawling. Our research suggests that most exploited reef fishes (e.g., groupers and snappers) are being overfished. The numbers and sizes of sought-after species are down considerably from presumed historical levels. Grouper, for example, are now approximately 5 to 10 percent of their historical spawning population sizes, a level considered serious for management. The implementation of new "no take" marine protected areas in the Tortugas (i.e., ecological reserves in Florida Keys National Marine Sanctuary and a research natural area in Dry Tortugas National Park) requires precise spatial assessments of the baseline status of reef fishery resources and coral reef habitats to assess the efficacy of these protected areas. A spatially-explicit database also is necessary to understand resource distribution, support decision making capabilities, and develop monitoring strategies to achieve multiple management objectives. Building sustainable reef fisheries, for example, requires knowing stock distribution and abundance and the ability to estimate model parameters for management forecast models. Thus, the spatial description, quantification, and understanding of the Tortugas coral reef fish ecosystem and its dynamics are critical to achieving conservation goals of sustainable fisheries and habitat protection throughout the Florida Keys.

This report details our quantitative fishery monitoring and stock assessments from data obtained during 1999 and 2000 millennial expeditions to the Dry Tortugas to assess baseline status of coral

reef fish resources and coral reef habitats in the region. A team of collaborating Federal, State and University scientists conducted synoptic fishery-independent sampling surveys throughout the Tortugas using a circular plot reef fish visual census (RVC) technique with the ultimate goal of better understanding how the Tortugas reserves contribute to fishery production throughout the Florida Keys. Our previous Keys-wide research established a state-of-the-art and cost-effective sampling strategy for obtaining precise baseline data on the multispecies coral reef fish community using visual monitoring methods. Data were acquired using sophisticated SCUBA Nitrox support vessels and RVC methodologies deployed in a two-stage stratified random sampling design. These research expeditions surveyed more than 220 fish species and dozens of different corals and sponges around the Dry Tortugas. Expeditions also led to the discovery of new and unique areas of luxuriant coral reefs, habitat richness, and isolated pockets of incredible fish abundance and habitat complexity. We also noted a distinct paucity of shark encounters and frequent occurrences of shrimp trawl damage in the region that included obliterated habitats and nets and cables draped over coral.

Using these data we developed a new quantitative multispecies fish stock assessment methodology relying primarily on fishery-independent data. This new approach is ideal for assessment purposes because the fishery-dependent statistical reporting base that forms the backbone of traditional fishery assessment and management will become substantially more restricted to non-existent as commercial and recreational fishing fleets pull out of "no take" zones. In our multispecies stock assessments, we combined population-dynamic parameters and estimates of fisheries indices with stock assessment computer algorithms to evaluate estimated current exploitation levels relative to a number of reliable fishery management benchmarks. We compared estimates of current stock biomass and fishing mortality levels to Federal and internationally used fishery management standards for sustainable fisheries. The following points summarize our findings:

- *For all of the fished species analyzed, the average sized fish within the exploited phase was very close to minimum fished sizes as compared to much larger average sizes in natural historical unexploited populations.* Many species with extremely small average lengths have shown very little change in average length even though new minimum size and bag limits were imposed in recent years. For example, the average size of black grouper is now 40% of what it was circa 1930 and the spawning stock is now less than 10% of its historical unfished maximum.

- *Overall, 40% or 14 of the 35 individual stocks that could be analyzed for the Tortugas region are overfished.* Spawning potential ratio (SPR) analysis of exploited reef fishes shows that 6 of 14 grouper species, 3 of 9 snapper species, barracuda, and 5 of 11 grunt species for which there are reliable population dynamics data were below the SPR that constitutes overfishing by Federal standards. In addition, a total of 45% of the 35 individual stocks analyzed exceeded the Federal fishing mortality target by 2 to 6 times. We found that overfishing was substantially more pronounced for Dry Tortugas National Park (DTNP) where 45%, or 13 of the 29 individual stocks that could be analyzed are overfished. A total of 62% or 18 of the 29 individual stocks analyzed exceeded the Federal fishing mortality target by 2 to 6 times. The DTNP fishery for many reef fish stocks is in worse shape than

the surrounding broader Tortugas region.

- *Increased fishing effort from growing regional fishing fleets has likely been an important factor in these declines.* The recreational fishing fleet in south Florida has grown at a near exponential rate with no limits on the number of boats allowed to fish. The number of registered boats increased 444% from 1964 to 1998. Also during that time, the estimated effective vessel "fishing power" of individual commercial and recreational boats has approximately quadrupled due to technological innovations, such as depth indicators, sonar fish finders, global positioning navigation systems, improved vessel designs, larger and more reliable motors, and improved radio communications.

- *Stock biomass is critically low for most of the targeted species within the recreational fishery.* For example, the current level of fishing mortality for grouper stocks range from 2 to 10 times the exploitation level that would achieve Maximum Sustainable Yield (MSY). These results are consistent with our Florida Keys-wide research which shows that more than 70% of these stocks are overfished, reflecting the spatial gradient of more intense exploitation around human population centers, as well as the growing fishing power of the fleets.

- *High and sustained exploitation pressures have precipitated "serial overfishing", where the largest most vulnerable species are removed first, and then moving to smaller and less desirable species as larger more vulnerable species are sequentially eliminated.* The most vulnerable species are left with too few large and mature fish to provide sufficient spawn to supply future populations. Our data indicate that some stocks have been chronically depleted since at least the late 1970's.

- *Our data suggest that the reef fish fisheries are not sustainable in the Florida Keys and Tortugas under the levels of exploitation existing prior to establishing no-take marine reserves.* Conventional single-species management approaches of placing more restrictive size and bag limits on individual species have so far failed to sufficiently protect some stocks under open access as evidenced by the fact that fisheries for goliath grouper (*Epinephelus itajara*, formerly jewfish), Nassau grouper (*Epinephelus striatus*), and queen conch (*Strombus gigas*) have been closed to all fishing for over a decade. The history of regional State and Federal Fishery Management Council actions for the Florida Keys clearly reflects the problems of trying to manage fisheries under increasing exploitation with conventional single-species management approaches. Actions have been taken only after declines had already occurred and were finally fully acknowledged. Most actions taken were minimal and not sufficient to ensure that recovery will take place.

Baseline stock assessments in this study provide insights to management actions needed to rebuild a sustainable reef fish fishery in the Tortugas and Florida Keys. Results from this research provide scientific guidance necessary to facilitate design of a long-term monitoring and assessment program to ensure sustainable fisheries and conservation of economically and ecologically important reef fish resources. A broader, more integrated strategy of monitoring, assessment and modeling

is needed for effective fishery management in the Tortugas, as well as the Florida Keys ecosystem. Such a plan should support regional fishery management efforts. Our recommendations to support such a plan follow:

- *We recommend development of a regional, ecosystem-based fishery management plan for the combined Dry Tortugas and Florida Keys coral reef ecosystem.* Such a plan acknowledges that the coral reef ecosystems cross political boundaries and that management must be coordinated and integrate expertise from various sources including State, Federal and University collaborators. Current, piecemeal reef fish and habitat monitoring programs should be reconfigured to meet stock assessment and fishery management demands by integration into an overarching statistical design. Fisheries, biological, physical and "habitat" monitoring data must be integrated effectively. Besides coral reefs, a comprehensive management strategy must link reef associated habitats, such as coastal bays, mangroves, seagrasses, and near-reef pelagic environments.

- *Improved "habitat" maps and bathymetry of the Florida Keys coral reef ecosystem are clearly required to effectively monitor and manage coral reefs and fishery resources in the Florida Keys.* Surprisingly, we still don't know where all of the coral reefs are located, much less their condition. An enhanced understanding of the physical environment could be realized by linking biological and "habitat" studies. Monitoring can refine the resolution and precision of existing habitat maps and should include directed efforts to fill in data gaps. We also recommend exploring the use of new data collection and monitoring technologies, such as hydroacoustics, airborne lasers and multispectral optics, stereo cameras and ROVs for visual census. Synoptic sampling methods meshed with finer scale studies can eventually provide necessary detail for 'real time' and cost-effective fishery forecasting. Research and management should be supported by an integrated digital information system for data visualization and management analyses.

- *Development of regional hydrodynamic physical circulation models is needed.* Such models should "connect" the Florida Keys-Dry Tortugas coral reef ecosystem and fisheries to northern Caribbean circulation dynamics. Such models can also be used to evaluate potential water quality effects of Everglades restoration on fishes and coral reefs. This effort would facilitate needed studies to improve our mechanistic understanding of the impacts of biophysical linkages on reef fish and coral habitat dynamics. Such models are critical to envisaged ecosystem modeling and management endeavors.

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Introduction

The Tortugas region, sometimes called "Florida's Yellowstone", is located west of the Florida Keys on the southwestern Florida shelf. It includes an island archipelago in Dry Tortugas National Park; and, Tortugas Bank, Riley's Hump, and Rebecca-Isaac Shoals in the Florida Keys National Marine Sanctuary. The Marquesas lie to the east and extend to Key West. The Tortugas are enveloped by tropical marine waters ranging from sea level down to about 50 m as part of a bathymetric rise on the southwestern extension of the Florida shelf (**Figure 1.1**). The Tortugas region is a unique tropical marine environment of national significance, renown for its productive coral reef ecosystem, diverse fisheries resources, broad fishing opportunities, and spectacular scenic beauty. The Tortugas play a critical role in regional ecosystem function and dynamics and support economically-important fisheries for reef fish, kingfish, mackerels, pink shrimp and spiny lobster. Because of its upstream position in the Florida Current, the Tortugas region is widely considered a principal spawning ground that repopulates waters and supports fishery production throughout the Florida Keys and south Florida, while oceanographic variability influences reef fish recruitment and abundance.

The Tortugas region probably plays a critical role in the function and dynamics of the larger regional coral reef ecosystem, supporting some of the Florida Keys' most luxuriant coral reefs and pockets of high fish abundance and diversity. The Tortugas' reef fish community is comprised of more than 220 species. Coral reef "habitats" consist of dozens of different hard- and soft-corals and sponges. The many varied inter-dependent habitats are linked by ocean circulation and life history patterns of thousands of mobile and dispersive vertebrate (fish) and invertebrate (corals, shrimp, lobster) organisms. Oceanographic features like gyres, eddys, and seasonal current reversals (Lee and Williams 1999) are important mechanisms that facilitate physical transport and dispersal of larvae to suitable downstream coastal bays and nearshore nursery habitats. These inshore areas provide habitat for many juvenile fishes and macroinvertebrates that occupy reefs as adults including barracuda, hogfish, lobsters, pink shrimp, many grunts, and most snappers and groupers. Spawning migrations, biophysical oceanographic processes, and the life histories of many key reef species help to provide critical sources of upstream biological production of essential nutrients, foods, larvae and adult biomass to downstream nursery areas and adult production zones in the Florida Keys. The Tortugas region also provides essential food resources for a host of coral reef predator-prey interactions, and supports substantial populations of migrating sea turtles, sea birds, marine mammals, and large pelagic fishes like mackerels, tunas and billfishes.

Despite its remoteness from urban development, the Dry Tortugas are considered a fragile marine frontier potentially threatened by overfishing and habitat degradation from trawling. Habitats of fish and shellfish in the Florida Keys ecosystem have been impacted and compromised by human activities. Over the last eight decades, the coastal marine environment in south Florida and the Florida Keys have undergone dramatic changes in environmental conditions due to human alteration of the natural hydrology in south Florida. These changes are now the focus of intensive efforts to restore the ecosystem by returning the hydrology to more natural conditions (Harwell et al. 1996, RESTUDY www.evergladesplan.org). The Everglades restoration includes a comprehensive effort to understand and model the physical and biological processes of Florida Bay and Biscayne Bay and their connectivity to the Keys' coral reef tract. Coastal nursery grounds will likely bear the brunt of the proposed changes in freshwater outflows

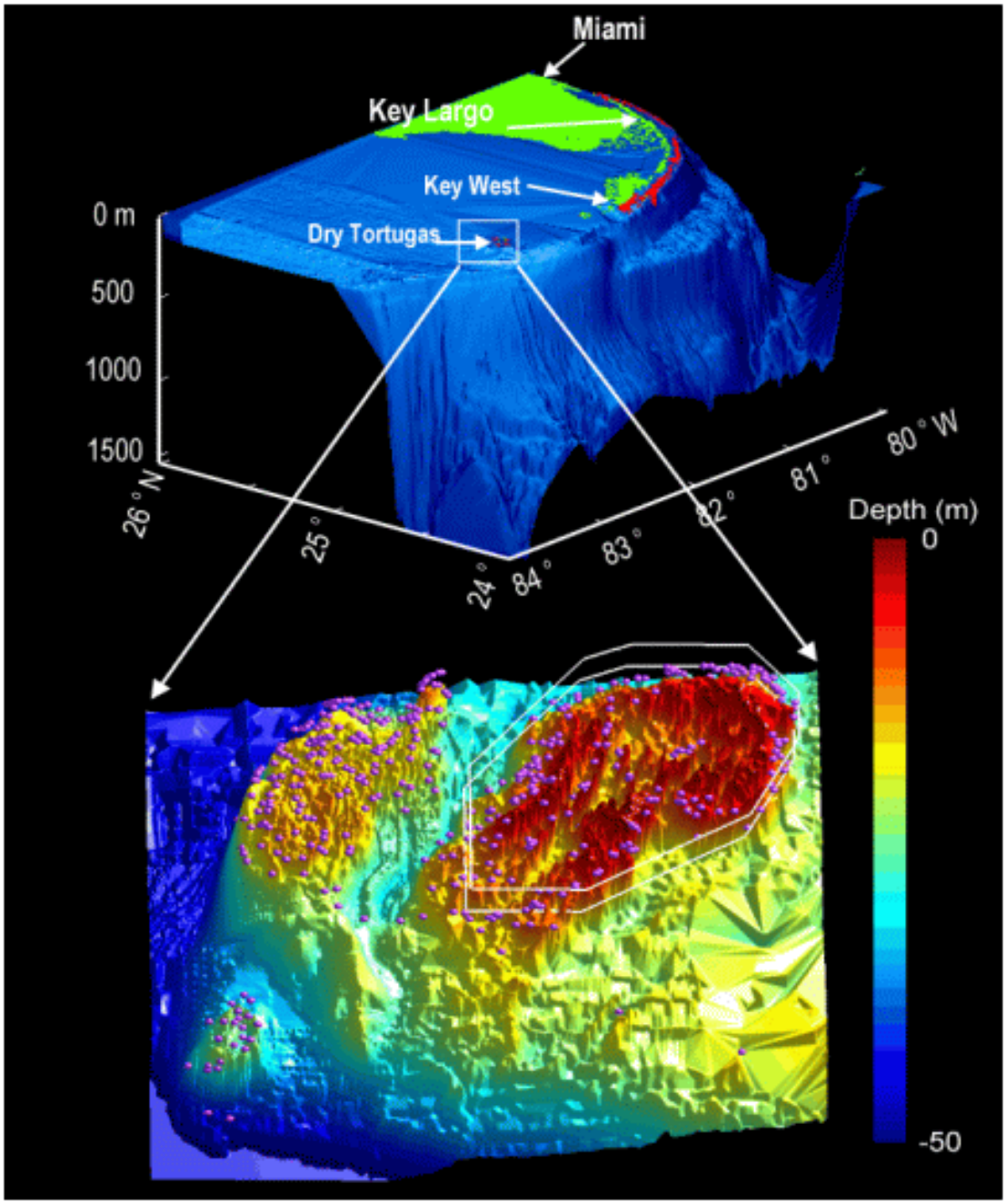


Figure 1.1 - Three-dimensional maps of the Florida Keys coral reef ecosystem showing: (A) South Florida and the coral reef tract (red) from Key Biscayne to the Dry Tortugas; and (B) the bathymetry of the Tortugas region showing Dry Tortugas National Park, Tortugas Bank and Riley's Hump where the purple balls represent primary sampling units from the millenial RVC and reef habitat surveys.

to estuarine and marine environments, but these changes will be inextricably conveyed to coral reef environments through circulation transport dynamics and the ontogenetic migrations of mature reef fishes and macroinvertebrates.

The Tortugas region also supports the multibillion dollar fishing and tourism industries in south Florida, including economically important commercial-recreational fisheries for pink shrimp, lobster, and reef fish (snapper-groupers), kingfish and Spanish mackerel. However, continued explosive regional human population growth in south Florida has raised serious concerns about the future of these precious fishery resources. Over the past several decades, public use of and conflicts over fishery resources have increased sharply, while some fishery catches from historically productive snapper and grouper stocks have declined (Bohnsack et al. 1994, Ault et al. 1998). Fishes are extremely important to monitor with precision, because in terms of the species composition, size/age structures, fishery catches and attendant economic productivity, they are of direct public concern and obvious measures of management successes (Bohnsack and Ault 1996; Ault et al. 1997a, 1998; Meester et al. 1999). Recent quantitative assessments of the Florida Keys multispecies reef fish community have shown that exploitation levels are very high, that many stocks are "overfished", and that signs of overfishing have been clearly evident since the late 1970's (Ault et al. 1997a, 1998, 2001). This suggests that the Dry Tortugas region, due to its relatively great distance from ports and attendant lower levels of fishing effort, has de facto supported the broader Florida Keys reef fishery for more than two decades with larvae and export of adult biomass. A series of management actions, begun in the early- to mid-1980s, included establishing size, season, and bag limits on a number of species. These traditional management efforts have been largely insufficient and several species have since been closed to fishing altogether including queen conch (*Strombus gigas*), Nassau grouper, and goliath grouper (formerly jewfish). The Tortugas region is increasingly being exploited despite its remote location 70 miles west of Key West.

Thus, the combination of rapidly growing human populations, overfishing, habitat degradation, and changes in regional water quality from Everglades “restoration” make the Keys region an "ecosystem-at-risk" as one of the nation's most significant, yet most stressed, marine resource regions under management of NOAA, the State of Florida, and the National Park Service (Ault et al. 1997a, 1998, 2000; Schmidt et al. 1999, NPS 2000). Recent management plans implemented by the Florida Keys National Marine Sanctuary and Dry Tortugas National Park aim to reverse declines in important fishery and coral reef resources. The most important proposal includes use of spatial protection including the establishment of 'no-take' marine protected areas or research natural areas. These have been recently implemented, but there is broader scientific and management interest in developing a better understanding of their design and ultimate performance in rebuilding fisheries and conserving marine biodiversity. In addition, as the south Florida restoration efforts proceeds, it will be essential to have effective monitoring programs and predictive models to assess ecosystem changes. Ensuring the sustained function and productivity of this unique environment through prudent use and strategic management decision making will result in substantial biological, ecological and economic benefits to the scientific, commercial fishing and public communities.

An integrated fishery management system has been proposed (Ault 1996) for managing Gulf of Mexico/Florida Keys coral reef fishery resources that is consistent with recent Federal legislation to characterize 'essential fishery habitats' in all US Fishery Management Plans (NOAA 1996). Unfortunately, definitions of 'essential' and 'habitat' vary among biologists, ecologists, and managers.

In the case of tropical coral reef fishes of economic and ecological value, these identifications are critical to the sustainability of the resources. Spawning and settlement areas of exploited tropical reef fishes (e.g., snappers, groupers) are essential fish habitats that are often spatially discrete and vulnerable to exploitation and habitat damage. Many species aggregate on deep reefs to spawn, resulting in the concentration of recruits that later settle in particular inshore habitats. Identification and protection of spatially discrete habitats that facilitate ontogenetic migrations within much broader species ranges provides clear foci for linked habitat-fisheries management. The National Park Service requires development and implementation of a management framework that sets forth the decision making philosophy and problem solving approach in National Parks to meet current and future conservation objectives that protect resources, while enhancing visitor experiences. This framework requires development of an assessment and management approach that emphasizes strategy over tactics. To accomplish the task of developing an integrated fishery management system, we viewed fisheries assessment and management from a systems science perspective (Ault 1996, Bohnsack and Ault 1996, Rothschild et al. 1996, Ault et al. 1998, Ault and Luo 1998, Bohnsack et al. 1999, Lindeman et al. 2000, Ault et al. 2000, 2001), illustrated in **Figure 1.2**. In our systems approach, the fisheries assessment and management "system" is an organized set of scientific protocols and methods designed to achieve three main goals: (1) to understand fisheries resources and habitats within the context of the aquatic ecosystem; (2) to assess the impacts of human activities and economic drivers on these resources; and (3) to analyze and evaluate the degree of success of proposed and implemented management policies in mitigating human impacts on fisheries resources. The goal of this report is to formally employ the systems science approach to assess the baseline status of multispecies fishery resources in the Dry Tortugas *circa* 2000 (**Figure 1.3**). The systems approach links the acquisition and assimilation of physical, biological and fishery databases to advanced statistical and modeling procedures to conduct multispecies stock assessments.

This report characterizes the current baseline status of the Tortugas' (i.e., for both DTNP and FKNMS) fisheries resources and associated habitats, prior to implementation of marine reserves in the region. Our study was designed to provide a baseline assessment of the multispecies coral reef fishery resources in the Dry Tortugas, and to compare that status to the broader Florida Keys ecosystem. This report also identifies priorities for more comprehensive fishery assessment and management planning for the Dry Tortugas region on issues important to DTNP and FKNMS. We hope to facilitate strategic formulation of policy alternatives that optimize conservation and use of regional fishery resources, and to help assess the likelihood a given policy will be successful in achieving NPS, FKNMS, and State of Florida natural resource management goals. Therefore, the objectives of this report are:

- To assimilate DTNP and Dry Tortugas regional resource databases, including those derived from spatially-intensive fishery-independent surveys that co-sampled fish communities and habitat resources throughout the Tortugas region based on thousands of SCUBA dives across the region using reef fish visual census and rapid reef habitat assessment methods.

- To quantify biological indicators of stock status and map critical and essential "habitats" in the region.

- To develop a sampling design and quantify survey precision.
- To provide analyses that quantify inter-relationships between fish communities and habitat parameters.
- To synthesize a suite of population dynamics parameters for multispecies stock assessments and biophysical model building required to assess reserve efficacy.
- To conduct multispecies stock assessments for key exploited fishery resources in DTNP and the Tortugas region, and to compare current estimates of exploitation to state-of-the-art fishery management benchmarks for fisheries sustainability.
- To provide guidance from a preliminary risk assessment of fishery management strategies for overfished stocks consistent with the Magnuson-Stevens Fishery Management Conservation Act and to provide input on the design and assessment of marine reserve placement and performance.

Figure 1.2 - Conceptual overview of a systems science approach to fisheries assessment and management. Dashed line indicates adaptive steps. Arrows indicate direction of impacts.

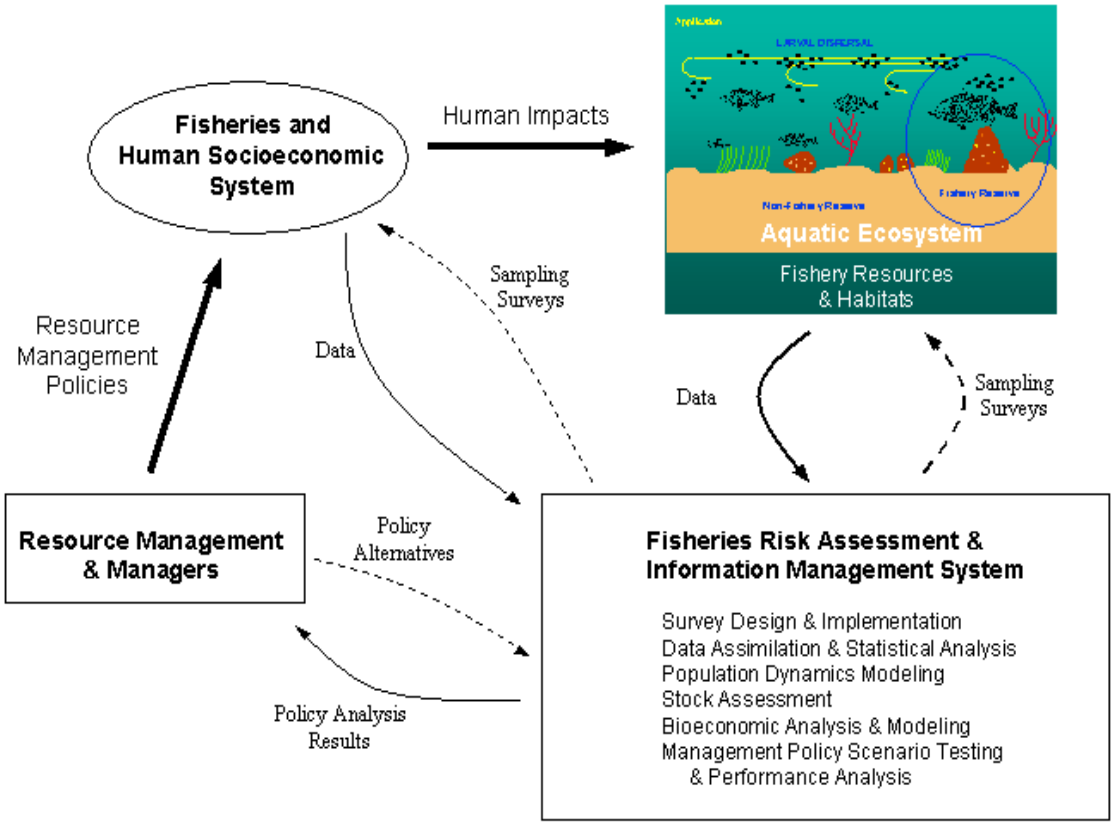
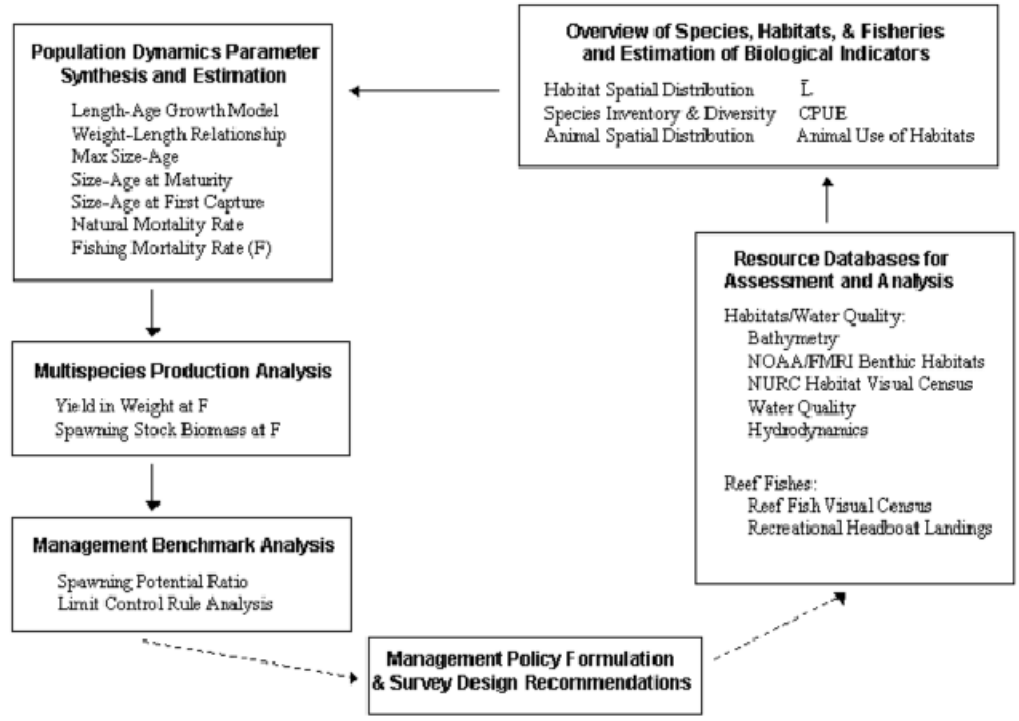


Figure 1.3 - Flow diagram of the systems science approach employed to assess Tortugas region coral reef fishery resources. Solid lines depict analyses flow of this report, while dashed lines indicate future steps in fishery management plan development.



2.0 Sampling Survey Methodology

During the summers of 1999 and 2000, we conducted a quantitative study of coral reef fish communities and their associated habitats in the Tortugas region in collaboration with a team of scientists from University of Miami RSMAS, NOAA Fisheries, University of North Carolina at Wilmington, and Florida Marine Research Institute. Our sampling strategy integrated statistical survey design principles in an innovative process linking digital computer maps (models) of "habitats" (e.g., benthic substrates, bathymetry, coral reef benthic biota), diver visual survey methodologies, and statistical associations between fishes and habitats. The survey team concurrently sampled the size-at-age structure and spatial distribution of fishes and the complexity of adjacent habitats. The survey design took full advantage of the relationship between species life history stages and density relative to "habitat" types. The basic goal of the survey mechanism was to generate precise estimates of total stock abundance, biomass and size distributions, mature stock size, and recruitment for each reef fish population in the coral reef fish community. In addition, the sampling survey provided estimates of average size of fish in the exploited phase of the stock, an indicator variable that quantifies the status of a population subjected to fishing or other environmental changes. These quantitative estimates also provided the foundation to sophisticated spatial demographic models that are fundamental to the assessment of stock/community responses to invasive use and environmental change and variability with risk profiles, and to evaluation of the

efficacy of proposed spatial management alternatives (e.g., Ault et al. 2000). This unique dataset establishes a baseline that directs decadal-term monitoring and assessment efforts and facilitates future comparative studies of these critical resources.

2.1 Overview of Sampling Design and Diving Operations

Our spatially-intensive study employed a two stage stratified random survey design to optimize sampling effort and to choose sampling locations, and is illustrated for DTNP in **Figure 2.1.** The Tortugas region sampling domain was partitioned into unique "habitat" strata based on geographical location and benthic habitat characteristics. The process of delineating habitat-based sampling strata is described in section 2.4. The sampling domain was overlain in a Geographical Information System (GIS) with a grid of 200 x 200 m cells which are the primary sample units. Each cell that contained reef habitat was assigned a unique number and randomly selected for sampling from a discrete uniform probability distribution to ensure that each primary unit had equal selection probability. Second stage sample units, i.e., diver visual census locations, were then randomly positioned on appropriate habitat within each primary unit. For the fish survey (described in section 2.3), there are 226 non-overlapping possible 7.5 m radius fish sampling stations within a given primary sample unit. Two second stage units were sampled in each primary unit. Because of concerns about autocorrelation and safe diving practices, each fish sampling station (i.e., second stage unit) consisted of the average of combined stationary point estimates from two individual divers (i.e., a "buddy pair"). In **Figure 2.2**, each orange circle denotes a primary unit sampling location where four scientific divers were deployed and conducted a reef fish visual census sample. For the benthic habitat survey (described in section 2.2), four second stage units were sampled within each primary unit (**Figure 2.1**).

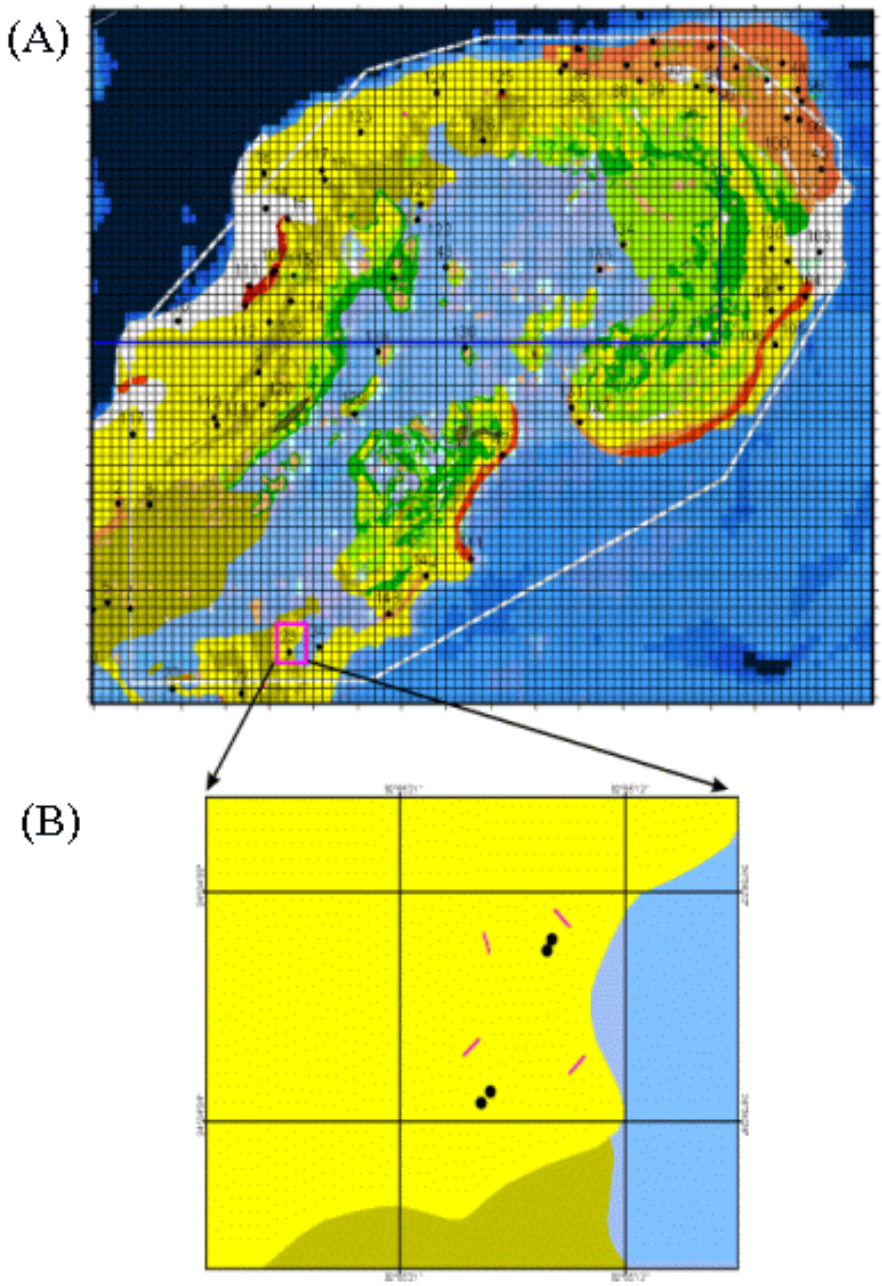


Figure 2.1 – Benthic habitat map of the Dry Tortugas National Park: (A) divided into approximately 200 m x 200 m (or approximateky 40,000 m^2 subunits; (B) to determine the sampling allocation for a two-stage stratified random survey design.

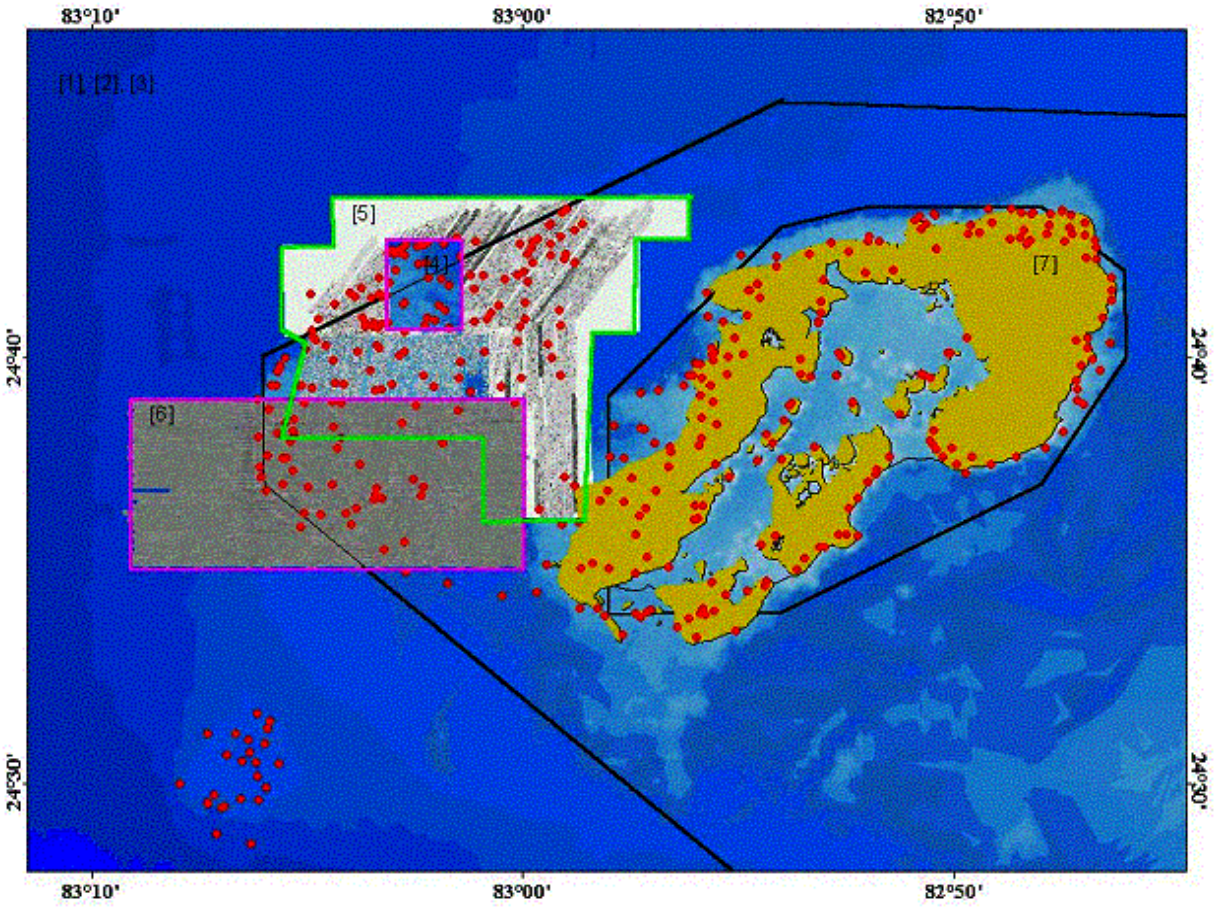


Figure 2.2 - Graphical depiction of georeferenced data sources used to characterize marine habitats in the Tortugas region. See text for further explanation.

The Tortugas millennial expedition cruises during 1999-2000 accomplished a combined total of 2,158 science dives, compared to 2,172 science dives in a similar survey effort conducted in the Florida Keys during the same period (**Table 2.1**). The Tortugas operations were completed within a 3- to 4-week period in each year, whereas the Florida Keys surveys encompassed 5-6 months. A number of logistical factors contributed to the exceptional sampling efficiency of the Tortugas cruises, including use of a large, live-aboard dive vessel (**Figure 2.3**) equipped with SCUBA Nitrox, "live-boating" at dive sites, and utilizing NURC/UNCW divemasters to oversee the complex diving operations.

Table 2.1 - Dry Tortugas and Florida Keys coral reef fish visual census (RVC) and coral "habitat" sampling during 1999 and 2000. DTNP is Dry Tortugas National Park,; TLB is Tortugas Bank and Little Bank; RIS/MARQ is Rebbea and Issacs Shoals and the Marquesas region; and RH is Riley's Hump. Coral habitat sampling for the Florida Keys was combined for the two year period.

(A) Dry Tortugas

	CORAL REEF FISHES					CORAL HABITATS				
Year	DTNP	TLB	RIS/ MARQ	RH	Totals	DTNP	TLB	RIS/ MARQ	RH	Totals
1999	378	360	133	70	**941**	73	69	26	13	**181**
2000	500	320	64	0	**884**	86	55	11	0	**152**
TOTAL	**878**	**680**	**197**	**70**	**1,825**	**159**	**124**	**37**	**13**	**333**

(B) Florida Keys

	CORAL REEF FISHES					CORAL HABITATS				
Year	BNP	Upper	Middle	Lower	Totals	BNP	Upper	Middle	Lower	Totals
1999	69	95	227	286	**677**	--	--	--	--	--
2000	144	216	248	324	**932**	--	--	--	--	--
TOTAL	**213**	**311**	**475**	**610**	**1,609**	**0**	**104**	**153**	**306**	**563**

2.2 Benthic Community Assessments

Benthic community assessments were strategically integrated with the reef fish sampling effort allocations to optimize the performance and provide maximum structural coherence of both fish and habitat surveys, and to provide a quantitative basis for comparison and calibration of survey efforts that improved mapping and spatial stratifications of the survey domain. Several techniques were used to measure a suite of variables to characterize the status of benthic communities including process-related phenomena such as the recruitment and condition of corals. At each site, underwater surveys using SCUBA diving (nitrox) were conducted to measure coverage, octocoral abundance, species richness of coral, octocoral, and sponges, coral size and condition, juvenile coral abundance and size, and the abundance of aquarium-trade invertebrate species such as anemones and corallimorpharians (**Table 2.2**). Video surveys were also conducted to quantify topographic complexity and to produce an archival record of each site. These methods enabled a relatively "rapid" and accurate picture of each primary sampling unit to be obtained.

Table 2.2.- Sampling effort for benthic variables measured in the Tortugas region.

Variable or Method	Field methods	Effort per Primary Unit
Linear point intercept	25-m transects/100 points per line	4 transects (400 points)
Coral size/condition	0.4-m x 25-m strip transect (10 m^2)	2 transects (20 m^2)
Juvenile coral abundance	Ten 0.312 m^2 quadrats per transect	2 transects (20 m^2)
Octocoral abundance	0.4-m x 25-m strip transect (10 m^2)	2 transects (20 m^2)
Species richness	0.4-m x 25-m strip transect (10 m^2)	4 transects (40 m^2)
Other cnidarian abundance	0.4-m x 25-m strip transect (10 m^2)	4 transects (40 m^2)
Urchin abundance and size	0.4-m x 25-m strip transect (10 m^2)	4 transects (40 m^2)

2.3 Reef Fish Visual Census

Biological data from the Tortugas reef fish sampling surveys were collected by standard, non-destructive, *in situ*, fishery-independent, visual monitoring methods by highly trained and experienced divers using open circuit Nitrox SCUBA. Visual methods are ideal for assessing reef fishes in the Tortugas and Florida Keys because of prevailing good visibility and management concerns requiring the use of non-destructive assessment methods. Reef fish data are collected by a stationary diver centered in a randomly selected circular plot (Bohnsack and Bannerot 1986). The circular plot method provides reliable quantitative estimates of species composition, abundance (density per plot), frequency-of-occurrence, and individual size composition for the reef fish community.

Divers sample 15 m diameter circular plots for 5 minutes attempting to count all fish observed within each imaginary cylinder extending from the bottom to the limits of vertical visibility (usually the surface) (**Figure 2.4**). Divers begin each sample by facing in one direction and listing all species within the field of view. When no new species are noted, new sectors of the cylinder are scanned by rotating in one direction for the 5 min period. Several complete rotations were usually made for each plot. After the initial 5 min, data are then collected on the abundance and minimum, mean, and maximum lengths for each species sighted. Depth, bottom composition, estimated percentage cover, and maximum relief are recorded for each plot from the polar perspective of the centrally located observer. An all purpose tool (APT), consisting of a ruler connected perpendicularly to the end of a meter stick, is used to as a reference device to reduce apparent magnification errors in fish size estimates. We have also designed and deployed an innovative state-of-the-art digital laser video

Figure 2.3 - Photograph of the M/V Spree used in synoptic RVC sampling survey for reef fish and coral habitats in the Tortugas region. The SCUBA support system includes 4 compressor banks of Nitrox for deep and repeated diving.

camera system for increasing the precision of the process for both sizing and counting reef fish species. The technical methodology is being calibrated against standard divers using the visual census methods and APT meter sticks. In usual operations, divers periodically calibrate their sample radius estimates with the meter stick or fiberglass tape. Species with few individuals (e.g. angelfish, barracuda, hogfish) are counted and their size estimated immediately. Highly mobile species that are unlikely to remain in the area (e.g. sharks, carangids, *Clepticus parrai*) are tabulated when first observed and then ignored. For common species (e.g. damselfish, wrasses, etc.) one 360° rotation is made for each species by working back up the list in reverse order of recording to reduce potential bias by avoiding counting a species when they were particularly abundant or obvious. The time required to record each sample averaged 15-20 min (range 5 - 30), depending on the habitat.

Visual survey data are entered into an electronic database using the RVC (Reef Fish Visual Census) Data Entry Program (Weinberger 1998). This program was designed to standardize data entry and help eliminate errors during the data entry process. The RVC diver data sheet and data fields are shown in **Appendix 2**. Data are entered into the RVC program through four 'cards' or data entry screens. The first screen accepts sample identifier information. The second screen

accepts bottom-type classification data. The third screen accepts reef fish length-frequency data and the fourth screen is for recording species seen after the initial five minutes allowed by the sampling protocol. The RVC program then checks the data for errors and, once corrected, processes the data for future entry into a database program. An overview of the Tortugas RVC database is given in **Appendix 1** (database [8]).

2.4 Delineation of Habitat-Based Sampling Strata

Using the relationship between animal density and habitat variables (e.g., depth, bottom type, salinity, etc.) to partition or 'stratify' the environment into geographical units of high, moderate, and low density levels can substantially improve sampling efficiency (Smith and Ault 1993, Ault et al. 1999a). Prior to 1999, detailed habitat information was available only for a portion of Dry Tortugas National Park, and was completely lacking for other areas of the Tortugas region. A major component of survey design thus involved mapping and characterizing reef fish habitat, and then developing a habitat-based stratification scheme. These efforts are described in the following sections.

Figure 2.4 - Graphical depiction of the reef fish visual census (RVC) method (Bohnsack and Bannerot 1986).

2.4.1 Historical Bathymetry and Benthic Habitats Databases

We assimilated, analyzed and visualized a number of databases of physical and biological habitat features in the Tortugas region. The data sources used to characterize marine habitats in the Dry Tortugas region are depicted with respect to their spatial extent in **Figure 2.2**. In addition to the following descriptions, a brief summary of each database is provided in **Appendix 1**.

Water depths at latitude-longitude geographic locations in the Tortugas region were extracted from three separate databases (region numbers [1], [2], and [3] shown in **Figure 2.2** and listed in **Appendix 1**) and subsequently gridded into a single GIS coverage. Additional information on bathymetry and bottom topography for the Tortugas Bank area was obtained from relatively recent NOAA/NOS Hydrographic Surveys that utilized both sidescan and multibeam sonar systems to assess benthic substrates (databases [4], [5], and [6] in **Figure 2.2** and **Appendix 1**). Geographical information system (GIS) layers of bottom substrate classifications interpreted from aerial photographic surveys for areas of Dry Tortugas National Park (yellow shaded region in **Figure 2.2**, database [7] in **Appendix 1**) were provided by the Florida Marine Research Institute. Bottom types included multiple categories of coral reef, seagrass, hardbottom, and sand/rock substrates. Data layer coverages pertaining to land and shoreline delineations were also included. Spatial point information for classifying coral reef habitats (orange dots in **Figure 2.2**) was obtained during the course of fish and benthic invertebrate surveys conducted in 1999 and 2000 (database [8] in **Appendix 1**).

