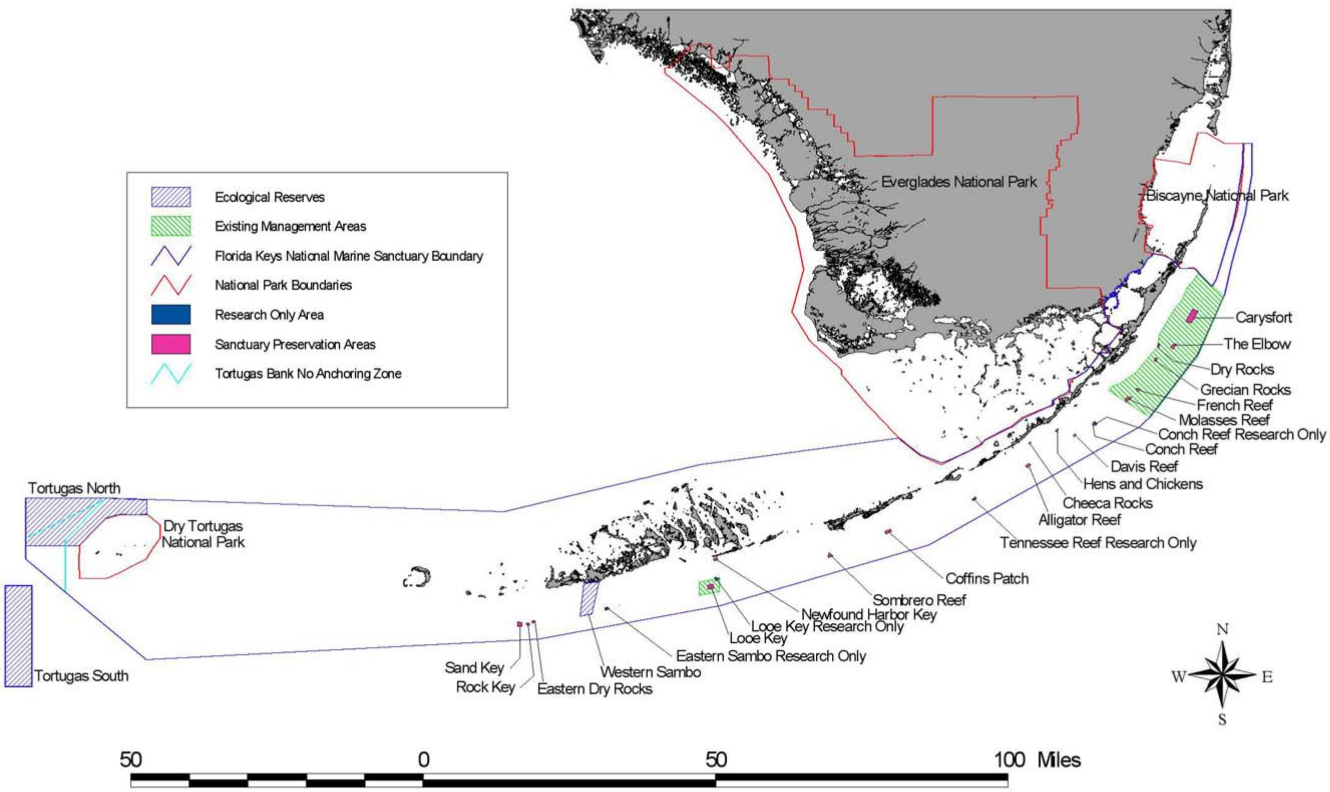
Florida Keys National Marine Sanctuary

Comprehensive Science Plan



1 November 2002 Final Draft

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PREFACE

The purpose of this *Comprehensive Science Plan* is to identify and prioritize the science needs of the Florida Keys National Marine Sanctuary. This is a “living document” that the Sanctuary’s management team plans to revisit and revise regularly. It complements the Research and Monitoring Action Plan of the Sanctuary’s Management Plan by assessing science needs at a far-more detailed level. The Action Plan establishes a framework – the Science Plan identifies management objectives and associated monitoring and research needs in a systematic fashion.