Supplemental information on multispecies stock status in the greater Florida Keys-Dry Tortugas coral reef ecosystem was obtained from reef fish visual surveys conducted during 1979-1999 (database [9] in **Appendix 1**).

The 1981-1995 NMFS headboat landings database (Bohnsack et al., 1994; Dixon and Huntsman, 1992) also provided supplemental information on multispecies stock status in the greater Florida Keys-Dry Tortugas coral reef ecosystem (database [10] in **Appendix 1**).

2.4.2 Geographical Regions

We divided the sampling domain of the Tortugas cruises into five separate geographical areas: Marquesas Keys (MARQ), Rebecca/Isaac Shoals (RIS), Dry Tortugas National Park (DTNP), Tortugas Bank and Little Bank (TB), and Riley's Hump (RH). In this report, we principally focus our analyses and assessments on the DTNP, TB and RH areas (**Figure 2.5**).

2.4.3 Reef Habitat Classification

"Habitats" were described in terms of the surface area of bathymetry and bottom substrates found in each subregion. The general bathymetric structure of the Tortugas region and the Florida Keys is shown in **Figure 1.1**. Coral reef habitats are located on three distinct bank or atoll-like formations (DTNP, TB, and RH) arising from the west Florida Shelf proximal to the very deep channel of the Florida Straits. These formations are distinguished by the respective depths of the shallowest portions: DTNP, sea level to 5 m; Tortugas Bank, approx. 20 m; Riley's Hump, approx. 30 m.

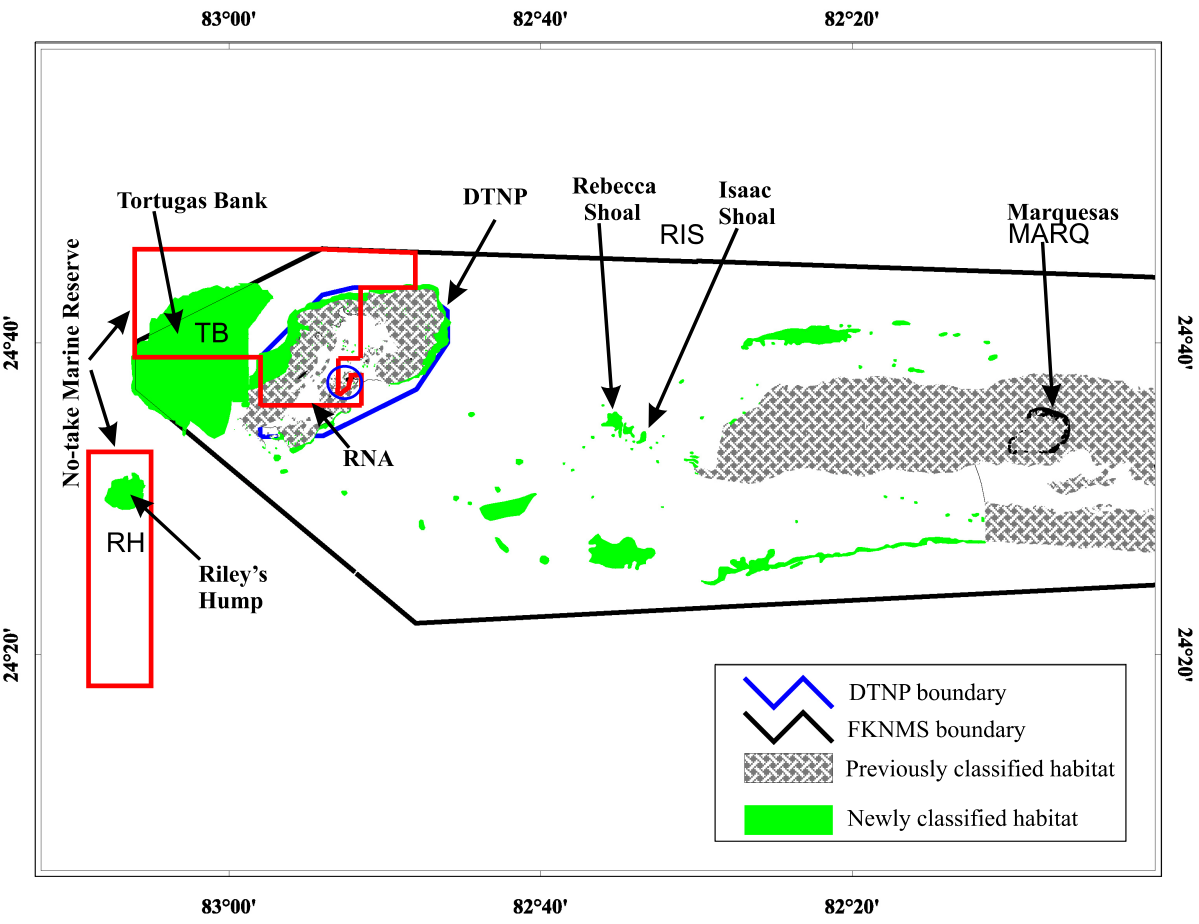


Figure 2.5 - Distribution of mapped benthic habitats by zone in the Tortugas region.

Coral reefs are the most prominent substrate feature of the Tortugas region. During the course of the 1999 and 2000 sampling surveys, a coral reef classification scheme for the Tortugas was developed by the NURC/UNCW benthic invertebrate team led by Dr. Steven Miller, Mark Chiappone and Dione Swanson.

Reef habitats were distinguished by two main features: (1) the degree of 'patchiness', i.e., contiguous hard substrate vs. reef patches interspersed with sand substrates; and (2) hard substrate vertical relief and complexity. Nine reef habitats occurred throughout the greater Tortugas region (**Figure 2.6**), four of which occurred exclusively within DTNP (denoted by *):

Patchy Hard-Bottom in Sand: Low vertical relief (<0.5m) and complexity; sandy plain with patches of hard-bottom. Typically, the sand plain encompasses greater than 40% of the benthic coverage. Distribution includes southern terminus of Tortugas Bank.

Low-Relief Hard-Bottom: Contiguous reef substrate characterized by low structural complexity and an absence of active reef accretion, typically by octocorals and algae. May be comprised of a mosaic of low-relief, limestone outcroppings interspersed with carbonate sediments. Referred to as an ecotone between the shallow rubble habitat and the deeper reef at Bird Key. The substrate may consist of reef rock or eroded beach-rock (e.g. west of Loggerhead Key). Distributed on the central, western, northern, and southern Tortugas Bank.

***Low-Relief Spur and Groove:** Distinct coralline fingers or 'spurs' presently dominated by algae, but formerly consisting of coralline fingers constructed by staghorn coral and separated by sand grooves. Low-relief consists of broad individual spurs up to 5 m wide with 1 m vertical relief from the sand grooves to top of spur. Distribution includes areas west and east of Loggerhead Key, and near Garden Key at 8-10 m depth.

***Patch Reefs:** Aggregate or clusters of dome-shaped reef substrates interspersed with bare or sand substrates; moderate vertical relief and complexity; analogous to patch reefs occurring in Hawk's Channel in the Florida Keys coral reef environment.

***Medium Profile Reefs:** Contiguous reef substrate of moderate vertical relief and complexity

Rocky Outcrops: Distinct hard-bottom aggregations of moderate vertical relief (0.5-1.5m) and complexity surrounded by large sand plains. Typically found on the periphery of consolidated reef structure such as reef terraces.

Pinnacles: High-complexity patch and reef knoll structures that rise up to 15 m from the sea floor. These structures may occur in clusters and are typically surrounded by large sand plains.

***High Relief Spur and Groove:** Distinct coralline fingers or 'spurs" separated by sand grooves. High-Relief consists of individual spurs projecting up to 3 m from the sea floor,

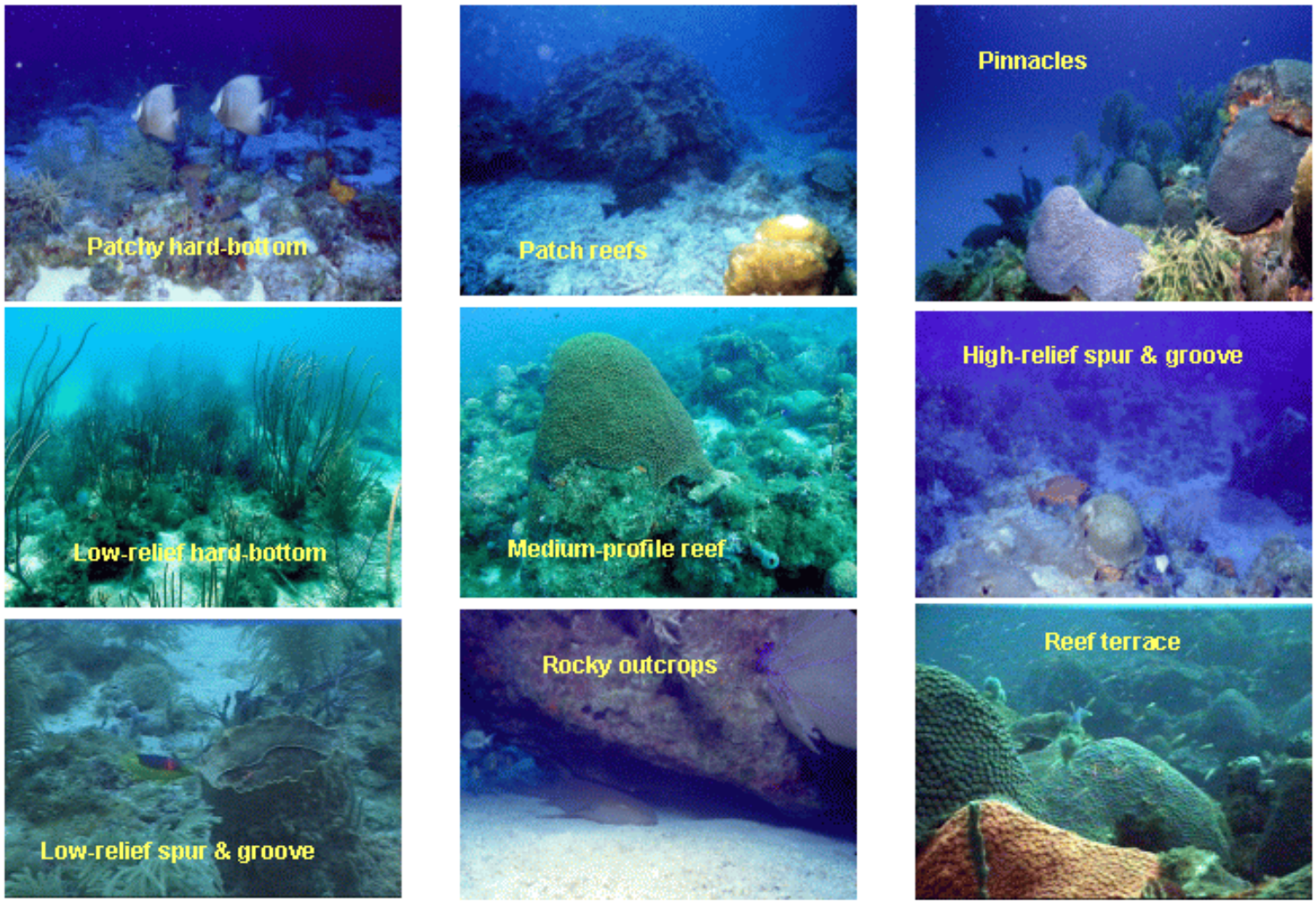


Figure 2.6 – Photographs depicting the benthic classification scheme of hard-bottom and coral reef habitats for the Tortugas region including the Dry Tortugas National Park and western Florida Keys National Marine Sanctuary.

Table 2.3 - Areal extent of Dry Tortugas reef habitat types by geographical region. Also listed are areal proportions of a given habitat (i) protected within a no-take marine reserve [p(R)], and (ii) within a geographical region [p(A)]

	DTNP			Tortugas Bank			Riley's Hump			Total		
Habitat	**Area (km^2)**	**p(R) (%)**	**p(A) (%)**	**Area (km^2)**	**p(R) (%)**	**p(A) (%)**	**Area (km^2)**	**p(R) (%)**	**p(A) (%)**	**Area (km^2)**	**p(R) (%)**	**p(A) (%)**
Patchy Hard-Bottom in Sand	33.6	51.1	18.1	30.5	48.9	22.2	2.6	100.0	21.6	66.7	52.0	19.9
Low-Relief Hard-Bottom	95.7	46.3	51.5	75.0	59.7	54.6	—	—	—	170.8	52.2	50.9
Rocky Outcrops	1.8	22.2	1.0	16.6	67.8	12.1	9.4	100.0	78.4	27.9	75.8	8.3
Patch Reef	28.1	49.1	15.1	—	—	—	—	—	—	28.1	49.1	8.4
Medium Profile Reef	7.8	18.6	4.2	—	—	—	—	—	—	7.8	18.6	2.3
Low-Relief Spur & Groove	11.8	2.7	6.4	—	—	—	—	—	—	11.8	2.7	3.5
High-Relief Spur & Groove	5.1	20.5	2.7	—	—	—	—	—	—	5.1	20.5	1.5
Reef Pinnacles	0.3	62.5	0.2	0.4	100.0	0.3	—	—	—	0.7	82.4	0.2
Reef Terrace	1.5	81.6	0.8	15.0	87.4	10.9	—	—	—	16.5	86.9	4.9
Total	185.8	43.0	100.0	137.5	61.4	100.0	12.0	100.0	100.0	335.3	52.6	100.0

typically covered with a diverse assemblage of corals, octocorals, and sponges. Elkhorn coral is absent and reefs are constructed primarily by massive head coral species. Spurs may project 100+ m seaward and merge with a sand plain. This habitat may have up to 2-m of vertical relief, with grooves 1-1.5 m wide, spurs 3.5-4 m wide, and a visual dominance by *Montastraea*, *Colpophyllia*, *Siderastrea*, *Pseudopterogorgia* and *Briareum*, but also abundant silt on spur surfaces. Dominant algae are *Dictyota* and *Lobophora.* Distributed in eastern DTNP near Long Key.

Reef Terrace: High relief (>2m), highly complex contiguous reef substrate characterized by abundant mushroom corals with undercuts/caverns with abundant platy fungus and lettuce corals (**Figure 2.7**). The substratum is dominated by algae and corals. Examples of reef terrace habitats are Sherwood Forest off of northeastern Tortugas Bank and 'Loggerhead forest' east of Loggerhead Key in DTNP.

We created a benthic habitat map for the Tortugas region in the following manner. RVC survey sampling locations (orange dots, **Figure 2.2**) were classified according to the above scheme. The spatial coverage of a given habitat type was estimated from associations between these survey point locations and GIS coverages for bathymetry, sonar imagery, and aerial photogrammetry (**Figure 2.2**).

Our composite habitat map for the area encompassing DTNP, TB, and Riley's Hump is shown in **Figure 2.8**. The map is a collage of all habitat survey data available to us (**Appendix 1**). Areal extents of reef habitats by geographical regions are provided in **Table 2.3**. As shown in **Figure 2.5**, our mapping efforts have classified substantial new areas of previously unknown benthic substrate. It should be pointed out, however, that vast reaches of the benthos are still unknown and unquantified (i.e., white areas of **Figure 2.5**). Tortugas Bank and DTNP were dominated by low-relief hard-bottoms, while rocky outcrops are the primary reef habitats of Riley's Hump. Of particular note is the fairly extensive and luxuriant reef terrace habitats (15 km^2) along the northern and western rims of Tortugas Bank (**Figure 2.7**), as well as, spur-and-groove habitats along the north and western rims of DTNP. Bottom substrates in DTNP also include extensive shallow areas covered with seagrass beds.

2.5 Sample Allocation

The sampling domain was partitioned into strata comprised of habitat type within each geographical region. Primary sampling units were allocated to strata according to stratum area and variance of fish density for a representative suite of species. This ensured synoptic geographical coverage of the Tortugas region, and also ensured sampling of representative reef habitats within each region (Glynn and Ault 2000).

It should be noted, however, that survey stratification and allocation evolved along with efforts to map and classify reef habitats in the Tortugas. Prior to sampling in 1999, stratification and allocation were based on initial habitat maps produced from some of the historical bathymetry and bottom substrate databases (Schmidt et al. 1999). After the 1999 survey, new maps were developed using benthic habitat information collected during the survey.

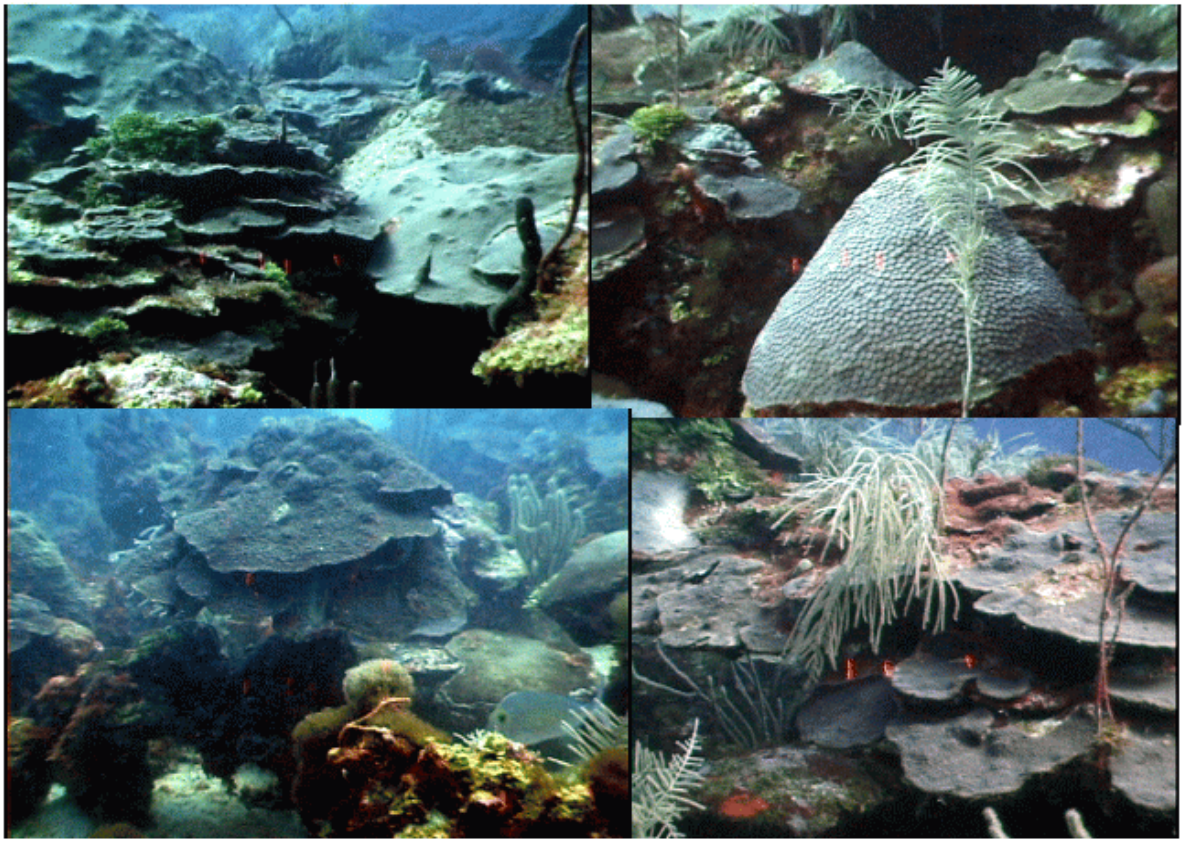


Figure 2.7 - Photographs of luxuriant coral reef terrace habitats typical of "Sherwood Forest" on western Tortugas Bank in FKNMS and "Loggerhead Forest" in western Dry Tortugas National Park.

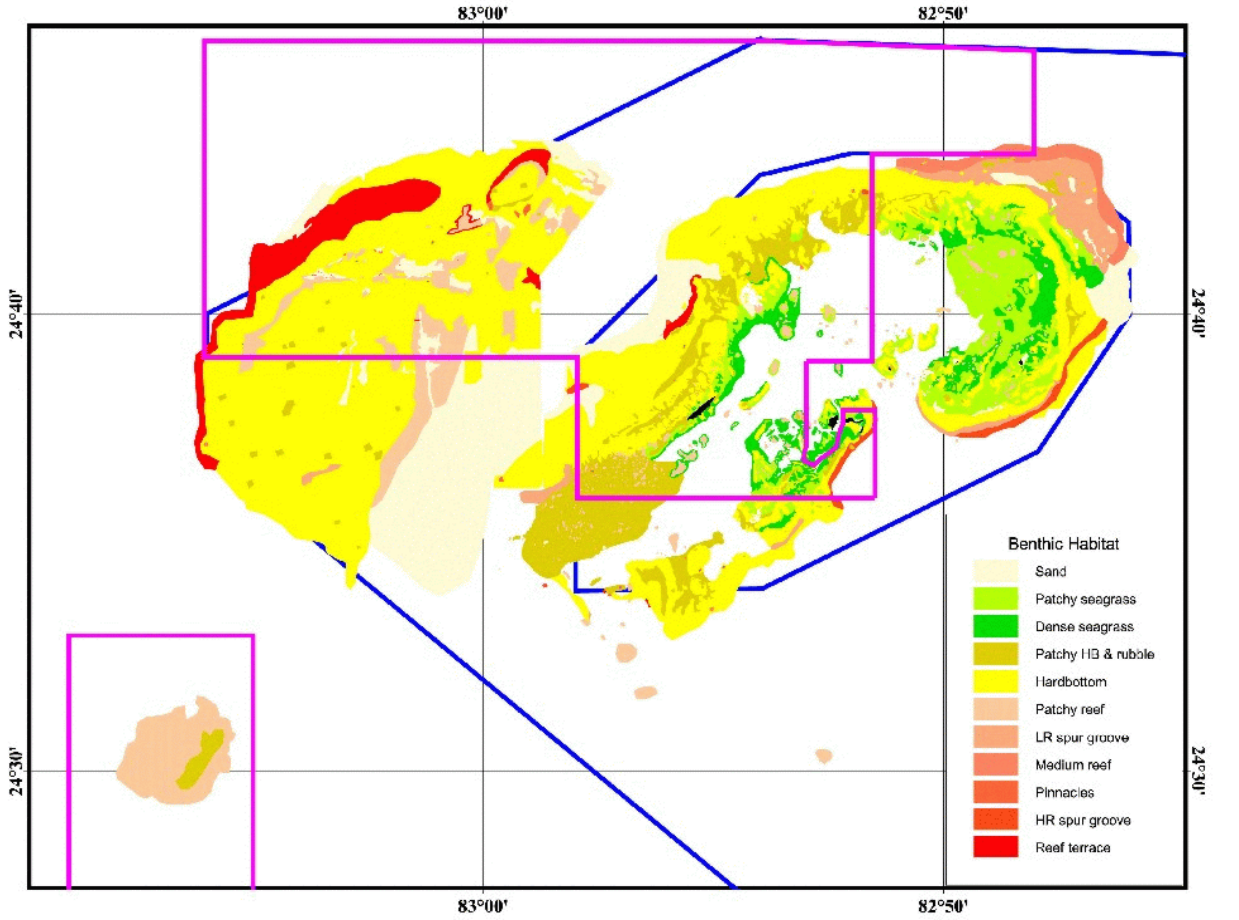


Figure 2.8 - Benthic habitat map of the Tortugas region. Black areas denote land and pink boundaries delineate implemented/proposed no-take marine reserves.

It was at this point that the habitat classification scheme was developed. The final maps were updated after completion of the 2000 survey. Our efforts to optimally allocate samples among strata were thus undone in many instances because during the actual surveys, sampling locations were often in habitats different from the 'mapped' habitat type.

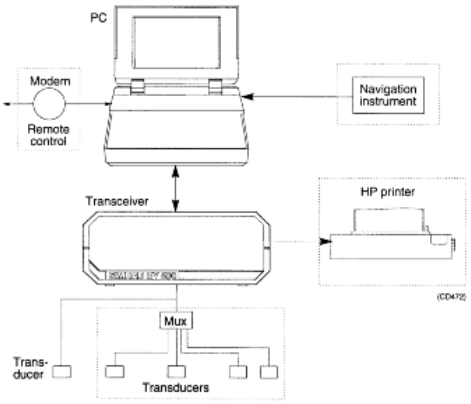
2.6 Experimentation With Advanced Survey Technologies

With an eye towards future synoptic reef monitoring and assessment surveys, during the 1999-2000 cruises to the Dry Tortugas we pursued innovative uses of hydroacoustic and optical technologies (i.e., SIMRAD multibeam ecolocator, Delta submersible, Phantom ROV, laser digital underwater camera systems). Of particular interest was the evaluation of the "in-reef" faunal component that makes itself available as pelagic biomass during dark hours of the day. We are exploring what the distribution and dynamics of these in-faunal resources means to the sustainability of fisheries and the conservation of marine biodiversity in the Tortugas and Florida Keys. During the 1999-2000 cruises, we evaluated the use of a 120 kHz SIMRAD EY 500 Split Beam scientific echo sounder to test the feasibility of using hydroacoustics to synoptically survey reef fishes across broader areas than those available in the RVC method, and in areas beneath the lower depth tolerance for SCUBA divers. The SIMRAD EY 500 scientific echo sounder is designed for biomass

estimation where portability and low power consumption is important. This high-performance, portable scientific sounder system is the result of combining state-of-the-art echo sounder technology with the latest achievements in personal computers. The system includes substantial processing power. Bottom detection, echo integration and target strength algorithms area carried out solely in software. The concept used in the receiver design provides an instantaneous dynamic range of 160 dB. At the same time the absolute amplitude measurement accuracy is very high, and combined with a low self-noise this assures correct measurement of all targets. The transducer was mounted on a tow-body, which was towed at 3 knots (about 1.5 m/s) alongside the ship outside of the vessel wake.

Specifications:

Transmitting power: 60 W
Pulse duration: 0.1, 0.3, 1.0 (ms)
Bandwidth (kHz): 1.2 (Narrow), 12.0 (Wide)
Resolution: 3 (cm)
Beam angle: 7x7 (degree)
Max detection depth: 260m (for TS=-30dB fish), 140m (for TS=-50dB fish), 700m (bottom)



SIMRAD Hydroacoustic Survey System Configuration

3.0 Survey Design Performance

This section describes the statistical procedures for estimating mean and variance of animal density, and then evaluates the performance of our Tortugas region sampling survey design for selected reef fishery species.

3.1 Survey Design Statistics and Performance Measures

We implemented a two-stage stratified random sampling (StRS) design following procedures described in Cochran (1977) to optimize the sampling effort and chose sampling locations. A glossary of sampling design statistical symbols is provided in **Table 3.1**. We define fish density D as the number of individuals observed per diver station, i.e., number per 177 m^2 (the area of the basic sampling unit). Fish density D_{ij} at each diver station j (i.e., the second-stage unit) in primary unit i was obtained by averaging densities for the buddy team of divers (usually two divers, but sometimes three). Mean density within primary unit i in stratum h was estimated by

$$\overline{D}_{hi} = \frac{1}{m_{hi}} \sum_{j} D_{hij} \qquad (3.1)$$

where m_{hi} is the number of diver stations in primary unit i and stratum h. Stratum mean density was computed as

$$\overline{D}_{hi} = \frac{1}{m_{hi}} \sum_j D_{hij} \tag{3.1}$$

where m_{hi} is the number of diver stations in primary unit i and stratum h. Stratum mean density was computed as

$$\overline{\overline{D}}_h = \frac{1}{n_h} \sum_i \overline{D}_{hi} \tag{3.2}$$

where n_h is the number of primary units sampled in stratum h. The sample variance among primary unit means in stratum h was estimated using

$$s_{1h}^2 = \frac{\sum_i \left(\overline{D}_{hi} - \overline{\overline{D}}_h \right)^2}{n_h - 1} \tag{3.3}$$

and the stratum sample variance among diver stations within primary units was estimated as

$$s_{2h}^2 = \frac{1}{n_h} \sum_i \left[\frac{\sum_j \left(D_{hij} - \overline{\overline{D}}_{hi} \right)^2}{m_{hi} - 1} \right] \tag{3.4}$$

The variance of mean density in stratum h was then estimated by

$$\text{var}\left[\overline{\overline{D}}_h \right] = \frac{\left(1 - \frac{n_h}{N_h} \right)}{n_h} s_{1h}^2 + \frac{\frac{n_h}{N_h} \left(1 - \frac{m_h}{M_h} \right)}{n_h m_h} s_{2h}^2 \tag{3.5}$$

where $n_h m_h$ is the total diver stations sampled, m_h is the average diver stations sampled per primary unit, M_h is the total possible diver stations within a primary unit, and N_h is the total possible primary units in stratum h. We set M_h=226 for all strata, obtained by dividing the area of a primary unit (40,000 m^2) by the area of a diver station (177 m^2). Values of N_h were computed directly from the GIS digital habitat maps.

Table 3.1 - Glossary of sampling design statistical symbols.

Symbol	Description
j	Diver station (second-stage unit) subscript
i	Primary unit subscript
h	Stratum number
m_{hi}	Number of diver stations sampled in primary unit i and stratum h
m_h	Average number of diver "buddy pair" stations sampled per primary unit in stratum h
M_h	Number of total diver stations per primary unit in stratum h
m^*_h	Optimum number of diver station samples per primary unit in stratum h
n_h	Number of primary units sampled in stratum h
N_h	Number of total primary units in stratum h
n^*	Number of primary unit samples required to achieve a specified variance
$n_h m_h$	Number of diver stations sampled in stratum h
$N_h M_h$	Number of total diver stations in stratum h
w_h	Stratum weighting factor
D_{hij}	Fish density at diver station j within primary unit i in stratum h
$\overline{D}_{hi}$	Mean density within primary unit i in stratum h
$\overline{\overline{D}}_h$	Mean density in stratum h
$\overline{\overline{D}}_{st}$	Overall mean density for a stratified random survey
$\overline{\overline{D}}_{ran}$	Overall mean density for a simple random survey
s^2_{1h}	Sample variance of density among primary unit means in stratum h
s^2_{2h}	Sample variance among diver stations within primary units in stratum h
var[ ]	Variance of an estimate
SE[ ]	Standard error of an estimate
CV[ ]	Coefficient of variation of an estimate
V[ ]	Target variance of an estimate for a future survey

The overall stratified mean density estimate was obtained as

$$\overline{\overline{D}}_{st} = \sum_h w_h \overline{\overline{D}}_h \tag{3.6}$$

while the stratum weighting factor w_h was defined as

$$w_h = \frac{N_h M_h}{\sum_h N_h M_h} \tag{3.7}$$

The variance of $\overline{\overline{D}}_{st}$ was estimated by

$$\mathbf{var}\left[\overline{\overline{D}}_{st}\right] = \sum_h w_h^2 \, \mathbf{var}\left[\overline{\overline{D}}_h\right] \tag{3.8}$$

The standard error, $SE\left[\overline{\overline{D}}_{st}\right]$, is obtained by taking the square root of equation (3.8).

We evaluated sampling design performance according to several statistical measures following Cochran (1977). Coefficient of variation (CV) of mean density was determined as the standard error expressed as a proportion of the mean density,

$$CV\left[\overline{\overline{D}}_{st}\right] = \frac{SE\left[\overline{\overline{D}}_{st}\right]}{\overline{\overline{D}}_{st}} \tag{3.9}$$

The optimum number of second-stage units m^*_h (i.e., diver stations) to sample within a given primary unit in stratum h was estimated as

$$m^*_h = \frac{s_{2h}}{s_{uh}} \tag{3.10}$$

where s_{uh} is defined as

$$s_{uh} = \sqrt{s_{1h}^2 - \frac{s_{2h}^2}{M_h}} \tag{3.11}$$

The required number of primary units n^* in a future survey to achieve a specified variance was estimated in the following manner. The desired variance $V\left[\overline{\overline{D}}_{st}\right]$ was expressed as

$$V\left[\overline{\overline{D}}_{st}\right] = \left(CV\left[\overline{\overline{D}}_{st}\right] \cdot \overline{\overline{D}}_{st}\right)^2 \tag{3.12}$$

using a target CV of stratified fish density. Future survey primary units n_h are presumed to be allocated among strata according to a Neyman scheme,

$$n_h = \frac{n^* w_h s_{uh}}{\sum_h w_h s_{uh}} \tag{3.13}$$

which bases the sample allocation on both stratum size (w_h; equation 3.7) and variance (s_{uh}; equation 3.11). Using population variance $Var\left[\overline{\overline{D}}_{st}\right]$ (in contrast to sample variance $\mathbf{var}\left[\overline{\overline{D}}_{st}\right]$),

$$Var\left[\overline{\overline{D}}_{st}\right] = \sum_h W_h^2 \left(\frac{1}{n_h} S_{uh}^2 + \frac{1}{n_h m_h} S_{2h}^2 - \frac{1}{N_h} S_{1h}^2\right) \tag{3.14}$$

substituting $V\left[\overline{\overline{D}}_{st}\right]$ (equation 3.12) for $Var\left[\overline{\overline{D}}_{st}\right]$, n_h from equation (3.13), w_h for W_h, estimates of m^*_h (equation 3.10) for m_h, and sample estimates of s^2_{uh}, s^2_{2h}, and s^2_{1h} for their respective population values, and then solving for n^* yields the formal estimator

$$n^* = \frac{\sum_h w_h s_{uh}\left(\sum_h w_h s_{uh} + \sum_h \frac{w_h^2 s_{2h}^2}{m^*_h w_h s_{uh}}\right)}{V\left[\overline{\overline{D}}_{st}\right] + \sum_h \frac{w_h^2 s_{1h}^2}{N_h}} \qquad (3.15)$$

An overview of the sampling effort for 1999 and 2000 by geographical area is given in **Table 3.2**.

3.2 Design Performance for Selected Reef Fishery Species

Performance measures are useful quantitative benchmarks of efficacy of a sampling survey design to meet cost-benefit criteria and management objectives. Benchmark targets could be couched as either best precision for a given cost, or desired precision at a specified cost (Cochran 1977). Performance measures CV and n* were estimated for several species of snappers, groupers, and grunts for the 1999 and 2000 stratified random visual surveys (**Table 3.3**). Survey domain stratification was based on our development of a 9 category reef classification scheme (**Figure 2.6**) within geographical areas (e.g., Tortugas Bank and DTNP). The optimal number of diver stations within a primary sample unit was estimated to be m*=2 (equation 3.10) for nearly all species lifestages in all strata. This corresponded exactly to the target *m* for the 1999 and 2000 surveys which was based on estimates of m* for visual surveys conducted during 1997 and 1998 in the Florida Keys.

The survey design performed reasonably well for a number of species' life stages, as evidenced by consistent average density estimates fo the two survey years with CV<25% (**Table 3.3:** red grouper juveniles and adults, black grouper juveniles, yellowtail snapper juveniles and adults, hogfish adults, white grunt adults). Survey precision generally increased in 2000 compared to 1999 for these cases. Survey precision of adult white grunt and mutton snapper was high enough to even detect a statistically significant increase in mean density from 1999 to 2000. We obtained consistent estimates of mean density for gray snapper juveniles and adults and bluestriped grunt juveniles, but the CVs were somewhat high. Survey performance was lowest for particularly rare species life stages (black grouper adults and mutton snapper juveniles). It also appears that the design may have been suboptimal with respect to stratification and allocation in some cases (hogfish juveniles and bluestriped grunt adults).

Table 3.2 - The number of RVC primary units (*n*) and diver "buddy pair" stations (*nm*) sampled by geographical area and year during the 1999-2000 Dry Tortugas reef fish visual survey.

	1999		2000		Total	
Geographical Area	***n***	***nm***	***n***	***nm***	***n***	***nm***
DTNP	85	170	130	248	215	418
Tortugas Bank	93	179	84	158	177	337
Riley's Hump	24	30	—	—	24	30
Rebecca/Isaac Shoals	6	12	—	—	6	12
Marquesas Keys	19	37	16	32	35	69
Total	227	428	230	438	457	866

Table 3.3.- Two-stage stratified random visual survey performance measures for selected reef fishes in the area encompassing Tortugas Bank and DTNP. CV is coefficient of variation; n* is primary sample units needed to achieve CV=10% in a future survey.

		1999 (*n*=170, *nm*=326)			2000 (*n*=207, *nm*=381)		
Species	**Life Stage**	**Mean Density**	**CV (%)**	**n***	**Mean Density**	**CV (%)**	**n***
Red Grouper	Juvenile	0.4390	10.1	135	0.3787	8.4	183
Red Grouper	Adult	0.1921	13.4	334	0.2033	11.1	309
Black Grouper	Juvenile	0.1037	20.8	418	0.0950	16.5	629
Black Grouper	Adult	0.0050	52.8	1550	0.0224	81.6	340
Yellowtail Snapper	Juvenile	2.1400	18.1	446	3.6457	10.2	218
Yellowtail Snapper	Adult	1.8801	28.3	1121	1.3220	17.4	432
Gray Snapper	Juvenile	1.0169	65.0	1985	0.8264	37.9	918
Gray Snapper	Adult	0.7347	33.0	1037	0.9597	61.8	563
Mutton Snapper	Juvenile	0.0007	100.2	667	0.0114	40.8	2420
Mutton Snapper	Adult	0.0540	24.9	1087	0.1028	23.6	965
Hogfish	Juvenile	0.1958	38.2	437	0.0812	24.1	907
Hogfish	Adult	0.4377	12.1	262	0.3789	11.2	302
White Grunt	Juvenile	3.2726	17.7	316	3.6244	22.8	626
White Grunt	Adult	1.0192	26.5	372	1.9281	19.9	764
Bluestriped Grunt	Juvenile	0.0682	48.8	2474	0.0536	46.6	1288
Bluestriped Grunt	Adult	0.0340	39.1	1003	0.1375	54.3	2091

4.0 Descriptive Ecological Results

In this section, we present some descriptive ecological results documenting species inventories and community diversity of benthic invertebrates and fishes in the Tortugas region. We also show some preliminary results of diel migration patterns obtained from hydroacoustic sampling.

4.1 Species Inventories

4.1.1 Benthic Invertebrates

A list of stony coral, octocoral, and sponge species observed in the Tortugas region during the 1999 and 2000 surveys is provided in **Table 4.1**. A total of 43 species of stony corals were observed, along with 28 octocoral and 58 sponge species. Juveniles were documented for 24 coral species. In addition, a number of species of anemones, corallimorpharians, and urchins were seen (**Table 4.2**).

4.1.2 Fishes

An overall species inventory of reef fishes for the Dry Tortugas region was compiled from the 1999-2000 visual surveys (**Table 4.3**). The survey database contained 224 species of fishes identified to genus and species level, representing 46 different families (**Table 4.4**). In addition, a number of species were only observed in particular geographical areas (**Table 4.4**).

At present, none of the fishes that inhabit DTNP are on Federal or Florida lists of threatened or endangered species. However, it is only very recently that marine fish species have been proposed for inclusion on national and international rare or endangered animal lists (Musick 1998, 1999; Musick et al. 2000; Hudson and Mason 1996). This situation exists in part because: (1) there is societal and scientific doubt that marine fish species can become extinct, (2) the out of sight – out of mind concept; and, (3) they have traditionally been of lower conservation concern than their terrestrial counterparts. In 1996, the World Conservation Union (IUCN) and the World Wildlife Fund (WWF) published rare/threatened marine species criteria and revised animal lists to include marine fish species. The IUCN list includes 6 species found in Dry Tortugas National Park (**Table 4.5**) and surrounding waters. Concurrently, the American Fisheries Society (AFS) has evaluated the risk of extinction for marine fish species using new quantitative criteria adopted by IUCN (Hudson and Mason 1996), and published a list of 82 marine fish species at risk in North America (Musick et al. 2000). Of these 82 marine finfish species, 9 are found in the Dry Tortugas region.

4.2 Community Diversity

4.2.1 Benthic Invertebrates

Species richness values (number of species) for Scleractinian corals, octocorals, and sponges are respectively plotted onto the revised benthic habitat map for the Tortugas region in **Figures 4.1**, **4.2**, and **4.3** . Highest diversity of corals occurred in habitats with high complexity and vertical relief. In contrast, octocoral and sponge diversity was typically higher in moderate- to low-relief habitats.

4.2.2 Fishes

Spatial point values of fish community species richness, a measure of diversity, were overlain on benthic habitat maps (**Figures 4.4-4.7**). Point values represent the number of fish

Table 4.1 - Species list for hard coral, octocoral, sponge and juvenile corals from 1999 and 2000 Tortugas region surveys.

Coral species	Sponge species	Octocoral species	Observed juvenile corals
Acropora cervicornis	*Agelas clathrodes*	*Briareum asbestinum*	*Agaricia agaricites*
Agaricia agaricites	*Agelas dispar*	*Erythropodium caribaeorum*	*Agaricia humilus*
Agaricia fragilis	*Agelas schmidti*	*Eunicea calyculata*	*Agaricia lamarcki*
Agaricia humilus	*Agelas wiedenmayaari*	*Eunicea fusca*	*Colpophyllia natans*
Agaricia lamarcki	*Amphimedon compressa*	*Eunicea laciniata*	*Dichocoenia stokesi*
Colpophyllia natans	*Amphimedon viridis*	*Eunicea mammosa*	*Diploria clivosa*
Dichocoenia stokesi	*Anthosigmella varians*	*Eunicea succinea*	*Diploria strigosa*
Diploria clivosa	*Aplysina archeri*	*Eunicea tourneforti*	*Eusmilia fastigiata*
Diploria labyrinthiformis	*Aplysina cauliformis*	*Gorgonia ventalina*	*Favia fragum*
Diploria strigosa	*Aplysina fistularis*	*Muricea atlantica*	*Favia fragum*
Eusmilia fastigiata	*Aplysina fulva*	*Muricea muricata*	*Madracis formosa*
Favia fragum	*Aplysina lacunosa*	*Muriceopsis flavida*	*Manicina areolata*
Isophyllastrea rigida	*Callyspongia plicifera*	*Plexaura flexuosa*	*Meandrina meandrites*
Isophyllia sinuosa	*Callyspongia vaginalis*	*Plexaura homomalla*	*Millepora alcicornis*
Leptoseris cucullata	*Chondrilla nucula*	*Plexaurella dichotoma*	*Millepora complanata*
Madracis decactis	*Cinachyra sp.*	*Plexaurella grisea*	*Montastraea cavernosa*
Madracis formosa	*Cliona deletrix*	*Plexaurella nutans*	*Montastraea faveolata*
Madracis mirabilis	*Cliona* sp.	*Pseudoplexaura crucis*	*Porites astreoides*
Manicina areolata	*Diplastrella megastellata*	*Pseudoplexaura flagellosa*	*Porites divaricata*
Meandrina meandrites	*Dysidea etheria*	*Pseudoplexaura porosa*	*Porites porites/furcata*
Millepora alcicornis	*Ectyoplasia ferox*	*Pseudoplexaura wagenaari*	*Scolymia sp.*
Montastraea annularis	*Erylus formosus*	*Pseudopterogorgia acerosa*	*Siderastrea radians*
Montastraea faveolata	*Geodia neptuna*	*Pseudopterogorgia americana*	*Siderastrea siderea*
Montastraea franksi	*Haliclona hogarthi*	*Pseudopterogorgia bipinnata*	*Stephanocoenia michelini*
Montastraea cavernosa	*Holapsamma helwigi*	*Pseudopterogorgia rigida*	
Mussa angulosa	*Halisarca* sp.	*Pterogorgia anceps*	
Mycetophyllia aliciae	*Iotrochota birotulata*	*Pterogorgia guadalupensis*	
Mycetophyllia danaana	*Ircinia campana*	*Pterorgorgia citrina*	
Mycetophyllia ferox	*Ircinia felix*		
Mycetophyllia lamarckiana	*Ircinia strobilina*		
Oculina diffusa	*Monanchora barbadensis*		
Porites astreoides	*Monanchora unguifera*		
Porites branneri	*Mycale laevis*		
Porites colonensis	*Niphates digitalis*		
Porites porites	*Niphates erecta*		
Porites porites divaricata	*Pandaros acanthifolium*		
Porites porites furcata	*Phorbas* sp.		
Scolymia cubensis	*Pseudoceratina crassa*		
Scolymia lacera	*Pseudoaxinella lunaecharta*		
Siderastrea radians	*Ptilocaulis* sp.		
Siderastrea siderea	*Rhaphidophlus juniperinis*		
Solenastrea bournoni	*Siphonodictyon coralliphagum*		

Table 4.1 (cont.) - Species list for hard coral, octocoral, sponge and juvenile corals from 1999 and 2000 Tortugas region surveys.

Coral species	Sponge species	Octocoral species	Observed juvenile corals
Stephanocoenia michelini	*Spinosella tenerrima*		
	Strongylacidon sp.		
	Ulosa ruetzleri		
	Verongula gigantea		
	Verongula rigida		
	Xestospongia muta		
	Unknown blue tube sponge		
	Unknown bowling ball sponge		
	Unknown brown encrusting sponge		
	Unknown brown lumpy tube sponge		
	Unknown brown smooth sponge		
	Unknown carmine red sponge		
	Unknown mauve lumpy sponge		
	Unknown red encrusting sponge		
	Unknown red lumpy sponge		
	Unknown red squishy sponge		
43 species	**58 species**	**28 species**	**24 species**

Table 4.2 - Species list of anemones, corallimorpharians, and urchins from 1999 and 2000 Tortugas region surveys.

Anemones and Corallimorpharians	Urchins
Bartholomea annulata	*Diadema antillarum*
Condylactis gigantea	*Echinometra viridis*
Discosoma sanctithomae	*Eucidaris tribuloides*
Discosoma carigreni	
Epicystis crucifer	
Lebrunia danae	
Ricordea florida	
Palythoa mammilosa	

Table 4.3 - Fish species inventory from the 1999-2000 Dry Tortugas RVC survey denoting binary presence (1) or absence (0) by geographical area (DTNP, Dry Tortugas National Park; BHS, Tortugas Bank, Riley's Hump and Rebecca/Isaac Shoals;MARQ, Marquesas Keys). Species arranged in alphabetical order by Latin name.

Family	Latin Name	Common Name	DTNP	BHS	MARQ
Pomacentridae	*Abudefduf saxatilis*	sergeant major	1	1	1
Clinidae	*Acanthemblemaria aspera*	roughhead blenny	1	1	0
Acanthuridae	*Acanthurus bahianus*	ocean surgeon	1	1	1
Acanthuridae	*Acanthurus chirurgus*	doctorfish	1	1	1
Acanthuridae	*Acanthurus coeruleus*	blue tang	1	1	1
Myliobatidae	*Aetobatus narinari*	spotted eagle ray	1	0	0
Balistidae	*Aluterus schoepfi*	orange filefish	1	1	0
Balistidae	*Aluterus scriptus*	scrawled filefish	0	1	0
Cirrhitidae	*Amblycirrhitus pinos*	redspotted hawkfish	1	1	1
Haemulidae	*Anisotremus surinamensis*	black margate	0	1	0
Haemulidae	*Anisotremus virginicus*	porkfish	1	1	1
Antennariidae	*Antennarius ocellatus*	ocellated frogfish	0	1	0
Apogonidae	*Apogon binotatus*	barred cardinalfish	1	1	0
Apogonidae	*Apogon maculatus*	flamefish	0	1	1
Apogonidae	*Apogon pseudomaculatus*	twospot cardinalfish	1	1	0
Apogonidae	*Apogon quadrisquamatus*	sawcheek cardinalfish	1	0	0
Apogonidae	*Astrapogon puncticulatus*	blackfin cardinalfish	1	0	0
Atherinidae	*Atherinomorus stipes*	hardhead silverside	1	0	0
Aulostomidae	*Aulostomus maculatus*	trumpetfish	1	1	1
Balistidae	*Balistes capriscus*	gray triggerfish	0	1	0
Labridae	*Bodianus pulchellus*	spotfin hogfish	1	1	1
Labridae	*Bodianus rufus*	spanish hogfish	1	1	1
Sparidae	*Calamus bajonado*	jolthead porgy	1	1	0
Sparidae	*Calamus calamus*	saucereye porgy	1	1	1
Sparidae	*Calamus penna*	sheepshead porgy	0	1	1
Sparidae	*Calamus proridens*	littlehead porgy	1	1	1
Balistidae	*Cantherhines macrocerus*	whitespotted filefish	1	1	1
Balistidae	*Cantherhines pullus*	orangespotted filefish	0	1	1
Balistidae	*Cantherhines sufflamen*	ocean triggerfish	1	1	1
Tetraodontidae	*Canthigaster rostrata*	sharpnose puffer	1	1	1
Carangidae	*Caranx bartholomaei*	yellow jack	1	1	1
Carangidae	*Caranx crysos*	blue runner	1	1	1
Carangidae	*Caranx hippos*	crevalle jack	1	1	0
Carangidae	*Caranx latus*	horse-eye jack	0	0	1
Carangidae	*Caranx ruber*	bar jack	1	1	1
Carcharhinidae	*Carcharhinus leucas*	bull shark	1	0	0
Pomacanthidae	*Centropyge argi*	cherubfish	0	1	0
Clinidae	*Chaenopsis limbaughi*	yellowface pikeblenny	1	0	0
Ephippidae	*Chaetodipterus faber*	atlantic spadefish	0	1	1
Chaetodontidae	*Chaetodon aculeatus*	longsnout butterflyfish	0	0	1
Chaetodontidae	*Chaetodon capistratus*	foureye butterflyfish	1	1	1

Table 4.3 (cont.) - Fish species inventory from the 1999-2000 Dry Tortugas RVC survey denoting binary presence (1) or absence (0) by geographical area (DTNP, Dry Tortugas National Park; BHS, Tortugas Bank, Riley's Hump and Rebecca/Isaac Shoals;MARQ, Marquesas Keys). Species arranged in alphabetical order by Latin name.

Family	Latin Name	Common Name	DTNP	BHS	MARQ
Chaetodontidae	*Chaetodon ocellatus*	spotfin butterflyfish	1	1	1
Chaetodontidae	*Chaetodon sedentarius*	reef butterflyfish	1	1	1
Chaetodontidae	*Chaetodon striatus*	banded butterflyfish	1	1	1
Pomacentridae	*Chromis cyanea*	blue chromis	1	1	1
Pomacentridae	*Chromis enchrysurus*	yellowtail reeffish	1	1	1
Pomacentridae	*Chromis insolata*	sunshinefish	1	1	1
Pomacentridae	*Chromis multilineata*	brown chromis	1	1	1
Pomacentridae	*Chromis scotti*	purple reeffish	1	1	1
Labridae	*Clepticus parrae*	creole wrasse	1	1	1
Clinidae	*Coralliozetus bahamensis*	blackhead blenny	1	0	0
Gobiidae	*Coryphopterus dicrus*	colon goby	1	1	1
Gobiidae	*Coryphopterus eidolon*	pallid goby	1	0	0
Gobiidae	*Coryphopterus glaucofraenum*	bridled goby	1	1	1
Gobiidae	*Coryphopterus personatus*	masked goby	1	1	1
Scaridae	*Cryptotomus roseus*	bluelip parrotfish	1	1	1
Dasyatidae	*Dasyatis americana*	southern stingray	0	1	0
Carangidae	*Decapterus macarellus*	mackerel scad	1	1	0
Carangidae	*Decapterus punctatus*	round scad	0	1	0
Tetraodontidae	*Diodon holocanthus*	balloonfish	1	1	0
Tetraodontidae	*Diodon hystrix*	porcupinefish	1	1	0
Serranidae	*Diplectrum formosum*	sand perch	1	1	1
Sparidae	*Diplodus holbrooki*	spottail pinfish	1	0	0
Echeneidae	*Echeneis naucrates*	sharksucker	1	1	0
Carangidae	*Elagatis bipinnulata*	rainbow runner	1	1	0
Clinidae	*Emblemaria pandionis*	sailfin blenny	1	1	0
Serranidae	*Epinephelus adscensionis*	rock hind	1	1	1
Serranidae	*Epinephelus cruentatus*	graysby	1	1	1
Serranidae	*Epinephelus flavolimbatus*	yellowedge grouper	0	1	0
Serranidae	*Epinephelus fulvus*	coney	1	1	1
Serranidae	*Epinephelus guttatus*	red hind	1	1	1
Serranidae	*Epinephelus itajara*	jewfish	1	0	0
Serranidae	*Epinephelus morio*	red grouper	1	1	1
Serranidae	*Epinephelus striatus*	nassau grouper	1	1	1
Sciaenidae	*Equetus acuminatus*	high-hat	1	1	1
Sciaenidae	*Equetus lanceolatus*	jackknife-fish	1	1	0
Sciaenidae	*Equetus punctatus*	spotted drum	1	1	0

Table 4.3 (cont.) - Fish species inventory from the 1999-2000 Dry Tortugas RVC survey denoting binary presence (1) or absence (0) by geographical area (DTNP, Dry Tortugas National Park; BHS, Tortugas Bank, Riley's Hump and Rebecca/Isaac Shoals;MARQ, Marquesas Keys). Species arranged in alphabetical order by Latin name.

Family	Latin Name	Common Name	DTNP	BHS	MARQ
Sciaenidae	*Equetus umbrosus*	cubbyu	0	0	1
Gerreidae	*Gerres cinereus*	yellowfin mojarra	1	0	0
Rhincodontidae	*Ginglymostoma cirratum*	nurse shark	1	1	1
Gobiidae	*Gnatholepis thompsoni*	goldspot goby	1	1	1
Gobiidae	*Gobionellus stigmalophius*	spotfin goby	0	0	1
Gobiidae	*Gobiosoma evelynae*	sharknose goby	0	1	1
Gobiidae	*Gobiosoma oceanops*	neon goby	1	1	1
Gobiidae	*Gobiosoma xanthiprora*	yellowprow goby	1	1	1
Muraenidae	*Gymnothorax funebris*	green moray	0	1	1
Muraenidae	*Gymnothorax miliaris*	goldentail moray	1	1	0
Muraenidae	*Gymnothorax moringa*	spotted moray	1	1	1
Haemulidae	*Haemulon album*	margate	1	1	1
Haemulidae	*Haemulon aurolineatum*	tomtate	1	1	1
Haemulidae	*Haemulon carbonarium*	ceasar grunt	1	1	1
Haemulidae	*Haemulon chrysargyreum*	smallmouth grunt	1	1	1
Haemulidae	*Haemulon flavolineatum*	french grunt	1	1	1
Haemulidae	*Haemulon macrostomium*	spanish grunt	1	1	1
Haemulidae	*Haemulon melanurum*	cottonwick	1	1	0
Haemulidae	*Haemulon parra*	sailors choice	1	1	1
Haemulidae	*Haemulon plumieri*	white grunt	1	1	1
Haemulidae	*Haemulon sciurus*	bluestriped grunt	1	1	1
Haemulidae	*Haemulon striatum*	striped grunt	0	1	1
Labridae	*Halichoeres bivittatus*	slippery dick	1	1	1
Labridae	*Halichoeres cyanocephalus*	yellowcheek wrasse	1	1	1
Labridae	*Halichoeres garnoti*	yellowhead wrasse	1	1	1
Labridae	*Halichoeres maculipinna*	clown wrasse	1	1	1
Labridae	*Halichoeres pictus*	rainbow wrasse	1	1	0
Labridae	*Halichoeres poeyi*	blackear wrasse	1	1	1
Labridae	*Halichoeres radiatus*	puddingwife	1	1	1
Clinidae	*Hemiemblemaria simulus*	wrasse blenny	0	1	0
Labridae	*Hemipteronotus martinicensis*	rosy razorfish	1	1	0
Labridae	*Hemipteronotus novacula*	pearly razorfish	1	1	0
Labridae	*Hemipteronotus splendins*	green razorfish	1	1	0
Pomacanthidae	*Holacanthus bermudensis*	blue angelfish	1	1	1
Pomacanthidae	*Holacanthus ciliaris*	queen angelfish	1	1	1
Pomacanthidae	*Holacanthus tricolor*	rock beauty	1	1	1
Pomacanthidae	*Holocanthus sp.*	townsend angelfish	1	1	1
Holocentridae	*Holocentrus adscensionis*	squirrelfish	1	1	1
Holocentridae	*Holocentrus rufus*	longspine squirrelfish	1	1	1
Holocentridae	*Holocentrus vexillarius*	dusky squirrelfish	1	1	0

Table 4.3 (cont.) - Fish species inventory from the 1999-2000 Dry Tortugas RVC survey denoting binary presence (1) or absence (0) by geographical area (DTNP, Dry Tortugas National Park; BHS, Tortugas Bank, Riley's Hump and Rebecca/Isaac Shoals;MARQ, Marquesas Keys). Species arranged in alphabetical order by Latin name.

Family	Latin Name	Common Name	DTNP	BHS	MARQ
Blenniidae	*Hypleurochilus bermudensis*	barred blenny	1	1	0
Serranidae	*Hypoplectrus gemma*	blue hamlet	1	1	1
Serranidae	*Hypoplectrus guttavarius*	shy hamlet	0	0	1
Serranidae	*Hypoplectrus indigo*	indigo hamlet	1	1	1
Serranidae	*Hypoplectrus nigricans*	black hamlet	1	1	0
Serranidae	*Hypoplectrus puella*	barred hamlet	1	1	1
Serranidae	*Hypoplectrus tann*	tan hamlet	1	1	1
Serranidae	*Hypoplectrus unicolor*	butter hamlet	1	1	1
Inermiidae	*Inermia vittata*	boga	1	1	0
Gobiidae	*Ioglossus calliurus*	blue goby	1	1	1
Gobiidae	*Ioglossus helenae*	hovering goby	1	1	0
Kyphosidae	*Kyphosus sectatrix*	bermuda chub	1	1	1
Clinidae	*Labrisomus gobio*	palehead blenny	1	0	0
Clinidae	*Labrisomus nuchipinnus*	hairy blenny	1	0	0
Labridae	*Lachnolaimus maximus*	hogfish	1	1	1
Ostraciidae	*Lactophrys bicaudalis*	spotted trunkfish	1	1	0
Ostraciidae	*Lactophrys polygonia*	honeycomb cowfish	1	1	0
Ostraciidae	*Lactophrys quadricornis*	scrawled cowfish	1	1	1
Ostraciidae	*Lactophrys trigonus*	trunkfish	0	0	1
Ostraciidae	*Lactophrys triqueter*	smooth trunkfish	1	1	1
Lutjanidae	*Lutjanus analis*	mutton snapper	1	1	1
Lutjanidae	*Lutjanus apodus*	schoolmaster	1	1	1
Lutjanidae	*Lutjanus buccanella*	blackfin snapper	1	0	0
Lutjanidae	*Lutjanus cyanopterus*	cubera snapper	1	0	0
Lutjanidae	*Lutjanus griseus*	gray snapper	1	1	1
Lutjanidae	*Lutjanus jocu*	dog snapper	1	1	1
Lutjanidae	*Lutjanus mahogoni*	mahogony snapper	1	1	0
Lutjanidae	*Lutjanus synagris*	lane snapper	1	1	0
Malacanthidae	*Malacanthus plumieri*	sand tilefish	1	1	1
Clinidae	*Malacoctenus macropus*	rosy blenny	1	1	0
Clinidae	*Malacoctenus triangulatus*	saddled blenny	1	1	1
Mobulidae	*Manta birostris*	manta	1	0	0
Balistidae	*Melicthys niger*	black durgon	0	1	0
Gobiidae	*Microgobius carri*	seminole goby	1	0	0
Pomacentridae	*Microspathodon chrysurus*	yellowtail damselfish	1	1	1
Balistidae	*Monacanthus ciliatus*	fringed filefish	1	1	0
Balistidae	*Monacanthus hispidus*	planehead filefish	1	0	0
Balistidae	*Monacanthus tuckeri*	slender filefish	1	1	1
Mullidae	*Mulloidichthys martinicus*	yellow goatfish	1	1	1
Muraenidae	*Muraena retifera*	reticulate moray	0	1	0

Table 4.3 (cont.) - Fish species inventory from the 1999-2000 Dry Tortugas RVC survey denoting binary presence (1) or absence (0) by geographical area (DTNP, Dry Tortugas National Park; BHS, Tortugas Bank, Riley's Hump and Rebecca/Isaac Shoals;MARQ, Marquesas Keys). Species arranged in alphabetical order by Latin name.

Family	Latin Name	Common Name	DTNP	BHS	MARQ
Serranidae	*Mycteroperca bonaci*	black grouper	1	1	1
Serranidae	*Mycteroperca interstitialis*	yellowmouth grouper	1	1	1
Serranidae	*Mycteroperca microlepis*	gag	1	1	1
Serranidae	*Mycteroperca phenax*	scamp	1	1	1
Serranidae	*Mycteroperca tigris*	tiger grouper	1	1	0
Serranidae	*Mycteroperca venenosa*	yellowfin grouper	1	1	1
Holocentridae	*Myripristis jacobus*	blackbar soldierfish	0	1	1
Gobiidae	*Nes longus*	orangespotted goby	0	0	1
Lutjanidae	*Ocyurus chrysurus*	yellowtail snapper	1	1	1
Sciaenidae	*Odontoscion dentex*	reef croaker	1	1	0
Blenniidae	*Ophioblennius atlanticus*	redlip blenny	1	0	0
Opistognathidae	*Opistognathus aurifrons*	yellowhead jawfish	1	1	1
Opistognathidae	*Opistognathus whitehursti*	dusky jawfish	1	1	0
Haemulidae	*Orthopristis chrysoptera*	pigfish	0	1	0
Blenniidae	*Parablennius marmoreus*	seaweed blenny	1	1	1
Clinidae	*Paraclinus nigripinnis*	blackfin blenny	1	0	0
Callionymidae	*Paradiplogrammus bairdi*	lancer dragonet	1	1	0
Serranidae	*Paranthias furcifer*	creole-fish	1	1	1
Pomacanthidae	*Pomacanthus arcuatus*	gray angelfish	1	1	1
Pomacanthidae	*Pomacanthus paru*	french angelfish	1	1	1
Pomacentridae	*Pomacentrus diencaeus*	longfin damselfish	1	1	1
Pomacentridae	*Pomacentrus fuscus*	dusky damselfish	1	1	0
Pomacentridae	*Pomacentrus leucostictus*	beaugregory	1	1	1
Pomacentridae	*Pomacentrus partitus*	bicolor damselfish	1	1	1
Pomacentridae	*Pomacentrus planifrons*	threespot damselfish	1	1	1
Pomacentridae	*Pomacentrus variabilis*	cocoa damselfish	1	1	1
Priacanthidae	*Priacanthus arenatus*	bigeye	1	1	0
Priacanthidae	*Priacanthus cruentatus*	glasseye snapper	1	1	1
Gobiidae	*Priolepis hipoliti*	rusty goby	1	0	0
Lutjanidae	*Pristipomoides aquilonaris*	wenchman	1	0	0
Mullidae	*Pseudupeneus maculatus*	spotted goatfish	1	1	1
Serranidae	*Rypticus saponaceus*	greater soapfish	0	0	1
Blenniidae	*Scartella cristata*	molly miller	1	1	1
Scaridae	*Scarus coelestinus*	midnight parrotfish	1	1	1
Scaridae	*Scarus coeruleus*	blue parrotfish	1	1	1
Scaridae	*Scarus croicensis*	striped parrotfish	1	1	1
Scaridae	*Scarus guacamaia*	rainbow parrotfish	1	1	1
Scaridae	*Scarus taeniopterus*	princess parrotfish	1	1	1
Scaridae	*Scarus vetula*	queen parrotfish	1	1	1
Scombridae	*Scomberomorus cavalla*	king mackerel	1	1	0

Table 4.3 (cont.) - Fish species inventory from the 1999-2000 Dry Tortugas RVC survey denoting binary presence (1) or absence (0) by geographical area (DTNP, Dry Tortugas National Park; BHS, Tortugas Bank, Riley's Hump and Rebecca/Isaac Shoals;MARQ, Marquesas Keys). Species arranged in alphabetical order by Latin name.

Family	Latin Name	Common Name	DTNP	BHS	MARQ
Scombridae	*Scomberomorus maculatus*	spanish mackerel	1	0	1
Scombridae	*Scomberomorus regalis*	cero	1	1	1
Scorpaenidae	*Scorpaena plumieri*	spotted scorpionfish	0	1	0
Carangidae	*Seriola dumerili*	greater amberjack	1	1	1
Carangidae	*Seriola rivoliana*	almaco jack	1	1	1
Serranidae	*Serranus annularis*	orangeback bass	0	1	0
Serranidae	*Serranus baldwini*	lantern bass	1	1	1
Serranidae	*Serranus phoebe*	tattler	0	1	0
Serranidae	*Serranus tabacarius*	tobaccofish	1	1	1
Serranidae	*Serranus tigrinus*	harlequin bass	1	1	1
Serranidae	*Serranus tortugarum*	chalk bass	1	1	1
Scaridae	*Sparisoma atomarium*	greenblotch parrotfish	1	1	1
Scaridae	*Sparisoma aurofrenatum*	redband parrotfish	1	1	1
Scaridae	*Sparisoma chrysopterum*	redtail parrotfish	1	1	1
Scaridae	*Sparisoma radians*	bucktooth parrotfish	1	1	1
Scaridae	*Sparisoma rubripinne*	redfin parrotfish	1	1	1
Scaridae	*Sparisoma viride*	stoplight parrotfish	1	1	1
Tetraodontidae	*Sphoeroides spengleri*	bandtail puffer	1	1	1
Tetraodontidae	*Sphoeroides testudineus*	checkered puffer	1	0	0
Sphyraenidae	*Sphyraena barracuda*	great barracuda	1	1	1
Sphyraenidae	*Sphyraena guachancho*	guaguanche	1	0	0
Bothidae	*Syacium micrurum*	channel flounder	1	0	0
Synodontidae	*Synodus foetens*	inshore lizardfish	0	1	0
Synodontidae	*Synodus intermedius*	sand diver	1	1	0
Labridae	*Thalassoma bifasciatum*	bluehead	1	1	1
Carangidae	*Trachinotus falcatus*	permit	1	1	0
Urolophidae	*Urolophus jamaicensis*	yellow stingray	1	1	0

Table 4.4 - Number of species, families, and species apparently unique to geographical area as determined by the 1999-2000 Dry Tortugas reef fish visual surveys. DTNP is Dry Tortugas National Park. BHS is the combined areas of Tortugas Bank, Little Bank, Riley's Hump, and Rebecca-Isaacs Shoals. MARQ is the Marquesas region.

	DTNP	BHS	MARQ	Total
Species	192	190	142	224
Families	42	40	32	46
Unique Species	25	16	8	

Table 4.5 - Draft list of marine and estuarine fish stocks at risk in the Tortugas region and surrounding waters.Source: Tom Schmidt, NPS. Superscript [1] by common name indicates species were not observed in RVC surveys.

Family	Common Name	Scientific Name	Habitat	Protection Criteria
Acanthuridae	Gulf surgeonfish[1]	*Acanthurus randalli*	Coral, seagrass	AFS vulnerable
Balistidae	Queen triggerfish[1]	*Balistes vetula*	Coral reefs	IUCN vulnerable
Carcharhinidae	Blacktip shark[1]	*Carcharhinus limbatus*	Coastal bays and reefs	IUCN vulnerable
Carcharhinidae	Dusky shark[1]	*Carcharhinus obscurus*	Coral, grassbeds	IUCN endangered
Centropomidae	Swordspine snook[1]	*Centropomus ensiferus*	Mangrove, estuarine	AFS vulnerable
Centropomidae	Fat snook[1]	*Centropomus parallelus*	Mangrove, estuarine	AFS vulnerable
Centropomidae	Tarpon snook[1]	*Centropomus pectinatus*	Mangrove, estuarine	AFS vulnerable
Gobiidae	Spot-tail goby[1]	*Gobionellus stigmaturus*	Seagrass, tidal flats	AFS vulnerable
Gobiidae	Orangespotted goby	*Nes longus*	Mud and sand bottoms	AFS vulnerable
Labridae	Hogfish	*Lachnolaimus maximus*	Coral reefs, seagrass	IUCN vulnerable
Lutjanidae	Mutton snapper	*Lutjanus analis*	Coral reefs, seagrass	IUCN vulnerable
Lutjanidae	Cubera snapper	*Lutjanus cyanopterus*	Coral reefs, seagrass	IUCN vulnerable
Myliobatidae	Spotted eagle ray	*Aetobatus narinari*	Coastal bays and reefs	State of Florida protected
Pristidae	Smalltooth sawfish[1]	*Pristis pectinata*	Coastal bays	IUCN/AFS endangered, FL protected
Scaridae	Rainbow parrotfish	*Scarus guacamia*	Coral reefs, seagrass	IUCN vulnerable
Sciaenidae	Blue croaker[1]	*Bairdella batabana*	hardbottoms, seagrass	AFS vulnerable
Scombridae	Bluefin tuna[1]	*Thunnus thynnus*	Oceanic	IUCN endangered
Serranidae	Speckled hind[1]	*Epinephelus drummondhayi*	Coral reefs	IUCN/AFS critically endangered
Serranidae	Yellowedge grouper	*Epinephelus flavolimbatus*	Coral reefs	AFS endangered
Serranidae	Goliath grouper (formerly Jewfish)	*Epinephelus itajara*	Coral reefs, mangroves	AFS endangered, U.S./FL protected
Serranidae	Marbled grouper[1]	*Epinephelus inermis*	Coral reefs	IUCN vulnerable
Serranidae	Warsaw grouper[1]	*Epinephelus nigritus*	Coral reefs, hardbottoms	IUCN/AFS critically endangered
Serranidae	Snowy grouper[1]	*Epinephelus niveatus*	offshore hardbottoms	IUCN/AFS vulnerable
Serranidae	Nassau grouper	*Epinephelus striatus*	Coral reefs, seagrass	AFS/IUCN threatened, U.S./FL protected
Serranidae	Blue hamlet	*Hypoplectus gemma*	Coral reefs	AFS vulnerable
Serranidae	Black grouper	*Mycteroperca bonaci*	Coral reefs, hardbottoms	AFS vulnerable
Serranidae	Yellowmouth grouper	*Mycteroperca interstitialis*	Coral reefs, hardbottoms	AFS vulnerable
Serranidae	Gag grouper	*Mycteroperca microlepis*	Coral reefs, seagrass	AFS/IUCN vulnerable
Serranidae	Scamp	*Mycteroperca phenax*	Coral reefs, hardbottoms	AFS vulnerable
Syngnathidae	Fringed pipefish[1]	*Anarchopterus cringer*	Seagrass	AFS vulnerable
Syngnathidae	Lined seahorse[1]	*Hippocampus erectus*	Seagrass	IUCN vulnerable
Syngnathidae	Longsnout seahorse[1]	*Hippocampus reidi*	Seagrass	AFS/IUCN vulnerable
Syngnathidae	Dwarf seahorse[1]	*Hippocampus zosterae*	Seagrass	AFS/IUCN vulnerable
Syngnathidae	Oppossum pipefish[1]	*Microphis brachyurus*	Seagrass	AFS vulnerable

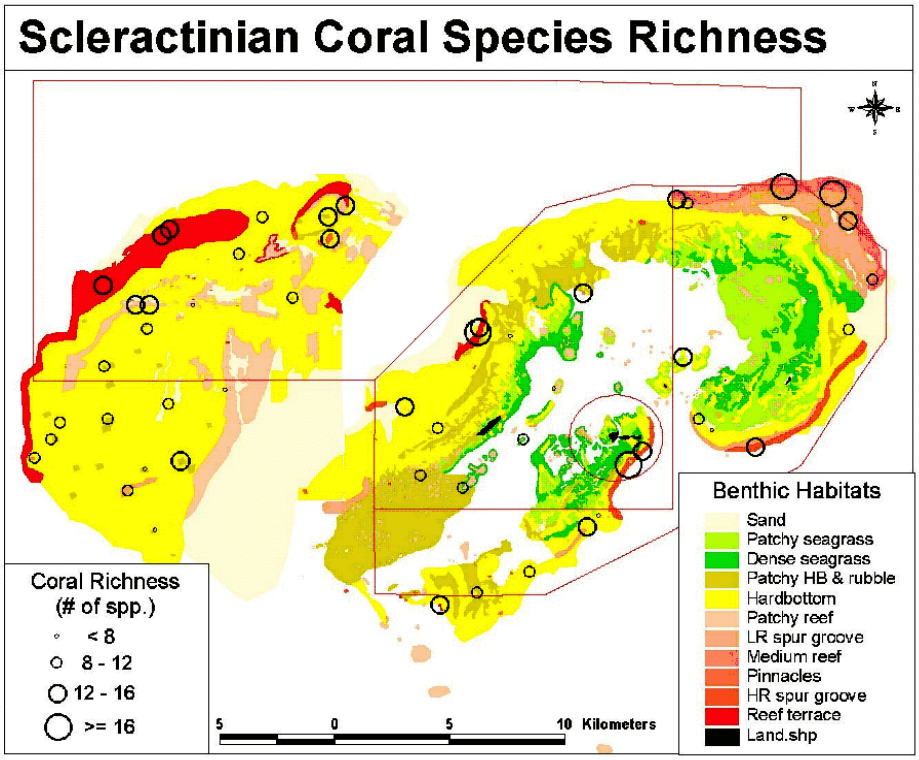


Figure 4.1 - Scleractinian coral species richness for the Tortugas region.

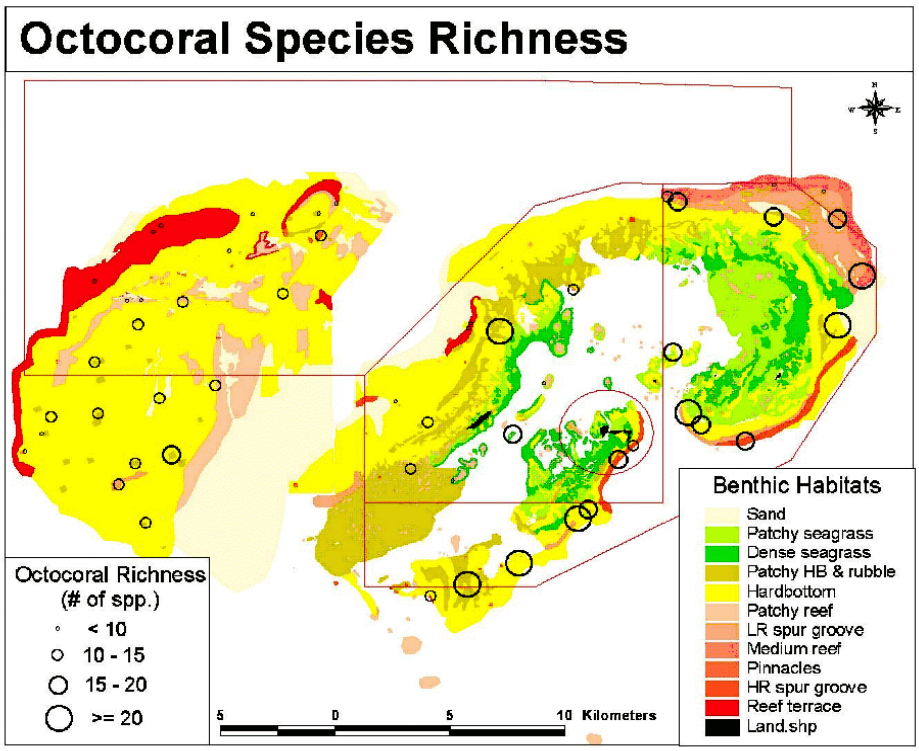


Figure 4.2 - Octocoral species richness for the Tortugas region.

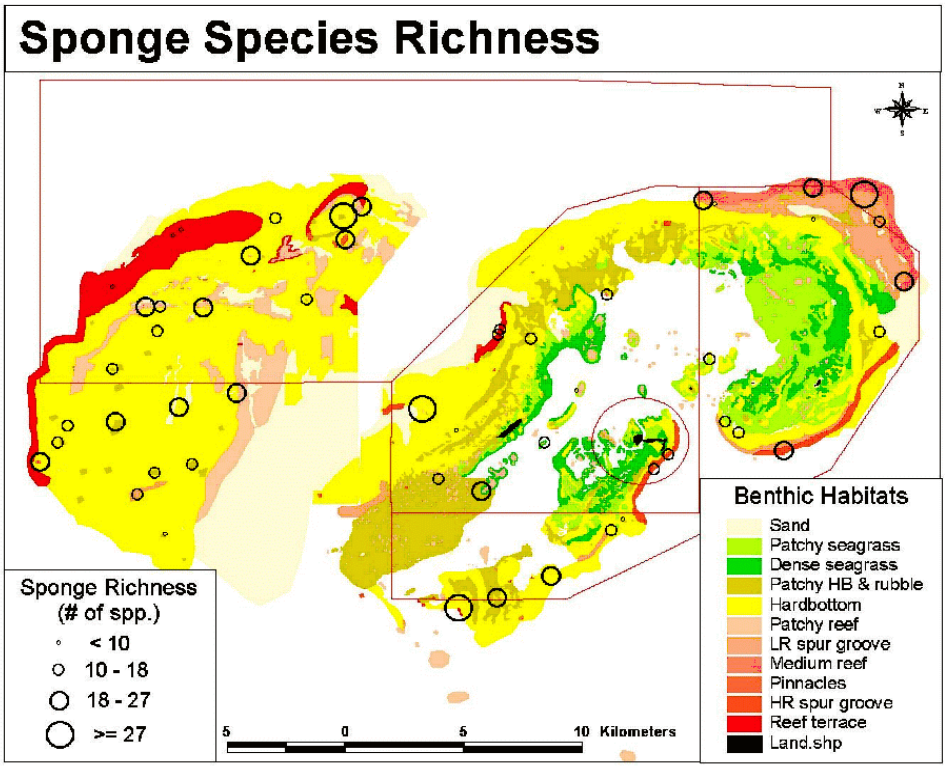


Figure 4.3 - Sponge species richness for the Tortugas region.

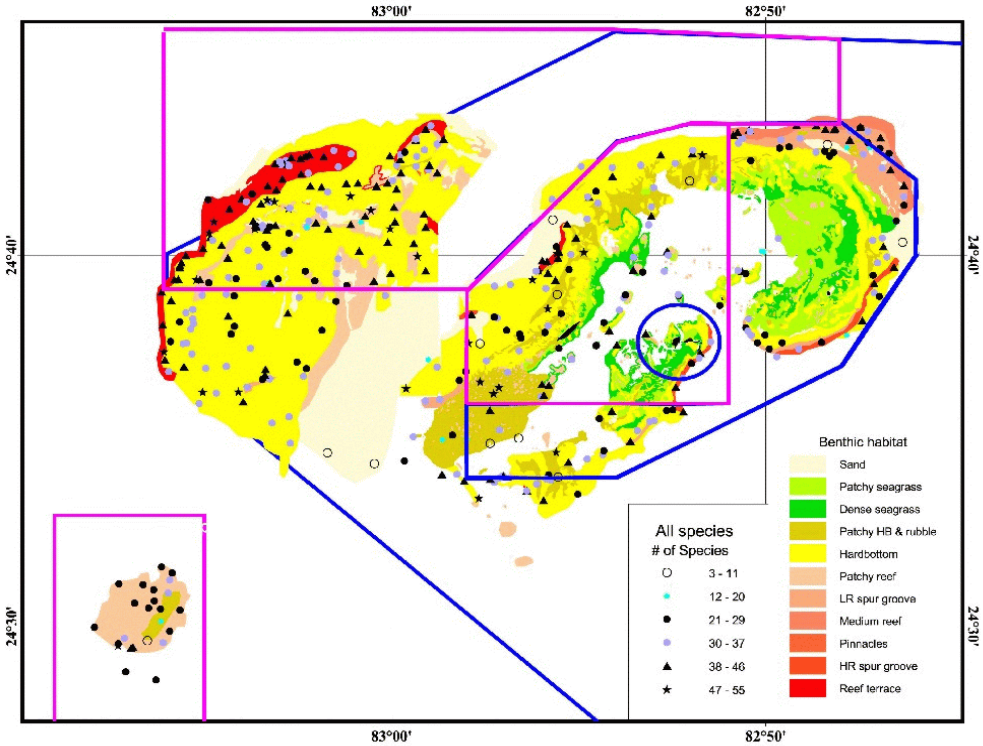


Figure 4.4 - Diversity of Tortugas region fish community (number of species per surveyed primary sampling unit, 1999-2000) overlain on digital map of benthic habitats.

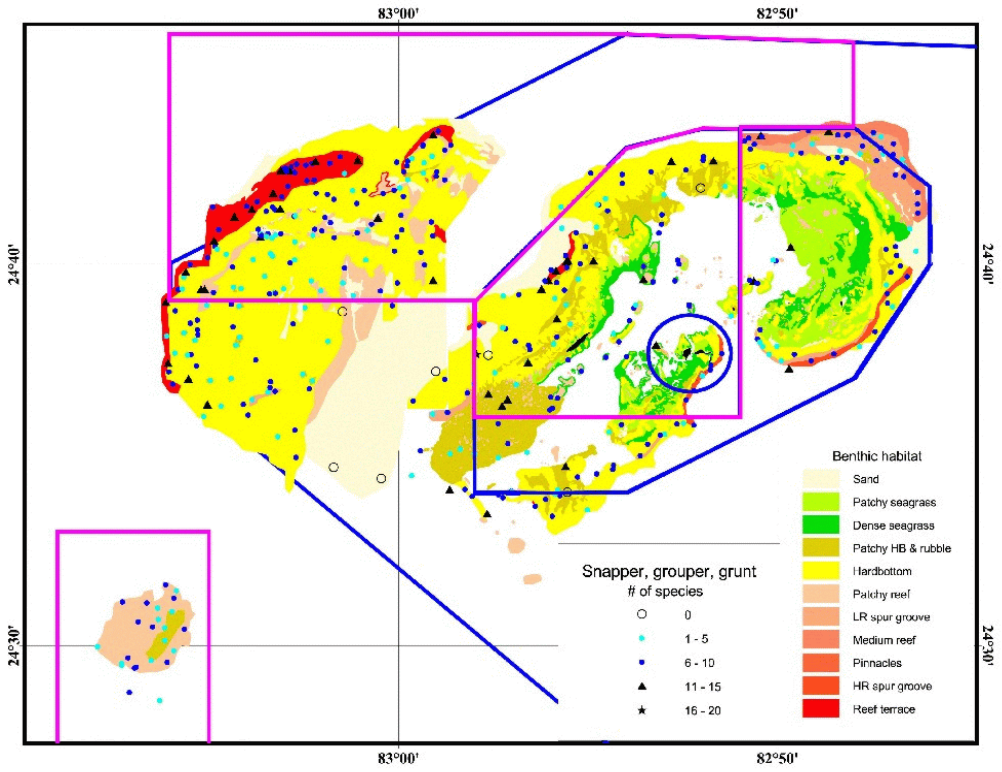


Figure 4.5 - Diversity of Tortugas region snapper-grouper-grunt complex (number of species per surveyed primary sampling unit, 1999-2000) overlain on digital map of benthic habitats.

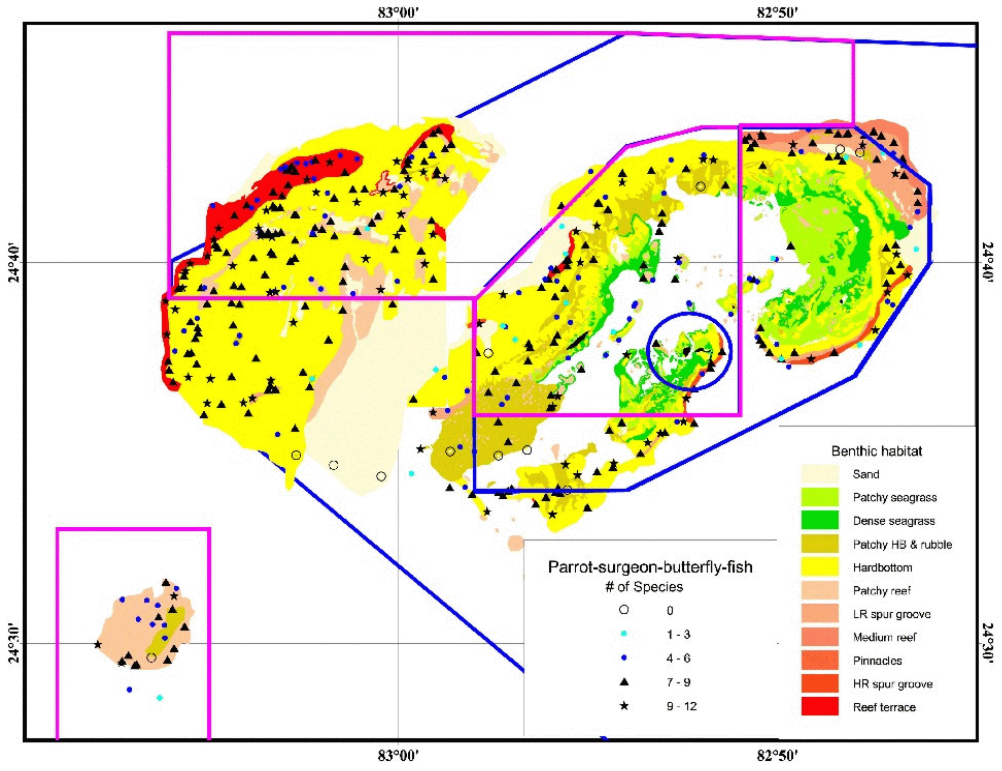


Figure 4.6 - Diversity of Tortugas region parrotfish-surgeonfish-butterflyfish complex (number of species per surveyed primary sampling unit, 1999-2000) overlain on digital map of benthic habitats.

species observed by divers within a 200 m by 200 m primary sampling unit. As a general rule, diversity was highest in the most complex reef habitats and lowest in areas with little or no reef substrate. This held true for the reef community at large (**Figure 4.4**), as well as for the snapper-grouper-grunt complex (**Figure 4.5**) and various herbivore complexes (**Figures 4.6** and **4.7**).

4.3 Diel Migration Patterns

To find the best time period of the day when reef fish are most easily detected by hydroacoustics, we operated the echo sounder at four different time periods: dawn (5-7 am), midday (11 am-1 pm), dusk (6-8 pm), and midnight (11pm-1am). A GIS-based rectangular area was selected as reef survey site (e.g., Sherwood Forest). During each sampling period, the perimeter of the box (about 30 minutes at 3 kts) was surveyed first, followed by four transect lines surveyed inside the box (about 60 min). The same operation was repeated for each of the four time periods. Our experimental survey design produced some very interesting results over a diel cycle. During the day (**Figure 4.8** upper panel, 2-3 pm), schools of fishes were detected just above the reef, while in the water column there were patches of small (purple) targets, presumably plankton. At dusk, the patches of small mid-water targets increased, especially in deeper waters (top right panel, 8-9 pm). At mid-night, the entire water column was crowded with organisms (possibly plankton, mysids, and pink shrimp). At dawn, things started to disappear, presumably back into the reef. By noon, the previous day's pattern re-emerged.

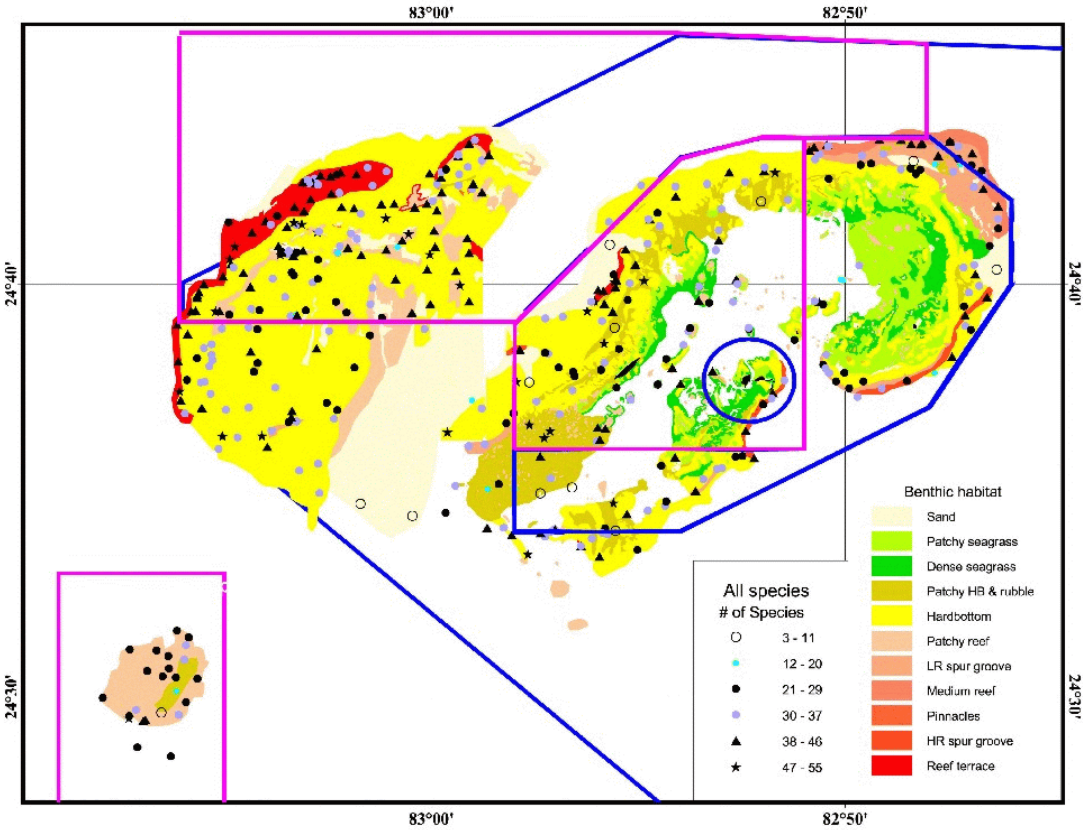


Figure 4.7 - Diversity of Tortugas region angelfish-triggerfish complex (number of species per surveyed primary sampling unit, 1999-2000) overlain on digital map of benthic habitats.

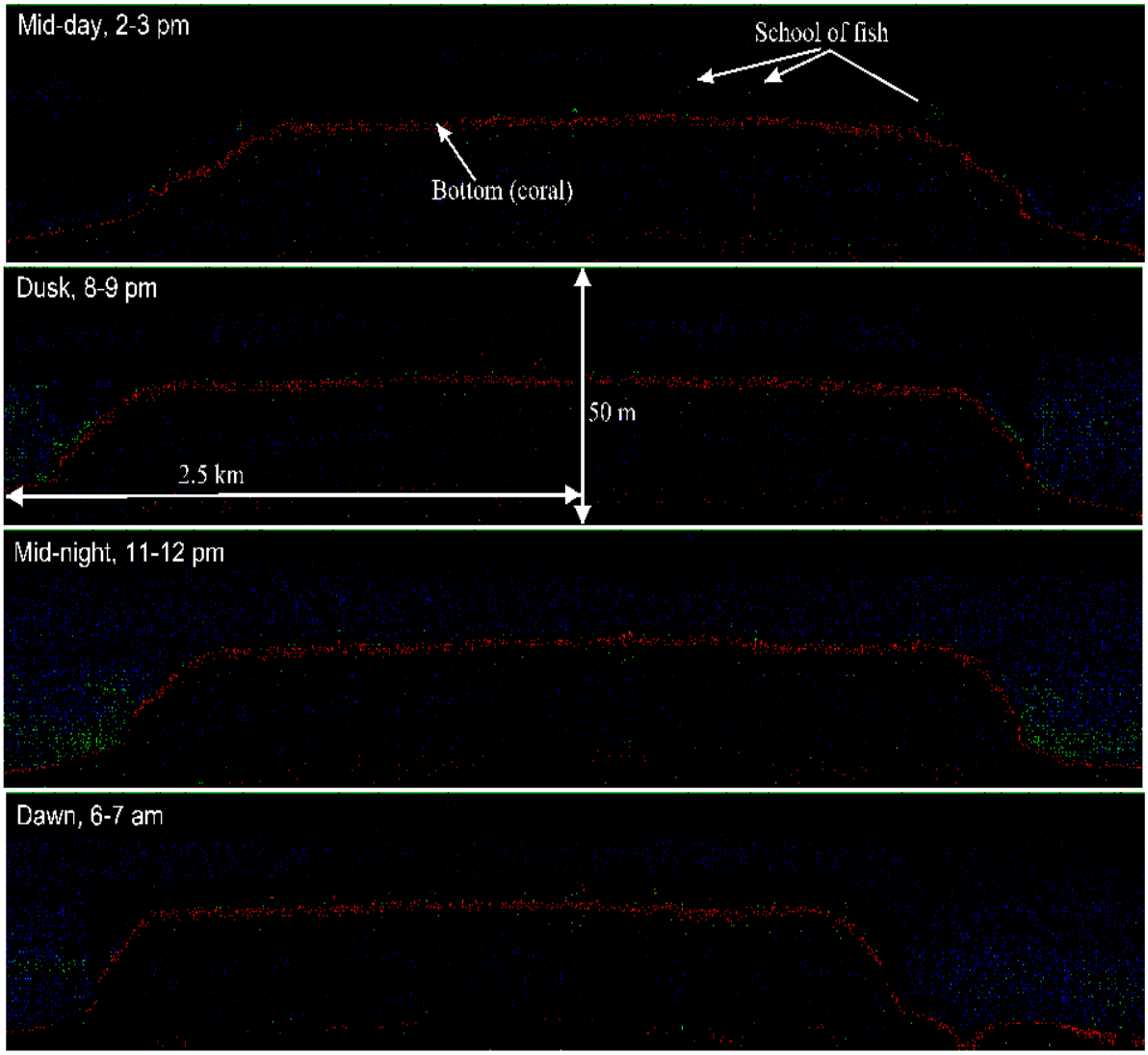


Figure 4.8 - Visual output from echo sounder surveys illustrating diel migration patterns of the resident coral reef fish community

5.0 Fishery Overview and Statistical Estimation of Stock Status Indices

In this section we review scientific and technical literature and analyze a host of fishery-dependent and fishery-independent databases on fishery resources in the Dry Tortugas and the broader Florida Keys region. These results were then used to facilitate evaluation of the current and historical levels of fishery catch and effort. From the development of statistical methods to estimate the spatial abundance, species size structure, and population biomass in the survey domain outlined in Section 4.0, we also used the RVC data to estimate CPUE (catch-per-unit-effort) and $\overline{L}$ (average length of exploited phase individuals), two principal population statistics or indicator variables essential to the conduct of quantitative fish stock assessments.