The genesis of this plan began in December 2000 when Sanctuary scientists and managers presented to an independent Science Advisory Panel the existing monitoring and research program for observations and recommendations. Sanctuary managers then held a planning retreat in April 2001 to address the panel’s recommendations including the need to develop a directed research program to investigate patterns emerging from existing monitoring projects. Robert Brock (Everglades and Dry Tortugas National Parks), David Johnson (NOAA, Coastal Ocean Program), and Paula Souik (NOAA, National Marine Sanctuary Program) joined the discussion, which was facilitated by Joanne Delaney (FKNMS) and supported by Ben Richards (FKNMS). Staff prepared a draft Science Plan that was reviewed by the Sanctuary’s Technical Advisory Committee in June 2001. This final draft addresses the comments provided by the Technical Advisory Committee and, pending its approval, will be posted at the Sanctuary’s web site for further comment.

The Sanctuary management committee hopes that the *Comprehensive Science Plan* will provide the scientific community with a clear set of high-priority monitoring and research needs in the FKNMS for the next few years.

SCIENCE ADVISORY PANEL

Felicia Coleman, Florida State University
Jonathan Garber, U.S. Environmental Protection Agency, Narragansett, RI
John Hunt, Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute
Ronald Kneib, University of Georgia, Marine Institute, Sapelo Island
Michael Risk, McMaster University
Susan Williams, University of California at Davis, Bodega Marine Laboratory

SANCTUARY MANAGEMENT COMMITTEE

Billy Causey, FKNMS
Brian Keller, FKNMS
Fred McManus, U.S. EPA
Bill Kruczynski, U.S. EPA
Fritz Wettstein, Florida Department of Environmental Protection
George Garrett, Monroe County, Division of Marine Resources

INTRODUCTION

The Florida Keys extend over 360 km from Key Biscayne southwest to the Dry Tortugas (Chiappone, 1996a). Paralleling the Keys is the Florida Reef Tract, the third largest bank-barrier reef system in the world. The offshore bank reefs are semi-continuous and include the only emergent reefs off the continental U.S. During the 1980s, oil drilling off the Florida Keys was being considered. At the same time, there were reports of deteriorating water quality throughout the region. Also, scientists were investigating effects of coral bleaching, the mass die-off of the long-spined urchin, loss of live coral, a major seagrass die-off in Florida Bay, declines in reef fish populations, and the spread of coral diseases (NOAA, 1996). As a consequence of these circumstances and three consecutive, large ship groundings on the reef tract, the Florida Keys National Marine Sanctuary (FKNMS) was designated in 1990. The purpose of the Sanctuary is to protect and conserve the nationally significant natural and cultural resources of the area, including critical coral reef habitats (Causey et al., 2000). Partners in the management of the FKNMS are NOAA and the State of Florida. Because water quality is critical to the survival of coral and seagrass habitats, Congress directed the U.S. Environmental Protection Agency and the State of Florida to prepare and implement a water quality protection program for the Sanctuary.

The Florida Keys ecosystem is one of this Nation's unique natural treasures. The marine component of the ecosystem is composed of tropical to subtropical waters that contain diverse benthic community types, including bank barrier coral reefs, patch reefs, hard bottoms, and seagrasses. This diversity of community types results in high species richness. The Keys are a popular tourist destination, in part because the faunal richness provides interesting snorkeling and diving venues. Also, the shallow water environments surrounding the Keys constitute extensive nursery areas and fishing grounds for a variety of commercially and recreationally important marine species. For example, Monroe County accounts for 91% of the total spiny lobster harvest and 44% of total pink shrimp harvest of Florida (Adams, 1992). Thus, the economy of the Keys, which is based upon tourism and fishing, is inextricably linked to a healthy marine ecosystem.

An overarching goal of the FKNMS is to preserve and enhance the living resources of the Sanctuary. A major problem with resource management is the difficulty in discriminating natural variation in ecosystems from changes or declines caused by human impacts that may be managed, such as wastewater and stormwater treatment and disposal. Research and monitoring funding cycles only rarely are long enough to capture the time course of natural phenomena, such as population explosions and declines, diseases, periodic oceanographic events, or natural processes, such as larval dispersal, recruitment, global warming trends, and sea level rise (Ogden et al., 1994). Long-term data sets and research to determine thresholds that result in shifts in community structure are required to understand and effectively manage marine ecosystems.