5.1 Growth in Regional Human Populations and Fishing Fleets

South Florida reef fish stocks in the Florida Keys and Dry Tortugas are exploited by large and diverse commercial and recreational fleets. These fleets have experienced dramatic growth over the last several decades (1964-1998) in both absolute numbers of registered vessels and in the relative "fishing power" of each of those vessels. The recreational fleet has grown significantly since 1964 (**Figure 5.1**). In Monroe County, the number of registered vessels increased 9.52 times between 1964 (2,242 vessels) and 1998 (21,336). The five county area of south Florida that includes Dade, Monroe, Collier, Broward and Palm Beach counties, experienced a 444% increase in the nominal fishing effort (i.e., number of registered vessels) over the same period of time (37,435 in 1964 to 166,343 in 1998). The commercial fleets have also grown over that same period, with a 1.91 times increase in the number of vessels registered in Monroe County (2,311 to 4,414), versus a 1.97 factor increase in the five county area (5,316 to 10,465). The growth of the fishing fleets is directly correlated with the growth of human populations in Florida (**Figure 5.2**). The Sunshine State has experienced explosive growth over the past 160 years. During 1960 to 2000 Florida's human population grew an astounding 223% (from 4.95 to 15.98 million persons)!

During this same period, in addition to the sheer increase in both recreational and commercial fleet sizes, the relative effective vessel "fishing power" of these fleets has quadrupled due to better hydroacoustics (fish finders and depth gauges), global positioning systems (GPS), improved vessel designs and propulsion systems, air conditioning, and more advanced and effective communication networks utilized by both recreational and commercial fishermen (Bohnsack and Ault 1996, Mace 1997). These increases in fleets sizes and effective fishing power have not only directly impacted multispecies fishery stocks through exploitation in DTNP and the Tortugas region, but have had negative indirect impacts through habitat degradation and destruction (Rothschild et al. 1994, Ault et al. 1997b). These conditions have fueled widespread user conflicts between recreational and commercial fishermen in south Florida waters through interactions precipitated by intensive use of gillnets, excessive bycatch from shrimp trawls for food and "bait", and over-use of baitfish resources compromising the sensitive ecological balance of predator-prey dynamics. Serious concern has arisen because of documented "serial overfishing" and continued decline of reef fishery resources in the Florida Keys (Bohnsack et al. 1994, Ault et al. 1997a, 1998, 2001ab).

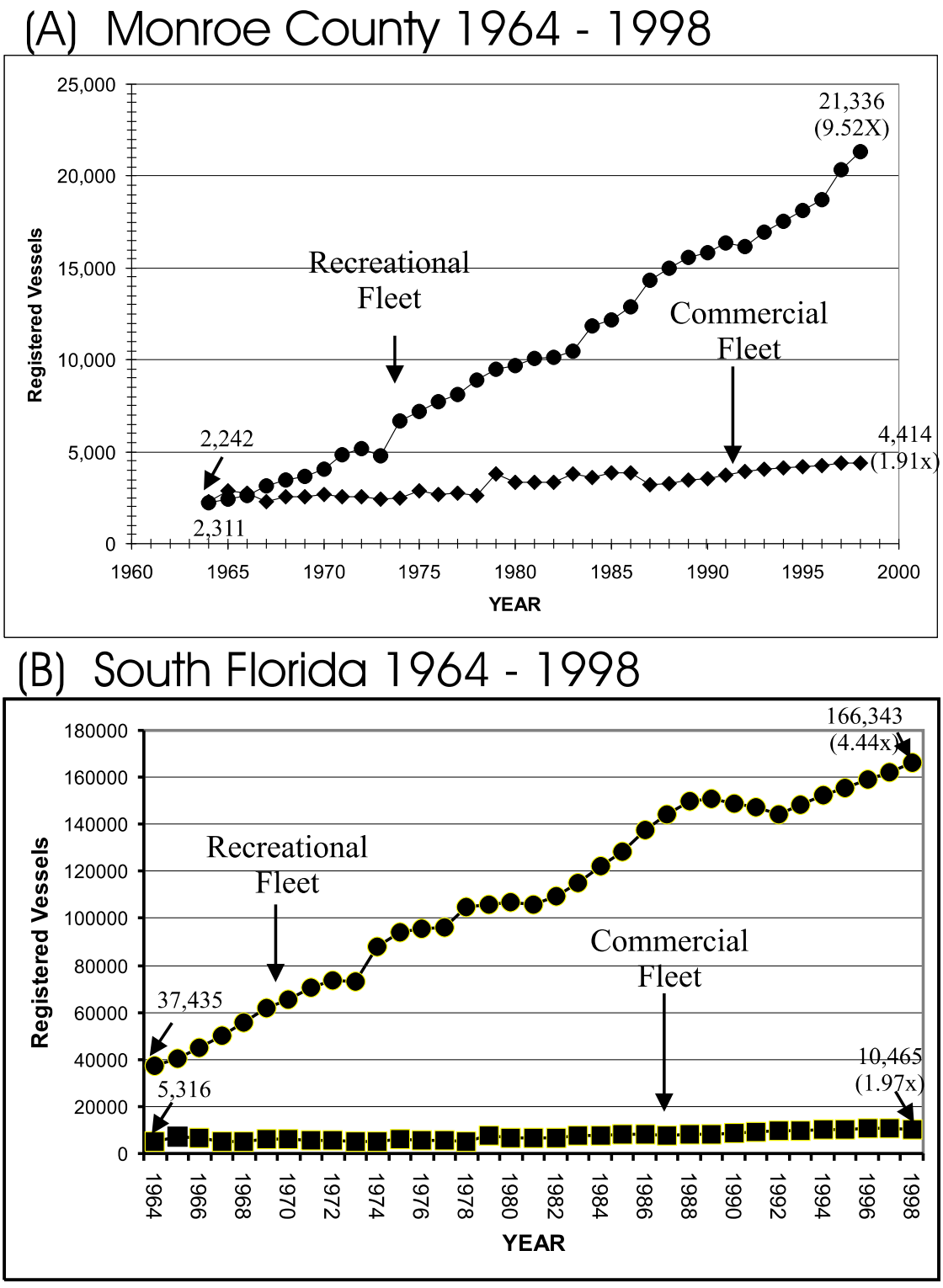


Figure 5.1 - Time series of two types of nominal fishing effort directed at Dry Tortugas reef fish from 1964 to 1998 based on recreational (dark circles) and commercial (dark square) vessels registered in: (A) Monroe County; and, (B) South Florida (Broward, Collier, Dade, Monroe and Palm Beach counties). Source: National Marine Fisheries Service SEFSC.

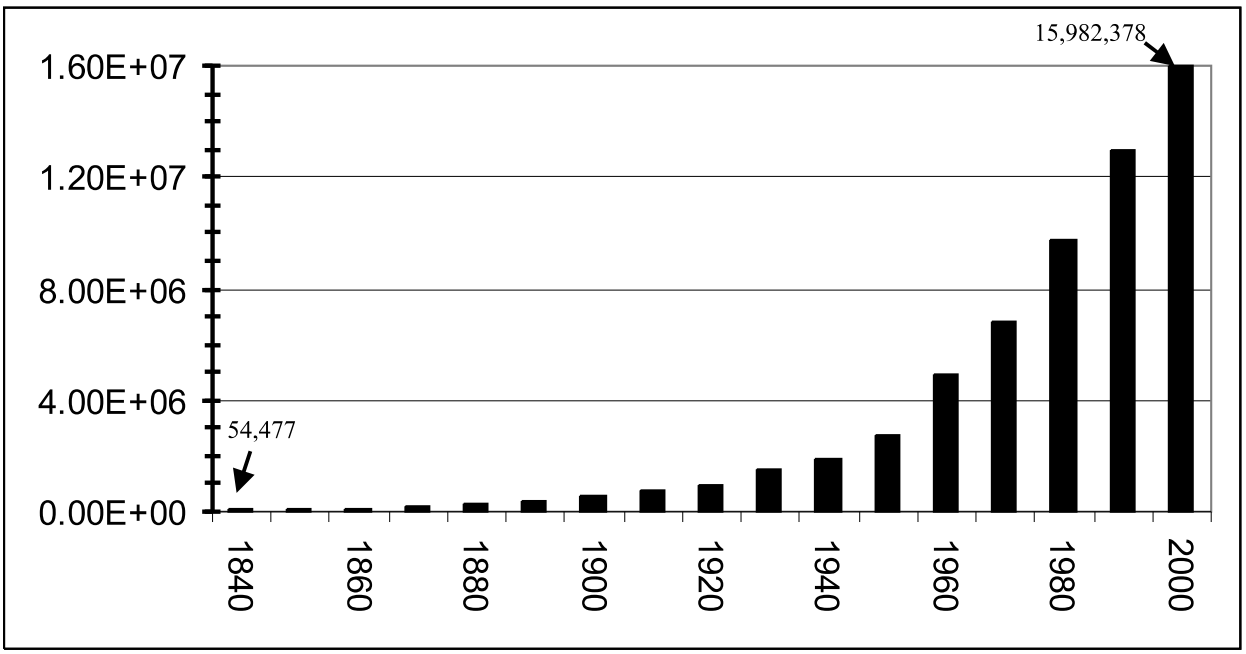


Figure 5.2 - The Sunshine State has experienced explosive growth over the past 160 years, making Florida the fourth largest state in the nation. State's human population has grown 223% since 1960. Source: U.S. Census Bureau.

5.2 Size at First Capture Restrictions

To stem the tide of decreasing fisheries catches and resource productivity, the principal methods used by fishery resource managers for regulating and controlling fisheries impacts has traditionally been fish minimum size and fishing effort restrictions. Implementation of minimum size restrictions sets lower bounds on the sizes of fish allowed to be captured and in catches of the commercial and recreational fleets. The history of implementation and use of minimum size regulations in south Florida and the Florida Keys is shown in **Table 5.1.** The fishery management system for south Florida and the Florida Keys was *laissez faire* prior to management measures implemented by the South Atlantic Fishery Management Council in 1983. In 1985 the Florida Marine Fisheries Commission was formed and began implementation of a series of size, bag limit and gear restrictions (**note:** the history of Florida regulations is listed at http://www.dep.state.fl.us/mfc/MFC-rule-hist.htm). Some notable changes in size regulations pertaining to the reef fish complex are as follows. In 1985 (due to observed reductions in catches) 18 inch minimum size limits were set for several groupers (jewfish, red, nassau, black, gag, yellowfin), and 12 inch limits were set for several snappers (mutton, red, yellowtail). By 1990, non-response of the jewfish stock to recovery by any conventional management efforts prompted a complete catch moratorium, which is still in effect today. In 1990, the red snapper size limit was increased to 13" (20" in 1992), and the FMC added schoolmaster (10"), blackfin, gray, dog, lane, silk, vermillion and queen snappers. Also in 1990, most groupers (and additionally yellowmouth and scamp) had minimum size limits increased to 20 inches. Hogfish size limits were set at 12" in 1994.

Normally, size restrictions are implemented to prevent "growth overfishing" and to prevent capture of individual species of fish before they have reached their individual maximum potential to produce yields (in weight) to the fishery. Variations in setting minimum size limits relates to the fact that different species (and taxa) grow at different rates and reach different maximum sizes (e.g., groupers grow to much larger sizes than grunts and are substantially older). But probably a more important aspect of the setting of minimum sizes relates to the potential production of future generations of fish by the mature parent stock. That is, the minimum size of first capture by the fishery should ideally be set higher than the first size of sexual maturity to ensure that each fish has a chance to produce offspring at least once in its lifetime.

5.3 Indicator Variables of Population (Fish Stock) Status

To understand the effects of fishing and environmental changes on fishery resources requires identification of a quantitative measure that reflects the status of a population subjected to fishing or other environmental changes, that is, a stock assessment indicator variable. Because reef fishes use various habitats over their lifetime, a robust measure of population "health" or status can provide a sensitive indicator of direct and indirect stress on the stock, and perhaps the regional marine ecosystem (Fausch et al. 1990). The 1999 and 2000 diver visual surveys were utilized to produce annual estimates of two biological indicators, average density of species lifestages and average length of exploited phase individuals ($\overline{L}$) for 64 exploited and/or ecologically important species in the Dry Tortugas region.

Table 5.1 - Fishing regulations promulgated by SAFMC and FLFMC from 1985-present. Regulations shown are the minimum size of capture (in inches), and the year in which The size limit is implemented. The last column shows the current restrictions. Ranges indicate size slot limits, and 'moratorium' means that the fishery for the species is completely closed.

	1983	1984	1985	1987	1989	1990	1992	1994	1996	1998	1999	2000	Current
Groupers													
Goliath			18			moratorium							closed
Red	12"		18			20							20
Nassau	12"		18			20					moratorium		closed
Black			18			20					24		24
Yellowmouth						20							20
Gag			18			20					24		24
Scamp						20							20
Yellowfin			18			20							20
Black Sea Bass			8								10		10
Southern Sea Bass			8										8
Snappers													
Mutton Snapper			12					16					16
Schoolmaster						10							10
Blackfin						12							12
Red Snapper	12"		12			13	20						20
Yellowtail Snapper			12										12
Cubera						12							12
Gray						10							10
Dog						12							12
Mahogany						12							12
Lane						8							8
Silk						12							12
Vermillion						8	10-20			10	11		11
Hogfish								12					12
Queen						12							12
Pelagics and Others													
Gray Trigger								12					12
Permit									10-20				10-20
Pompano					10				10-20				10-20
African Pompano									24				24
King Mackerel								20				24	24
Spanish Mackerel											12		12
Amberjack						28							28
Lesser Amberjack										14-20		14-22	14-22
Red Porgy								12					12
Snook			24							26-34			26-34
Lobster				3									3
Spotted Sea Trout					14-24							15-20	15-20
Tripletail									15				15

5.4 Species Density by Life Stage

Annual mean density (equation 3.6) was estimated using the methodology described in Section 3.1. Estimation was carried out for three life stages of each species, juvenile ($<L_m$), adult ($\geq L_m$), and exploited ($\geq L_c$), as defined by the following length intervals:

Life History Phase	Interval	Description
Juvenile Phase	L_r –> L_m	Immature juveniles from the size of first recruitment to the size of first sexual maturity.
Mature Adult Phase	L_m –> L	Size of first sexual maturity to the maximum size in the stock.
Exploited Phase	L_c –> L	Size of first capture to the maximum size in the stock.

These intervals reflect logical ontogenetic groupings that pattern animals in space and time over the Tortugas region seascape. Samples taken in sand habitats were excluded from analysis. The number of primary sampling units *n* and diver stations *nm* used in the computations are listed by year and geographical area in **Table 5.2**.

Density estimates for the region encompassing DTNP and Tortugas Bank are given in **Table 5.3.** These are the complete results for the stratification scheme analyzed above for survey design performance (section 3.2, **Table 3.3**). Density estimates by geographical area are provided in **Tables 5.4**, **5.5**, and **5.6** for DTNP, Tortugas Bank, and Riley's Hump, respectively. The most abundant juvenile groupers in DTNP (**Table 5.4**) and Tortugas Bank (**Table 5.5**) were red grouper, black grouper, scamp, and graysby. Juveniles of these species were also prevalent in Riley's Hump, along with rock hind, red hind, yellowmouth grouper and yellowfin grouper. In terms of adult groupers, red grouper and graysby were prevalent in all three areas, and were the principal species in DTNP. Black grouper adults exhibited moderately low densities in DTNP and Tortugas Bank, but were not observed in Riley's Hump. Red hind adults were observed in moderately low densities in Tortugas Bank and Riley's Hump but not in DTNP. Adults of some species were only observed in a particular area, e.g., yellowmouth grouper in Tortugas Bank, coney in Riley's Hump. In general, however, densities of adults were very low or zero for most grouper species in the three areas.

Among snapper species, juveniles and adults of both gray and yellowtail snapper exhibited the highest densities in DTNP and Tortugas Bank. Hogfish adults were also abundant in both of these areas, but hogfish juveniles exhibited higher densities in DTNP compared to Tortugas Bank. In the Riley's Hump area, gray snapper juveniles and adults were quite abundant, and adults of mutton snapper and hogfish were moderately abundant. For juvenile grunts, white grunt, french grunt, and tomtate were most abundant in DTNP and Tortugas Bank, whereas bluestriped and striped grunt predominated in Riley's Hump. White grunt and tomtate adults exhibited highest densities in DTNP and Tortugas Bank, but not Riley's Hump. French grunt adults, in contrast, were in highest densities in Tortugas Bank and Riley's Hump but not in DTNP. Adult porkfish were moderately abundant only in Tortugas Bank, whereas bluestriped grunt adults exhibited high densities only in Riley's Hump.

Table 5.2 - Two-stage stratified random survey sample sizes in the: **(A)** Tortugas by region and year; and, **(B)** inside and outside the RNA within DTNP for pooled years 1999 and 2000.

(A) Tortugas Region.-

	1999			2000		
Region	**No. of Strata**	***n***	***nm***	**No. of Strata**	***n***	***nm***
DTNP	9	78	151	9	124	228
Tortugas Bank	5	92	175	5	83	153
Riley's Hump	2	24	30	—	—	—

(B) Dry Tortugas National Park (DTNP).-

Region	**No. of Strata**	***n***	***nm***
RNA	9	80	156
Outside RNA	9	120	219

Table 5.3 - Two-stage stratified random survey estimates of mean densities (number per 177 m^2) and associated standard errors for juvenile, adult, and exploited life stages of 64 reef fishes in the region encompassing DTNP and Tortugas Bank during 1999 and 2000. Sample sizes are provided in Table 5.2.

		Juvenile 1999		Juvenile 2000		Adult 1999		Adult 2000		Exploited 1999		Exploited 2000	
Common	Latin	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)
Groupers													
rock hind	*Epinephelus adscensionis*	0.0063	0.0026	0.0022	0.0016	0.0033	0.0013	0.0043	0.0043	0.0086	0.0029	0.0066	0.0046
graysby	*Epinephelus cruentatus*	0.0909	0.0166	0.1249	0.0200	0.0718	0.0169	0.0775	0.0148	0.0718	0.0169	0.0775	0.0148
yellowedge grouper	*Epinephelus flavolimbatus*	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
coney	*Epinephelus fulvus*	0.0039	0.0032	0.0000	0.0000	0.0023	0.0017	0.0063	0.0045	0.0023	0.0017	0.0063	0.0045
red hind	*Epinephelus guttatus*	0.0112	0.0068	0.0058	0.0027	0.0050	0.0028	0.0133	0.0064	0.0088	0.0039	0.0161	0.0067
jewfish	*Epinephelus itajara*	0.0000	0.0000	0.0000	0.0000	0.0003	0.0003	0.0003	0.0002	0.0003	0.0003	0.0003	0.0002
red grouper	*Epinephelus morio*	0.4390	0.0444	0.3787	0.0319	0.1921	0.0258	0.2033	0.0225	0.0820	0.0155	0.1248	0.0192
nassau grouper	*Epinephelus striatus*	0.0044	0.0032	0.0007	0.0007	0.0037	0.0031	0.0000	0.0000	0.0004	0.0004	0.0000	0.0000
black grouper	*Mycteroperca bonaci*	0.1037	0.0215	0.0950	0.0157	0.0050	0.0026	0.0224	0.0183	0.0101	0.0038	0.0249	0.0185
yellowmouth grouper	*Mycteroperca interstitialis*	0.0035	0.0022	0.0188	0.0050	0.0025	0.0013	0.0048	0.0035	0.0011	0.0008	0.0048	0.0035
gag	*Mycteroperca microlepis*	0.0011	0.0008	0.0002	0.0002	0.0000	0.0000	0.0000	0.0000	0.0010	0.0008	0.0000	0.0000
scamp	*Mycteroperca phenax*	0.0635	0.0183	0.1136	0.0302	0.0007	0.0005	0.0007	0.0007	0.0007	0.0005	0.0007	0.0007
tiger grouper	*Mycteroperca tigris*	0.0011	0.0008	0.0075	0.0044	0.0004	0.0004	0.0014	0.0013	0.0014	0.0008	0.0071	0.0050
yellowfin grouper	*Mycteroperca venenosa*	0.0029	0.0017	0.0127	0.0044	0.0000	0.0000	0.0010	0.0010	0.0000	0.0000	0.0010	0.0010
Snappers													
mutton snapper	*Lutjanus analis*	0.0007	0.0007	0.0114	0.0047	0.0540	0.0135	0.1028	0.0243	0.0303	0.0095	0.0578	0.0180
schoolmaster	*Lutjanus apodus*	0.0004	0.0004	0.0000	0.0000	0.0535	0.0182	0.1153	0.0866	0.0277	0.0073	0.0923	0.0722

Table 5.3 (cont.) - Two-stage stratified random survey estimates of mean densities (number per 177 m^2) and associated standard errors for juvenile, adult, and exploited life stages of 64 reef fishes in the region encompassing DTNP and Tortugas Bank during 1999 and 2000. Sample sizes are provided in Table 5.2.

		Juvenile 1999		Juvenile 2000		Adult 1999		Adult 2000		Exploited 1999		Exploited 2000	
Common	Latin	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)
blackfin snapper	*Lutjanus buccanella*	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
yellowtail snapper	*Ocyurus chrysurus*	2.1400	0.3882	3.6457	0.3728	1.8801	0.5311	1.3220	0.2306	0.2069	0.0721	0.2866	0.1000
cubera snapper	*Lutjanus cyanopterus*	0.0000	0.0000	0.0013	0.0013	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0013	0.0013
gray snapper	*Lutjanus griseus*	1.0169	0.6606	0.8264	0.3130	0.7347	0.2424	0.9597	0.5934	0.5484	0.1673	0.6531	0.3979
dog snapper	*Lutjanus jocu*	0.0003	0.0003	0.0000	0.0000	0.0031	0.0016	0.0017	0.0012	0.0031	0.0016	0.0017	0.0012
mahogony snapper	*Lutjanus mahogoni*	0.0000	0.0000	0.0051	0.0026	0.0000	0.0000	0.0036	0.0022	0.0000	0.0000	0.0014	0.0009
lane snapper	*Lutjanus synagris*	0.0903	0.0818	0.0063	0.0050	0.0481	0.0324	0.0107	0.0045	0.0481	0.0324	0.0107	0.0045
hogfish	*Lachnolaimus maximus*	0.1958	0.0747	0.0812	0.0196	0.4377	0.0530	0.3789	0.0424	0.1970	0.0329	0.1568	0.0217
Grunts													
black margate	*Anisotremus surinamensis*	0.0000	0.0000	0.0024	0.0022	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0024	0.0022
porkfish	*Anisotremus virginicus*	0.1398	0.0420	0.2269	0.0788	0.0320	0.0105	0.6168	0.5306	0.0957	0.0258	0.7290	0.5499
margate	*Haemulon album*	0.0126	0.0066	0.0823	0.0582	0.0009	0.0008	0.0059	0.0043	0.0113	0.0056	0.0799	0.0523
tomtate	*Haemulon aurolineatum*	26.152	8.1958	5.8008	1.6550	0.2491	0.2351	1.7000	1.2804	0.2491	0.2351	0.1530	0.1353
ceasar grunt	*Haemulon carbonarium*	0.0038	0.0027	0.1652	0.1595	0.0004	0.0004	0.0032	0.0024	0.0037	0.0024	0.0563	0.0503
smallmouth grunt	*Haemulon chrysargyreum*	0.0000	0.0000	0.1403	0.1159	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
french grunt	*Haemulon flavolineatum*	0.8200	0.4075	0.4332	0.1575	0.0654	0.0286	0.1907	0.1041	0.1007	0.0403	0.2648	0.1233
spanish grunt	*Haemulon macrostomium*	0.2194	0.2159	0.2277	0.2182	0.0029	0.0013	0.1103	0.1062	0.0042	0.0015	0.2856	0.2699
cottonwick	*Haemulon melanurum*	1.1792	1.0362	0.0229	0.0145	0.0000	0.0000	0.0000	0.0000	0.9474	0.9469	0.0000	0.0000
sailors choice	*Haemulon parra*	0.0043	0.0043	0.0068	0.0049	0.0052	0.0037	0.0480	0.0438	0.0052	0.0037	0.0449	0.0409

Table 5.3 (cont.) - Two-stage stratified random survey estimates of mean densities (number per 177 m^2) and associated standard errors for juvenile, adult, and exploited life stages of 64 reef fishes in the region encompassing DTNP and Tortugas Bank during 1999 and 2000. Sample sizes are provided in Table 5.2.

		Juvenile 1999		Juvenile 2000		Adult 1999		Adult 2000		Exploited 1999		Exploited 2000	
Common	Latin	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)
white grunt	*Haemulon plumieri*	3.2726	0.5799	3.6244	0.8259	1.0192	0.2697	1.9280	0.3843	1.2140	0.2952	2.1669	0.4111
bluestriped grunt	*Haemulon sciurus*	0.0682	0.0333	0.0536	0.0250	0.0340	0.0133	0.1375	0.0746	0.0695	0.0251	0.1738	0.0958
striped grunt	*Haemulon striatum*	0.1977	0.1548	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Other Reef Fishes													
great barracuda	*Sphyraena barracuda*	0.0305	0.0091	0.0488	0.0115	0.0447	0.0123	0.0505	0.0122	0.0743	0.0162	0.0987	0.0183
jolthead porgy	*Calamus bajonado*	0.0051	0.0034	0.0043	0.0031	0.0000	0.0000	0.0011	0.0011	0.0004	0.0004	0.0033	0.0024
saucereye porgy	*Calamus calamus*	1.9287	0.1734	1.1191	0.0808	0.0249	0.0093	0.0082	0.0050	0.6102	0.1020	0.3711	0.0490
yellow jack	*Caranx bartholomaei*	0.1227	0.0871	0.0564	0.0202	0.0134	0.0097	0.0341	0.0241	0.1092	0.0786	0.0895	0.0366
blue runner	*Caranx crysos*	0.2358	0.1971	0.2818	0.1677	0.0000	0.0000	0.0046	0.0028	0.0400	0.0229	0.1991	0.1183
crevalle jack	*Caranx hippos*	0.0000	0.0000	0.0102	0.0075	0.0000	0.0000	0.0022	0.0022	0.0000	0.0000	0.0124	0.0077
bar jack	*Caranx ruber*	1.8015	0.7362	1.8872	0.9366	1.2079	0.6388	1.3649	0.5233	1.2079	0.6388	1.3649	0.5233
bermuda chub	*Kyphosus sectatrix*	0.2813	0.2201	0.0408	0.0269	0.0452	0.0340	0.0129	0.0088	0.3265	0.2231	0.0515	0.0264
gray angelfish	*Pomacanthus arcuatus*	0.3639	0.0458	0.3054	0.0338	0.0796	0.0227	0.0398	0.0098	0.0796	0.0227	0.0398	0.0098
blue parrotfish	*Scarus coeruleus*	0.0500	0.0179	0.0582	0.0284	0.0000	0.0000	0.0010	0.0010	0.0000	0.0000	0.0010	0.0010
rainbow parrotfish	*Scarus guacamaia*	0.0346	0.0176	0.0050	0.0031	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
princess parrotfish	*Scarus taeniopterus*	0.1985	0.0675	0.1241	0.0337	0.0188	0.0109	0.0131	0.0048	0.0188	0.0109	0.0131	0.0048
queen parrotfish	*Scarus vetula*	0.0112	0.0059	0.0076	0.0048	0.0050	0.0044	0.0000	0.0000	0.0050	0.0044	0.0000	0.0000
greenblotch parrotfish	*Sparisoma atomarium*	0.6387	0.1541	0.9156	0.1151	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
redband parrotfish	*Sparisoma aurofrenatum*	2.3706	0.6195	1.7920	0.1739	0.4389	0.0834	0.3984	0.0542	0.4389	0.0834	0.3984	0.0542

Table 5.3 (cont.) - Two-stage stratified random survey estimates of mean densities (number per 177 m^2) and associated standard errors for juvenile, adult, and exploited life stages of 64 reef fishes in the region encompassing DTNP and Tortugas Bank during 1999 and 2000. Sample sizes are provided in Table 5.2.

		Juvenile 1999		Juvenile 2000		Adult 1999		Adult 2000		Exploited 1999		Exploited 2000	
Common	Latin	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)
redtail parrotfish	*Sparisoma chrysopterum*	0.0899	0.0333	0.0639	0.0216	0.0778	0.0231	0.0775	0.0283	0.0778	0.0231	0.0775	0.0283
bucktooth parrotfish	*Sparisoma radians*	0.0296	0.0143	0.0289	0.0159	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
redfin parrotfish	*Sparisoma rubripinne*	0.0683	0.0217	0.0617	0.0164	0.0476	0.0200	0.0176	0.0058	0.0476	0.0200	0.0176	0.0058
stoplight parrotfish	*Sparisoma viride*	0.8961	0.1232	0.9816	0.0883	0.0460	0.0116	0.0311	0.0099	0.0460	0.0116	0.0311	0.0099
gray triggerfish	*Balistes capriscus*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0022	0.0022	0.0000	0.0000	0.0022	0.0022
ocean triggerfish	*Cantherhines sufflamen*	0.0026	0.0013	0.0324	0.0141	0.0152	0.0091	0.0633	0.0418	0.0168	0.0093	0.0869	0.0435
doctorfish	*Acanthurus chirurgus*	0.3856	0.0870	0.5318	0.0948	0.1355	0.0268	0.0354	0.0116	0.1348	0.0268	0.0349	0.0114
permit	*Trachinotus falcatus*	0.0002	0.0001	0.0016	0.0016	0.0000	0.0000	0.0007	0.0007	0.0002	0.0001	0.0022	0.0017
king mackerel	*Scomberomorus cavalla*	0.0000	0.0000	0.0021	0.0022	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
spanish mackerel	*Scomberomorus maculatus*	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001
cero	*Scomberomorus regalis*	0.0123	0.0085	0.0108	0.0051	0.0000	0.0000	0.0000	0.0000	0.0123	0.0085	0.0108	0.0051
greater amberjack	*Seriola dumerili*	0.0000	0.0000	0.0004	0.0003	0.0000	0.0000	0.0136	0.0131	0.0000	0.0000	0.0136	0.0131

Table 5.4 - Two-stage stratified random survey estimates of mean densities (number per 177 m^2) and associated standard errors for juvenile, adult, and exploited life stages of 64 reef fishes in DTNP during 1999 and 2000. Sample sizes are provided in Table 5.2.

		Juvenile 1999		Juvenile 2000		Adult 1999		Adult 2000		Exploited 1999		Exploited 2000	
Common	Latin	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)
Groupers													
rock hind	*Epinephelus adscensionis*	0.0027	0.0015	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0016	0.0012	0.0000	0.0000
graysby	*Epinephelus cruentatus*	0.0525	0.0160	0.0536	0.0142	0.0355	0.0151	0.0367	0.0176	0.0355	0.0151	0.0367	0.0176
yellowedge grouper	*Epinephelus flavolimbatus*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
coney	*Epinephelus fulvus*	0.0054	0.0054	0.0000	0.0000	0.0026	0.0026	0.0000	0.0000	0.0026	0.0026	0.0000	0.0000
red hind	*Epinephelus guttatus*	0.0131	0.0108	0.0023	0.0015	0.0000	0.0000	0.0003	0.0003	0.0014	0.0010	0.0014	0.0012
jewfish	*Epinephelus itajara*	0.0000	0.0000	0.0000	0.0000	0.0006	0.0006	0.0005	0.0003	0.0006	0.0006	0.0005	0.0003
red grouper	*Epinephelus morio*	0.4728	0.0642	0.3369	0.0400	0.1894	0.0346	0.1654	0.0273	0.0846	0.0218	0.1139	0.0251
nassau grouper	*Epinephelus striatus*	0.0070	0.0055	0.0012	0.0012	0.0058	0.0054	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
black grouper	*Mycteroperca bonaci*	0.1600	0.0369	0.1331	0.0242	0.0000	0.0000	0.0336	0.0316	0.0031	0.0022	0.0362	0.0317
yellowmouth grouper	*Mycteroperca interstitialis*	0.0000	0.0000	0.0011	0.0011	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
gag	*Mycteroperca microlepis*	0.0006	0.0006	0.0003	0.0004	0.0000	0.0000	0.0000	0.0000	0.0006	0.0006	0.0000	0.0000
scamp	*Mycteroperca phenax*	0.0578	0.0286	0.1545	0.0504	0.0006	0.0006	0.0000	0.0000	0.0006	0.0006	0.0000	0.0000
tiger grouper	*Mycteroperca tigris*	0.0000	0.0000	0.0064	0.0064	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0064	0.0064
yellowfin grouper	*Mycteroperca venenosa*	0.0032	0.0027	0.0078	0.0048	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Snappers													
mutton snapper	*Lutjanus analis*	0.0000	0.0000	0.0105	0.0059	0.0429	0.0151	0.1047	0.0362	0.0164	0.0086	0.0684	0.0287
schoolmaster	*Lutjanus apodus*	0.0000	0.0000	0.0000	0.0000	0.0287	0.0256	0.0049	0.0026	0.0040	0.0022	0.0043	0.0026
blackfin snapper	*Lutjanus buccanella*	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
yellowtail snapper	*Ocyurus chrysurus*	2.8111	0.5514	4.7180	0.6044	1.1363	0.3349	1.3378	0.3498	0.1730	0.0620	0.2520	0.1284
cubera snapper	*Lutjanus cyanopterus*	0.0000	0.0000	0.0023	0.0023	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0023	0.0023

Table 5.4 (cont.) - Two-stage stratified random survey estimates of mean densities (number per 177 m^2) and associated standard errors for juvenile, adult, and exploited life stages of 64 reef fishes in DTNP during 1999 and 2000. Sample sizes are provided in Table 5.2.

		Juvenile 1999		Juvenile 2000		Adult 1999		Adult 2000		Exploited 1999		Exploited 2000	
Common	**Latin**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**
gray snapper	*Lutjanus griseus*	0.5363	0.2354	0.9583	0.4130	0.9090	0.3993	0.4623	0.1576	0.6632	0.2673	0.3245	0.1395
dog snapper	*Lutjanus jocu*	0.0006	0.0006	0.0000	0.0000	0.0041	0.0025	0.0007	0.0007	0.0041	0.0025	0.0007	0.0007
mahogony snapper	*Lutjanus mahogoni*	0.0000	0.0000	0.0054	0.0037	0.0000	0.0000	0.0027	0.0027	0.0000	0.0000	0.0000	0.0000
lane snapper	*Lutjanus synagris*	0.0155	0.0119	0.0109	0.0087	0.0365	0.0306	0.0070	0.0050	0.0365	0.0306	0.0070	0.0050
hogfish	*Lachnolaimus maximus*	0.3175	0.1296	0.1219	0.0330	0.3877	0.0592	0.3383	0.0506	0.1608	0.0268	0.1062	0.0191
Grunts													
black margate	*Anisotremus surinamensis*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
porkfish	*Anisotremus virginicus*	0.1914	0.0689	0.3468	0.1338	0.0271	0.0119	0.1028	0.0714	0.0964	0.0381	0.2506	0.1203
margate	*Haemulon album*	0.0125	0.0085	0.1044	0.0960	0.0001	0.0001	0.0034	0.0032	0.0127	0.0086	0.0934	0.0849
tomtate	*Haemulon aurolineatum*	33.3104	12.9726	7.0677	2.3614	0.0057	0.0057	2.0328	2.0268	0.0057	0.0057	0.0324	0.0272
ceasar grunt	*Haemulon carbonarium*	0.0063	0.0047	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0057	0.0042	0.0000	0.0000
smallmouth grunt	*Haemulon chrysargyreum*	0.0000	0.0000	0.0487	0.0487	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
french grunt	*Haemulon flavolineatum*	1.2503	0.7070	0.2416	0.0876	0.0327	0.0182	0.0560	0.0414	0.0558	0.0215	0.0826	0.0555
spanish grunt	*Haemulon macrostomium*	0.3796	0.3758	0.0117	0.0080	0.0017	0.0012	0.0010	0.0005	0.0025	0.0013	0.0094	0.0076
cottonwick	*Haemulon melanurum*	0.1760	0.1256	0.0379	0.0251	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sailors choice	*Haemulon parra*	0.0000	0.0000	0.0079	0.0076	0.0079	0.0063	0.0010	0.0011	0.0079	0.0063	0.0010	0.0011
white grunt	*Haemulon plumieri*	4.8890	0.9786	5.7641	1.4312	1.3234	0.4610	2.4915	0.5977	1.4795	0.4632	2.8429	0.6448

Table 5.4 (cont.) - Two-stage stratified random survey estimates of mean densities (number per 177 m^2) and associated standard errors for juvenile, adult, and exploited life stages of 64 reef fishes in DTNP during 1999 and 2000. Sample sizes are provided in Table 5.2.

		Juvenile 1999		Juvenile 2000		Adult 1999		Adult 2000		Exploited 1999		Exploited 2000	
Common	**Latin**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**
bluestriped grunt	*Haemulon sciurus*	0.0503	0.0334	0.0714	0.0412	0.0398	0.0196	0.1404	0.1135	0.0879	0.0398	0.1856	0.1511
striped grunt	*Haemulon striatum*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Other Reef Fishes													
great barracuda	*Sphyraena barracuda*	0.0215	0.0093	0.0451	0.0146	0.0428	0.0136	0.0711	0.0204	0.0634	0.0184	0.1151	0.0276
jolthead porgy	*Calamus bajonado*	0.0000	0.0000	0.0038	0.0038	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
saucereye porgy	*Calamus calamus*	2.3631	0.2880	1.3335	0.1233	0.0369	0.0156	0.0100	0.0083	0.7157	0.1718	0.3959	0.0762
yellow jack	*Caranx bartholomaei*	0.0525	0.0284	0.0694	0.0304	0.0215	0.0168	0.0590	0.0419	0.0420	0.0266	0.1267	0.0612
blue runner	*Caranx crysos*	0.3891	0.3427	0.4887	0.2919	0.0000	0.0000	0.0080	0.0048	0.0484	0.0370	0.3447	0.2059
crevalle jack	*Caranx hippos*	0.0000	0.0000	0.0177	0.0130	0.0000	0.0000	0.0038	0.0038	0.0000	0.0000	0.0215	0.0134
bar jack	*Caranx ruber*	2.7547	1.2687	3.0298	1.6263	1.5091	1.0710	1.6257	0.8599	1.5091	1.0710	1.6257	0.8599
bermuda chub	*Kyphosus sectatrix*	0.4672	0.3827	0.0648	0.0464	0.0207	0.0146	0.0009	0.0008	0.4878	0.3836	0.0620	0.0428
gray angelfish	*Pomacanthus arcuatus*	0.3262	0.0581	0.3055	0.0422	0.0921	0.0370	0.0271	0.0092	0.0921	0.0370	0.0271	0.0092
blue parrotfish	*Scarus coeruleus*	0.0129	0.0085	0.0693	0.0407	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
rainbow parrotfish	*Scarus guacamaia*	0.0423	0.0287	0.0087	0.0054	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
princess parrotfish	*Scarus taeniopterus*	0.2322	0.1050	0.0642	0.0194	0.0210	0.0166	0.0061	0.0039	0.0210	0.0166	0.0061	0.0039
queen parrotfish	*Scarus vetula*	0.0052	0.0052	0.0019	0.0013	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
greenblotch parrotfish	*Sparisoma atomarium*	0.4283	0.1128	0.9520	0.1392	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
redband parrotfish	*Sparisoma aurofrenatum*	2.9578	1.0641	2.0214	0.2625	0.3218	0.0484	0.4710	0.0836	0.3218	0.0484	0.4710	0.0836

Table 5.4 (cont.) - Two-stage stratified random survey estimates of mean densities (number per 177 m^2) and associated standard errors for juvenile, adult, and exploited life stages of 64 reef fishes in DTNP during 1999 and 2000. Sample sizes are provided in Table 5.2.

		Juvenile 1999		Juvenile 2000		Adult 1999		Adult 2000		Exploited 1999		Exploited 2000	
Common	**Latin**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**
redtail parrotfish	*Sparisoma chrysopterum*	0.1245	0.0560	0.0875	0.0363	0.0830	0.0338	0.1154	0.0486	0.0830	0.0338	0.1154	0.0486
bucktooth parrotfish	*Sparisoma radians*	0.0396	0.0237	0.0463	0.0274	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
redfin parrotfish	*Sparisoma rubripinne*	0.0941	0.0369	0.1019	0.0283	0.0520	0.0264	0.0289	0.0100	0.0520	0.0264	0.0289	0.0100
stoplight parrotfish	*Sparisoma viride*	0.9240	0.1939	1.0007	0.1040	0.0391	0.0146	0.0300	0.0139	0.0391	0.0146	0.0300	0.0139
gray triggerfish	*Balistes capriscus*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ocean triggerfish	*Cantherhines sufflamen*	0.0034	0.0020	0.0035	0.0030	0.0063	0.0039	0.0002	0.0002	0.0080	0.0046	0.0035	0.0031
doctorfish	*Acanthurus chirurgus*	0.4945	0.1440	0.4732	0.0941	0.1779	0.0422	0.0166	0.0068	0.1779	0.0422	0.0166	0.0068
permit	*Trachinotus falcatus*	0.0003	0.0002	0.0027	0.0027	0.0000	0.0000	0.0000	0.0000	0.0003	0.0002	0.0027	0.0027
king mackerel	*Scomberomorus cavalla*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
spanish mackerel	*Scomberomorus maculatus*	0.0000	0.0000	0.0002	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0002
cero	*Scomberomorus regalis*	0.0215	0.0149	0.0141	0.0085	0.0000	0.0000	0.0000	0.0000	0.0215	0.0148	0.0141	0.0084
greater amberjack	*Seriola dumerili*	0.0000	0.0000	0.0007	0.0006	0.0000	0.0000	0.0235	0.0228	0.0000	0.0000	0.0235	0.0228

Table 5.5 - Two-stage stratified random survey estimates of mean densities (number per 177 m^2) and associated standard errors for juvenile, adult, and exploited life stages of 64 reef fishes in Tortugas Bank during 1999 and 2000. Sample sizes are provided in Table 5.2.

		Juvenile 1999		Juvenile 2000		Adult 1999		Adult 2000		Exploited 1999		Exploited 2000	
Common	Latin	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)
Groupers													
rock hind	*Epinephelus adscensionis*	0.0112	0.0058	0.0053	0.0036	0.0077	0.0031	0.0101	0.0101	0.0180	0.0066	0.0154	0.0107
graysby	*Epinephelus cruentatus*	0.1429	0.0325	0.2211	0.0430	0.1208	0.0341	0.1326	0.0253	0.1208	0.0341	0.1326	0.0253
yellowedge grouper	*Epinephelus flavolimbatus*	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0001	0.0000	0.0000
coney	*Epinephelus fulvus*	0.0019	0.0019	0.0000	0.0000	0.0019	0.0019	0.0147	0.0105	0.0019	0.0019	0.0147	0.0105
red hind	*Epinephelus guttatus*	0.0087	0.0063	0.0106	0.0060	0.0117	0.0066	0.0308	0.0151	0.0187	0.0091	0.0359	0.0156
jewfish	*Epinephelus itajara*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
red grouper	*Epinephelus morio*	0.3934	0.0581	0.4351	0.0520	0.1959	0.0385	0.2544	0.0380	0.0785	0.0215	0.1394	0.0296
nassau grouper	*Epinephelus striatus*	0.0008	0.0008	0.0000	0.0000	0.0008	0.0008	0.0000	0.0000	0.0008	0.0008	0.0000	0.0000
black grouper	*Mycteroperca bonaci*	0.0277	0.0090	0.0434	0.0172	0.0116	0.0061	0.0073	0.0050	0.0194	0.0084	0.0096	0.0073
yellowmouth grouper	*Mycteroperca interstitialis*	0.0081	0.0051	0.0426	0.0117	0.0060	0.0031	0.0112	0.0081	0.0026	0.0019	0.0112	0.0081
gag	*Mycteroperca microlepis*	0.0017	0.0017	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0017	0.0017	0.0000	0.0000
scamp	*Mycteroperca phenax*	0.0712	0.0187	0.0582	0.0202	0.0008	0.0008	0.0016	0.0016	0.0008	0.0008	0.0016	0.0016
tiger grouper	*Mycteroperca tigris*	0.0025	0.0018	0.0090	0.0056	0.0008	0.0008	0.0032	0.0031	0.0034	0.0020	0.0080	0.0078
yellowfin grouper	*Mycteroperca venenosa*	0.0026	0.0019	0.0193	0.0082	0.0000	0.0000	0.0025	0.0023	0.0000	0.0000	0.0025	0.0023
Snappers													
mutton snapper	*Lutjanus analis*	0.0017	0.0017	0.0127	0.0075	0.0690	0.0242	0.1003	0.0293	0.0491	0.0191	0.0435	0.0170
schoolmaster	*Lutjanus apodus*	0.0008	0.0008	0.0000	0.0000	0.0870	0.0254	0.2645	0.2036	0.0598	0.0169	0.2112	0.1696
blackfin snapper	*Lutjanus buccanella*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
yellowtail snapper	*Ocyurus chrysurus*	1.2335	0.5271	2.1972	0.3183	2.8848	1.1637	1.3007	0.2657	0.2527	0.1473	0.3332	0.1584
cubera snapper	*Lutjanus cyanopterus*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 5.5 (cont.) - Two-stage stratified random survey estimates of mean densities (number per 177 m^2) and associated standard errors for juvenile, adult, and exploited life stages of 64 reef fishes in Tortugas Bank during 1999 and 2000. Sample sizes are provided in Table 5.2.