FLORIDA KEYS CONCEPTUAL MODEL

Designing a comprehensive and efficient research and monitoring program is a challenge that may be assisted by the development of a conceptual model. The conceptual model presented here is a simplified presentation of the relative importance of known forcing functions on the major biological components of the ecosystem. Measures are identified that are critical in monitoring changes in important attributes of the ecosystem. The following description of major elements in the conceptual model is not meant to be a comprehensive literature review of the Florida Keys marine ecosystem, but rather a primer on the marine ecology of the Florida Keys. This conceptual model is meant to be a starting point in summarizing our knowledge of the Florida Keys marine ecosystem, and to help identify areas of required research and measures to monitor its "pulse". A thorough understanding of the interaction of the forcing functions and stressors acting on different scales on the biotic components is required to set goals and effectively manage the ecosystem attributes that are essential to a healthy marine ecosystem. Measures must be quantified through research and long-term monitoring in order to understand and predict the consequences of environmental changes. Measures must be integrated across disciplines and at geographic and temporal scales of natural oceanic processes, upon which the human impacts, that we seek to manage, are superimposed.

FORCING FUNCTIONS

Forcing functions occur on global, regional, and local scales, and management of resources must include coordinated efforts at those scales. Global warming may be a major cause of the increasing incidence of coral bleaching events. Hot, calm conditions have been correlated with the onset of coral bleaching. Over the past twenty years, coral bleaching events in the Florida Keys have increased in frequency, duration, and extent. In the Florida Keys and worldwide, 1997 and 1998 were the worst coral bleaching years on record and average seawater temperature was the warmest recorded. The link between bleaching events and other conditions, such as ultraviolet light, needs further definition, as does the potential link between bleaching and onset of coral diseases. It is possible that bleached corals may be more susceptible to onset of diseases than unstressed corals. The study of biochemical responses of corals to various stressors may provide an important tool in predicting ecosystem change. Reducing global threats, such as global warming, requires global action.

A primary regional physical forcing function of the marine system is the regional circulation pattern. Although components of the regional circulation are known, there is a need for a comprehensive study on the long-term and short-term variations in circulation, ultimately leading to the development of a Florida Keys circulation model. Development of a circulation model may be complex because of the various sources of water that converge on the Florida Keys. Water generally flows from the Gulf of Mexico through the Keys passes to the Atlantic Ocean. However, there are times when that pattern is reversed (Smith and Pitts, 1998), which is undoubtedly important for dispersal of larvae. If a simplifying assumption is made, that currents disperse larvae passively, then surface current patterns should reveal routes of larval transport and patterns of connectivity (Roberts, 1997). For example, larvae of lobsters that spawn in the Atlantic Ocean may be swept to the Gulf side of the Keys during periods of flow reversals. Larval behavior patterns in response to ocean currents and other environmental factors may complicate larval dispersal and are questions that require further research.