		Juvenile 1999		Juvenile 2000		Adult 1999		Adult 2000		Exploited 1999		Exploited 2000	
Common	Latin	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)
gray snapper	*Lutjanus griseus*	1.6660	1.5201	0.6482	0.4800	0.4992	0.1835	1.6315	1.3786	0.3932	0.1559	1.0969	0.9161
dog snapper	*Lutjanus jocu*	0.0000	0.0000	0.0000	0.0000	0.0019	0.0019	0.0030	0.0027	0.0019	0.0019	0.0030	0.0027
mahogony snapper	*Lutjanus mahogoni*	0.0000	0.0000	0.0048	0.0035	0.0000	0.0000	0.0048	0.0035	0.0000	0.0000	0.0032	0.0022
lane snapper	*Lutjanus synagris*	0.1914	0.1915	0.0000	0.0000	0.0638	0.0638	0.0156	0.0081	0.0638	0.0638	0.0156	0.0081
hogfish	*Lachnolaimus maximus*	0.0314	0.0132	0.0264	0.0117	0.5052	0.0954	0.4337	0.0725	0.2459	0.0684	0.2251	0.0441
Grunts													
black margate	*Anisotremus surinamensis*	0.0000	0.0000	0.0055	0.0053	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0057	0.0053
porkfish	*Anisotremus virginicus*	0.0700	0.0331	0.0650	0.0410	0.0388	0.0187	1.3110	1.2436	0.0948	0.0321	1.3752	1.2825
margate	*Haemulon album*	0.0127	0.0104	0.0524	0.0435	0.0019	0.0019	0.0093	0.0092	0.0095	0.0060	0.0617	0.0444
tomtate	*Haemulon aurolineatum*	16.4834	8.0088	4.0895	2.2273	0.5779	0.5526	1.2505	1.2509	0.5779	0.5526	0.3158	0.3159
ceasar grunt	*Haemulon carbonarium*	0.0004	0.0004	0.3884	0.3750	0.0010	0.0009	0.0075	0.0056	0.0011	0.0009	0.1324	0.1183
smallmouth grunt	*Haemulon chrysargyreum*	0.0000	0.0000	0.2642	0.2643	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
french grunt	*Haemulon flavolineatum*	0.2387	0.0754	0.6921	0.3508	0.1094	0.0627	0.3727	0.2382	0.1613	0.0902	0.5111	0.2800
spanish grunt	*Haemulon macrostomium*	0.0030	0.0019	0.5196	0.5127	0.0045	0.0027	0.2580	0.2498	0.0064	0.0031	0.6586	0.6344
cottonwick	*Haemulon melanurum*	2.5343	2.4301	0.0026	0.0026	0.0000	0.0000	0.0000	0.0000	2.2270	2.2260	0.0000	0.0000
sailors choice	*Haemulon parra*	0.0101	0.0101	0.0053	0.0053	0.0016	0.0017	0.1115	0.1031	0.0016	0.0017	0.1042	0.0961
white grunt	*Haemulon plumieri*	1.0892	0.3330	0.7342	0.1802	0.6083	0.1185	1.1670	0.4054	0.8555	0.3003	1.2538	0.4188
bluestriped grunt	*Haemulon sciurus*	0.0925	0.0640	0.0295	0.0188	0.0263	0.0166	0.1336	0.0851	0.0446	0.0240	0.1578	0.0950
striped grunt	*Haemulon striatum*	0.4648	0.3639	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 5.5 (cont.) - Two-stage stratified random survey estimates of mean densities (number per 177 m^2) and associated standard errors for juvenile, adult, and exploited life stages of 64 reef fishes in Tortugas Bank during 1999 and 2000. Sample sizes are provided in Table 5.2.

		Juvenile 1999		Juvenile 2000		Adult 1999		Adult 2000		Exploited 1999		Exploited 2000	
Common	Latin	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)
Other Reef Fishes													
great barracuda	*Sphyraena barracuda*	0.0426	0.0172	0.0538	0.0184	0.0472	0.0223	0.0228	0.0081	0.0890	0.0289	0.0765	0.0216
jolthead porgy	*Calamus bajonado*	0.0121	0.0080	0.0051	0.0050	0.0000	0.0000	0.0026	0.0026	0.0008	0.0008	0.0077	0.0057
saucereye porgy	*Calamus calamus*	1.3418	0.1217	0.8294	0.0914	0.0086	0.0055	0.0058	0.0034	0.4677	0.0600	0.3376	0.0518
yellow jack	*Caranx bartholomaei*	0.2176	0.2012	0.0388	0.0237	0.0026	0.0020	0.0004	0.0004	0.2001	0.1812	0.0392	0.0237
blue runner	*Caranx crysos*	0.0286	0.0198	0.0023	0.0023	0.0000	0.0000	0.0000	0.0000	0.0286	0.0198	0.0023	0.0023
crevalle jack	*Caranx hippos*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
bar jack	*Caranx ruber*	0.5140	0.2422	0.3437	0.1479	0.8012	0.4031	1.0127	0.4049	0.8012	0.4031	1.0127	0.4049
bermuda chub	*Kyphosus sectatrix*	0.0303	0.0196	0.0083	0.0079	0.0783	0.0774	0.0291	0.0206	0.1085	0.0809	0.0374	0.0220
gray angelfish	*Pomacanthus arcuatus*	0.4149	0.0737	0.3052	0.0553	0.0628	0.0188	0.0568	0.0192	0.0628	0.0188	0.0568	0.0192
blue parrotfish	*Scarus coeruleus*	0.1001	0.0406	0.0430	0.0378	0.0000	0.0000	0.0023	0.0023	0.0000	0.0000	0.0023	0.0023
rainbow parrotfish	*Scarus guacamaia*	0.0241	0.0143	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
princess parrotfish	*Scarus taeniopterus*	0.1529	0.0710	0.2051	0.0748	0.0157	0.0125	0.0224	0.0099	0.0157	0.0125	0.0224	0.0099
queen parrotfish	*Scarus vetula*	0.0192	0.0120	0.0153	0.0111	0.0118	0.0102	0.0000	0.0000	0.0118	0.0102	0.0000	0.0000
greenblotch parrotfish	*Sparisoma atomarium*	0.9229	0.3287	0.8664	0.1944	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
redband parrotfish	*Sparisoma aurofrenatum*	1.5774	0.2333	1.4821	0.2033	0.5971	0.1849	0.3003	0.0593	0.5971	0.1849	0.3003	0.0593
redtail parrotfish	*Sparisoma chrysopterum*	0.0431	0.0201	0.0321	0.0130	0.0708	0.0296	0.0263	0.0107	0.0708	0.0296	0.0263	0.0107
bucktooth parrotfish	*Sparisoma radians*	0.0162	0.0106	0.0053	0.0051	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
redfin parrotfish	*Sparisoma rubripinne*	0.0336	0.0113	0.0074	0.0053	0.0415	0.0307	0.0023	0.0023	0.0415	0.0307	0.0023	0.0023
stoplight parrotfish	*Sparisoma viride*	0.8585	0.1233	0.9558	0.1528	0.0554	0.0187	0.0326	0.0138	0.0554	0.0187	0.0326	0.0138
gray triggerfish	*Balistes capriscus*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0050	0.0050	0.0000	0.0000	0.0050	0.0050

Table 5.5 (cont.) - Two-stage stratified random survey estimates of mean densities (number per 177 m^2) and associated standard errors for juvenile, adult, and exploited life stages of 64 reef fishes in Tortugas Bank during 1999 and 2000. Sample sizes are provided in Table 5.2.

		Juvenile 1999		Juvenile 2000		Adult 1999		Adult 2000		Exploited 1999		Exploited 2000	
Common	Latin	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)
ocean triggerfish	*Cantherhines sufflamen*	0.0015	0.0015	0.0714	0.0328	0.0272	0.0206	0.1485	0.0982	0.0287	0.0210	0.1995	0.1022
doctorfish	*Acanthurus chirurgus*	0.2384	0.0628	0.6110	0.1830	0.0783	0.0271	0.0608	0.0258	0.0767	0.0268	0.0596	0.0253
permit	*Trachinotus falcatus*	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0016	0.0016	0.0001	0.0001	0.0016	0.0016
king mackerel	*Scomberomorus cavalla*	0.0000	0.0000	0.0051	0.0050	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
spanish mackerel	*Scomberomorus maculatus*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
cero	*Scomberomorus regalis*	0.0000	0.0000	0.0064	0.0037	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0064	0.0037
greater amberjack	*Seriola dumerili*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0001

Table 5.6 - Two-stage stratified random survey estimates of mean densities (number per 177 m^2) and associated standard errors for juvenile, adult, and exploited life stages of 64 reef fishes in Riley's Hump during 1999. Sample sizes are provided in Table 5.2.

		Juvenile 1999		Adult 1999		Exploited 1999	
Common	**Latin**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**
Groupers							
rock hind	*Epinephelus adscensionis*	0.0588	0.0289	0.0000	0.0000	0.0294	0.0208
graysby	*Epinephelus cruentatus*	0.2156	0.0754	0.2809	0.0728	0.2809	0.0728
yellowedge grouper	*Epinephelus flavolimbatus*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
coney	*Epinephelus fulvus*	0.0196	0.0188	0.2010	0.0770	0.1274	0.0550
red hind	*Epinephelus guttatus*	0.0686	0.0360	0.0425	0.0235	0.0621	0.0396
jewfish	*Epinephelus itajara*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
red grouper	*Epinephelus morio*	0.5603	0.1242	0.1666	0.0527	0.0098	0.0100
nassau grouper	*Epinephelus striatus*	0.0000	0.0000	0.0130	0.0125	0.0000	0.0000
black grouper	*Mycteroperca bonaci*	0.0327	0.0180	0.0000	0.0000	0.0229	0.0156
yellowmouth grouper	*Mycteroperca interstitialis*	0.0294	0.0220	0.0000	0.0000	0.0000	0.0000
gag	*Mycteroperca microlepis*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
scamp	*Mycteroperca phenax*	0.0457	0.0304	0.0130	0.0125	0.0000	0.0000
tiger grouper	*Mycteroperca tigris*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
yellowfin grouper	*Mycteroperca venenosa*	0.0270	0.0262	0.0000	0.0000	0.0000	0.0000
Snappers							
mutton snapper	*Lutjanus analis*	0.0000	0.0000	0.1920	0.0903	0.0988	0.0394
schoolmaster	*Lutjanus apodus*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
blackfin snapper	*Lutjanus buccanella*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
yellowtail snapper	*Ocyurus chrysurus*	0.0130	0.0125	0.0638	0.0532	0.0540	0.0523
cubera snapper	*Lutjanus cyanopterus*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
gray snapper	*Lutjanus griseus*	7.2896	3.7613	4.9294	1.9681	3.9426	1.6761
dog snapper	*Lutjanus jocu*	0.0000	0.0000	0.0261	0.0250	0.0261	0.0250
mahogony snapper	*Lutjanus mahogoni*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
lane snapper	*Lutjanus synagris*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
hogfish	*Lachnolaimus maximus*	0.2058	0.0935	0.9883	0.3233	0.5505	0.2871

Table 5.6 (cont.) - Two-stage stratified random survey estimates of mean densities (number per 177 m^2) and associated standard errors for juvenile, adult, and exploited life stages of 64 reef fishes in Riley's Hump during 1999. Sample sizes are provided in Table 5.2.

		Juvenile 1999		Adult 1999		Exploited 1999	
Common	**Latin**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**
Grunts							
black margate	*Anisotremus surinamensis*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
porkfish	*Anisotremus virginicus*	0.0662	0.0457	0.0261	0.0250	0.0792	0.0564
margate	*Haemulon album*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
tomtate	*Haemulon aurolineatum*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ceasar grunt	*Haemulon carbonarium*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
smallmouth grunt	*Haemulon chrysargyreum*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
french grunt	*Haemulon flavolineatum*	0.1764	0.1688	0.5162	0.4938	0.6338	0.6063
spanish grunt	*Haemulon macrostomium*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
cottonwick	*Haemulon melanurum*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sailors choice	*Haemulon parra*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
white grunt	*Haemulon plumieri*	0.0000	0.0000	0.0956	0.0491	0.0956	0.0491
bluestriped grunt	*Haemulon sciurus*	1.5092	1.2278	0.3920	0.3750	1.0862	0.7163
striped grunt	*Haemulon striatum*	3.6262	3.4692	0.0000	0.0000	0.0000	0.0000
Other Reef Fishes							
great barracuda	*Sphyraena barracuda*	0.1945	0.0854	0.2648	0.0891	0.4592	0.1458
jolthead porgy	*Calamus bajonado*	0.0540	0.0523	0.0000	0.0000	0.0540	0.0523
saucereye porgy	*Calamus calamus*	2.3200	0.3436	0.0327	0.0220	1.3921	0.3157
yellow jack	*Caranx bartholomaei*	0.3201	0.2533	0.0196	0.0188	0.3397	0.2572
blue runner	*Caranx crysos*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
crevalle jack	*Caranx hippos*	1.8621	1.9035	0.0000	0.0000	1.8621	1.9035
bar jack	*Caranx ruber*	0.0000	0.0000	0.0294	0.0208	0.0294	0.0208
bermuda chub	*Kyphosus sectatrix*	1.6727	1.3289	0.0000	0.0000	1.6727	1.3289
gray angelfish	*Pomacanthus arcuatus*	0.1470	0.0564	0.0490	0.0279	0.0490	0.0279
blue parrotfish	*Scarus coeruleus*	0.0621	0.0396	0.0000	0.0000	0.0000	0.0000
rainbow parrotfish	*Scarus guacamaia*	0.0098	0.0100	0.0000	0.0000	0.0000	0.0000

Table 5.6 (cont.) - Two-stage stratified random survey estimates of mean densities (number per 177 m^2) and associated standard errors for juvenile, adult, and exploited life stages of 64 reef fishes in Riley's Hump during 1999. Sample sizes are provided in Table 5.2.

		Juvenile 1999		Adult 1999		Exploited 1999	
Common	**Latin**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**
princess parrotfish	*Scarus taeniopterus*	0.1764	0.0881	0.0098	0.0100	0.0098	0.0100
queen parrotfish	*Scarus vetula*	0.0196	0.0188	0.0000	0.0000	0.0000	0.0000
greenblotch parrotfish	*Sparisoma atomarium*	0.4068	0.1653	0.0000	0.0000	0.0000	0.0000
redband parrotfish	*Sparisoma aurofrenatum*	1.0837	0.2869	0.6466	0.2334	0.6466	0.2334
redtail parrotfish	*Sparisoma chrysopterum*	0.0000	0.0000	0.0858	0.0403	0.0858	0.0403
bucktooth parrotfish	*Sparisoma radians*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
redfin parrotfish	*Sparisoma rubripinne*	0.0294	0.0220	0.0098	0.0100	0.0098	0.0100
stoplight parrotfish	*Sparisoma viride*	0.3626	0.1053	0.0098	0.0100	0.0098	0.0100
gray triggerfish	*Balistes capriscus*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ocean triggerfish	*Cantherhines sufflamen*	0.1274	0.0819	0.2940	0.2623	0.4214	0.2740
doctorfish	*Acanthurus chirurgus*	0.4965	0.1880	0.3096	0.0947	0.3096	0.0947
permit	*Trachinotus falcatus*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
king mackerel	*Scomberomorus cavalla*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
spanish mackerel	*Scomberomorus maculatus*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
cero	*Scomberomorus regalis*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
greater amberjack	*Seriola dumerili*	0.4540	0.3060	0.0000	0.0000	0.0000	0.0000

With respect to other reef fish species, bar jack and redband parrotfish juveniles and adults were found in high densities in DTNP, as were saucereye porgy juveniles. On Tortugas Bank, the most abundant juvenile life stages observed were saucereye porgy and three parrotfish species: redband, stoplight, and greenblotch. Among adult life stages, bar jack and redband parrotfish were most prevalent on Tortugas Bank. Highest observed densities of juveniles in Riley's Hump were saucereye porgy, redband parrotfish, crevalle jack, and Bermuda chub. Adult redband parrotfish were also quite abundant on Riley's Hump, as were adult stage doctorfish, ocean triggerfish, and great barracuda.

Density estimates within and outside the RNA for DTNP for pooled survey years 1999 and 2000 are provided in **Table 5.7**. Juvenile red and black grouper exhibited higher densities outside the RNA compared to inside, whereas juvenile scamp exhibited similar densities in both areas. For adult groupers, graysby were more abundant inside the RNA, black grouper were more abundant outside, and red grouper were equally abundant in both areas. Among snappers, juvenile and adult yellowtail exhibited higher densities outside the RNA as did hogfish juveniles, but no density differences were observed for adult hogfish and juvenile and adult gray snapper. Juvenile and adult white grunt were more abundant outside the RNA, whereas juvenile and adult tomtate were more abundant inside the RNA. For other abundant reef fish species, density of saucereye porgy juveniles was higher outside the RNA, as were densities for juvenile and adult redband parrotfish. Interestingly, bar jack juveniles and adults showed opposite abundance patterns, with juveniles higher inside than outside and adults more abundant outside compared to inside the RNA.

5.5 Average Size in Exploited Phase ($\overline{L}$)

To describe baseline status for a fish population in multispecies community settings, a robust population dynamic variable is required to relate current trends in human and environmental stressors to expected future condition of the stocks over relatively broad spatial and temporal scales. A powerful choice is the metabolic-based pool variable average size of animals (in either length or weight) in the exploited phase of the stock (Beverton and Holt 1957, Gulland 1983, Ault 1988, Ault and Ehrhardt 1991, Ehrhardt and Ault 1992). 'Average size', denoted as $\overline{L}$, is a physiologically-based indicator variable that is a very sensitive measure of direct and indirect stress on marine ecosystems (Ault et al. 1997a, 1998, Quinn and Deriso 1999). The $\overline{L}$ of a reef fish stock (or population if closed intra-breeding unit) is strongly correlated with population size in both numbers and biomass, and thus can be used as an indicator variable of population health. The formal mathematical definition of $\overline{L}(t)$ is expressed as

$$\overline{L}(t) = \frac{F(t)\int_{t_c}^{t_\lambda} N(a,t)\,L(a,t)\,da}{F(t)\int_{t_c}^{t_\lambda} N(a,t)\,da} \qquad (5.1)$$

Table 5.7 - Density estimates within and outside the RNA for DTNP for pooled survey years 1999 and 2000.

		Juvenile RNA		Juvenile Outside		Adult RNA		Adult Outside		Exploited RNA		Exploited Outside	
Common	Latin	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)	Mean D	SE(D)
Groupers													
rock hind	*Epinephelus adscensionis*	0.0002	0.0002	0.0022	0.0014	0.0000	0.0000	0.0000	0.0000	0.0002	0.0002	0.0011	0.0011
graysby	*Epinephelus cruentatus*	0.0146	0.0059	0.0332	0.0074	0.0297	0.0150	0.0114	0.0037	0.0297	0.0150	0.0114	0.0037
yellowedge grouper	*Epinephelus flavolimbatus*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
coney	*Epinephelus fulvus*	0.0000	0.0000	0.0018	0.0018	0.0000	0.0000	0.0008	0.0008	0.0000	0.0000	0.0008	0.0008
red hind	*Epinephelus guttatus*	0.0005	0.0003	0.0052	0.0037	0.0002	0.0002	0.0000	0.0000	0.0005	0.0003	0.0004	0.0004
jewfish	*Epinephelus itajara*	0.0000	0.0000	0.0000	0.0000	0.0002	0.0002	0.0007	0.0005	0.0002	0.0002	0.0007	0.0005
red grouper	*Epinephelus morio*	0.1108	0.0235	0.2625	0.0263	0.0978	0.0225	0.0867	0.0107	0.0637	0.0190	0.0512	0.0095
nassau grouper	*Epinephelus striatus*	0.0004	0.0002	0.0029	0.0021	0.0036	0.0034	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
black grouper	*Mycteroperca bonaci*	0.0645	0.0138	0.0917	0.0139	0.0002	0.0001	0.0119	0.0104	0.0011	0.0004	0.0151	0.0105
yellowmouth grouper	*Mycteroperca interstitialis*	0.0003	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
gag	*Mycteroperca microlepis*	0.0003	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0002	0.0000	0.0000
scamp	*Mycteroperca phenax*	0.0689	0.0332	0.0634	0.0228	0.0002	0.0002	0.0000	0.0000	0.0002	0.0002	0.0000	0.0000
tiger grouper	*Mycteroperca tigris*	0.0000	0.0000	0.0021	0.0021	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0021	0.0021
yellowfin grouper	*Mycteroperca venenosa*	0.0036	0.0034	0.0065	0.0050	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Snappers													
mutton snapper	*Lutjanus analis*	0.0033	0.0034	0.0070	0.0053	0.0609	0.0305	0.0343	0.0086	0.0356	0.0241	0.0174	0.0055
schoolmaster	*Lutjanus apodus*	0.0000	0.0000	0.0000	0.0000	0.0174	0.0137	0.0011	0.0010	0.0043	0.0026	0.0010	0.0010
blackfin snapper	*Lutjanus buccanella*	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
yellowtail snapper	*Ocyurus chrysurus*	1.4581	0.2598	2.7127	0.4582	0.4121	0.1260	0.9036	0.1956	0.0922	0.0709	0.1324	0.0595
cubera snapper	*Lutjanus cyanopterus*	0.0000	0.0000	0.0016	0.0016	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0016	0.0016

Table 5.7 (cont.) - Density estimates within and outside the RNA for DTNP for pooled survey years 1999 and 2000.

		Juvenile RNA		Juvenile Outside		Adult RNA		Adult Outside		Exploited RNA		Exploited Outside	
Common	**Latin**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**
gray snapper	*Lutjanus griseus*	0.3797	0.2226	0.3067	0.1615	0.2109	0.0539	0.3100	0.1250	0.1616	0.0455	0.1936	0.0752
dog snapper	*Lutjanus jocu*	0.0002	0.0002	0.0000	0.0000	0.0006	0.0004	0.0017	0.0015	0.0006	0.0004	0.0017	0.0015
mahogony snapper	*Lutjanus mahogoni*	0.0025	0.0017	0.0000	0.0000	0.0013	0.0013	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
lane snapper	*Lutjanus synagris*	0.0072	0.0017	0.0027	0.0028	0.0173	0.0095	0.0014	0.0012	0.0173	0.0095	0.0014	0.0012
hogfish	*Lachnolaimus maximus*	0.0337	0.0092	0.1254	0.0310	0.1584	0.0306	0.2197	0.0254	0.0653	0.0155	0.0759	0.0107
Grunts													
black margate	*Anisotremus surinamensis*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
porkfish	*Anisotremus virginicus*	0.1137	0.0348	0.3487	0.2043	0.0140	0.0061	0.0458	0.0244	0.0590	0.0246	0.2414	0.1700
margate	*Haemulon album*	0.0030	0.0027	0.0375	0.0320	0.0001	0.0001	0.0011	0.0011	0.0031	0.0028	0.0338	0.0283
tomtate	*Haemulon aurolineatum*	7.5397	7.6968	3.4451	0.9135	0.9529	0.9504	0.0099	0.0099	0.0156	0.0130	0.0099	0.0099
ceasar grunt	*Haemulon carbonarium*	0.0013	0.0013	0.0011	0.0011	0.0000	0.0000	0.0000	0.0000	0.0011	0.0011	0.0011	0.0011
smallmouth grunt	*Haemulon chrysargyreum*	0.0228	0.0228	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
french grunt	*Haemulon flavolineatum*	0.1772	0.1139	0.5170	0.2718	0.0041	0.0022	0.0892	0.0743	0.0114	0.0046	0.1216	0.0990
spanish grunt	*Haemulon macrostomium*	0.2365	0.2344	0.0098	0.0062	0.0005	0.0003	0.0012	0.0009	0.0010	0.0004	0.0058	0.0039
cottonwick	*Haemulon melanurum*	0.0188	0.0135	0.0332	0.0147	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sailors choice	*Haemulon parra*	0.0001	0.0001	0.0036	0.0036	0.0034	0.0005	0.0000	0.0000	0.0034	0.0005	0.0000	0.0000
white grunt	*Haemulon plumieri*	1.5706	0.5293	3.8380	0.8064	0.8946	0.3016	1.4450	0.3712	1.0712	0.3187	1.6935	0.4947
bluestriped grunt	*Haemulon sciurus*	0.0049	0.0029	0.0498	0.0225	0.0047	0.0026	0.0920	0.0547	0.0085	0.0040	0.1306	0.0733
striped grunt	*Haemulon striatum*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 5.7 (cont.) - Density estimates within and outside the RNA for DTNP for pooled survey years 1999 and 2000.

		Juvenile RNA		Juvenile Outside		Adult RNA		Adult Outside		Exploited RNA		Exploited Outside	
Common	**Latin**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**
Other Reef Fishes													
great barracuda	*Sphyraena barracuda*	0.0110	0.0046	0.0227	0.0079	0.0223	0.0083	0.0376	0.0107	0.0328	0.0095	0.0595	0.0133
jolthead porgy	*Calamus bajonado*	0.0000	0.0000	0.0018	0.0018	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
saucereye porgy	*Calamus calamus*	0.4651	0.0669	1.1827	0.1242	0.0030	0.0024	0.0138	0.0058	0.1401	0.0279	0.3448	0.0685
yellow jack	*Caranx bartholomaei*	0.0415	0.0225	0.0393	0.0256	0.0201	0.0119	0.0788	0.0740	0.0565	0.0248	0.1146	0.0988
blue runner	*Caranx crysos*	0.1959	0.1680	0.3397	0.2458	0.0007	0.0007	0.0070	0.0053	0.1931	0.1646	0.0541	0.0393
crevalle jack	*Caranx hippos*	0.0000	0.0000	0.0076	0.0058	0.0000	0.0000	0.0018	0.0018	0.0000	0.0000	0.0094	0.0061
bar jack	*Caranx ruber*	2.3052	1.3958	1.1547	0.5656	0.0885	0.0346	1.1425	0.4823	0.0885	0.0346	1.1425	0.4823
bermuda chub	*Kyphosus sectatrix*	0.0871	0.0645	0.0401	0.0269	0.0091	0.0068	0.0002	0.0002	0.0962	0.0658	0.0384	0.0254
gray angelfish	*Pomacanthus arcuatus*	0.1249	0.0285	0.1835	0.0236	0.0202	0.0080	0.0226	0.0065	0.0202	0.0080	0.0226	0.0065
blue parrotfish	*Scarus coeruleus*	0.0198	0.0125	0.0289	0.0190	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
rainbow parrotfish	*Scarus guacamaia*	0.0281	0.0177	0.0054	0.0037	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
princess parrotfish	*Scarus taeniopterus*	0.0406	0.0213	0.0897	0.0372	0.0034	0.0034	0.0084	0.0052	0.0034	0.0034	0.0084	0.0052
queen parrotfish	*Scarus vetula*	0.0000	0.0000	0.0033	0.0019	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
greenblotch parrotfish	*Sparisoma atomarium*	0.2171	0.0549	0.4473	0.0718	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
redband parrotfish	*Sparisoma aurofrenatum*	0.7899	0.1220	1.6059	0.3769	0.1730	0.0440	0.2433	0.0391	0.1730	0.0440	0.2433	0.0391
redtail parrotfish	*Sparisoma chrysopterum*	0.0607	0.0306	0.0602	0.0220	0.0558	0.0348	0.0585	0.0209	0.0558	0.0348	0.0585	0.0209
bucktooth parrotfish	*Sparisoma radians*	0.0047	0.0047	0.0351	0.0154	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
redfin parrotfish	*Sparisoma rubripinne*	0.0381	0.0222	0.1007	0.0315	0.0100	0.0048	0.0288	0.0108	0.0100	0.0048	0.0288	0.0108

Table 5.7 (cont.) - Density estimates within and outside the RNA for DTNP for pooled survey years 1999 and 2000.

		Juvenile RNA		Juvenile Outside		Adult RNA		Adult Outside		Exploited RNA		Exploited Outside	
Common	**Latin**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**	**Mean D**	**SE(D)**
stoplight parrotfish	*Sparisoma viride*	0.5077	0.0858	0.5471	0.0691	0.0100	0.0052	0.0194	0.0072	0.0100	0.0052	0.0194	0.0072
gray triggerfish	*Balistes capriscus*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ocean triggerfish	*Cantherhines sufflamen*	0.0021	0.0009	0.0004	0.0004	0.0016	0.0011	0.0004	0.0004	0.0032	0.0016	0.0007	0.0007
doctorfish	*Acanthurus chirurgus*	0.1829	0.0479	0.3343	0.0626	0.0192	0.0071	0.0497	0.0150	0.0192	0.0071	0.0497	0.0150
permit	*Trachinotus falcatus*	0.0001	0.0000	0.0049	0.0049	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0049	0.0049
king mackerel	*Scomberomorus cavalla*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
spanish mackerel	*Scomberomorus maculatus*	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000
cero	*Scomberomorus regalis*	0.0092	0.0069	0.0080	0.0051	0.0000	0.0000	0.0000	0.0000	0.0092	0.0069	0.0080	0.0051
greater amberjack	*Seriola dumerili*	0.0000	0.0000	0.0010	0.0008	0.0001	0.0001	0.0118	0.0109	0.0001	0.0001	0.0118	0.0109

where t_c is minimum age at first capture, t is oldest age in the stock, $N(a,t)$ is abundance for age class a, $L(a,t)$ is length, and $F(t)$ is the instantaneous fishing mortality rate at time t.

The use of $\bar{L}$ in stock assessment has deep roots in traditional fisheries management (Beverton and Holt 1956, 1957, Ricker 1975). In general, it is well-known that $\bar{L}$ is highly correlated with average population size, and so reflects the rate of fishing mortality operating in the fishery. As fishing mortality rate increases, $\bar{L}$ decreases at a rate proportional to the population-dynamic tolerance of a stock. Minimally, average size is greatest when fishing mortality is lowest (or near zero), and decreases as the rate increases. Assuming that mortality occurs proportionally to stock age-size spatial distributions, $\bar{L}$ will continue to decrease until at high exploitation rates it will be nearly equal to the minimum size of first capture regulated by fishery management. Secondly, there exists a value of $\bar{L}$ corresponding to a population size that produces maximum sustainable yields on a continuing basis.

For the 1999 and 2000 surveys, we computed 'average length' for 64 species. Estimates of the mean, variance, and 95% confidence interval followed Sokal and Rohlf (1969). Average lengths for the two survey years were estimated separately for the DTNP area (**Table 5.8**) and for the combined DTNP and Tortugas Bank areas (**Table 5.9**). Average length estimates within and outside the RNA for DTNP for pooled survey years 1999 and 2000 are provided in **Table 5.10**. To understand the status of stocks in the Dry Tortugas relative to the greater Florida Keys ecosystem, we also computed $\bar{L}$ from several region-wide survey databases, both fishery-independent (visual surveys in the Florida Keys) and fishery-dependent (headboat surveys in the Keys, Tortugas). We noted from time series of $\bar{L}$ estimates constructed from six different types of survey data that exploited fishes that species' estimates of average size (e.g., black grouper, gray snapper, and yellowtail snapper) have been relatively constant for about the past 25 years. This constant "average size" has been very close to the minimum size of first capture. Secondly, estimates of average size have been smallest in the northern Florida Keys reef tract (i.e., Biscayne National Park and Key Largo) relative to the more southern Keys and Dry Tortugas. The third item to note is that many species have displayed extremely small average lengths in the past, and that very little increase of average length (i.e., no apparent recovery of stocks) has occurred, even as minimum size limits were imposed by fishery management.

Estimates of average length for fishery-dependent surveys and fishery-independent surveys are extremely close for most of the species analyzed. This would indicate that the two data sources are producing similar estimates of the effects of mortality on these stocks. An important factor in the use of the $\bar{L}$ statistic to measure population mortality rates and to assess the effects of exploitation is that it can be reliably computed from both fishery-dependent and fishery-independent data sources. Theoretically, the average size of fish in the exploited phase landed for any given exploited species should be equal to the average size in the exploited phase of the remaining population in the sea just after fishing. The greater the correlation between the two independent estimates of $\bar{L}$, the more robust 'average length' should be as an indicator of stock status subject to exploitation. This is a robust conclusion in that it allows several independent observations of 'average length' to be computed and compared for consistency and

Table 5.8 - Average length in the exploitable phase (LBAR) for 64 species of reef fish in 13 families in the Dry Tortugas National Park. The number of fish from which the estimate is derived is given (N) as well as the standard error of the estimate (SE_LBAR).

			1999			2000		
COMMON	**LATIN**	**FAMILY**	**N**	**LBAR**	**SE_LBAR**	**N**	**LBAR**	**SE_LBAR**
Groupers								
rock hind	*Epinephelus adscensionis*	Serranidae	1.50	24.67	5.21	0.00	.	.
graysby	*Epinephelus cruentatus*	Serranidae	9.50	23.00	1.12	13.50	26.00	1.56
yellowedge grouper	*Epinephelus flavolimbatus*	Serranidae	0.00	.	.	0.00	.	.
coney	*Epinephelus fulvus*	Serranidae	0.50	28.00	0.00	0.00	.	.
red hind	*Epinephelus guttatus*	Serranidae	1.00	20.00	0.00	1.00	29.50	0.00
jewfish	*Epinephelus itajara*	Serranidae	0.50	240.00	0.00	1.50	175.00	68.07
red grouper	*Epinephelus morio*	Serranidae	18.00	59.28	1.08	24.00	62.71	1.89
nassau grouper	*Epinephelus striatus*	Serranidae	0.00	.	.	0.00	.	.
black grouper	*Mycteroperca bonaci*	Serranidae	2.00	55.00	0.00	11.75	66.29	3.97
yellowmouth grouper	*Mycteroperca interstitialis*	Serranidae	0.00	.	.	0.00	.	.
gag	*Mycteroperca microlepis*	Serranidae	0.50	65.00	0.00	0.00	.	.
scamp	*Mycteroperca phenax*	Serranidae	0.50	60.00	0.00	0.00	.	.
tiger grouper	*Mycteroperca tigris*	Serranidae	0.00	.	.	1.00	30.00	0.00
yellowfin grouper	*Mycteroperca venenosa*	Serranidae	0.00	.	.	0.00	.	.
Snappers								
mutton snapper	*Lutjanus analis*	Lutjanidae	4.50	52.89	5.17	13.50	49.59	1.61
schoolmaster	*Lutjanus apodus*	Lutjanidae	4.25	30.00	1.78	28.75	32.38	0.95
blackfin snapper	*Lutjanus buccanella*	Lutjanidae	0.00	.	.	0.00	.	.
yellowtail snapper	*Ocyurus chrysurus*	Lutjanidae	46.75	37.03	1.05	39.13	33.35	0.38
cubera snapper	*Lutjanus cyanopterus*	Lutjanidae	0.00	.	.	1.00	51.00	0.00
gray snapper	*Lutjanus griseus*	Lutjanidae	126.50	31.40	0.37	146.63	31.31	0.31
dog snapper	*Lutjanus jocu*	Lutjanidae	3.50	49.29	4.34	5.00	51.00	4.56
mahogony snapper	*Lutjanus mahogoni*	Lutjanidae	0.00	.	.	0.00	.	.
lane snapper	*Lutjanus synagris*	Lutjanidae	123.00	26.09	0.28	6.50	25.31	0.79
hogfish	*Lachnolaimus maximus*	Labridae	34.50	41.59	1.58	31.63	40.20	1.39
Grunts								
black margate	*Anisotremus surinamensis*	Haemulidae	0.00	.	.	0.00	.	.
porkfish	*Anisotremus virginicus*	Haemulidae	40.83	22.00	0.72	111.25	20.81	0.41
margate	*Haemulon album*	Haemulidae	24.50	33.65	1.08	17.75	26.62	1.75
tomtate	*Haemulon aurolineatum*	Haemulidae	7.00	20.00	0.00	5.00	15.00	0.00
ceasar grunt	*Haemulon carbonarium*	Haemulidae	5.00	18.15	0.79	40.00	22.04	0.62
smallmouth grunt	*Haemulon chrysargyreum*	Haemulidae	0.00	.	.	0.00	.	.
french grunt	*Haemulon flavolineatum*	Haemulidae	23.88	19.27	0.74	38.38	18.90	0.56

Table 5.8 (cont.) - Average length in the exploitable phase (LBAR) for 64 species of reef fish in 13 families in the Dry Tortugas National Park. The number of fish from which the estimate is derived is given (N) as well as the standard error of the estimate (SE_LBAR).

			1999			2000		
COMMON	**LATIN**	**FAMILY**	**N**	**LBAR**	**SE_LBAR**	**N**	**LBAR**	**SE_LBAR**
Grunts (cont)								
spanish grunt	*Haemulon macrostomium*	Haemulidae	2.50	26.00	2.48	69.00	25.91	0.41
cottonwick	*Haemulon melanurum*	Haemulidae	0.00	.	.	0.00	.	.
sailors choice	*Haemulon parra*	Haemulidae	27.50	27.73	0.61	3.00	30.00	2.17
white grunt	*Haemulon plumieri*	Haemulidae	292.87	22.55	0.24	680.75	22.62	0.16
bluestriped grunt	*Haemulon sciurus*	Haemulidae	22.25	21.12	0.58	32.25	22.09	0.60
striped grunt	*Haemulon striatum*	Haemulidae	0.00	.	.	0.00	.	.
Other Reef Fishes								
great barracuda	*Sphyraena barracuda*	Sphyraenidae	22.50	87.74	7.01	25.00	94.34	5.04
jolthead porgy	*Calamus bajonado*	Sparidae	0.00	.	.	0.00	.	.
saucereye porgy	*Calamus calamus*	Sparidae	98.96	24.56	0.49	88.63	23.03	0.37
yellow jack	*Caranx bartholomaei*	Carangidae	4.00	42.00	4.16	34.25	38.89	1.58
blue runner	*Caranx crysos*	Carangidae	80.50	21.64	0.56	99.50	25.29	0.85
crevalle jack	*Caranx hippos*	Carangidae	0.00	.	.	2.50	63.60	5.88
bar jack	*Caranx ruber*	Carangidae	293.42	30.97	0.38	279.13	27.66	0.22
bermuda chub	*Kyphosus sectatrix*	Kyphosidae	101.00	36.51	0.95	87.00	31.70	0.69
gray angelfish	*Pomacanthus arcuatus*	Pomacanthidae	15.00	35.93	0.57	15.50	37.13	0.77
blue parrotfish	*Scarus coeruleus*	Scaridae	0.00	.	.	0.00	.	.
rainbow parrotfish	*Scarus guacamaia*	Scaridae	0.00	.	.	0.00	.	.
princess parrotfish	*Scarus taeniopterus*	Scaridae	3.50	27.29	1.11	3.00	31.83	0.75
queen parrotfish	*Scarus vetula*	Scaridae	0.00	.	.	0.00	.	.
greenblotch parrotfish	*Sparisoma atomarium*	Scaridae	0.00	.	.	0.00	.	.
redband parrotfish	*Sparisoma aurofrenatum*	Scaridae	48.38	21.87	0.70	102.13	21.24	0.39
redtail parrotfish	*Sparisoma chrysopterum*	Scaridae	10.75	28.13	1.29	21.50	28.40	0.96
bucktooth parrotfish	*Sparisoma radians*	Scaridae	0.00	.	.	0.00	.	.
redfin parrotfish	*Sparisoma rubripinne*	Scaridae	8.25	32.79	0.89	8.00	35.06	1.71
stoplight parrotfish	*Sparisoma viride*	Scaridae	5.50	40.68	1.72	7.88	41.52	1.47
gray triggerfish	*Balistes capriscus*	Balistidae	0.00	.	.	0.00	.	.
ocean triggerfish	*Cantherhines sufflamen*	Balistidae	7.00	43.21	2.96	10.50	30.95	1.03
doctorfish	*Acanthurus chirurgus*	Acanthuridae	34.25	25.55	0.86	13.00	23.96	0.77
permit	*Trachinotus falcatus*	Carangidae	1.00	50.00	0.00	0.50	60.00	0.00
Pelagics								
king mackerel	*Scomberomorus cavalla*	Scombridae	0.00	.	.	0.00	.	.
spanish mackerel	*Scomberomorus maculatus*	Scombridae	0.00	.	.	0.50	40.00	0.00
cero	*Scomberomorus regalis*	Scombridae	2.00	58.75	21.32	2.00	42.50	4.33
greater amberjack	*Seriola dumerili*	Carangidae	0.00	.	.	4.50	97.78	5.79

Table 5.9 - Average length in the exploitable phase (LBAR) for 64 species of reef fish in 13 families in the Tortugas region (Tortugas Bank and DTNP). The number of fish from which the estimate is derived is given (N) as well as the standard error of the estimate (SE_LBAR).

			1999			2000		
COMMON	**LATIN**	**FAMILY**	**N**	**LBAR**	**SE_LBAR**	**N**	**LBAR**	**SE_LBAR**
Groupers								
rock hind	*Epinephelus adscensionis*	Serranidae	11.50	29.65	1.59	2.00	29.50	6.18
graysby	*Epinephelus cruentatus*	Serranidae	43.79	24.89	0.69	36.50	24.92	0.80
yellowedge grouper	*Epinephelus flavolimbatus*	Serranidae	1.00	43.50	0.00	0.00	.	.
coney	*Epinephelus fulvus*	Serranidae	4.50	26.22	1.69	2.00	32.75	2.17
red hind	*Epinephelus guttatus*	Serranidae	8.83	28.89	2.63	6.00	31.58	3.04
jewfish	*Epinephelus itajara*	Serranidae	0.50	240.00	0.00	1.50	175.00	68.07
red grouper	*Epinephelus morio*	Serranidae	30.13	59.59	0.89	43.50	63.32	1.36
nassau grouper	*Epinephelus striatus*	Serranidae	0.50	55.00	0.00	0.00	.	.
black grouper	*Mycteroperca bonaci*	Serranidae	9.33	63.84	5.02	17.75	72.23	4.20
yellowmouth grouper	*Mycteroperca interstitialis*	Serranidae	1.50	60.00	0.00	3.50	72.86	10.64
gag	*Mycteroperca microlepis*	Serranidae	1.50	56.33	8.67	0.00	.	.
scamp	*Mycteroperca phenax*	Serranidae	1.00	57.50	0.00	0.50	60.00	0.00
tiger grouper	*Mycteroperca tigris*	Serranidae	2.00	45.75	7.01	3.50	46.43	10.79
yellowfin grouper	*Mycteroperca venenosa*	Serranidae	0.00	.	.	1.00	57.50	0.00
Snappers								
mutton snapper	*Lutjanus analis*	Lutjanidae	16.33	52.34	1.96	19.50	50.10	1.58
schoolmaster	*Lutjanus apodus*	Lutjanidae	61.25	35.89	0.66	73.75	38.21	0.85
blackfin snapper	*Lutjanus buccanella*	Lutjanidae	0.00	.	.	0.00	.	.
yellowtail snapper	*Ocyurus chrysurus*	Lutjanidae	115.13	35.99	0.46	112.50	34.36	0.26
cubera snapper	*Lutjanus cyanopterus*	Lutjanidae	0.00	.	.	1.00	51.00	0.00
gray snapper	*Lutjanus griseus*	Lutjanidae	355.81	33.22	0.30	397.13	32.19	0.19
dog snapper	*Lutjanus jocu*	Lutjanidae	4.67	48.93	3.55	7.00	50.64	3.76
mahogony snapper	*Lutjanus mahogoni*	Lutjanidae	0.00	.	.	1.00	38.00	0.00
lane snapper	*Lutjanus synagris*	Lutjanidae	139.88	25.66	0.27	9.00	27.72	2.18
hogfish	*Lachnolaimus maximus*	Labridae	93.92	40.32	0.83	62.00	40.67	1.05
Grunts								
black margate	*Anisotremus surinamensis*	Haemulidae	0.00	.	.	2.50	35.60	5.38
porkfish	*Anisotremus virginicus*	Haemulidae	76.92	22.55	0.64	409.75	27.92	0.31
margate	*Haemulon album*	Haemulidae	27.00	33.57	1.14	27.75	30.67	2.08
tomtate	*Haemulon aurolineatum*	Haemulidae	177.00	17.90	0.07	36.25	15.03	0.03
ceasar grunt	*Haemulon carbonarium*	Haemulidae	7.00	19.18	1.15	67.75	20.33	0.49
smallmouth grunt	*Haemulon chrysargyreum*	Haemulidae	0.00	.	.	0.00	.	.
french grunt	*Haemulon flavolineatum*	Haemulidae	138.42	20.80	0.35	168.00	19.27	0.24

Table 5.9 (cont.) - Average length in the exploitable phase (LBAR) for 64 species of reef fish in 13 families in the Tortugas region (Tortugas Bank and DTNP). The number of fish from which the estimate is derived is given (N) as well as the standard error of the estimate (SE_LBAR).

			1999			2000		
COMMON	**LATIN**	**FAMILY**	**N**	**LBAR**	**SE_LBAR**	**N**	**LBAR**	**SE_LBAR**
Grunts (Cont)								
spanish grunt	*Haemulon macrostomium*	Haemulidae	7.00	26.93	1.70	209.50	27.44	0.55
cottonwick	*Haemulon melanurum*	Haemulidae	180.63	16.97	0.03	0.00	.	.
sailors choice	*Haemulon parra*	Haemulidae	37.50	29.13	0.62	28.38	32.15	1.00
white grunt	*Haemulon plumieri*	Haemulidae	408.62	22.15	0.20	865.75	22.44	0.14
bluestriped grunt	*Haemulon sciurus*	Haemulidae	78.83	21.89	0.47	75.75	24.93	0.67
striped grunt	*Haemulon striatum*	Haemulidae	0.00	.	.	0.00	.	.
Other Reef Fishes								
great barracuda	*Sphyraena barracuda*	Sphyraenidae	54.33	88.18	4.07	41.50	91.13	4.87
jolthead porgy	*Calamus bajonado*	Sparidae	1.50	33.33	5.33	1.00	35.50	0.00
saucereye porgy	*Calamus calamus*	Sparidae	219.46	24.04	0.29	137.63	23.35	0.30
yellow jack	*Caranx bartholomaei*	Carangidae	37.17	33.54	1.38	39.75	38.36	1.49
blue runner	*Caranx crysos*	Carangidae	85.50	21.85	0.54	100.00	25.31	0.85
crevalle jack	*Caranx hippos*	Carangidae	95.00	40.65	0.30	2.50	63.60	5.88
bar jack	*Caranx ruber*	Carangidae	529.04	32.71	0.28	696.50	30.28	0.19
bermuda chub	*Kyphosus sectatrix*	Kyphosidae	209.17	39.22	0.63	97.50	33.20	0.81
gray angelfish	*Pomacanthus arcuatus*	Pomacanthidae	31.00	37.13	0.69	24.00	37.98	0.96
blue parrotfish	*Scarus coeruleus*	Scaridae	0.00	.	.	0.50	70.00	0.00
rainbow parrotfish	*Scarus guacamaia*	Scaridae	0.00	.	.	0.00	.	.
princess parrotfish	*Scarus taeniopterus*	Scaridae	7.00	27.07	1.67	5.50	29.18	1.95
queen parrotfish	*Scarus vetula*	Scaridae	2.00	36.50	3.50	0.00	.	.
greenblotch parrotfish	*Sparisoma atomarium*	Scaridae	0.00	.	.	0.00	.	.
redband parrotfish	*Sparisoma aurofrenatum*	Scaridae	160.13	22.76	0.42	150.75	21.34	0.30
redtail parrotfish	*Sparisoma chrysopterum*	Scaridae	21.75	29.74	1.01	25.50	28.39	0.88
bucktooth parrotfish	*Sparisoma radians*	Scaridae	0.00	.	.	0.00	.	.
redfin parrotfish	*Sparisoma rubripinne*	Scaridae	15.25	35.80	1.40	8.50	34.76	1.66
stoplight parrotfish	*Sparisoma viride*	Scaridae	15.13	42.11	1.31	11.38	41.01	1.10
gray triggerfish	*Balistes capriscus*	Balistidae	0.00	.	.	0.50	35.00	0.00
ocean triggerfish	*Cantherhines sufflamen*	Balistidae	27.50	39.67	1.23	33.50	40.01	2.82
doctorfish	*Acanthurus chirurgus*	Acanthuridae	56.21	24.95	0.64	25.00	23.02	0.66
permit	*Trachinotus falcatus*	Carangidae	1.50	66.67	35.28	1.00	67.50	0.00
Pelagics								
king mackerel	*Scomberomorus cavalla*	Scombridae	0.00	.	.	0.00	.	.
spanish mackerel	*Scomberomorus maculatus*	Scombridae	0.00	.	.	0.50	40.00	0.00
cero	*Scomberomorus regalis*	Scombridae	2.00	58.75	21.32	4.00	51.88	7.35
greater amberjack	*Seriola dumerili*	Carangidae	0.00	.	.	5.00	97.00	5.27

Table 5.10 - Average length in the exploitable phase (LBAR) for 64 species of reef fish in 13 families both within and outside the RNA in the DTNP. The number of fish from which the estimate is derived is given (N) as well as the standard error of the estimate (SE_LBAR).

			Outside RNA			Within RNA		
COMMON	LATIN	FAMILY	N	LBAR	SE_LBAR	N	LBAR	SE_LBAR
Groupers								
rock hind	*Epinephelus adscensionis*	Serranidae	1.00	22.50	0.00	0.50	29.00	0.00
graysby	*Epinephelus cruentatus*	Serranidae	10.00	25.80	1.44	13.00	23.96	1.52
yellowedge grouper	*Epinephelus flavolimbatus*	Serranidae	0.00	.	.	27.50	86.83	5.65
coney	*Epinephelus fulvus*	Serranidae	0.50	28.00	0.00	0.00	.	.
red hind	*Epinephelus guttatus*	Serranidae	0.50	19.00	0.00	1.50	26.67	14.44
jewfish	*Epinephelus itajara*	Serranidae	1.50	175.00	68.07	0.00	.	.
red grouper	*Epinephelus morio*	Serranidae	19.50	59.54	1.08	22.00	62.89	2.02
nassau grouper	*Epinephelus striatus*	Serranidae	0.00	.	.	0.00	.	.
black grouper	*Mycteroperca bonaci*	Serranidae	7.50	69.93	5.65	6.25	58.30	2.39
yellowmouth grouper	*Mycteroperca interstitialis*	Serranidae	0.00	.	.	0.00	.	.
gag	*Mycteroperca microlepis*	Serranidae	0.00	.	.	0.50	65.00	0.00
scamp	*Mycteroperca phenax*	Serranidae	0.00	.	.	0.50	60.00	0.00
tiger grouper	*Mycteroperca tigris*	Serranidae	1.00	30.00	0.00	66.83	23.51	0.47
yellowfin grouper	*Mycteroperca venenosa*	Serranidae	0.00	.	.	0.00	.	.
Snappers								
mutton snapper	*Lutjanus analis*	Lutjanidae	9.00	50.44	2.68	8.50	49.82	2.27
schoolmaster	*Lutjanus apodus*	Lutjanidae	0.50	50.00	0.00	32.50	31.80	0.78
blackfin snapper	*Lutjanus buccanella*	Lutjanidae	0.00	.	.	0.00	.	.
yellowtail snapper	*Ocyurus chrysurus*	Lutjanidae	42.50	33.49	0.39	43.38	37.18	1.12
cubera snapper	*Lutjanus cyanopterus*	Lutjanidae	1.00	51.00	0.00	0.00	.	.
gray snapper	*Lutjanus griseus*	Lutjanidae	70.50	32.58	0.48	202.63	30.92	0.27
dog snapper	*Lutjanus jocu*	Lutjanidae	2.50	51.00	6.09	6.00	50.00	3.86
mahogony snapper	*Lutjanus mahogoni*	Lutjanidae	0.00	.	.	0.00	.	.
lane snapper	*Lutjanus synagris*	Lutjanidae	6.00	26.17	1.11	123.50	26.05	0.28
hogfish	*Lachnolaimus maximus*	Labridae	30.13	39.11	1.32	36.00	42.44	1.56
Grunts								
black margate	*Anisotremus surinamensis*	Haemulidae	0.00	.	.	0.00	.	.
porkfish	*Anisotremus virginicus*	Haemulidae	60.00	20.36	0.66	92.08	21.63	0.40
margate	*Haemulon album*	Haemulidae	14.75	25.07	1.67	27.50	33.72	1.05
tomtate	*Haemulon aurolineatum*	Haemulidae	0.00	.	.	12.00	17.92	0.74
ceasar grunt	*Haemulon carbonarium*	Haemulidae	1.50	19.67	1.76	43.50	21.67	0.60
smallmouth grunt	*Haemulon chrysargyreum*	Haemulidae	0.00	.	.	0.00	.	.
french grunt	*Haemulon flavolineatum*	Haemulidae	32.00	20.28	0.74	30.25	17.74	0.34

Table 5.10 (cont.) - Average length in the exploitable phase (LBAR) for 64 species of reef fish in 13 families both within and outside the RNA in the DTNP. The number of fish from which the estimate is derived is given (N) as well as the standard error of the estimate (SE_LBAR).

			1999			2000		
COMMON	**LATIN**	**FAMILY**	**N**	**LBAR**	**SE_LBAR**	**N**	**LBAR**	**SE_LBAR**
Grunts (Cont.)								
spanish grunt	*Haemulon macrostomium*	Haemulidae	3.00	27.50	1.95	68.50	25.84	0.41
cottonwick	*Haemulon melanurum*	Haemulidae	0.00	.	.	0.00	.	.
sailors choice	*Haemulon parra*	Haemulidae	0.00	.	.	30.50	27.95	0.59
white grunt	*Haemulon plumieri*	Haemulidae	458.25	22.25	0.19	510.87	22.92	0.19
bluestriped grunt	*Haemulon sciurus*	Haemulidae	27.88	21.34	0.54	26.63	22.07	0.68
striped grunt	*Haemulon striatum*	Haemulidae	0.00	.	.	0.00	.	.
Other Reef Fishes								
great barracuda	*Sphyraena barracuda*	Sphyraenidae	20.00	97.25	6.28	0.00	.	.
jolthead porgy	*Calamus bajonado*	Sparidae	0.00	.	.	0.50	240.00	0.00
saucereye porgy	*Calamus calamus*	Sparidae	117.25	24.10	0.43	0.00	.	.
yellow jack	*Caranx bartholomaei*	Carangidae	22.00	41.30	1.23	16.25	36.41	2.95
blue runner	*Caranx crysos*	Carangidae	67.50	21.73	0.87	112.50	24.81	0.69
crevalle jack	*Caranx hippos*	Carangidae	2.50	63.60	5.88	0.00	.	.
bar jack	*Caranx ruber*	Carangidae	396.25	29.73	0.27	176.29	28.51	0.45
bermuda chub	*Kyphosus sectatrix*	Kyphosidae	19.00	27.76	1.66	169.00	35.02	0.65
gray angelfish	*Pomacanthus arcuatus*	Pomacanthidae	16.50	35.94	0.45	14.00	37.25	0.90
blue parrotfish	*Scarus coeruleus*	Scaridae	0.00	.	.	0.00	.	.
rainbow parrotfish	*Scarus guacamaia*	Scaridae	0.00	.	.	0.00	.	.
princess parrotfish	*Scarus taeniopterus*	Scaridae	6.00	29.92	0.92	0.50	23.00	0.00
queen parrotfish	*Scarus vetula*	Scaridae	0.00	.	.	0.00	.	.
greenblotch parrotfish	*Sparisoma atomarium*	Scaridae	0.00	.	.	0.00	.	.
redband parrotfish	*Sparisoma aurofrenatum*	Scaridae	79.75	21.23	0.42	69.75	21.68	0.57
redtail parrotfish	*Sparisoma chrysopterum*	Scaridae	20.25	28.54	1.11	12.00	27.92	0.87
bucktooth parrotfish	*Sparisoma radians*	Scaridae	0.00	.	.	0.00	.	.
redfin parrotfish	*Sparisoma rubripinne*	Scaridae	10.25	33.95	1.19	6.00	33.83	1.81
stoplight parrotfish	*Sparisoma viride*	Scaridae	6.00	40.83	1.49	7.38	41.46	1.63
gray triggerfish	*Balistes capriscus*	Balistidae	0.00	.	.	0.00	.	.
ocean triggerfish	*Cantherhines sufflamen*	Balistidae	1.00	37.50	0.00	16.50	35.76	2.07
doctorfish	*Acanthurus chirurgus*	Acanthuridae	21.25	23.96	0.88	26.00	26.06	0.93
permit	*Trachinotus falcatus*	Carangidae	0.50	60.00	0.00	1.00	50.00	0.00
Pelagics								
king mackerel	*Scomberomorus cavalla*	Scombridae	0.00	.	.	0.00	.	.
spanish mackerel	*Scomberomorus maculatus*	Scombridae	0.00	.	.	0.50	40.00	0.00
cero	*Scomberomorus regalis*	Scombridae	2.00	38.75	2.17	2.00	62.50	17.85
greater amberjack	*Seriola dumerili*	Carangidae	4.00	97.50	6.61	0.50	100.00	0.00

reliability. Our results corroborate previous research which demonstrated close agreement between fishery-independent RVC estimates of average length and fishery-dependent headboat survey $\bar{L}$ estimates for Florida Keys reef fishes (Ault et al. 1997a, 1998).

5.6 Spatial Maps of Population Density and $\bar{L}$

A spatial perspective of stock biological indicator variables estimated throughout the greater Florida Keys ecosystem is given in **Figures 5.3-5.12**. These maps illustrate respective juvenile density and $\bar{L}$ point estimates at primary sampling unit locations for black grouper (**Figures 5.3** and **5.4**), red grouper (**Figures 5.5** and **5.6**), gray snapper (**Figures 5.7** and **5.8**), yellowtail snapper (**Figures 5.9** and **5.10**), and white grunt (**Figures 5.11** and **5.12**). Spatial density patterns of juvenile red (**Figure 5.3**) and black (**Figure 5.5**) grouper were fairly uniform throughout the Florida Keys (Miami to Key West) and Tortugas regions. Similar results were obtained for juvenile yellowtail snapper (**Figure 5.9**) and white grunt (**Figure 5.11**). In contrast, densities of juvenile gray snapper (**Figure 5.7**) were generally higher in the Florida Keys region compared to the Tortugas region. This spatial pattern is perhaps not surprising since it has been established that gray snapper early juveniles utilize coastal bay habitats (e.g., Florida Bay, Biscayne Bay) almost exclusively before migrating offshore to the coral reef system as late juveniles (c.f., Ault et al. 2001).

Perhaps the most striking feature of the $\bar{L}$ maps for black grouper (**Figure 5.4**) and red grouper (**Figure 5.6**) was the infrequent occurrence of sightings of exploited phase individuals. This phenomenon was more pronounced in the Florida Keys region than in the Tortugas region. Following the same trend, average sizes of gray snapper (**Figure 5.8**) and white grunt (**Figure 5.12**) were generally higher in the lower Keys and Tortugas compared to the upper Keys and Biscayne National Park. Yellowtail snapper, on the other hand, exhibited fairly uniform spatial patterns of average size (**Figure 5.10**) from Key Largo to the Tortugas.

The contrast in spatial patterns of juvenile density and $\bar{L}$ for red and black groupers, gray snapper, and white grunt are somewhat disturbing and encouraging at the same time. While exploited phase stocks of these species appear to be in a depleted condition, particularly the groupers, juveniles seem to be moderately abundant throughout the ecosystem, suggesting that these stocks have not as yet undergone complete recruitment failure. Thus, there may be a window of opportunity in the next several years to begin rebuilding adult and exploited phase stocks of these species back to sustainable levels.

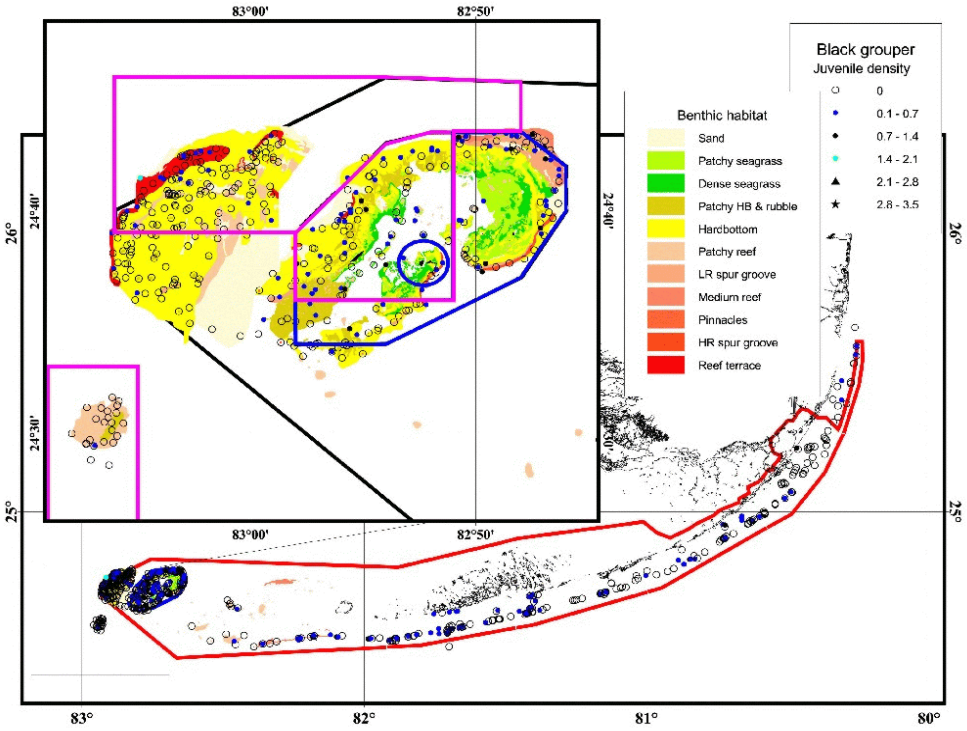


Figure 5.3 - Mean density (number per 177 m^2) of black grouper juveniles at visual survey primary sampling unit locations in the Florida Keys-Dry Tortugas ecosystem, 1997-2000. The FKNMS boundary is delineated in red. (Inset) Spatial density values overlain on digital map of benthic habitats in the Dry Tortugas region. Pink boundaries delineate proposed/implemented marine reserves.

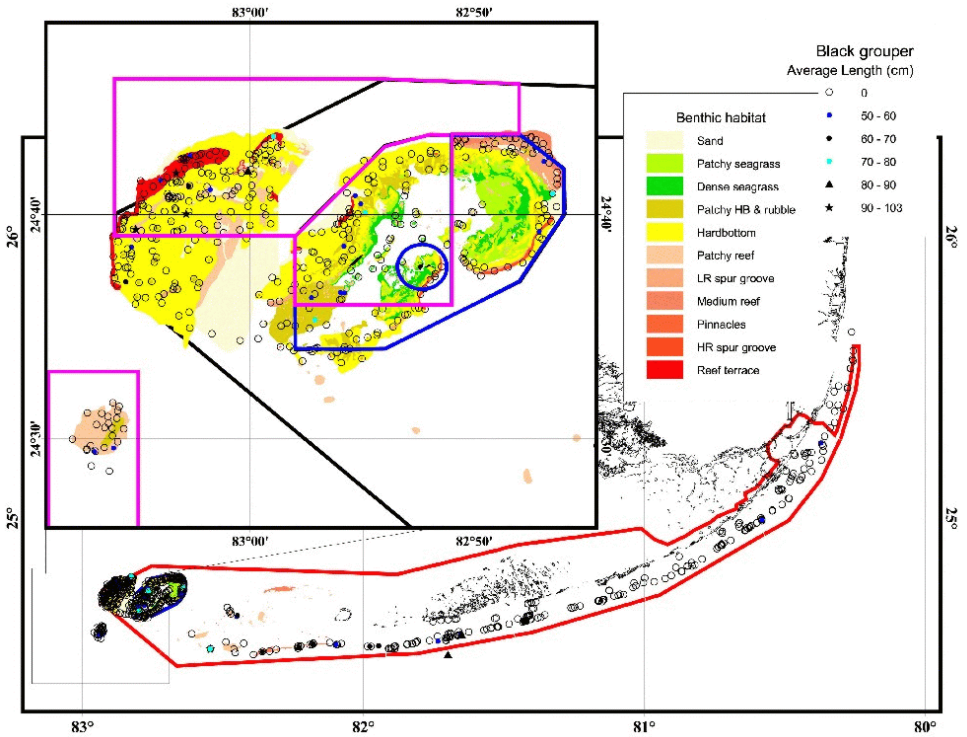


Figure 5.4 - Average length (cm) of black grouper exploited phase individuals at visual survey primary sampling unit locations in the Florida Keys-Dry Tortugas ecosystem, 1997-2000. The FKNMS boundary is delineated in red. (Inset) Spatial average length values overlain on digital map of benthic habitats in the Dry Tortugas region. Pink boundaries delineate proposed/implemented marine reserves.

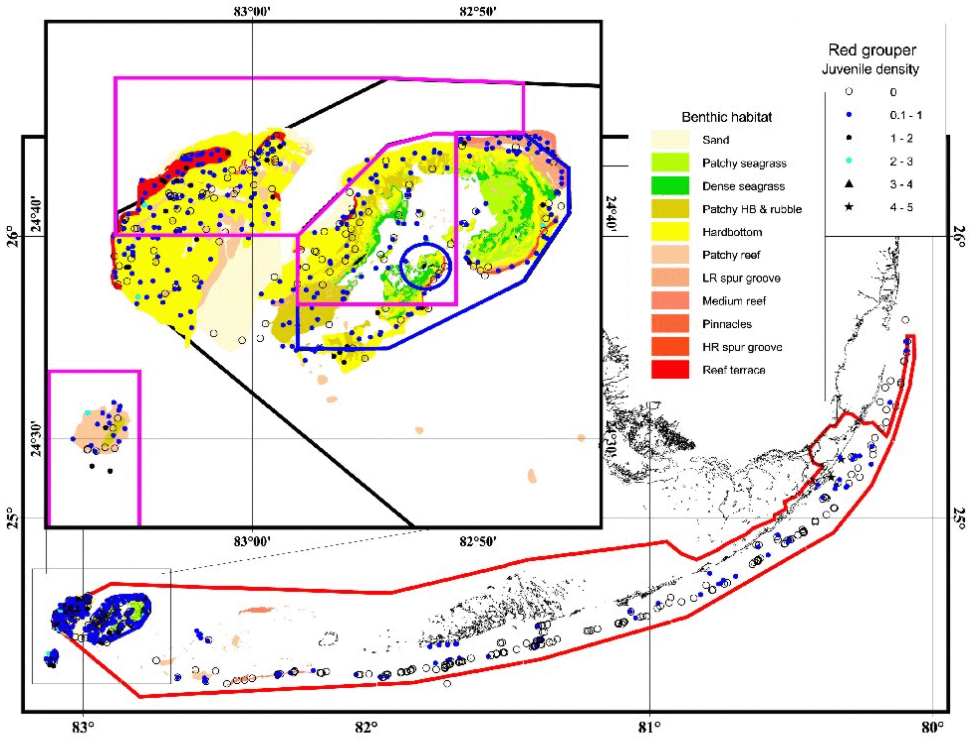


Figure 5.5 - Mean density (number per 177 m²) of red grouper juveniles at visual survey primary sampling unit locations in the Florida Keys-Dry Tortugas ecosystem, 1997-2000. The FKNMS boundary is delineated in red. (Inset) Spatial density values overlain on digital map of benthic habitats in the Dry Tortugas region. Pink boundaries delineate proposed/implemented marine reserves.

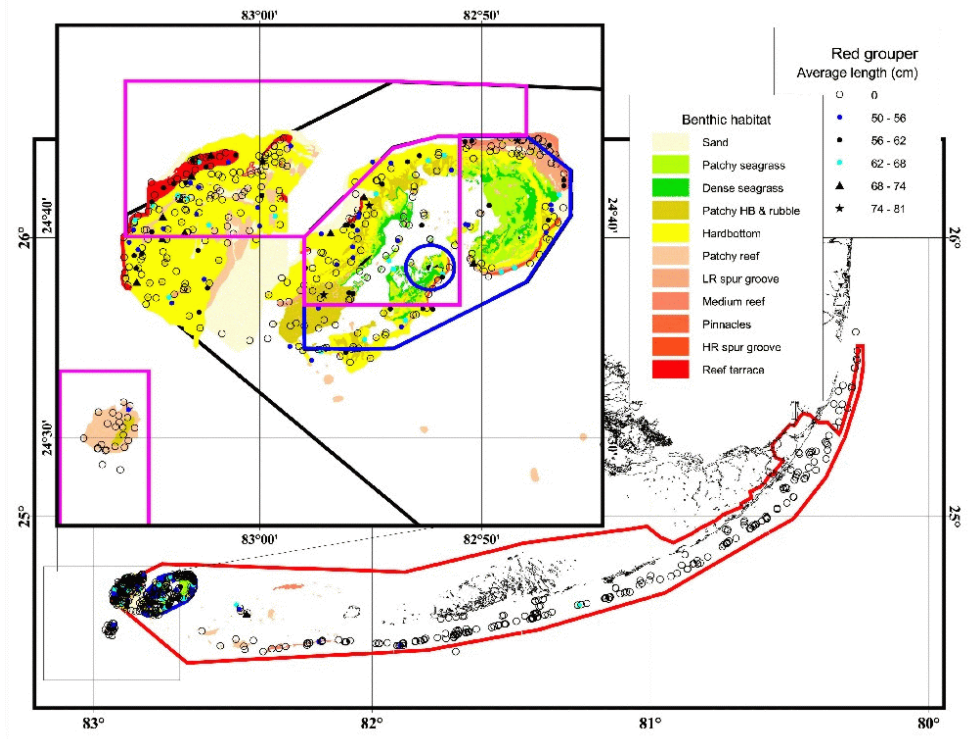


Figure 5.6 - Average length (cm) of red grouper exploited phase individuals at visual survey primary sampling unit locations in the Florida Keys-Dry Tortugas ecosystem, 1997-2000. The FKNMS boundary is delineated in red. (Inset) Spatial average length values overlain on digital map of benthic habitats in the Dry Tortugas region. Pink boundaries delineate proposed/implemented marine reserves.

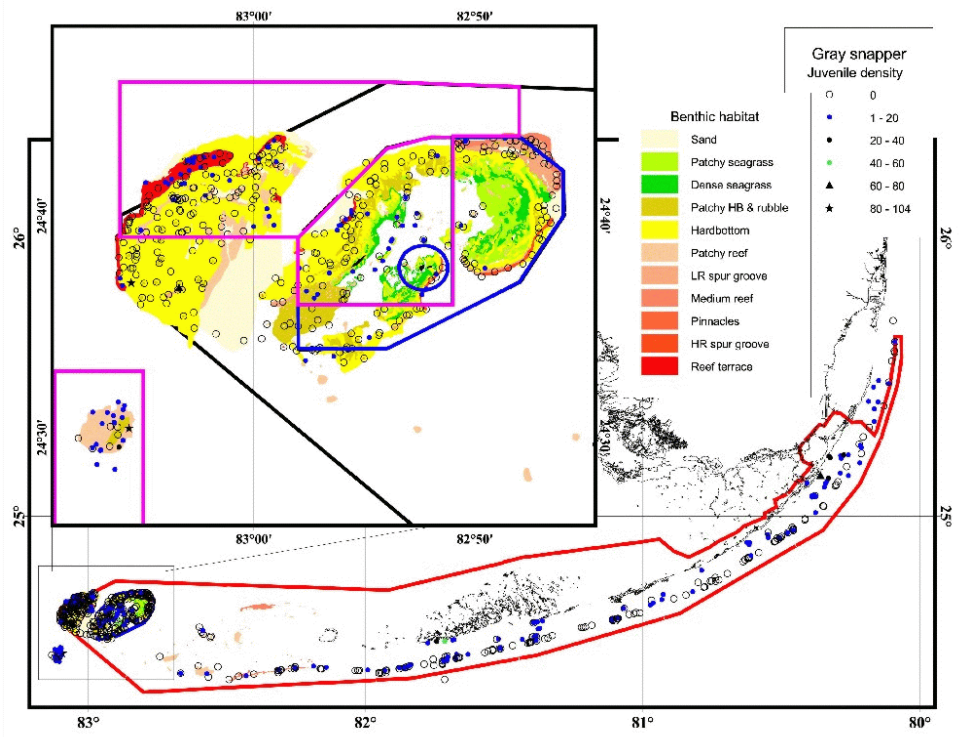


Figure 5.7 - Mean density (number per 177 m^2) of gray snapper juveniles at visual survey primary sampling unit locations in the Florida Keys-Dry Tortugas ecosystem, 1997-2000. The FKNMS boundary is delineated in red. (Inset) Spatial density values overlain on digital map of benthic habitats in the Dry Tortugas region. Pink boundaries delineate proposed/implemented marine reserves.

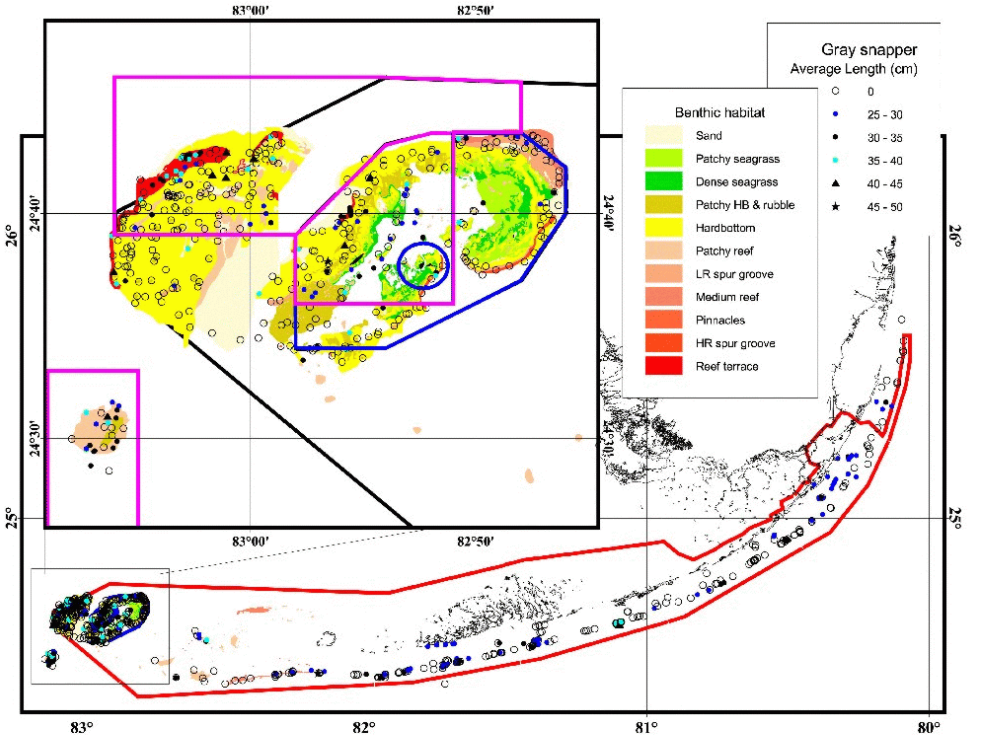


Figure 5.8 - Average length (cm) of gray snapper exploited phase individuals at visual survey primary sampling unit locations in the Florida Keys-Dry Tortugas ecosystem, 1997-2000. The FKNMS boundary is delineated in red. (Inset) Spatial average length values overlain on digital map of benthic habitats in the Dry Tortugas region. Pink boundaries delineate proposed/implemented marine reserves.

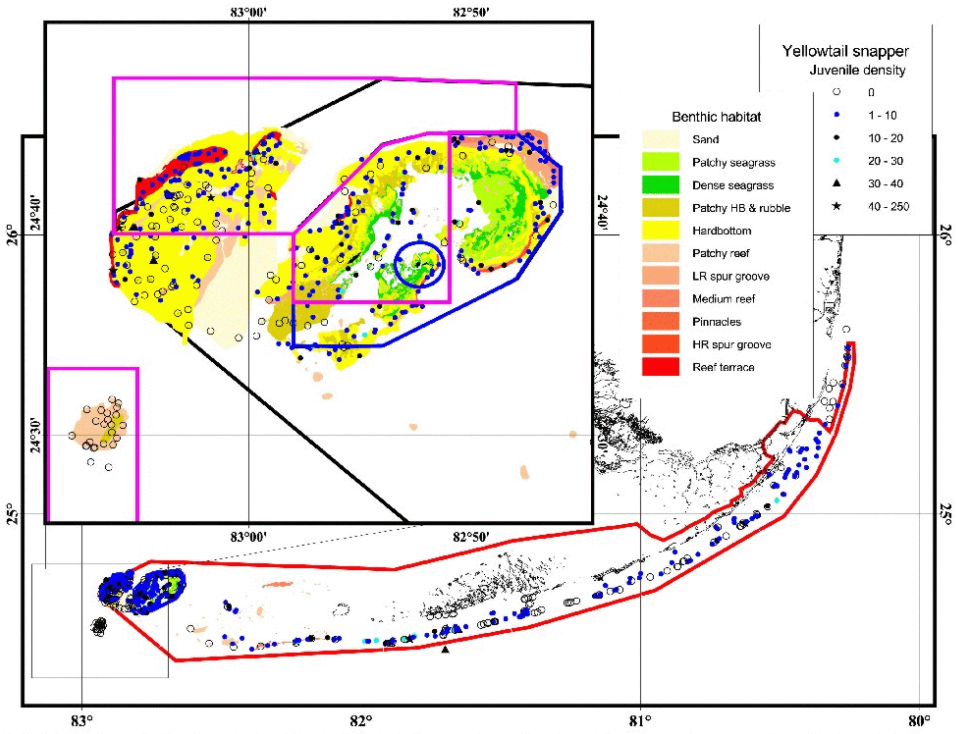


Figure 5.9 - Mean density (number per 177 m^2) of yellowtail snapper juveniles at visual survey primary sampling unit locations in the Florida Keys-Dry Tortugas ecosystem, 1997-2000. The FKNMS boundary is delineated in red. (Inset) Spatial density values overlain on digital map of benthic habitats in the Dry Tortugas region. Pink boundaries delineate proposed/implemented marine reserves.

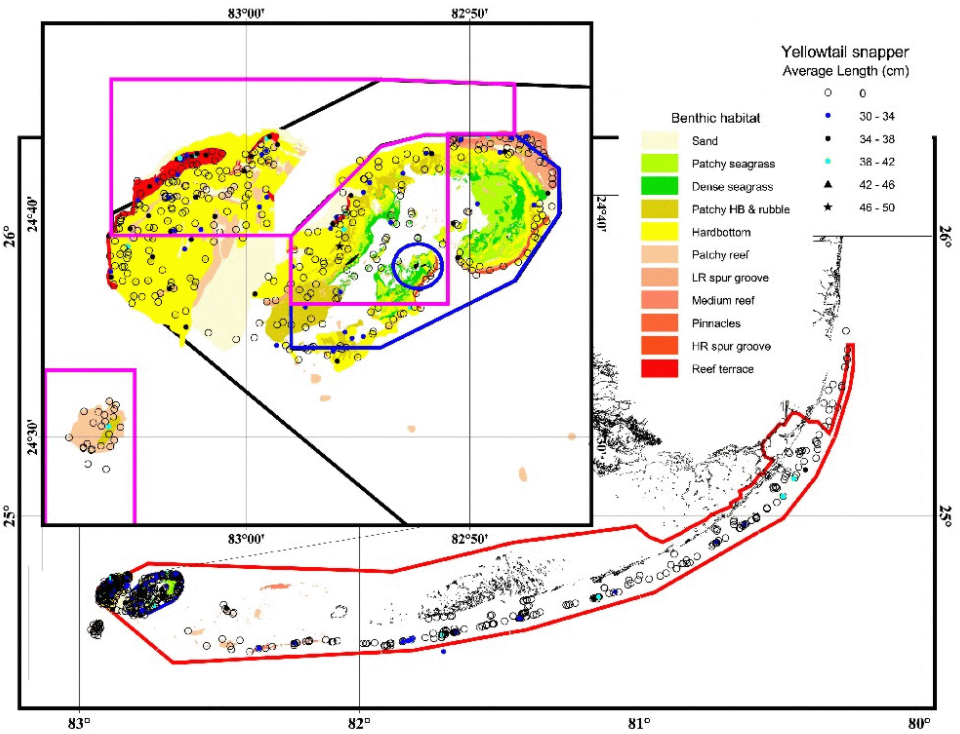


Figure 5.10 - Average length (cm) of yellowtail snapper exploited phase individuals at visual survey primary sampling unit locations in the Florida Keys-Dry Tortugas ecosystem, 1997-2000. The FKNMS boundary is delineated in red. (Inset) Spatial average length values overlain on digital map of benthic habitats in the Dry Tortugas region. Pink boundaries delineate proposed/implemented marine reserves.

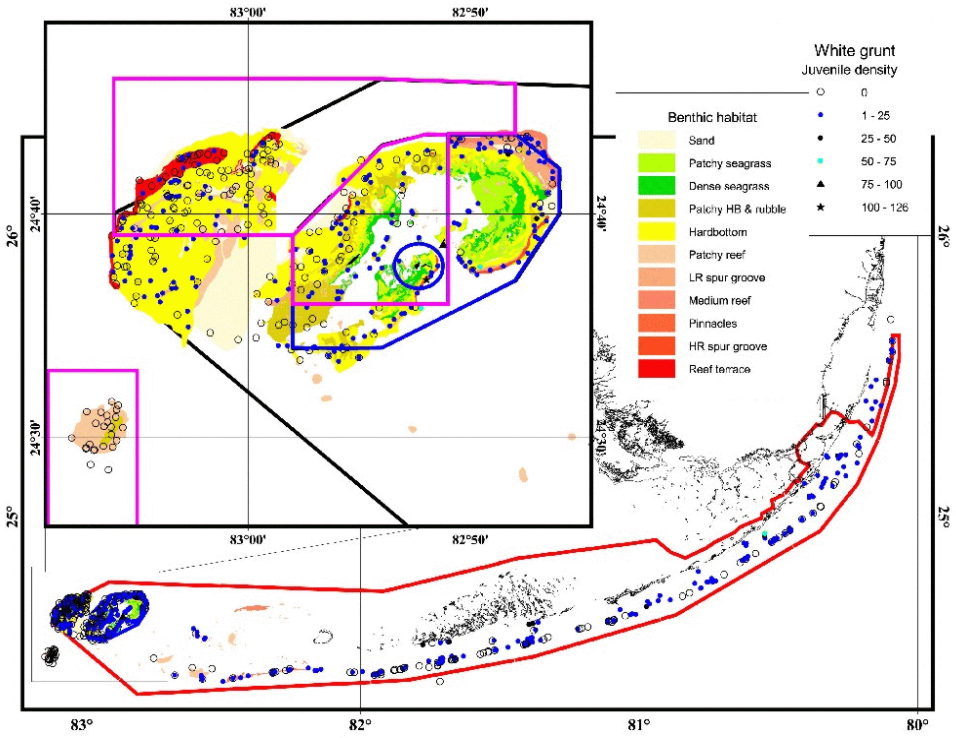


Figure 5.11 - Mean density (number per 177 m^2) of white grunt juveniles at visual survey primary sampling unit locations in the Florida Keys-Dry Tortugas ecosystem, 1997-2000. The FKNMS boundary is delineated in red. (Inset) Spatial density values overlain on digital map of benthic habitats in the Dry Tortugas region. Pink boundaries delineate proposed/implemented marine reserves.

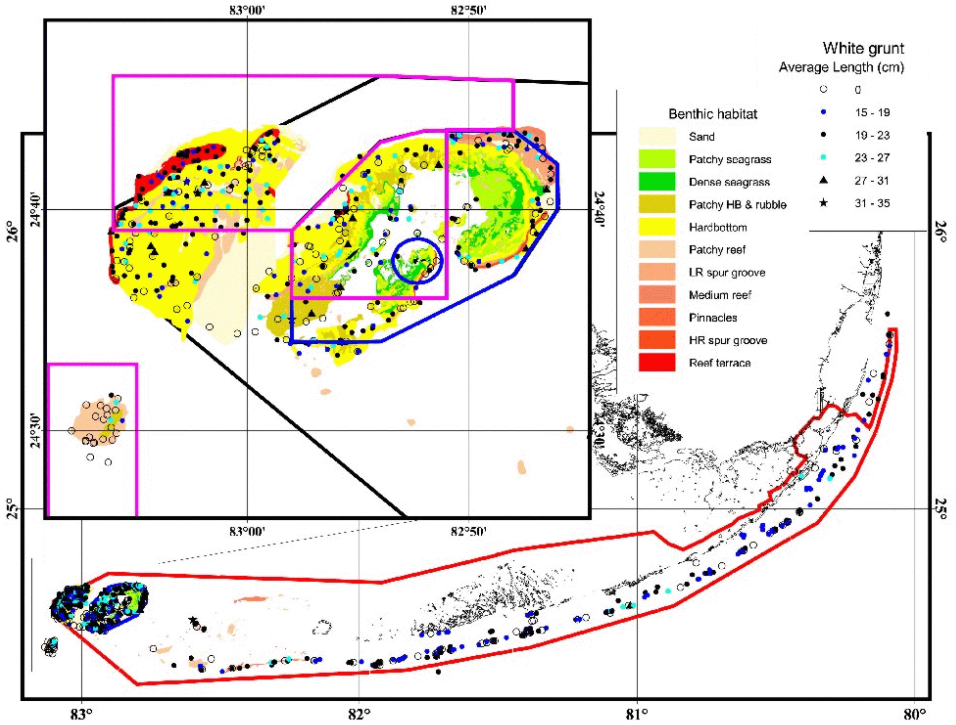


Figure 5.12 - Average length (cm) of white grunt exploited phase individuals at visual survey primary sampling unit locations in the Florida Keys-Dry Tortugas ecosystem, 1997-2000. The FKNMS boundary is delineated in red. (Inset) Spatial average length values overlain on digital map of benthic habitats in the Dry Tortugas region. Pink boundaries delineate proposed/implemented marine reserves.

6.0 Multispecies Fishery Stock Assessments

In this section, we conduct a quantitative assessment of the exploited coral reef fish stocks in the Tortugas region, and evaluate the current status of these stocks relative to established Federal and International benchmarks for sustainable management of fishery resources. An overview of our general assessment procedure, comprised of 8 separate steps, is summarized in the flow diagram (**Figure 6.1**). Steps 1 to 3 have already been described. This section details Steps 4 through 8 of the multispecies stock assessment methodology.

6.1 Synthesis of Population Dynamics Parameters

As background for the quantitative assessment of the multispecies fisheries resources in the Tortugas region, we conducted a thorough search of the scientific and technical literature (c.f., Claro 1994; Schmidt and Pikula 1997; FISHBASE, Froese and Pauly 2000). These data were combined with our own databases to assemble a comprehensive suite of biological and population dynamic information that contains key rate parameters necessary for computing the relevant management benchmarks for fishery sustainability. These population dynamics parameters included age-length, weight-length and weight-fecundity relationships, size-age at first recruitment, minimum size-age at first sexual maturity, maximum size-age, sex ratios and age (size) class distributions, natural mortality rates, and other key fisheries indices (**Table 6.1**) These data were required to run our suite of multispecies fishery stock assessment computer models (Ehrhardt and Ault 1992; FAO 1997, Ault et al. 1996, 1997a, 1998; Ault in prep.). Of the more than 90 exploited and/or ecologically-important species we identified within the databases, we found that the available population dynamics parameters varied widely in breadth and statistical precision (**Table 6.2**). Therefore, we classified each species' parameter set according to a 'parameter confidence' rating that ranged from no data available (scored 0) to high confidence (scored 3). These data were essential to producing the baseline multispecies stock assessments.

6.2 Estimation of Total Mortality Rate from 'Average Size' Statistics

While persistent heavy fishing reduces the average fishable population size over time, it also leaves a distinguishing size-age structure signature on the exploited population, which provides a robust basis for mortality estimation. We capitalized on this aspect of demographic theory by using the "average size" $\bar{L}$ statistic, a population metric that represents a weighted sum of individuals in the exploited population, to assess the current levels of exploitation of the multispecies reef fish community. To estimate the total instantaneous mortality rate $Z(t)$ given an estimate of $\bar{L}(t)$, we used a length-based algorithm following Ault and Ehrhardt (1991) and Ehrhardt and Ault (1992)

$$\left[\frac{L_\infty - L_\lambda}{L_\infty - L_c}\right]^{\frac{Z(t)}{K}} = \frac{Z(t)\left(L_c - \bar{L}(t)\right) + K\left(L_\infty - \bar{L}(t)\right)}{Z(t)\left(L_\lambda - \bar{L}(t)\right) + K\left(L_\infty - \bar{L}(t)\right)} \qquad (6.1)$$

where L_c is size at first capture, L is maximum size in the stock, K and L are parameters of the von Bertalanffy growth equation, and t is year. While no explicit formula exists for analytical estimation of $Z(t)$, this can be achieved fairly easily using an iterative numerical algorithm called LBAR developed by Ault et al. (1996) (also found in the FAO stock assessment library, FAO 1997). The algorithm provides a means to an unbiased estimator of total instantaneous population mortality rate $Z(t)$ (Quinn and Deriso 1999). Estimation of instantaneous fishing mortality rate $F(t)$ is accomplished by subtracting the rate of natural mortality M from the $\hat{Z}(t)$ estimate. The $\hat{Z}(t)$ statistic is robust to any population survey measure (i.e., visual census, creel, or headboat survey data). Iterative application of the mortality estimation method using annual

estimates of $\bar{L}$ provided time-series information on fishing mortality rates, and thus abundance, for all key species included in the analysis. This estimation procedure is explained in detail in Ault et al. (1998). Current estimates of $\hat{F}$ are given in **Table 6.4** and **Table 6.5.**

Figure 6.1 - Flow chart showing the steps used in the multispecies reef fish assessment. See Ault et al. (1998) for additional details.

Begin Multispecies Assessment

Step 1: Conduct fishery surveys (RVC, etc.) for fish community in year *t* and intercalibrate sampling efficiency by species, site, and year.

Begin Management Analyses for species s

Step 2: Using intercalibrated survey data, compute annual estimates of $\bar{L}$ and associated 95% confidence intervals from size and abundance data integrated over the range of exploitable sizes.

Step 3: Compute CPUE by species by lifestage by year t for each data type.

Step 4: Use population dynamics parameters (**Table 6.2**) to parameterize the LBAR (Ault et al. 1996, FAO 1997) and REEFS (Ault et al. 1998) computer algorithms.

Step 5: Use $\bar{L}(t)$ estimate in LBAR computer algorithm to estimate fishing mortality rates as $\hat{F}(t) = \hat{Z}(t) - M$ for each species by year for the several data sources, i.e., time series of RVC and headboat data.

Step 6: Use the REEFS numerical model to: (1) compute expected $\bar{L}(t)$ given the reported population dynamics and $\hat{F}$ parameter values; (2) compute yield per recruit (YPR) and assess growth overfishing; and, (3) compute spawning stock biomass (SSB) for the fishery in unexploited and (for maximum sustainable yield and current) exploited states (i.e., $F=0$, $F=F_{msy}$, *and* $F=\hat{F}(t)$, respectively) and evaluate spawning potential ratio (SPR) to assess recruitment overfishing.

Step 7: Use REEFS to compute $\hat{B}_0$, B_{msy}, $\hat{B}(t)$ and assess limit control rules.

Step 8: From these results make specific fishery management recommendations on control strategies of F and L_c consistent with eumetric fishing principles and the precautionary approach of the MSFMCA that minimize the potential for overfishing.

Conduct next species analyses?
STOP

Table 6.1 - Parameters, definitions and units for life table variables common to the LBAR mortality algorithm and REEFS numerical simulation model used in analysis of Florida Keys reef fish populations dynamics. See **Table 6.2** for parameter values.

Parameter	Definition	Units
s	Reef fish species (s=1, ,n)	
a	Cohort age class (a=1,…,t)	
t_r	Age of recruitment	months
L_r	Size at recruitment	mm
t_m	Minimum age of maturity	months
L_m	Minimum size of maturity	mm
t_c	Minimum age of first capture	months
L_c	Minimum size of first capture	mm
t	Oldest (largest) age	years
L	Largest (oldest) size	mm
W	Ultimate weight	kg
L	Ultimate length	mm
K	Brody growth coefficient	$year^{-1}$
t_0	Age at which size equals 0	years
$_{WL}$	Scalar coefficient of weight-length function	dimensionless
$ß_{WL}$	Power coefficient of weight-length function	dimensionless
W(a,t)	Weight at age *a* at time *t*	g
L(a,t)	Length at age *a* at time *t*	mm
N(a,t)	Numbers at age *a* at time *t*	number of fish
M(a,t)	Natural mortality rate at age *a* at time *t*	$year^{-1}$
$\bar{L}_s(t)$	Average size in exploited phase for stock *s*	mm
F(a,t)	Fishing mortality rate at age *a* at time *t*	$year^{-1}$
S(a)	Survivorship to age *a*	dimensionless
Z(t)	Total mortality rate in year *t*	dimensionless
(a)	Sex ratio at age *a*	dimensionless
B(a,t)	Biomass at age *a* in year *t*	kg
$Y_w(t)$	Yield in weight in year t	mt
SSB(t)	Spawning stock biomass in year *t*	mt
SPR(t)	Spawning potential ratio in year *t*	dimensionless
B_0	Stock spawning biomass at zero exploitation	mt
B_{msy}	Stock spawning biomass at MSY	mt

Table 6.2 - Population dynamics parameters for exploited fishes in the Dry Tortugas and Florida Keys necessary to LBAR and REEFS assessment and management models.