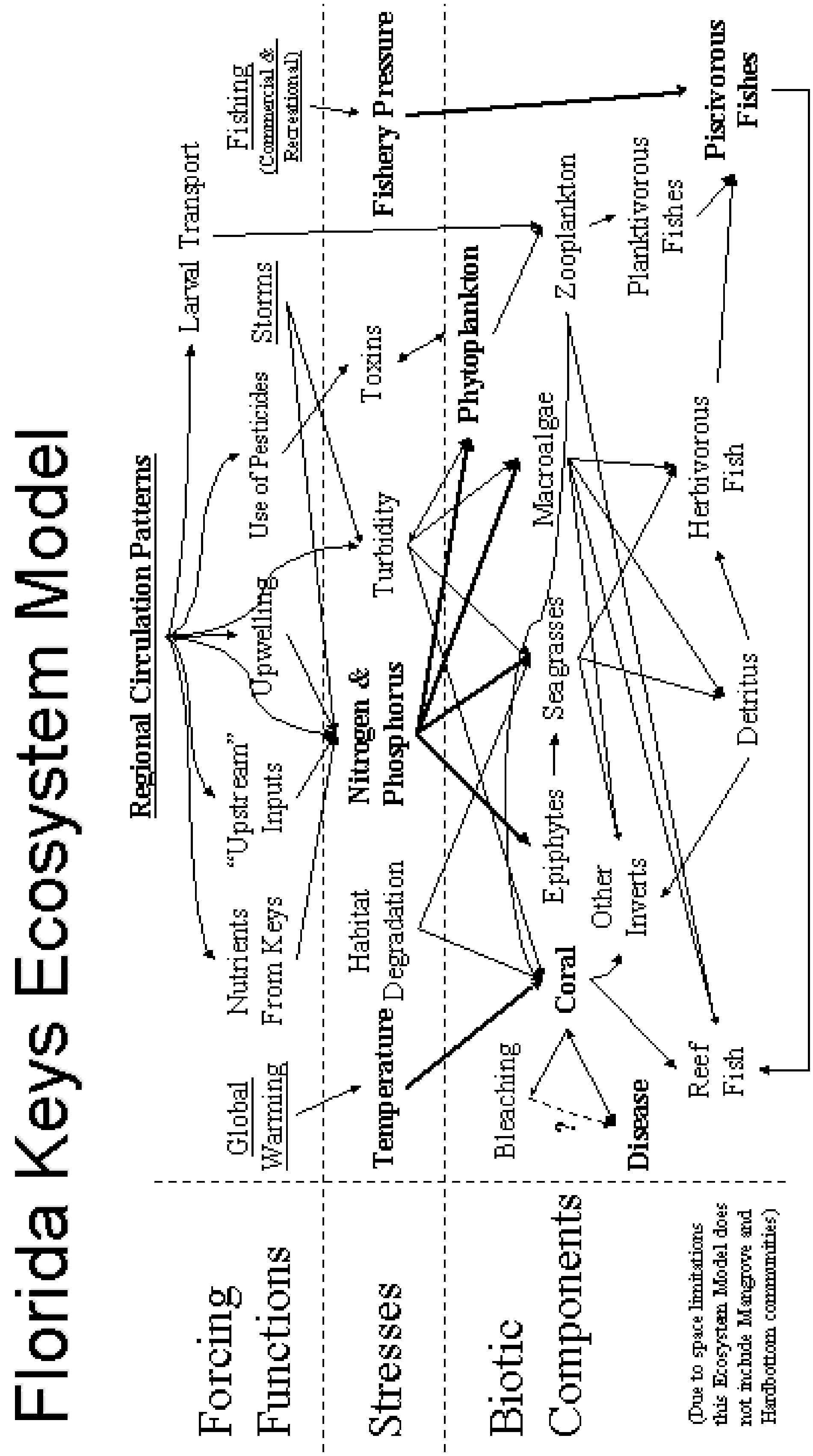
Regionally, the Florida Keys are hydrologically linked with the Everglades, Florida Bay, and the remainder of the South Florida ecosystem. Thus, the health of the Florida Keys ecosystem requires that projects developed as part of the Comprehensive Everglades Restoration Plan seriously consider the effects that those projects will have downstream. Continuation of the Sanctuary's monitoring program is essential to track the effects of South Florida ecosystem restoration on Florida Bay and the biological communities of the Florida Keys. Providing clean water in the right amounts, at the right times, and in the right places is essential to the ecological health of the Everglades, Florida Bay, and the Florida Keys.

Water that flows through the passes in the upper Keys is generally captured by the Florida Current and flows northward. However, water that flows through the passes in the middle and lower Keys may flow westward in Hawk Channel and along the reef tract before getting entrained into the northward flow. This circulation phenomenon is predominantly in response to wind direction (Smith and Pitts, 1998) and may be responsible for delivering nutrient-rich waters from upstream sources to the reef tract in the lower Keys.