	Common Name	Scientific Name	Population Dynamics Rate Parameters													Parameter Confidence
			M(a,t)	T_λ	L_∞	W_∞	K	t_0	L_m	t_m	L_a	t_a	α_{WL}	β_{WL}	L_λ	
	Groupers															
1	Rock Hind	*Epinephelus adscensionis*	0.250	12	486.1	2.27	0.191	-2.160	336	48	200	7	6.00E-06	3.193	453.3	3
2	Graysby	*Epinephelus cruentatus*	0.370	8.1	340	0.62	0.350	-0.460	198	24	200	25	1.22E-05	3.044	350	3
3	Speckled Hind	*Epinephelus drummondhayi*	0.200	15	967	16.58	0.130	-1.010	463	48	290	21	1.11E-05	3.073	861	3
4	Yellowedge Grouper	*Epinephelus flavolimbatus*	0.115	26	1180	40.22	0.110	-1.070	606	66	240	12	2.82E-05	2.980	1150	1
5	Coney	*Epinephelus fulvus*	0.666	4.5	340	0.68	0.630	-0.250	198	13	220	17	1.74E-05	3.000	340	1
6	Red Hind	*Epinephelus guttatus*	0.176	17	392.7	1.01	0.207	-0.831	251	49	180	26	8.55E-06	3.112	382.9	3
7	Marbled Grouper	*Epinephelus inermis*	0.176	17	937	11.83	0.170	-0.700	493	44	200	9	1.13E-05	3.035	910	1
8	Jewfish	*Epinephelus itajara*	0.134	22.3	2010	180.72	0.130	-0.130	978	52	Closed		1.04E-05	3.100	2500	3
9	Red Grouper	*Epinephelus morio*	0.176	17	938	11.86	0.153	-0.099	437	48	508	60	1.13E-05	3.035	869	3
10	Misty Grouper	*Epinephelus mystacinus*	0.187	16	1633	63.56	0.180	0.000	811	38			2.45E-05	2.930	1600	1
11	Warsaw Grouper	*Epinephelus nigritus*	0.073	41	2394	244.86	0.054	-3.616	807	48			2.09E-05	2.980	2328	3
12	Snowy Grouper	*Epinephelus niveatus*	0.200	15	1091.3	19.51	0.113	-0.915	465	48			2.45E-05	2.930	909	3
13	Nassau Grouper	*Epinephelus striatus*	0.176	17	698.9	5.87	0.145	-1.080	480	83	Closed		3.83E-06	3.229	648.2	3
14	Black Grouper	*Mycteroperca bonaci*	0.150	20	1200	31.59	0.160	-0.300	597	48	609.6	50	4.27E-06	3.205	1153.1	3
15	Yellowmouth Grouper	*Mycteroperca interstitialis*	0.176	17	881.8	8.60	0.063	-9.030	469	36	508	55	2.58E-05	2.894	710.7	3
16	Gag Grouper	*Mycteroperca microlepis*	0.230	13	1187.2	25.14	0.149	-0.802	687	60	609.6	48	1.21E-05	3.031	1034.4	3
17	Scamp	*Mycteroperca phenax*	0.143	21	999.7	19.26	0.126	-1.357	491	48	508	51	2.02E-05	2.993	932.2	3
18	Yellowfin Grouper	*Mycteroperca venenosa*	0.200	15	860	15.67	0.170	0.000	527	67	508	63	2.82E-05	2.980	960	3
19	Tiger Grouper	*Mycteropreca tigris*	0.116	26	740	6.38	0.110	-1.875	460	84	240	20	9.40E-03	3.120	705.361	1
	Snappers															
19	Mutton Snapper	*Lutjanus analis*	0.214	14	938.7	14.15	0.129	-0.738	279	24	406.4	44	1.57E-05	3.012	797.8	3
20	Schoolmaster	*Lutjanus apodus*	0.250	12	570	3.28	0.180	0.000	148	20	254	39	2.04E-05	2.978	503.8	3
21	Blackfin Snapper	*Lutjanus buccanella*	0.333	9	729.7	2.41	0.084	-2.896	232	20	304.8	43	7.40E-06	2.974	458.8	3
22	Red Snapper	*Lutjanus campechanus*	0.187	16	975	13.68	0.162	-0.010	308	28	508	54	2.04E-05	2.953	955	3
23	Yellowtail Snapper	*Lutjanus chrysurus*	0.214	14	454.7	1.30	0.209	-0.712	197	24	304.8	55	7.75E-05	2.718	433.4	3
24	Cubera Snapper	*Lutjanus cyanopterus*	0.150	20	1633	89.57	0.140	-0.710	819	50	304.8	9	1.32E-05	3.060	1600	1
25	Gray Snapper	*Lutjanus griseus*	0.300	10	722.3	5.25	0.136	-0.863	233	24	254	28	3.05E-05	2.881	556.2	3
26	Dog Snapper	*Lutjanus jocu*	0.333	9	854	10.19	0.100	-2.000	300	28	304.8	29	4.28E-05	2.857	790	3
27	Mahogony Snapper	*Lutjanus mahogoni*	0.300	10	618.3	3.18	0.250	-1.728	280	9	304.8	12	8.18E-05	2.719	585.0	1
28	Lane Snapper	*Lutjanus synagris*	0.300	10	618.3	3.24	0.097	-1.728	205	29	203.2	29	4.52E-05	2.815	418.4	3
29	Silk Snapper	*Lutjanus vivanus*	0.333	9	781.1	9.28	0.092	-2.309	305	37	304.8	37	1.00E-05	3.100	512	3
30	Black Snapper	*Apsilus dentatus*	0.681	4.4	638	3.87	0.650	-0.200	349	12			1.49E-05	3.000	650	2
31	Vermillion Snapper	*Rhomboplites aurorubens*	0.300	10	613.6	9.19	0.206	0.111	314	43	254	32	3.01E-05	3.044	541.6	3
32	Hogfish	*Lachnolaimus maximus*	0.250	12	566	3.51	0.190	-0.776	199	18	304.8	40	2.09E-05	2.988	439	3
	Grunts															
33	Black Margate	*Anisotremus surinamensis*	0.374	8	673	9.33	0.360	-0.350	366	22	220	10	2.39E-06	3.392	639.2	1
34	Porkfish	*Anisotremus virginicus*	0.428	7	397	1.72	0.410	-0.350	228	20	160	10	1.01E-05	3.167	381.1	1
35	Margate	*Haemulon album*	0.374	8	752.6	8.57	0.174	-0.450	426	52	200	16	1.52E-05	3.042	710	2
36	Tomtate	*Haemulon aurolineatum*	0.333	9	310	0.61	0.220	-1.280	130	14	150	21	6.19E-06	3.208	250	3
37	Caesar Grunt	*Haemulon carbonarium*	0.428	7	376	0.96	0.300	0.000	217	35	160	23	1.29E-05	3.056	329.4	1
38	Smallmouth Grunt	*Haemulon chrysargyreum*	0.499	6	242	0.38	0.470	-0.350	146	19	160	23	2.77E-03	2.157	230	1
39	French Grunt	*Haemulon flavolineatum*	0.333	9	294.31	0.57	0.179	0.000	176	62	160	53	9.06E-06	3.158	193.0	2
40	Spanish Grunt	*Haemulon macrostomum*	0.300	10	448	2.46	0.480	-0.290	254	18	200	12	2.28E-05	3.030	444.7	1
41	Cottonwick	*Haemulon melanurum*	0.333	9	350	0.82	0.320	-0.500	203	27	160	17	2.52E-05	2.953	333.0	2
42	Sailors Choice	*Haemulon parrai*	0.428	7	400.2	1.24	0.220	-0.355	103	12	200	34	2.02E-05	2.993	320.1	1
43	White Grunt	*Haemulon plumieri*	0.374	8	511.9	3.06	0.186	-0.776	177	18	170	17	8.35E-06	3.161	410.3	3
44	Bluestriped Grunt	*Haemulon sciurus*	0.499	6	412.7	1.36	0.300	0.000	205	24	180	23	1.94E-05	3.000	460	3
45	Striped Grunt	*Haemulon striatum*	0.499	6	294	0.62	0.470	-0.330	174	19	170	18	1.39E-05	3.099	280	1
46	Pigfish	*Orthopristis chrysoptera*									170		9.71E-06	3.189		0

Table 6.2 (cont.) - Population dynamics parameters for exploited fishes in the Dry Tortugas and Florida Keys necessary to LBAR and REEFS assessment and management models

	Common Name	Scientific Name	Population Dynamics Rate Parameters													Parameter Confidence
			M(at)	T_R	L_∞	W_∞	K	t_0	L_m	t_m	L_c	t_0	α_{WL}	β_{WL}	L_1	
	Other Reef Fishes															
47	Great Barracuda	*Sphyraena barracuda*	0.094	32	1780	42.95	0.09	-1.19	877	77	350	15	4.11E-06	3.083	2000	2
48	Jolthead Porgy	*Calamus bajonado*	0.230	13	704	7.03	0.22	-0.58	381	36	200	11	6.67E-05	2.818	680	1
49	Saucereye Porgy	*Calamus calamus*	0.428	7	581	3.75	0.41	-0.32	321	20	200	9	6.78E-05	2.801	560	1
50	Yellow Jack	*Caranx bartholomaei*	0.200	15	1028	18.41	0.19	-0.6	450	40	250	10	3.20E-05	2.909	1000	1
51	Blue Runner	*Caranx crysos*	0.272	11	724	5.28	0.26	-0.48	391	30	160	6	1.07E-04	2.690	700	2
52	Crevalle Jack	*Caranx hippos*	0.166	18	1271	29.37	0.16	-0.69	648	45	200	5	9.55E-05	2.734	1240	1
53	Horse-eye Jack	*Caranx latus*	0.250	12	826	20.12	0.24	-0.51	440	31	240	11	4.76E-06	3.300	800	1
54	Bar Jack	*Caranx ruber*	0.150	20	520	2.65	0.24	0	240	31	240	31	4.28E-06	3.237	520	3
55	Bermuda Chub	*Kyphosus sectatrix*	0.374	8	785	11.93	0.36	-0.34	420	21	180	5	1.45E-05	3.080	760	1
56	Gray Angelfish	*Pomacanthus arcuatus*	0.428	7	622	7.26	0.41	-0.31	341	19			3.71E-05	2.968	600	1
57	Bicolor Damselfish	*Pomacentrus partitus*											1.28E-05	3.152		0
58	Threespot Damselfish	*Pomacentrus planifrons*											5.27E-05	2.857		0
59	Blue Parrotfish	*Scarus coeruleus*	0.250	12	1231	39.56	0.24	-0.45	629	30			9.63E-06	3.111	1200	1
60	Striped Parrotfish	*Scarus croicensis*											1.29E-05	3.055		0
61	Rainbow Parrotfish	*Scarus guacamaia*	0.300	10	1231	39.16	0.29	-0.38	629	25			1.34E-05	3.063	1200	1
62	Princess Parrotfish	*Scarus taeniopterus*	0.499	6	366	0.58	0.48	-0.31	212	18			6.55E-05	2.709	350	1
63	Queen Parrotfish	*Scarus vetula*	0.599	5	551	2.26	0.6	-0.23	306	13			1.35E-05	3.000	610	1
64	Greenblotch Parrotfish	*Sparisoma atomarium*	0.599	5	263	0.21	0.57	-0.28	157	16			1.14E-05	3.000	250	1
65	Redband Parrotfish	*Sparisoma aurofrenatum*	0.599	5	294	0.41	0.57	-0.27	174	16			1.62E-05	3.000	280	1
66	Redtail Parrotfish	*Sparisoma chrysopterum*	0.832	3.6	418	1.43	0.79	-0.19	239	11			1.07E-05	3.100	460	2
67	Bucktooth Parrotfish	*Sparisoma radians*	0.599	5	211	0.11	0.57	-0.3	129	17			1.14E-05	3.000	200	2
68	Redfin Parrotfish	*Sparisoma rubripinne*	0.599	5	505	2.50	0.58	-0.24	283	14			1.94E-05	3.000	478	1
69	Stoplight Parrotfish	*Sparisoma viride*	0.300	10	663	5.78	0.29	-0.45	361	28			3.80E-05	2.900	640	2
70	Gray Triggerfish	*Balistes capriscus*	0.374	8	600	4.15	0.38	-0.36	330	20	304.8	18	2.91E-05	2.935	600	3
71	Queen Triggerfish	*Balistes vetula*	0.230	13	759	11.19	0.23	-0.57	408	33	240	13	2.73E-05	2.990	600	3
72	Ocean Triggerfish	*Cantherhines sufflamen*	0.333	9	673	6.78	0.32	-0.4	366	25	250	13	1.55E-05	3.055	650	1
73	Foureye Butterflyfish	*Chaetodon capistratus*											1.42E-05	3.190		0
74	Doctorfish	*Acanthurus chirurgus*	0.270	11	332	0.96	0.254	-0.63	194	32	200	36	1.19E-06	3.533	350	3
	Inshore Gamefishes															
75	Spotted Seatrout	*Cynoscion nebulosus*	0.158	19	794		0.15	-0.87	425	50	350	36			910	2
76	Permit	*Trachinotus falcatus*	0.176	17	1170	6.64	0.17	-0.66	601	4	254-508	9	1.01E-06	3.200	1140	1
77	African Pompano	*Alectis ciliaris*	0.200	15	1530	89.23	0.19	-0.54	767	37	609.6	26	5.19E-05	2.900	1500	1
	Pelagics															
78	Dolphinfish	*Coryphaena hippurus*	0.936	3.2	2340	215.18	0.92	-0.1	1121	7	300	1	7.93E-05	2.800	2100	2
79	Atlantic bonito	*Sarda sarda*	0.713	4.2	640	24.83	0.69	-0.19	350	12	300	9	2.60E-05	3.200	914	2
80	Little Tunny	*Euthynnus alletteratus*	0.197	15.2	1150	19.77	0.19	-0.62	592	38	290	11	1.30E-05	3.000	1220	2
81	Sailfish	*Istiophorus platypterus*	0.454	6.6	3410	167.75	0.44	-0.19	1571	14			1.10E-04	2.600	3400	3
82	Skipjack Tuna	*Katsuwonus pelamis*	0.666	4.5	791	10.46	0.64	-0.19	423	12	500	16	2.86E-06	3.300	1080	2
83	Blackfin Tuna	*Thunnus atlanticus*	0.344	8.7	780	11.29	0.33	-0.39	418	22	320	15	1.22E-05	3.100	1000	2
84	King Mackerel	*Scomberomorus cavalla*	0.155	19.3	1370	18.71	0.15	-0.75	693	47	609.6	38	8.83E-06	2.973	1840	2
85	Spanish Mackerel	*Scomberomorus maculatus*	0.208	14.4	964	7.30	0.2	-0.61	505	37	304.8	15	9.21E-06	2.982	830	2
86	Cero	*Scomberomorus regalis*	0.176	17	1864	45.99	0.17	-0.58	914	41	350	8	3.20E-05	2.800	1830	1
87	Greater Amberjack	*Seriola dumerili*	0.258	11.6	1581	48.71	0.25	-0.42	788	28	711.2	24	5.03E-05	2.809	1900	2
88	Tripletail	*Lobotes surinamensis*	0.200	15	1130	23.99	0.19	-0.59	583	38	381	19	6.78E-05	2.800	1110	1
89	Wahoo	*Acanthocybium solandri*	0.150	20	2534	123.26	0.15	-0.63	1204	44	600	14	1.58E-06	3.200	2500	1
	Macroinvertebrates															
90	Spiny Lobster	*Panulirus argus*									76.2					0
91	Pink shrimp	*Farfantapaneus duorarum*														

Parameter Confidence:

0 No Data Available
1 Based on Max Size
2 Max Size, but mixed
3 Relatively High Confidence

6.3 Management Benchmarks Analyses

To assess the status of the multispecies fishery from estimated rates of fishing mortality we used the LBAR algorithm (Ault et al. 1996). We then employed a population computer simulation model called REEFS (reef-fish equilibrium exploitation fishery simulator) (Ault et al. 1998, Ault 2001) to calibrate average size estimates, plus compute a number of benchmark statistics about the exploited population to reference these against Federal and International standards for fishery sustainability. A conceptual diagram of the REEFS population simulation model is shown (**Figure 6.2**). The REEFS model was applied to 35 reef fish species in 5 families: groupers, Serranidae; snappers, Lutjanidae; grunts, Haemulidae; the hogfish, Lachnolaimus maximus, Labridae (grouped with snappers for analytical purposes); and, the great barracuda, Sphyraena barracuda, Sphyraenidae. These species are among the primary fishery targets of the south Florida recreational and commercial fishing fleets.

We configured the REEFS model to assess several fishery management reference points, or benchmarks, including yield-per-recruit (YPR), spawning potential ratio (SPR), and limit control rules. REEFS models the age-size distribution of the population from larvae to mature adults to maximum size-age using a number of population dynamic functions to regulate birth, growth and survivorship processes, including selection and extraction by the fishery. The REEFS model is a size-based computer algorithm that embodies a stochastic age-independent population simulation model for ensemble numbers at given lengths ($\bar{N}_\gamma(L_\gamma,t)$) (Ault and Rothschild 1991, Ault and Olson 1996, Ault et al. 1998, 1999b, Ault in prep.)

$$\bar{N}_\gamma(L_\gamma,t) = \int_{t_r}^{t_\lambda} R(\tau - a)\ S(a)\ \Theta(a)\ P(L_\gamma \mid a)\ da \qquad (6.2)$$

where $R(\ -a)$ is cohort recruitment lagged back to birth date, $S(a)$ is survivorship to age a, $\ (a)$ is sex ratio at age a to account for hermaphroditic (i.e., protogynous or protandric) life histories common to tropical groupers and snappers, and $P(L\ a)$ is the probability of being length L given the fish is age a (Ault 1988, Ault and Rothschild 1991, Ault et al. 1997, 1998). The modeled fishing mortality rate of recreational and commercial fishers (or 'viewing power' of SCUBA divers) was assumed to remove (or sight) fish with a 'knife-edged selectivity pattern' (see Gulland, 1983) over the range of exploitable sizes (i.e., all sizes of fish are selected with equal probability)

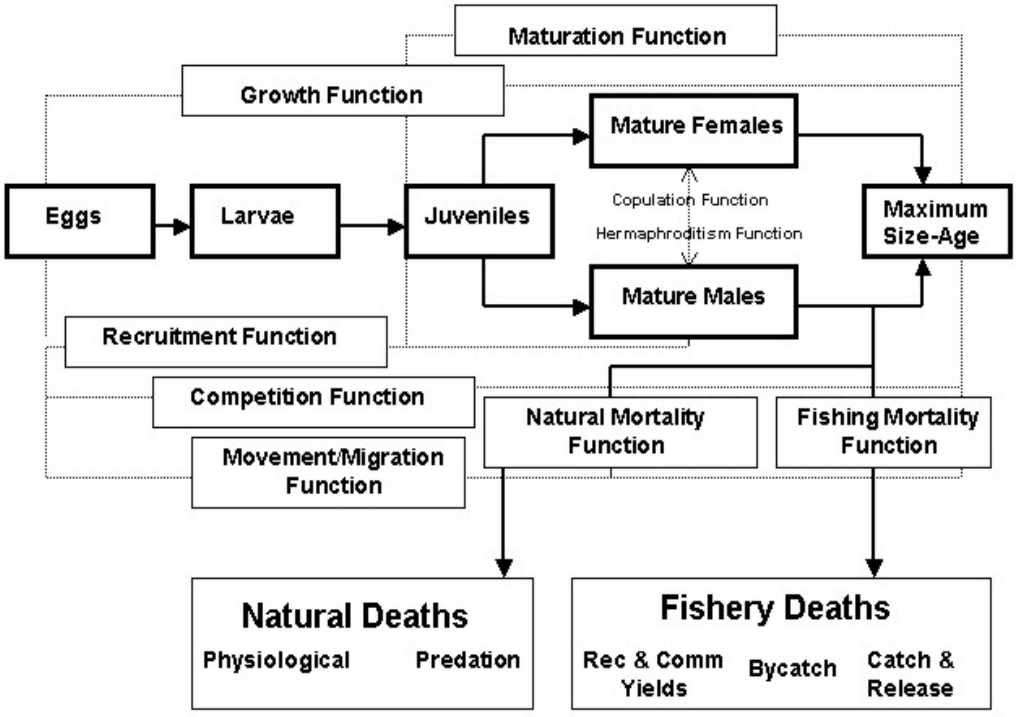


Figure 6.2 - Conceptual overview of the REEFS population simulation model used for multispecies reef fish stock assessment in the Dry Tortugas and Florida Keys coral reef ecosystem.

$$F(t) = \begin{cases} 0 & if \quad L|a < L_c \\ \hat{F}(t) & if \quad L|a \geq L_c \end{cases} \qquad (6.3)$$

where the size of first capture L_c is that regulated by regional fishery management (**Table 5.1**). Along with the estimated instantaneous rate of fishing mortality, species-specific population dynamics parameters were also used as model inputs (**Table 6.2**).

6.3.1 Fishery Yields and YPR

Since biomass *B(a,t)* is the product of numbers-at-age times weight-at-age, yield in weight Y_w from a given species *s* was calculated as

$$Y_w(F,L_c,t) = F(t)\int_{L_c}^{L_\lambda} B(L|a,t)\,dL = F(t)\int_{L_c}^{L_\lambda} N(L|a,t)W(L|a,t)\,dL \qquad (6.4)$$

Yield-per-recruit (YPR), or the lifetime yield expected from a single recruited individual, can then calculated by scaling yield to average recruitment.

6.3.2 Spawning Potential Ratios (SPR)

Mature or spawning stock biomass in year *t* (*SSB(t)*) is a measure of the stock's reproductive potential or capacity to produce newborn, ultimately realized at the population level as successful cohorts or year classes. Spawning stock biomass is obtained by integrating over individuals in the population between the minimum size of first maturity (L_m) and maximum reproductive size (here assumed to be the maximum size L)

$$SSB(t) = \int_{L_m}^{L_\lambda} B(L|a,t)\,dL \qquad (6.5)$$

Spawning potential ratio (SPR) is a contemporaneous management reference point that measures the stock's potential capacity to produce optimum yields on a sustainable basis. SPR is a fraction expressed as the ratio of exploited spawning stock biomass relative to the equilibrium unexploited SSB

$$SPR = \frac{SSB_{exploited}}{SSB_{unexploited}} \qquad (6.6)$$

Resultant estimated SPRs are then compared to the U.S. Federal standards which define 30% SPR as the "overfishing" threshold at which the stock is no longer sustainable at current exploitation levels (Rosenberg et al., 1996).

6.3.3 Biological Reference Points and Fishery Sustainability

The progressive decline of average size with increasing fishing mortality rates is shown for black grouper (**Figure 6.3**). Increasing exploitation successively eliminates older, more fecund size classes through a process known as "juvenescence", which ultimately produces an overall younger stock (Ricker 1963, Ault 1988) (**Figure 6.4**). This fact is extremely important in the context of stock and recruitment, since the fecundity potential of individuals increases exponentially with size. Such a phenomenon will be reflected by reductions of the stock's spawning capacity, which itself is related to the expectation of new recruits to sustain the population over the longer run. For black grouper, fishing at the rate of mortality that produces "maximum sustainable yield" reduces the spawning potential ratio (the proportion of the virgin spawning biomass available) to about 36% of the unexploited spawning population size (**Figure 6.4** and **Table 6.4**). Remarkably, the current estimated rate of fishing mortality in the Tortugas region has reduced the spawning potential ratio to less than 18% of its historical maximum. This is in comparison to 8% SPR for DTNP, and less than 6% Keys-wide. From the perspective of ecological theory, we believe this is an ominous result in terms of black grouper population stability and resilience for the longer run. From the perspective of fishers, a current 6% SPR implies that the average size (in weight) of a black grouper is now 40% of what it once was (circa 1930).

The YPR and SPR biological reference points are relatively robust measures of potential fishery yields and population recruitment, respectively. As such, they help to focus on biological (size) and fishing (intensity) controls for managing current and future fishery production. Taken together, these management benchmarks characterize the status of stocks under exploitation relative to Federal and International fishery management standards. Thus, these analyses provide the theoretical and quantitative basis for the assessment of the entire reef fish community, and indicate the efficacy of current fishery management practices and their sufficiency to provide sustainable fisheries now and into the future.

The expected theoretical relationship between YPR and SPR with respect to fishing mortality rate is shown for black grouper in **Figure 6.5.** Note that the current estimates of F for black grouper in the Tortugas region (DRTO), DTNP and the Florida Keys (BNP) place both SPR and YPR values well below the recommended optimal levels for sustainability of the fishery resource.

The summary of the SPRs for the Dry Tortugas region exploited reef fish complex in **Figure 6.6** shows that 6 of 14 groupers, 3 of 9 snappers, barracuda, and 5 of 11 grunts (or 40% of the 35 stocks analyzed) for which there are population dynamics data are below the SPR that constitutes overfishing. Overall, 45% of the 35 stocks that could be analyzed in DTNP were overfished by Federal standards (**Figure 6.7**). This analytical result is borne out in a simple comparison of 'average size' of some 66 species of exploited fish stocks in the Tortugas region relative to Dry Tortugas National Park (DTNP). We noted that "Bank" fish are bigger than "Park" fish on average (meaning larger spawning stock size too), suggesting either that the effective rate of fishing mortality is greater in the Park waters than in the surrounding region or perhaps bigger fish prefer deeper areas (**Figure 6.8**). This was a somewhat surprising result given that commercial fishing has not been allowed inside DTNP for over 30 years, and thus effectively represents the differential fishing power of the recreational fleet as compared to commercial fishing in the region. We feel a possible reason that DTNP is so low relative to the region (DRTO) is because of focused effect of fishing effort that is occurring on well-known reefs in DTNP, relative to the basically unknown spatial distribution and quality of reefs to the general public and recreational fishing community in

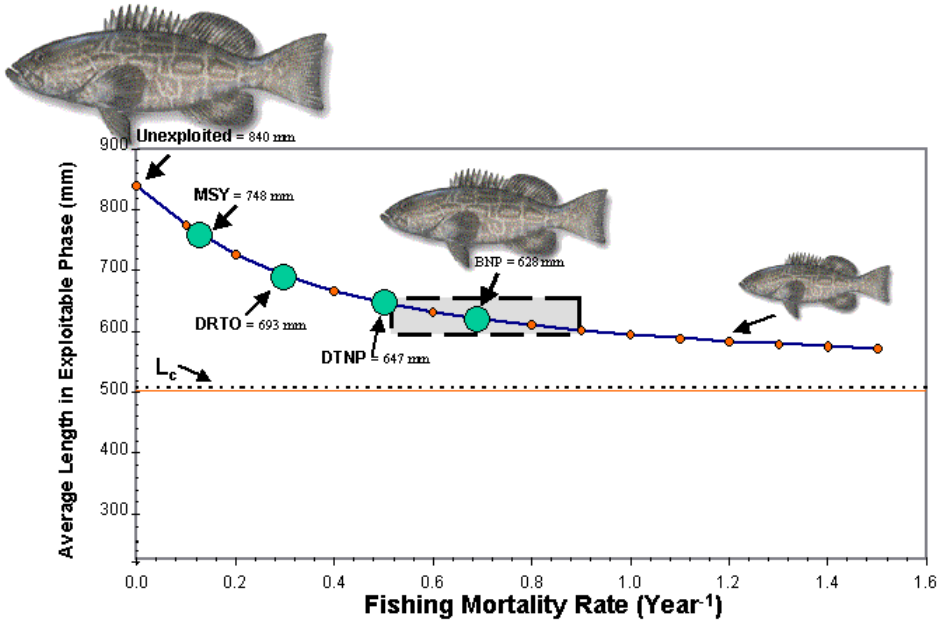


Figure 6.3 - Graphical example for Black Grouper showing theory of reduction of average length in the exploited phase of the stock dependence on increasing fishing mortality. Large darkened circles are average length estimates circa 2000. Dashed shaded horizontal rectangle shows the range of Florida Keys-wide fishing mortality estimates from 1979-2000.

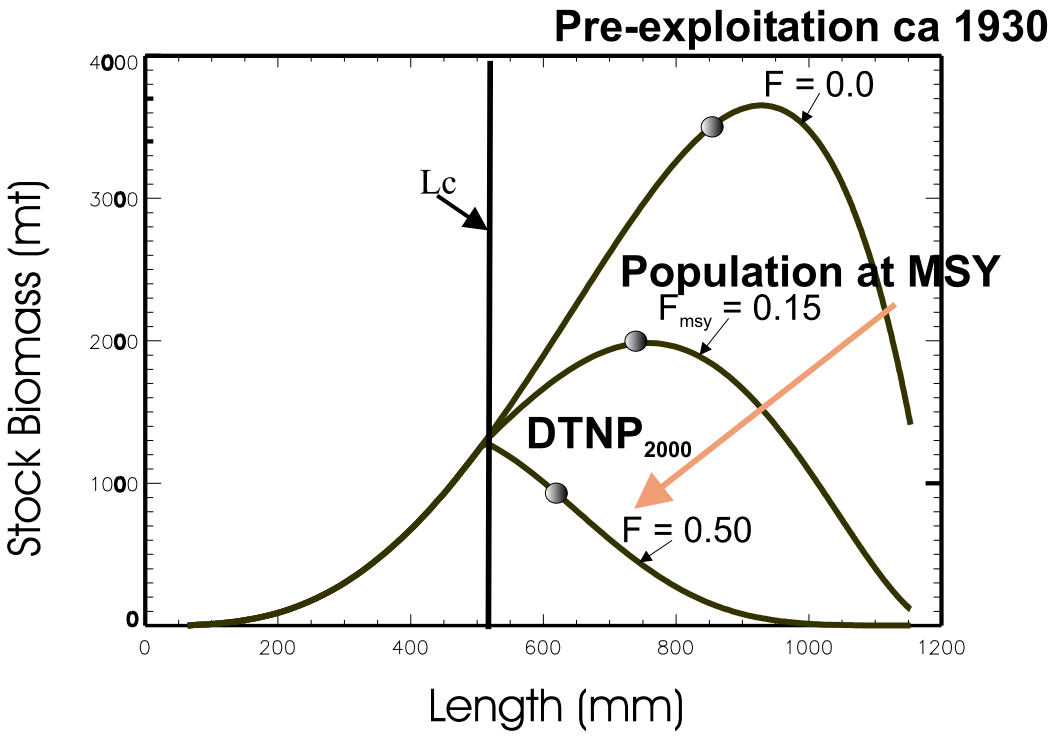


Figure 6.4 - Reduction of black grouper population biomass at length under increasng exploitation rates. Graph overlays show "juvenescense" (i.e., making the population younger) from pre-exploitation days circa 1930 to the 2000 estimate in DTNP. Shaded circles on each population biomass line represents the expected average size in the exploited phase for each exploitation scenario. Larger light arrow indicates juvenescense process.

Table 6.4 - Comparative regional exploitation history of black grouper (*Mycteroperca bonaci*) in the Florida Keys coral reef ecosystem. Unexploited represents the fishery circa 1930, MSY is the fishery exploited at maximum sustainable yield, DRTO is the Tortugas region, DTNP is Dry Tortugas National Park, and BNP is Biscayne National Park. DRTO, DTNP and BNP estimates are circa 2000. $\bar{L}$ And $\bar{W}$ are the average length and weight, respectively, in the exploited phase of the stock, SPR is spawning potential ratio, F/F_{msy} is the control rule ratio of current fishing mortality relative to the fishing mortality rate at MSY.

Status/Location	$\bar{L}$	$\bar{W}$	$\bar{W}$ as % of Virgin	SPR	F/F_{msy}
Unexploited	840 mm (= 33.6")	22.19 lbs	100.0	100.0	0.00
MSY	748 mm (= 29.4")	15.30 lbs	68.9	35.9	1.00
DRTO	693 mm (= 27.3")	11.98 lbs	54.0	17.7	1.95
DTNP	647 mm (= 25.5")	9.61 lbs	43.3	8.4	3.35
BNP	629 mm (=24.8")	8.78 lbs	39.6	5.9	4.17

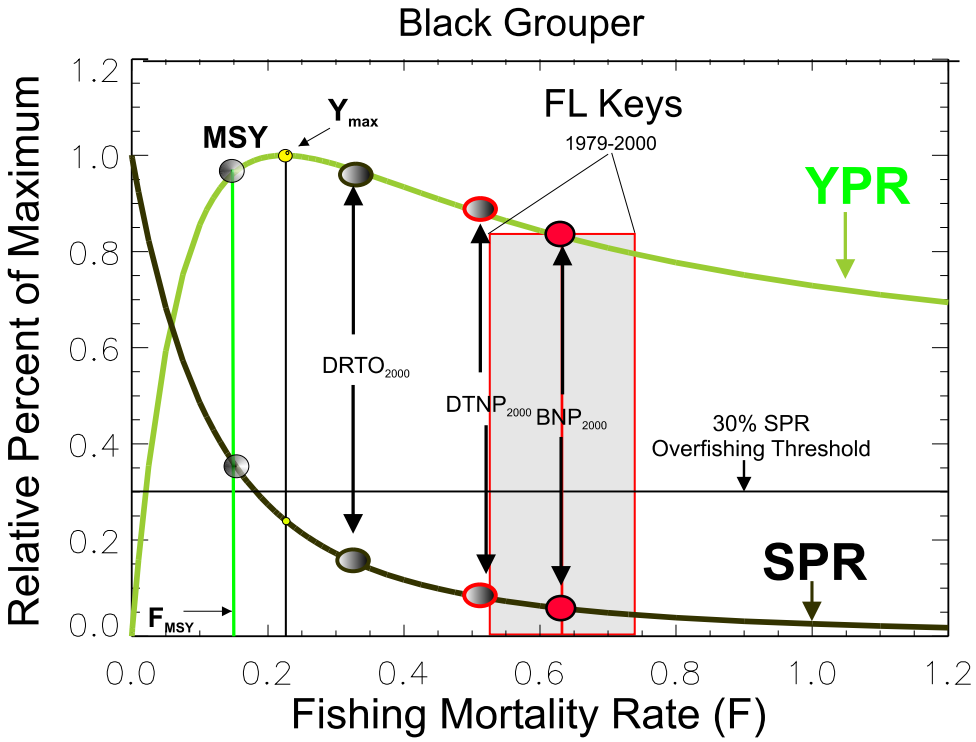


Figure 6.5 - Example of the black grouper stock response of relative spawning potential ratio SPR and yield-per-recruit YPR with increasing exploitation. Position of MSY (maximum sustainable yield) and F_{msy} are shown, as well as the estimated fishing mortality rates for BNP and the Florida Keys, Dry Tortugas National Park (DTNP), and the Dry Tortugas region (DRTO).

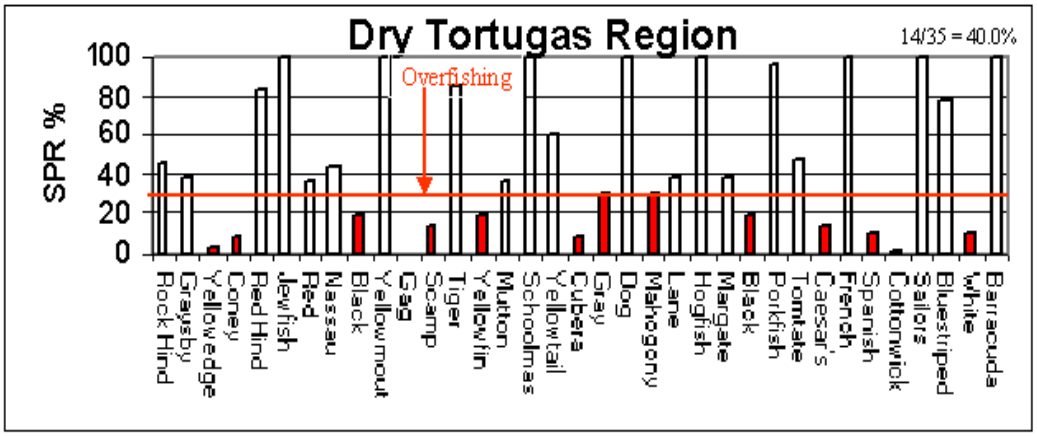


Figure 6.6 - Spawning potential ratios for 35 species of exploited reef fishes in Dry Tortugas region circa 2000. Any stock below the 30% SPR line is overfished according to U.S. Federal minimum standards for fishery sustainability.

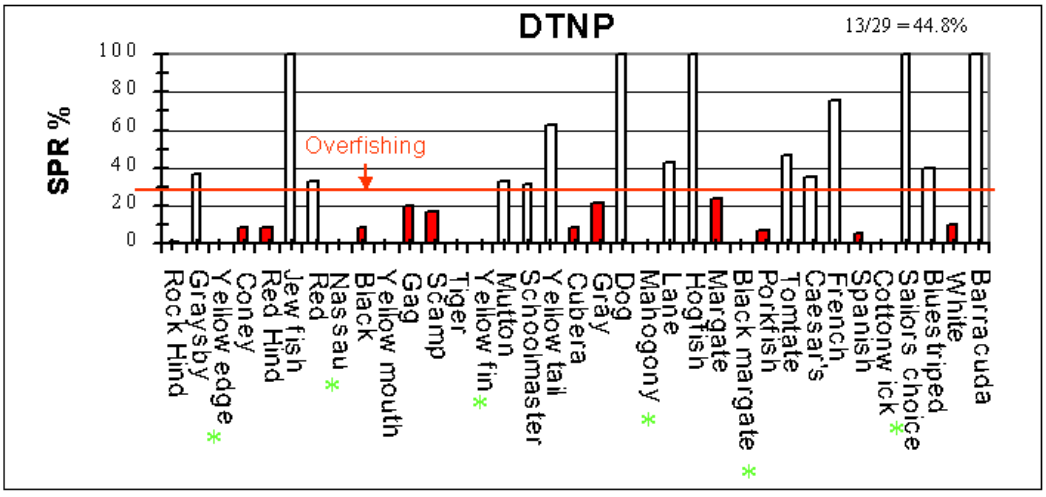


Figure 6.7 - Spawning potential ratios for 35 species of exploited reef fishes in Dry Tortugas National Park circa 2000.

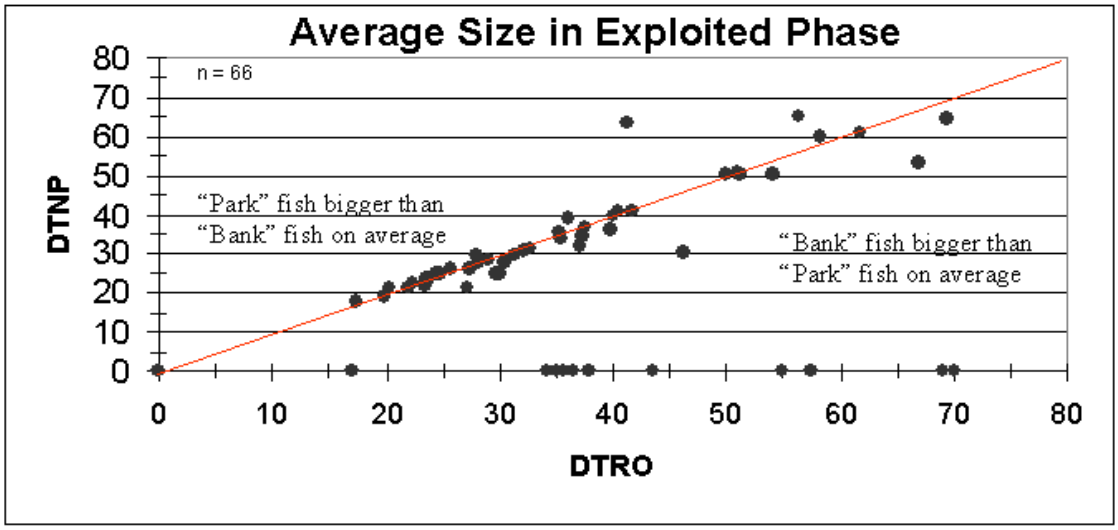


Figure 6.8 - Comparison of average length in the exploitable phase for 66 species of fishes in the Dry Tortugas National Park (DTNP) and Dry Tortugas region (DRTO) circa 2000.

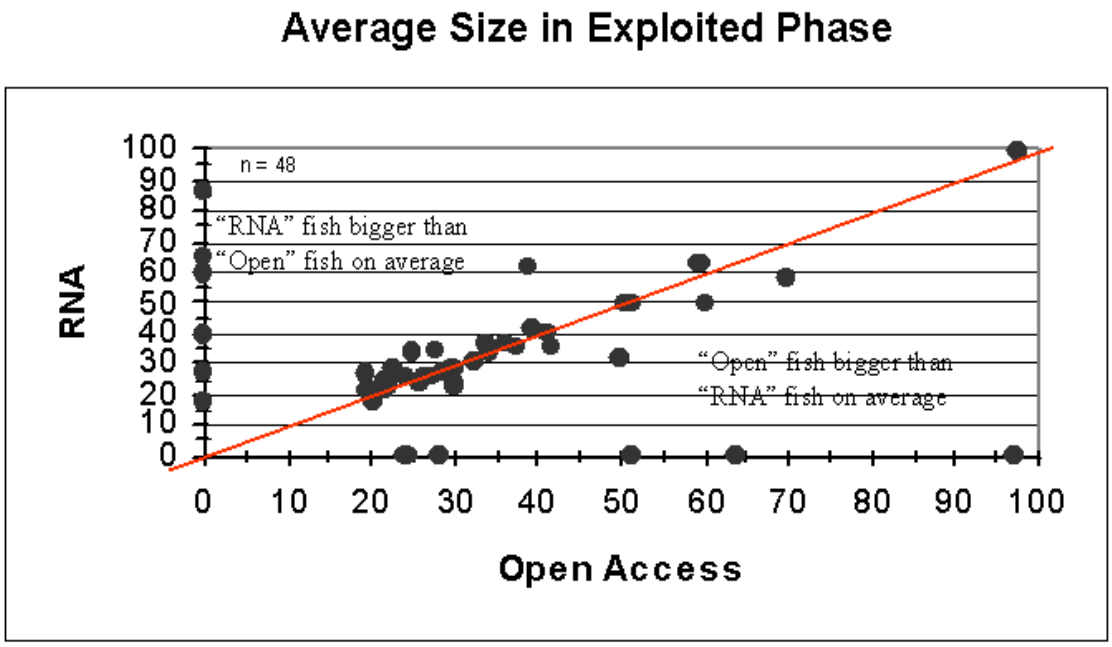


Figure 6.9 - Comparison of average length in the exploitable phase for 48 species of fishes in the Dry Tortugas National Park circa 2000 for the designated "no take" research natural area and DTNP area that will remain open access to recreational fishing.

the much broader and deeper DRTO. Finally, we noted that the average size of exploited fishes within DTNP was the same for the area of the proposed research natural area (RNA) as compared to the remaining area of the Park which will continue to be opened to recreational fishing activities (**Figure 6.9**). These analyses also strongly suggest a large exploitation gradient running from BNP in the north, which shows the greatest levels of exploitation and resultant serial overfishing, through FKNMS waters out to DTNP. To further investigate these phenomena, we used the REEFS stochastic simulation model to assess population risks relative to 'limit control rules' (e.g., NMFS 1999).

6.3.4 Limit Control Rules

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) contains a set of National Standards for fishery conservation and management, the first of which states:

> *"Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery for the United States fishing industry."*

The MSFCMA also required the Secretary of Commerce to "establish advisory guidelines (which shall not have the force and effect of law), based on the national standards, to assist in the development of fishery management plans". These national standard guidelines (NSGs) were published as a final rule in May 1998. Following the NSGs, Technical Guidelines were developed (NMFS 1999, Restrepo and Powers 1999) to translate the NSGs into criteria so that scientific advice could be offered to regional Fishery Management Councils to assist in implementing the MSFMCA. Key points arising were that: (1) maximum sustainable yield (MSY) is to be viewed as a limit (i.e., a threshold **NOT** to be exceeded); (2) two measures would determine a fish stock's management status, (a) the current fishing mortality rate relative to the fishing mortality rate that would produce MSY (denoted as F/F_{msy}), and (b) the current amount of spawning biomass relative to the spawning biomass at MSY (denoted as B/B_{msy}); (3) there should be maximum standards of fishing mortality rates which should not be exceeded, called Maximum Fishing Mortality Threshold (MFMT); (4) there should be a Minimum Stock Size Threshold (MSST) under which a stock's spawning biomass would be considered as depleted; and (5) these criteria and measures should be linked together through "control rules" which specify actions to be taken (i.e., changes in management measures to alter fishing mortality rates) depending upon the status of current spawning biomass relative to B_{msy} and MSST and the status of the fishing mortality rate relative to F_{msy} and MFMT.

To address these emerging fishery management benchmark criteria for the Dry Tortugas and Florida Keys, we conducted new analyses that established fishery limit control rules consistent with the "precautionary approach" (NMFS 1999, Restrepo and Powers 1999, Darcy and Matlock 1999, Butterworth and Punt 1999). Criteria used to set target catch levels as explained above are explicitly *risk averse*. A risk averse precautionary approach would set OY (optimum yield) below MSY as a function of uncertainty. Thus, the greater the uncertainty, the greater the distance between the two. The *precautionary approach* to fisheries management requires avoidance of overfishing, restoration of already overfished stocks, explicit specification of management objectives including operational targets and constraints (e.g., target and limit reference points), taking account of uncertainty by being more conservative, and avoidance of excess harvest capacity. In addition, this approach requires formulation of decision rules that stipulate in advance what actions will be taken to prevent overfishing and promote stock rebuilding.

Limit reference points are designed to constrain exploitation within safe biological limits so that stocks retain the ability to produce maximum sustainable yield. Overfishing is a level or rate of fishing mortality that jeopardizes the long-term capacity of a stock or stock complex to produce MSY on a continuing basis. In this arrangement, the fishing mortality rate which generates MSY should be regarded as the minimum standard for limit reference points. The limit MSST (minimum stock size threshold) is used to decide what level of fishing mortality indicates "overfishing", and when the stock is in an "overfished" condition. If spawning biomass drops below MSST, then the regional fishery management councils are mandated to take remedial actions to end overfishing and rebuild overfished stocks to MSY levels relatively rapidly (i.e., generally in less than 10 years).