Upwelling of deep waters is another source of nutrients to the Keys (Szmant and Forrester, 1996). Because of the volume of the water involved, upwelling events may overwhelm other sources of nutrients to the reef tract (Lapointe and Smith, 1987). Jones and Boyer (personal communication) have linked a Gulf upwelling event with a benthic algal bloom in the Dry Tortugas.

Storm events may result in changes in circulation patterns that can result in nutrient enrichment. Also, storm events may flush nutrients from land-based sources in the Keys to nearshore waters. Lapointe and Matzie (1996; 1997) tracked nutrient-enriched water from neighborhood septic tank drain fields to adjacent waters following rain events. A remaining question concerns the distance offshore that episodic flushing events cause changes in community structure.

Pesticides and other toxins may be delivered to the Keys from remote sources by ocean currents (Rumbold and Snedacker, 1999). Because they are largely hydrophobic and remain in the surface slick, toxins may be particularly detrimental to larval stages. Also, the impact of mosquito control measures in the Keys (adulticides and larvicides) on non-target organisms remains largely unknown. Preliminary research concluded that sprayed insecticides and their breakdown products could be transported from residential canals to the Atlantic Ocean at concentrations that may be harmful to marine organisms (Pierce, 1998). The export of pesticides from south Dade County agricultural fields through Florida Bay requires continued vigilance.


Florida Keys Ecosystem Model
Forcing Functions
Stresses
Biotic Components
(Due to space limitations this Ecosystem Model does not include Mangrove and Hardbottom communities)
Regional Circulation Patterns
Global Warming
Nutrients From Keys
"Upstream" Inputs
Upwelling
Use of Pesticides
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Larval Transport
Fishing (Commercial & Recreational)
Temperature
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Nitrogen & Phosphorus
Turbidity
Toxins
Fishery Pressure
Bleaching
?
Disease
Coral
Epiphytes
Seagrasses
Macroalgae
Phytoplankton
Zooplankton
Other Inverts
Reef Fish
Detritus
Herbivorous Fish
Planktivorous Fishes
Piscivorous Fishes

As the cornerstone of a thriving tourism and commercial fishing-based economy, the waters of the Florida Keys see an astounding amount of use. The islands receive more than 3 million visitors each year. The majority of visitors go snorkeling and scuba diving hoping to experience clean, clear water and healthy coral reefs with abundant and diverse marine life. Visitors annually spend $1.2 billion while in the Keys. Commercial fishing is the second-most economically important industry of the Florida Keys with commercial landings of $70 million (dockside value) every year. More than 6 million residents call South Florida home.

While the tourism and commercial fishing industries bring huge economic benefits to South Florida, they have historically done so at a high cost to the marine environment. Nutrients from poorly treated wastewater and stormwater runoff have increased the level of pollution in the nearshore waters of the Florida Keys. More than 7,000 cesspits, 900 shallow-injection wells and 25,000 septic tanks send water that is poorly treated or untreated through the porous rock of the Keys into nearshore waters. Heavy rains carry pollutants from roads, including animal waste and petroleum products, directly into surface waters.

Careless or inexperienced boaters run their vessels aground, scarring seagrass beds or destroying corals that took hundreds of years to grow. Inexperienced or careless snorkelers stand on, touch or kick delicate corals. Despite an extensive system of mooring buoys, anchor damage still poses a threat to many reefs. Primarily due to commercial and recreational fishing pressure, populations of many sought-after food fish have been reduced below a sustainable level, disrupting the ocean's food chain and the complicated web of life on the coral reefs.

STRESSES AND BIOTIC COMPONENTS

Many acres of coastal mangrove habitat have been lost from the Keys due to historic and continuing development. Many canal communities were created by dredging through mangroves and filling areas adjacent to the canal cuts to create fast land for development. Loss of mangrove habitat has undoubtedly resulted in increased nutrient export to adjacent waters by severely limiting filtration of runoff by natural plant communities. Seagrasses are under stress due to the proliferation of boating activities in shallow waters surrounding the Keys (Sargent et al., 1995). More research is needed on restoration of these important habitats.