A graphical application of limit control rule theory is shown in **Figure 6.10** for black grouper in the Florida Keys, overlain with current (circa 2000) estimates from DTNP, the Dry Tortugas region, and Biscayne National Park (BNP). The region defined by (A) represents a developing fishery where fishing mortality rates are below the level required to achieve MSY, and the stock biomass is greater than the biomass at MSY. The (B) region defines an area where overfishing is occurring and passes up to the threshold rate that will lead to an overfished stock. The (C) region formally defines an overfished stock that violates principles of sustainability and that requires strong intervention by fishery management. The (D) region defines a stock under recovery where the current fishing mortality rate has been reduced to level that meet Federal standards and promote rebuilding of the resource over a 10 year time horizon. We used the natural mortality rate as a proxy for F_{msy} (e.g., Gulland 1983). These estimates of F_{msy} were then input to REEFS to estimate $\hat{B}_{msy}(t)$. We note that all the yearly estimates of the black grouper fishery show that substantial overfishing has occurred, and that most recent estimates place the level of overfishing at 3-5 times the level of fishing required to produce maximum sustainable yield under Federal definitions (note that the 1981 estimate is dubious). Minimally, this means that fleet effort would need to be reduced by some 80% to achieve the longer-term sustainability goals under these standards. However, it should be noted that the National Park Service standards may be even more conservative than those established under the MSFMCA, and thus effort reductions would have to be even more severe to achieve NPS management goals.

While the limit control rule technique has been demonstrated for black grouper (**Figure 6.10**); the process is reflective of the analyses for every fish stock or community member (groupers, snappers, grunts, etc.). These estimates are shown for DTNP and DRTO in **Figure 6.11**. Remarkably, fishing effort in the Dry Tortugas for certain important grouper-snapper-grunt complex fish stocks ranges from 2-6 times the level that meet Federal criteria for sustainability. Further, it is somewhat shocking that in the northern Florida Keys (i.e., BNP), we estimated fishing mortality rates to be from 2 to 10 times higher than F_{msy} for 71% (i.e., 25/35) of the exploited species analyzed (**Figure 6.12**). Moreover, the current levels of stock biomass are critically low for more than 70% of the key targeted species in BNP and the Florida Keys. Our most current estimates and results for the Dry Tortugas region and the Dry Tortugas National Park are summarized in **Table 6.4** and **Table 6.5**.

6.4 Baseline Status of Dry Tortugas Exploited Fish Stocks

Our results indicate that Dry Tortugas region (both DTNP and DRTO) reef fish populations are currently heavily fished (**Figures 6.5-6.12, Tables 6.4 and 6.5**). Despite using conservative

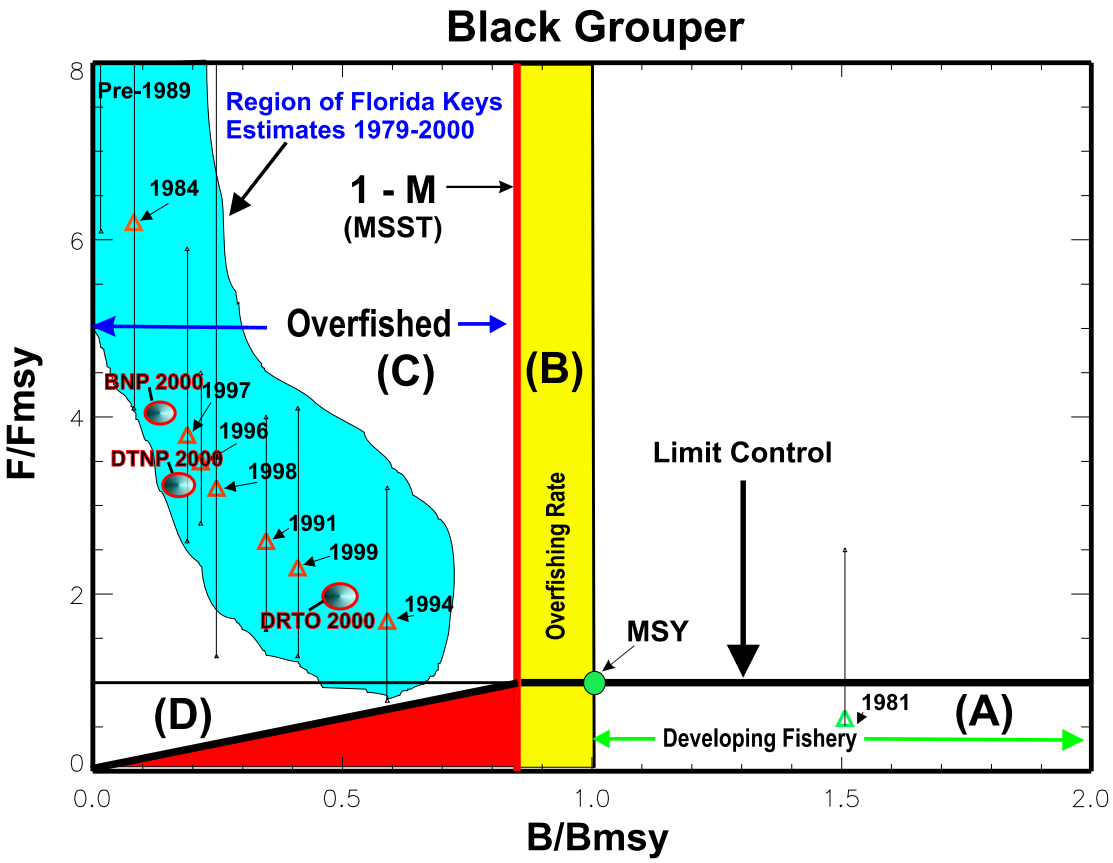


Figure 6.10 - Example of 'Limit Control Theory' applied to the Black Grouper (*Mycteroperca bonaci*) in the Florida Keys for the years 1979-2000. Note the highly "overfished" condition of the stock according to U.S. Federal Standards under the MSFMCA. Also plotted on the Figure are the estimates for DRTO, DTNP and BNP circa 2000.

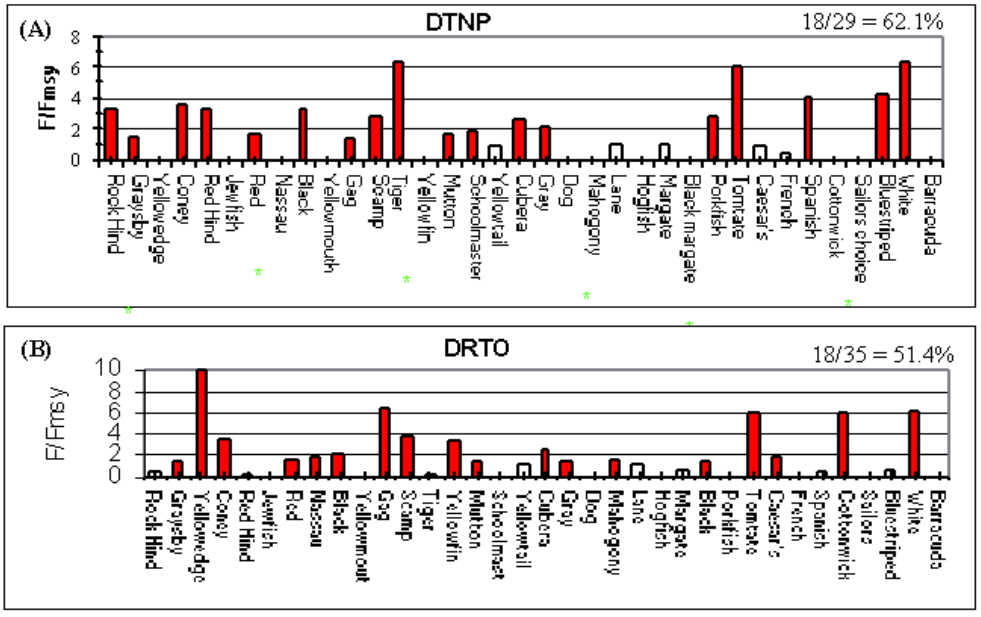


Figure 6.11- Fishery control rule management benchmark analyses for 35 exploited reef fishes: (A) Dry Tortugas National Park; and (B) Dry Tortugas region. The F/Fmsy criterion is the current fishing mortality rate relative to the fishing mortality rate that would produce MSY. A target value of 1.0 is the maximum allowed under the MSFMCA precautionary approach. Values above 1.0 consitute stock "overfishing" and represent the magnitude of fleet reduction required to meet Federal standards.

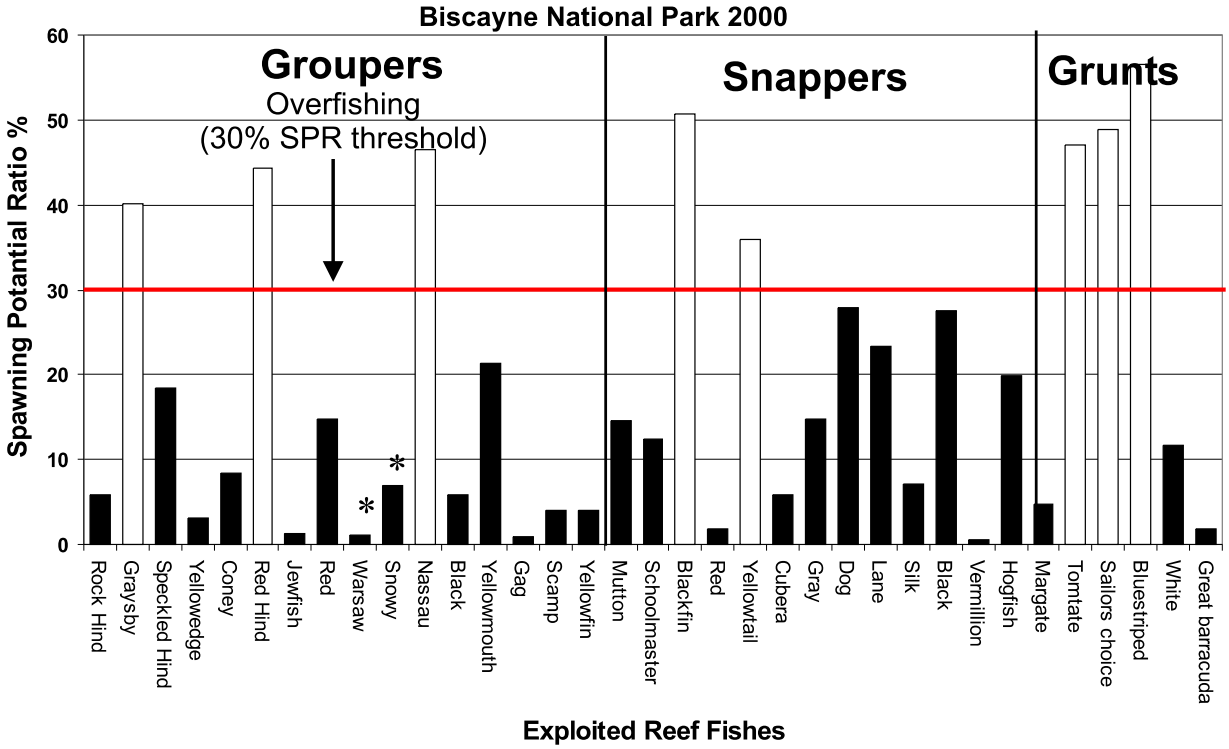


Figure 6.12.- Fishery management benchmark spawning potential ratio SPR annalyses for 35 exploited species of BNP-Florida Keys reef fish comprising groupers, snappers and hogfish, grunts and great barracuda. Darkened bars indicate stock "overfishing" and open bars indicate the stock is above the 30% SPR U.S. Federal Standard. Asterisk indicates estimate from headboat data outside BNP. The high SPR estimate for Nassau grouper is dubious.

Table 6.4 - Full fishery management benchmark analysis for 35 reef fish stocks in the **Dry Tortugas region** showing current estimates. Species with dashed boxes indicate current minimum size regulations are at or set lower than the minimum sexual maturity.

Taxa		Common name	Lbar	SE(Lbar)	F	M	K	M/K	L_m	L_c	L_λ	SPR	F/F_{msy}	B/B_{msy}	B_0	B_{msy}	B_{now}
Groupers	**1**	Rock Hind	29.63	1.51	0.1244	0.250	0.191	1.31	336.0	203.2	453.3	45.61	0.50	2.07	18367	4053	8377
	2	Graysby	24.90	0.52	0.2901	0.200	0.350	0.57	108.0	203.2	362.7	38.77	1.45	0.80	8824	4286	3421
	3	Yellowedge	43.50	0.00	**2.0000**	0.200	0.170	1.17	524.8	240.0	792.4	3.19	10.02	0.07	126653	58387	4037
	4	Coney	28.23	1.78	0.6155	0.180	0.145	1.24	185.1	203.2	647.8	8.91	3.42	0.26	22919	7859	2041
	5	Red Hind	29.98	1.95	0.0300	0.180	0.207	0.87	247.0	203.2	382.8	83.02	0.17	2.20	19520	7350	16206
	6	Jewfish	191.25	50.30	**0.0000**	0.130	0.130	1.00	978.0	508.0	2178.3	100.00	0.00	3.76	5827829	1548036	5827829
	7	Red	61.80	0.90	0.2821	0.180	0.153	1.18	433.8	508.0	869.0	36.40	1.57	0.75	125310	60588	45609
	8	Nassau	55.00	0.00	0.3466	0.180	0.145	1.24	480.0	508.0	648.2	44.03	1.93	0.73	48595	29247	21397
	9	Black	69.34	3.29	0.2932	0.150	0.160	0.94	597.0	508.0	1153.4	17.71	1.95	0.49	532994	191373	94410
	10	Yellowmouth	69.00	7.63	**0.0000**	0.180	0.063	2.86	468.0	508.0	710.7	100.00	0.00	2.24	170878	76345	170878
	11	Gag	56.33	8.67	1.4512	0.230	0.149	1.54	657.0	508.0	1034.4	0.54	6.31	0.02	133456	41421	725
	12	Scamp	58.33	3.33	0.5527	0.143	0.126	1.13	491.0	508.0	932.2	13.01	3.87	0.30	319185	138084	41532
	13	Tiger	46.18	6.72	0.0130	0.116	0.110	1.05	460.0	240.0	705.4	85.12	0.11	3.38	132702	33458	112960
	14	Yellowfin	57.50	0.00	0.5954	0.180	0.170	1.06	524.8	508.0	792.4	17.51	3.31	0.36	151123	74204	26461
Snappers	**15**	Mutton	51.12	1.24	0.3055	0.214	0.129	1.66	275.8	406.4	797.8	36.55	1.43	0.79	91558	42117	33468
	16	Schoolmaster	37.16	0.56	**0.0000**	0.250	0.180	1.39	144.6	254.0	503.8	100.00	0.00	2.16	20614	9563	20614
	17	Yellowtail	35.19	0.27	0.2147	0.210	0.209	1.00	194.3	304.8	433.4	60.71	1.02	1.00	17173	10438	10425
	18	Cubera	51.00	0.00	0.4081	0.150	0.140	1.07	407.3	304.8	1153.1	8.11	2.72	0.26	639420	196466	51885
	19	Gray	32.68	0.17	0.4340	0.300	0.136	2.21	230.2	254.0	556.5	30.46	1.45	0.75	17396	7077	5298
	20	Dog	49.96	2.56	**0.0000**	0.330	0.100	3.30	298.0	304.8	568.5	100.00	0.00	2.31	19922	8627	19922
	21	Mahogony	38.00	0.00	0.4776	0.300	0.250	1.20	280.0	304.8	585.0	29.44	1.59	0.71	39041	16293	11494
	22	Lane	25.79	0.28	0.3230	0.300	0.097	3.09	202.3	203.2	418.3	38.36	1.08	0.95	7396	2998	2837
	23	Hogfish	40.46	0.65	**0.0000**	0.250	0.190	1.32	195.5	304.8	515.4	100.00	0.00	1.93	32515	16857	32515
Grunts	**24**	Margate	32.10	1.20	0.2616	0.374	0.174	2.15	324.4	203.2	578.4	38.31	0.70	1.45	17222	4550	6598
	25	Black margate	35.60	5.38	0.5042	0.374	0.360	1.04	366.0	220.0	650.0	19.75	1.35	0.69	57524	16373	11361
	26	Porkfish	27.07	0.30	0.0165	0.428	0.440	0.97	228.0	160.0	381.1	94.92	0.04	3.11	10644	3246	10103
	27	Tomtate	17.41	0.09	**2.0000**	0.333	0.220	1.51	136.1	203.2	250.0	47.10	6.01	0.65	2533	1845	1193
	28	Caesar's	20.22	0.46	0.7982	0.428	0.300	1.43	217.0	160.0	360.0	14.45	1.86	0.44	2533	827	366
	29	French	19.96	0.21	**0.0000**	0.333	0.179	1.86	176.0	160.0	235.1	100.00	0.00	2.21	890	402	890
	30	Spanish	27.42	0.53	1.2343	0.300	0.480	0.63	254.0	200.0	430.0	11.41	4.11	0.31	35456	12934	4044
	31	Cottonwick	16.97	0.03	**2.0000**	0.333	0.320	1.04	203.0	160.0	333.0	1.61	6.01	0.05	6257	2117	101
	32	Sailors choice	30.43	0.58	**0.0000**	0.430	0.220	1.95	100.4	203.2	320.1	100.00	0.00	1.63	3139	1926	3139
	33	Bluestriped	23.38	0.42	0.2627	0.500	0.484	1.03	108.4	203.2	273.5	77.61	0.53	1.19	2269	1481	1761
	34	White	22.35	0.11	**2.2998**	0.375	0.186	2.01	174.0	203.2	410.9	10.65	6.14	0.25	8676	3695	924
Others	**35**	Great barracuda	89.46	3.11	**0.0000**	0.200	0.172	1.16	625.1	508.0	1151.0	100.00	0.00	2.90	140803	48491	140803

Table 6.5 - Full fishery management benchmark analysis for 35 reef fish stocks in the **Dry Tortugas National Park** region showing current estimates. Species with dashed boxes indicate current minimum size regulations are at or set lower than the minimum sexual maturity.

Taxa		Common name	Lbar	SE(Lbar)	F	M	K	M/K	L_m	L_c	L_∞	SPR	F/F_{msy}	B/B_{msy}	B_0	B_{msy}	B_{now}
Groupers	**1**	Rock Hind	24.67	5.21	0.8010	0.250	0.191	1.31	336.0	203.2	453.3	1.52	3.20	0.07	18367	4053	279
	2	Graysby	24.76	1.06	0.3127	0.200	0.350	0.57	108.0	203.2	362.7	36.91	1.56	0.76	8824	4286	3257
	3	Yellowedge	0.00			0.200	0.170	1.17	524.8	240.0	792.4	0.00	0.00	0.00	126653	58387	
	4	Coney	28.00	0.00	0.6449	0.180	0.145	1.24	185.1	203.2	647.8	8.41	3.58	0.25	22919	7859	1927
	5	Red Hind	24.75	2.44	0.5955	0.180	0.207	0.87	247.0	203.2	382.8	8.79	3.31	0.23	19520	7350	1715
	6	Jewfish	191.25	50.30	**0.0000**	0.130	0.130	1.00	978.0	508.0	2178.3	100.00	0.00	3.76	5827829	1548036	5827829
	7	Red	61.24	1.19	0.3191	0.180	0.153	1.18	433.8	508.0	869.0	33.41	1.77	0.69	125310	60588	41865
	8	Nassau	0.00			0.180	0.145	1.24	480.0	508.0	648.2	0.00	0.00	0.00	48595	29247	
	9	Black	64.65	3.55	0.5030	0.150	0.160	0.94	597.0	508.0	1153.4	8.35	3.35	0.23	532994	191373	44509
	10	Yellowmouth	0.00			0.180	0.063	2.86	468.0	508.0	710.7	0.00	0.00	0.00	170878	76345	
	11	Gag	65.00	0.00	0.3258	0.230	0.149	1.54	657.0	508.0	1034.4	20.34	1.42	0.66	133456	41421	27151
	12	Scamp	60.00	0.00	0.4036	0.143	0.126	1.13	491.0	508.0	932.2	17.76	2.82	0.41	319185	138084	56678
	13	Tiger	30.00	0.00	0.7393	0.116	0.110	1.05	460.0	240.0	705.4	0.18	6.37	0.01	132702	33458	237
	14	Yellowfin	0.00			0.180	0.170	1.06	524.8	508.0	792.4	0.00	0.00	0.00	151123	74204	
Snappers	**15**	Mutton	50.42	1.71	0.3557	0.214	0.129	1.66	275.8	406.4	797.8	32.87	1.66	0.71	91558	42117	30099
	16	Schoolmaster	32.08	0.86	0.4485	0.250	0.180	1.39	144.6	254.0	503.8	31.36	1.79	0.68	20614	9563	6465
	17	Yellowtail	35.35	0.63	0.1900	0.210	0.209	1.00	194.3	304.8	433.4	63.42	0.90	1.04	17173	10438	10891
	18	Cubera	51.00	0.00	0.4081	0.150	0.140	1.07	407.3	304.8	1153.1	8.11	2.72	0.26	639420	196466	51885
	19	Gray	31.35	0.24	0.6409	0.300	0.136	2.21	230.2	254.0	556.5	21.52	2.14	0.53	17396	7077	3743
	20	Dog	50.29	3.03	**0.0000**	0.330	0.100	3.30	298.0	304.8	568.5	100.00	0.00	2.31	19922	8627	19922
	21	Mahogony	0.00			0.300	0.290	1.03	280.0	304.8	480.0						
	22	Lane	26.06	0.27	0.2828	0.300	0.097	3.09	202.3	203.2	418.3	42.29	0.94	1.04	7396	2998	3128
	23	Hogfish	40.92	1.05	**0.0000**	0.250	0.190	1.32	195.5	304.8	515.4	100.00	0.00	1.93	32515	16857	32515
Grunts	**24**	Margate	30.70	1.10	0.3960	0.374	0.174	2.15	324.4	203.2	578.4	24.63	1.06	0.93	17222	4550	4242
	25	Black margate	0.00			0.374	0.360	1.04	366.0	220.0	650.0						
	26	Porkfish	21.13	0.36	1.2004	0.428	0.440	0.97	228.0	160.0	381.1	6.53	2.80	0.22	10694	3246	698
	27	Tomtate	17.92	0.74	**2.0000**	0.333	0.220	1.51	136.1	203.2	250.0	47.10	6.01	0.65	2533	1845	1193
	28	Caesar's	21.61	0.59	0.3886	0.428	0.300	1.43	217.0	160.0	360.0	35.89	0.91	1.10	2533	827	909
	29	French	19.05	0.44	0.1116	0.333	0.179	1.86	176.0	160.0	235.1	75.51	0.34	1.67	890	402	672
	30	Spanish	25.91	0.40	1.2343	0.300	0.480	0.63	254.0	200.0	444.7	5.97	4.11	0.16	35456	12934	2115
	31	Cottonwick	0.00			0.333	0.320	1.04	203.0	160.0	330.0						
	32	Sailors choice	27.95	0.59	**0.0000**	0.430	0.220	1.95	100.4	203.2	320.1	100.00	0.00	1.63	3139	1926	3139
	33	Bluestriped	21.69	0.43	2.1732	0.500	0.484	1.03	108.4	203.2	273.5	39.49	4.35	0.60	2269	1481	896
	34	White	22.60	0.13	**2.3289**	0.375	0.186	2.01	174.0	203.2	410.9	10.57	6.22	0.25	8676	3695	917
Others	**35**	Great barracuda	91.22	4.23	**0.0000**	0.200	0.172	1.16	625.1	508.0	1151.0	100.00	0.00	2.90	140803	48491	140803

assumptions, the estimated fishery exploitation rates suggest that many DTNP and Florida Keys reef fish stocks are overfished according to definitions for U.S. fisheries (Rosenberg et al. 1996). Many desirable grouper and snapper stocks now have extremely low spawning potential ratios (SPRs). Moreover, our analysis indicates that these stocks have experienced high rates of exploitation over at least the last two decades (see also Ault et al. 1998). The estimated average lengths in the exploitable phase from statistically independent data sources were highly comparable for groupers, snappers, and grunts, which supports their use in the multispecies assessment. The trends in average size for grouper, snapper and grunt stocks was relatively flat over the last 25 yr and close to the minimum exploitable length. The flatness is explained by considering expected $\bar{L}$ from a modeled range of F in an analytical model, given knowledge about current values of $\hat{F}$. The slope of $\bar{L}$ on F is very shallow in the range of the analytical model, corroborating empirical estimates. Some stocks appear to have been chronically overfished since at least the late 1970's.

There is also substantial corroborating evidence of these trends from our fishing effort and CPUE analyses. Total fishing effort has increased substantially because of greater average fishing power per vessel and a much larger recreational fishery fleet The arithmetic increase of recreational fishing vessels is an extremely important factor for any future assessments. However, the absolute magnitude of the recreational fishing effect on reef fish stocks is poorly known because the recreational fleet is heterogeneously distributed across south Florida and the Keys seascape, and has been poorly sampled or studied to date. Inverse relationships between increased fishing effort (particularly by the recreational sector) and the long-term decreased average size and stock biomass of the most desirable species (e.g., groupers and snappers) are of particular concern. Declining CPUE trends observed in fishery catch data also support our overfishing conclusions.

We also noted similarities in key population-dynamic relationships within various taxa that separate out into somewhat discrete clusters when plotting maximum size versus maximum age by species. This pattern suggests that species within the various taxa groupings will likely respond to exploitation in a similar manner. The sensitivity to exploitation is highest for groupers, followed by snappers and then grunts. The Florida Keys reef fishery shows the classic pattern of serial overfishing, in which the more vulnerable species are progressively depleted (Munro and Williams, 1985; Russ and Alcala, 1989). The longest lived, latest maturing, and lowest natural mortality (M) stocks (i.e., groupers) are those first to experience significant declines in population biomass, followed in sequence by intermediate-lived (snappers), and finally by short-lived stocks (grunts). Within families, the inverse relationships between the spawning potential ratio and ex-vessel market price is consistent with serial overfishing (Ault et al. 1998). As expected, the most valuable snappers and groupers also tend to have the lowest spawning potentials.

The process of serial overfishing has decimated the grouper stocks and current levels of fishing mortality range from 3 to more than 10 times the exploitation level that would achieve MSY. The only stocks at about the Federal target are rock hind, graysby, coney and red hind. This is because these species rarely reach a maximum size greater than about 16 inches in total length, and thus are not generally targeted by fishermen. However, given the current extremely poor status of the snapper-grouper fishery in the Florida Keys, these species too are now becoming targets. The serial overfishing phenomenon is clearly reflected in the fact that snapper, and now grunt, stock sizes are falling below federal target levels under the precautionary approach of the MSFMCA. Now there are hardly any fish big enough or mature enough to support the waning resources, or to affect any hopes of system recovery given the pervasive increases in fishers and fleet fishing power. This is a particularly distressing scenario when coupled with pervasive trends in increased population

growth, coastal development, habitat degradation, and coastal pollution in south Florida.

Our data suggest that there may have been substantial changes in the composition of the biomass and abundance of the reef fish community over the past several decades. While many groupers and snappers have apparently declined in response to growing fishing effort, other piscivorous fishes (e..g., some grunts) may have increased in relative abundance. Claro (1991) noted a similar process in the Golfo de Batabano, Cuba, and hypothesized that chronic over-harvesting of snappers resulted in community shifts in favor of grunts. Another indication of significant change shown by Ault et al. (1998) is the explosive growth of barracuda in the southern Keys, which may be explained by several factors. First, there is little directed commercial or recreational fishing for barracuda as food Keys-wide due to health concerns. Second, growth of catch-and-release fishing by sport anglers and reduced emphasis on spearfishing may have substantially lowered barracuda mortality. Third, other top predators such as groupers, snappers and sharks have been intensively fished which appears to have lowered competition while barracuda still retain a large and possibly increasing prey base of grunts and other small fishes. Increased abundance and biomass of a top predator like barracuda could be a management concern if barracuda substantially impact reef fish community dynamics. For example, excessive predation on popular sport fishes like snappers could counteract potential reductions in fishing mortality sought by traditional management.

During the time frame of this study, numerous measures have been taken to reduce fishing mortality in state and federal waters. Fish traps were progressively eliminated between 1980 and 1992 and numerous bag limits and minimum size limits were imposed. Fisheries were closed for queen conch (Strombus gigas), Goliath grouper (formerly jewfish, Epinephelus itajara), and Nassau grouper (E. striatus). These actions are evidence of trends reported in this study. These management measures have been largely ineffectual to reduce the observed declining trends in stock sizes and productivity. The patterns of fishery size regulations in south Florida have followed those characteristic of fisheries under stress, and reflect too little action too late. Ault et al. (1998) have shown the Florida Keys multispecies reef fisheries to have been seriously overfished since at least the late 1970s.

Adjusting minimum sizes of first capture (L_c) and fishing mortality rates (F) may mitigate the growth and recruitment overfishing conditions apparent in the fishery. A striking result we discovered, however, was that 13 of 35 species we closely analyzed have the minimum size of first capture by the fishery set lower than the minimum size of first sexual maturity (**Tables 6.4-6.5**). However, traditional management actions alone are unlikely to be sufficient because they can be circumvented and habitually fail to effectively control fishing effort, particularly in an open access fishery (Bohnsack and Ault 1996, Ault et al. 1998). For example, bycatch mortality and high fishing effort from the expanding fleets can make size limits ineffective. In theory, every fish can be caught once it reaches minimum legal size resulting in insufficient mature adult survival. The problems we have identified have been compounded by a clear lack of compliance of fishery regulations by sportfishers, and the apparent lack of enforcement of existing regulations. Surprisingly, there has been little to no follow-up plan to evaluate whether regulations and policies invoked are achieving their intended results. What is needed is a clear plan of action to ameliorate these trends in declining yields and to build sustainable fisheries and conserve marine biodiversity in the face of ecosystem changes and regional human population growth.

7.0 Conclusions and Recommendations

Using a quantitative systems approach we have conducted a multispecies coral reef fish stock assessment for the Tortugas region using new methodologies from advanced principles of fish population dynamics, combined with mathematical and statistical modeling. These baseline data provide the National Park Service and Florida Keys National Marine Sanctuary with information relevant to baseline status of the stocks and the spatial distribution of fishery and habitat resources. To obtain the data necessary for these assessments, we outlined a systems science strategy and then designed and implemented a cost-effective spatially-intensive fishery-independent monitoring survey in 1999 and 2000 in the Tortugas region. These data were used to improve population estimates of stock abundance and size structure and to conduct spatial modeling of linkages between fish community distribution and key "habitat" characteristics. We also generated precise estimates of population-dynamic and stock assessment parameters required to provide critical sampling guidance for future cost-effective monitoring and resource assessment efforts. In addition, we assimilated databases to conduct new stock assessments for the multispecies coral reef fishery community. A key to our assessments of the multispecies reef fish stocks involved strategic use of 'average size' (in length) of fish in the exploitable phase of the population as a quantitative indicator of stock response to exploitation. The average size statistic is extremely robust to the data source from which the population estimates are made (e.g., RVC or head boat survey data). Our analyses provides a rigorous reference point for reef fish stock status and spatial abundance. Our principal findings were:

- *Overall for the Tortugas region, 40% or 14 of the 35 individual stocks that could be analyzed are overfished.* Spawning potential ratio (SPR) analysis of exploited reef fishes shows that 6 of 14 grouper species, 3 of 9 snapper species, barracuda, and 5 of 11 grunt species for which there are reliable population dynamics data were below the SPR that constitutes overfishing by Federal standards. In addition, a total of 45% of the 35 individual stocks analyzed exceeded the Federal fishing mortality target by 2 to 6 times.

- *We found that overfishing was more pronounced for Dry Tortugas National Park (DTNP) where 45%, or 13 of the 29 individual stocks that could be analyzed are overfished.* A total of 62% or 18 of the 35 individual stocks analyzed exceeded the Federal fishing mortality target by 2 to 6 times. For many reef fish stocks, the DTNP fishery is in worse shape than the broader Dry Tortugas region.

- *Increased fishing effort from growing regional fishing fleets has likely been an important factor in these declines.* The recreational fishing fleet in south Florida has grown at a near exponential rate with no limits on the number of boats allowed to fish. The number of registered boats increased 444% from 1964 to 1998. Also during that time, the estimated effective vessel "fishing power" of individual commercial and recreational boats has approximately quadrupled due to technological innovations, such as depth indicators, sonar fish finders, global navigation systems, improved vessel designs, larger and more reliable motors, and improved radio communications.

- *Stock biomass is critically low for most of the targeted species within the recreational fishery.* For example, the current level of fishing mortality for grouper stocks range from 2 to 10 times the exploitation level that would achieve Maximum Sustainable Yield (MSY).

These results are consistent with our Florida Keys-wide research which shows that more than 70% of these stocks are overfished, reflecting the spatial gradient of more intense exploitation around human population centers, as well as the growing fishing power of the fleets.

- *High and sustained exploitation pressures have precipitated "serial overfishing", where the largest most vulnerable species are removed first and then moving to smaller and less desirable species as larger more vulnerable species are sequentially eliminated.* The most vulnerable species are left with too few large and mature fish to provide sufficient spawn to supply future populations. Our data indicate that some stocks have been chronically depleted since at least the late 1970's.

- *Our data suggest that the reef fish fisheries are not sustainable in the Florida Keys and Tortugas under the levels of exploitation existing prior to establishing no-take marine reserves.* Conventional single-species management approaches of placing more restrictive size and bag limits on individual species have so far failed to sufficiently protect some stocks under open access as shown by the fact that fisheries for goliath grouper (formerly jewfish), Nassau grouper, and queen conch (*Strombus gigas*) have been closed to all fishing for over a decade. The history of regional State and Federal Fishery Management Council actions for the Florida Keys clearly reflects the problems of trying to manage fisheries under increasing exploitation with conventional single-species management approaches. Actions have been taken only after declines had already occurred and were finally fully acknowledged. Most actions taken are minimal and not sufficient to ensure that recovery will take place.

Fishes are extremely important to monitor with precision in terms of the species composition, size/age structure, and fishery catch because they are a direct public concern, economically important, and an obvious measure of management success (Bohnsack and Ault 1996, Ault et al. 1998). Many species in the snapper-grouper complex use inshore "back reef" (inshore and coastal bay) habitats during critical and sensitive early life history stages (e.g., pink shrimp, spiny lobster, snapper, grunts and some groupers). The Everglades restoration includes a comprehensive effort to understand and model the physical and biological processes of Florida Bay and it's connectivity to the coral reef tract. As the restoration enters the implementation phase with many coral reef fish stocks currently overfished, it will be essential to have effective monitoring programs to assess system changes and to run predictive models that guide decision making. Ensuring the sustained function and productivity of this unique environment through prudent use and strategic management decision making will result in substantial biological, ecological and economic benefits to the scientific, commercial fishing and public communities.

This report also presents the quantitative bases required for preparation of an optimal sampling design analysis to produce precise statistics required for future implementation of a robust fishery management plan. To improve system efficacy, we recommend:

- Increasing the resolution and precision of base "habitat" maps for key environmental variables (i.e., salinity, benthic substrates, bathymetry, etc.). Existing "habitat" maps are imprecise and in some areas incomplete (e.g., Tortugas and Marquesas regions) and require

synoptic application of new technologies (e.g., airborne LIDAR) to detect and map critical hardbottom habitats with sufficient precision to aid in fish and habitat monitoring efforts.

- Conducting and analyzing broad sampling design issues such as habitats presently not monitored (e.g., seagrass, mangroves, deep reefs, and pelagic environments) but which may be important for management.

- Developing "statistical" habitat suitability models for individual reef fish and macroinvertebrate populations, taxa, and communities. These models would be used to optimize sampling survey designs for monitoring of trends following implementation of spatial management measures (Ault et al. 1999a, Ault and Luo 1998, Rubec et al. 1999, 2001).

An additional important consideration is that fishery-independent measures of stock status become even more important when spatial management strategies (i.e., such as marine protected areas or "no-take" marine reserves) are implemented. Because our fishery-independent size based methods are capable of estimating population mortality rates from both within the "closed" reserve areas and areas outside under exploitation in a non-intrusive and non-destructive way, we do not need to rely on fishery-dependent catch data.

The tradition of open-access management systems coupled with risk-prone management decisions remains a principal obstacle to achieving renewable resource sustainability (Rosenberg et al. 1996). Reversing adverse trends in the reef fishery are likely to require other innovative approaches to controlling exploitation rates. Rothschild et al. (1996) recommended that fishery management maintain a systems view of the resources that emphasizes strategy over tactics in development of fishery assessment and management approaches for building sustainable fisheries. With this in mind, we recommend consideration of management alternatives that couple traditional management measures with a spatial network of "no take" marine reserves (Fogarty et al. 2000, NAS 2001). Marine reserves provide an ecosystem management strategy for achieving long-term goals of protecting biodiversity while maintaining sustainable fisheries. The establishment of a network of small no-take reserves may be a first step. A key to the success of this effort is a conscientious, continuous assessment program using integrated fishery-independent and fishery-dependent data to evaluate their effectiveness (Bohnsack and Ault, 1996, Ault et al. 1998). With adaptive management (e.g., Walters, 1986), improvements can be implemented over time.

There is an increasing need to rely on fishery-independent data because fishery-dependent data will become less available and less useful as larger size limits, closed seasons, closed fishing areas, and prohibitions on species are imposed. Also, the shifting emphasis from commercial to recreational fishing in the Florida Keys makes collecting fishery-dependent data much more difficult and expensive. Fishery-dependent data has the potential to be biased by under-reporting and lack of cooperation on the part of the fishery itself. Although fishery-independent assessments can provide reliable measures of reef fish abundance, population dynamics and community composition (Gunderson, 1993), there have been few applications of the approach for optimizing the performance of multispecies fisheries in tropical coral reefs. We have therefore developed techniques and methods for the extraction of a useful indicator of reef fish stock health from fishery-independent and fishery-dependent monitoring and assessment surveys.

As a result, the quantitative multispecies stock assessment methods presented here should

help future fishery-independent and fishery-dependent assessment surveys and management decisions regarding fish stocks at broader levels. This could lead to development of spatial models of multicohort-multistock dynamics for DTNP, FKNMS and the Florida Keys coral reef ecosystem following Ault and Olson (1996), Ault et al. (1999b), and Cosner et al. (1999). These estimates and models are then the precursors to more exacting management analyses like multispecies stock assessments and modeling of spatial management alternatives. Furthermore, once determined these fundamental relationships could be embedded in a biophysical spatial simulation model (e.g., REEFS model has been generalized to incorporate space as well as time (Ault et al. 1999b, 2000; Meester 2000) to assess the consequences of preferred management alternatives, or to provide quantitative insights into the longer-term goals of maintaining ecosystem integrity, building sustainable fisheries, and conserving marine biodiversity that meet management targets and goals.

8.0 Acknowledgments

This analytical research was conducted under support provided by NPS grant No. CA5280-00-032 and FKNMS grant No. NA67RJ0149. RVC monitoring data were available under support provided from NOAA Fisheries, Florida Keys National Marine Sanctuary program, NOAA Coastal Ocean Program (Grant No. NA-95-WCH0631); and, NOAA South Florida Ecosystem Restoration Prediction and Modeling Program (Grant No. NA67RJ0149). The National Undersea Research Center (Grant Nos. NURC/UNCW J-98-23, NURC/UNCW1999-26 and 38NURC/UNCW2000-19) supported vessel and nitrox SCUBA diving operations and technical personnel. The NMFS SEFSC Coral Reef Initiative and the University of Miami RSMAS provided logistical support in the completion of this report. NOAA/FMRI provided digital benthic substrate habitat maps. Doug Harper of NMFS/SEFSC provided commercial and recreational vessel registered vessel digital database. Gene Huntsman of NMFS Beaufort, NC, provided headboat survey data. Tom Lee and John Wang provided information on the regional hydrodynamics. FISHBASE (www.fishbase.org) provided access to population dynamic parameters. We also thank a host of folks for required technical assistance to complete this exciting project including: Robert Brock, Donald J. Barry, Bob Johnson, Dick Ring, Paul Taylor, Brien Culhane, Jim Tilmant, Pat Kenney, John Hoesterey of NPS; Billy Causey, Ben Haskell, Steve Baumgartner, Gary Mangrela, Bruce Reyngoudt, Laurie MacLaughlin, Cheva Heck, Fritz Weinstein, Joanne Delaney, and Brian Keller of FKNMS; Don DeMaria; George Garrett of Monroe County Government; John Hunt, Chris Friel, Rod Bertlesen, Lynn Cox, and Rob Hudson of FWC; Steve Gittings and Mark Monaco of NOAA/NMS; Mike Crosby of NOAA/USAID; Gary Davis of USGS/BRD; Ken Lindeman of Environmental Defense; Jack Sobel of The Ocean Conservancy; John C. Ogden of Florida Institute of Oceanography; Robert N. Ginsburg of MGG, Dan Kalmanson and Pete Garcia of UM Media Relations, and, Rose Mann and Jennifer Richards of UM RSMAS Advancement. We sincerely thank those individuals whose participated on our Dry Tortugas millenial RVC SCUBA Team including: Peter Fischel, Doug Harper, David McClellan, Jack Javech, Guy Davenport, Anne Marie Eklund, Joe Contillo, Stephania Bolden, Jennifer Schull, and Mike Judge of the National Marine Fisheries Service SEFSC; Helena Molina, Robert Humston, Colin Schmidt, Amel Saied, Stacy Luthy, Tahzay Jones and Rick Gomez of the University of Miami RSMAS; Dione Swanson, Mark Chiappone, Susie Holst and Allison White of National Undersea Research Center; Erik Franklin and Ben Haskell of FKNMS; Jim Colvocorresses, James Kidney, and Mike Larkin of the Florida Fish and Wildlife Conservation Commission; Brian Ettinger of NOVA Southeast University; and, Leanne Rutten of Florida International University. Lance Horn, Sean Angsmiller, and Jennifer Dorton of NURC provided expert Nitrox SCUBA dive operations; and, Captains Ken McNeil, Frank Wasso, and divemaster Melanie Wasso of the M/V for exceptional vessel piloting, overall dive operations skills, and for being great hosts at sea. We also thank the Captains, crews and support personnel on our DRTO exploratory cruises aboard the NOAA R/V Ferrel (particularly Capt. Paul Moen and Stacy); and, the R/V Suncoaster. All these persons helped to make the Dry Tortugas millennial research cruises a pleasure and a breeze!

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Appendix 1
Tortugas Region Databases

(A) Benthic Habitat Databases

[1] NOAA/NOS Hydrographic Surveys

Source: NOAA/National Geophysical Data Center, Boulder, Colorado.
Description: Depth soundings, NOS Hydrographic Survey Data, Version 4.0 Vol. 1&2.
Spatial Coverage: Several discrete areas of the Tortugas region.
Variables: Latitude, Longitude, Depth.

[2] Marine Trackline Geophysics

Source: National Geophysical Data Center, Boulder, Colorado.
Description: Depth soundings, Marine Trackline Geophysics, Version 4.0 Vol.1,2,&3.
Spatial Coverage: Tracklines in the Tortugas region.
Variables: Latitude, Longitude, Depth.

[3] NMFS Acoustic Survey

Source: Chris Glendhill, NMFS Pascagoula
Description: Hydroacoustic survey of bathymetry.
Spatial Coverage: Widely spaced acoustic tracklines in discrete areas of the Tortugas region.
Variables: Latitude, Longitude, Depth.

[4] NOAA/NOS Hydrographic Surveys, multibeam 2000

Source: NOAA Silver Spring, MD.
Description: Depth soundings from multibeam sonar survey conducted by NOAA/NOS hydrographic teams (2000)
Spatial Coverage: About 4 km^2 around Sherwood Forest area of the Tortugas region.
Variables: Latitude, Longitude, Depth.

[5] NOAA/NOS Hydrographic Surveys, sidescan 1998

Source: NOAA Silver Spring, MD.
Description: Bathymetric and bottom substrate data from side-scan surveys conducted by NOAA/NOS hydrographic teams (1998).

Spatial Coverage: Several discrete areas of the Tortugas region.
Variables: Latitude, Longitude, Depth, Side-scan images.

[6] NOAA/NOS Hydrographic Surveys, sidescan 2000

Source: NOAA Silver Spring, MD.
Description: Bathymetric and bottom substrate data from side-scan surveys conducted by NOAA/NOS hydrographic teams (2000).
Spatial Coverage: Several discrete areas of the Tortugas region.
Variables: Latitude, Longitude, Depth, Side-scan images.

[7] FMRI Florida Keys Benthic Habitats Survey

Source: Chris Friel and Frank Sargeant, FMRI St. Petersburg
Description: Benthic habitat characterization interpreted from aerial photographic surveys.
Spatial Coverage: Entire Florida Keys region, including the Tortugas region.
Overview: GIS layers of bottom substrate classifications, generally limited to depths shallower than 30 feet.
Variables: Multiple categories of coral reef, seagrass, hardbottom, and sand/rock benthic substrates; land and shoreline coverages.

(B) Animals—Fisheries Databases

[8] NMFS / RSMAS Reef Fish Visual Census, Tortugas region

Source: James Bohnsack, SEFSC, and Jerald Ault, RSMAS
Description: Fishery-independent diver survey of reef fish population abundance and size structure using the Bohnsack and Bannerot (1986) stationary visual census technique.
Time Frame: 1999-2000
Spatial Coverage: 457 reef locations (200 m by 200 m primary sampling units) throughout the Tortugas region.
Sampling Overview: 1,825 total diver samples (see Table 4.1); 224 species; 46 families.
Variables: Sample ID, Date, Reef ID, Latitude, Longitude, Depth, Bottom type, Reef habitat, Species, Abundance (number observed), Length (cm).

[9] NMFS / RSMAS Reef Fish Visual Census, Florida Keys region

Source: James Bohnsack, SEFSC, and Jerald Ault, RSMAS
Description: Fishery-independent diver survey of reef fish population abundance and size structure using the Bohnsack and Bannerot (1986) stationary visual census technique.
Time Frame: 1999-2000
Spatial Coverage: 393 reef locations (200 m by 200 m primary sampling units) throughout the Florida Keys region.
Sampling Overview: 1,609 total diver samples (see Table 4.1); 218 species; 49 families.
Variables: Sample ID, Date, Reef ID, Latitude, Longitude, Depth, Bottom type, Reef habitat, Species, Abundance (number observed), Length (cm).

[10] NMFS Recreational Headboat Landings

Source: NMFS, Beaufort
Description: Fishery-dependent sampling survey conducted by NMFS personnel of the species and size composition of the recreational headboat catch.
Time Frame: 1979-1995
Spatial Coverage: Florida Keys and Tortugas regions.
Sampling Overview: 275 species categories
Variables: Trip ID, Date, Area, Number of Anglers, Species, Catch in Numbers, Catch in Weight, Sex, Length, Weight.