Tropical coral and seagrass communities have evolved to thrive in relatively low nutrient conditions. Because the Florida Keys region is near the northern limit of reef-building corals, the region's biological resources may be especially sensitive to other stressors, such as changes in nutrient supply (Fong and Harwell, 1994). These communities cannot successfully compete with organisms that have evolved to take advantage of elevated nutrient loads. Therefore, nutrients added to oligotrophic systems are very rapidly taken up by opportunistic species. There is evidence from similar ecosystems that increased nutrient loading results in a shift in community dominance from seagrasses to epiphytic or benthic algal dominated communities (Reyes and Merino, 1991; Fong and Harwell, 1994). Because of rapid uptake, nutrient concentrations may by quite low and may not be detectable using traditional water quality sampling methods.

Instead, changes in structure of the biological community are important measures of nutrient enrichment. There is ample evidence of the impact of nutrients on the biological communities of canals and other nearshore waters (U.S. EPA, 1999). The distance offshore that such changes can be detected remains to be quantified. It is thought that small but continued changes in nearshore community structure could result in a cascading effect throughout the ecosystem and result in disruption of ecosystem structure and function.

Coral coverage is decreasing at an alarming rate throughout the FKNMS, particularly at deep reef habitats (Porter et al., 1999; Jaap et al., 2000). The interaction of stressors resulting in this decline remains unresolved. Thresholds of 1 μM nitrogen and 0.1 μM phosphorus have been suggested for coral reefs (Bell, 1992; Lapointe, 1997). However, corals are known to thrive under those nutrient conditions at other locales. Dustan (1999) and Porter et al. (1999) have proposed multiple-stressor hypotheses to explain coral decline, including nutrients, turbidity, bleaching, disease, and physical impacts as the main stressors. Loss of the long-spined sea urchin, an important grazer, may have resulted in increased algal growth and decreased coral settlement on reefs. Testing of these hypotheses requires additional "process-oriented" research.

Commercial and recreational fishing has resulted in the removal of large, predatory fishes from many locales. The abundance and average size of grouper and snapper are declining at all reefs that have been studied (Bohnsack et al., 1994; Ault et al., 1998). This shift in fish community structure has led to a proliferation of other reef fish species through a reduction of a "top-down" control mechanism. For example, increases in the numbers and size of parrotfishes, wrasses, damselfishes, and other reef fishes may be a result of fishing pressure on large "game" fishes.

ECOSYSTEM ATTRIBUTES AND ECOLOGICAL MEASURES

Ecosystem attributes are metrics essential to the understanding of the structure and function of the system. Long-term monitoring of ecological measures assesses the status and trends of ecosystem attributes. Standard water quality measures, such as temperature, salinity, nutrients, and chlorophyll, are required to assess the source of the water in different parts of the FKNMS and its potential impact on community structure. An understanding of the direction and speed of currents is required to assess delivery rates and potential impacts. Nutrient concentrations and a hydrodynamic model are required to develop a nutrient loading and water quality model for the Keys marine ecosystem. Water quality monitoring should also include episodic event monitoring because periodic flushing events may represent the greatest portion of nutrient additions. Water quality and circulation monitoring should incorporate remote sensing technologies to provide maximum coverage and efficiency.

Percent coverage of living coral is an important metric of the ecological condition of coral reef communities. Diversity of coral species and the relationship between growth and bioerosion and/or disease are also important measures in status and trends monitoring. Use of remote sensing to monitor changes in coral community structure should be investigated. The relationship between bleaching events and the onset and severity of diseases requires further quantification.

The production and viability of coral spawn may be an important measure of sublethal, physiological response to stresses. Factors that limit coral larval settlement and recruitment success must be quantified. The detailed relationship between water quality parameters and the condition of coral communities requires further research.

Seagrasses cover a large percentage of the FKNMS and are generally healthy (Fourqurean et al., 1999). Long-term monitoring of seagrasses must include percent coverage, species diversity, and some measure of productivity. The use of remote sensing to monitor long-term changes in seagrass coverage and diversity should be investigated. The relationship between water quality parameters and the condition of seagrass communities and methods to maximize recovery of damaged seagrasses are areas that require further research.

Several species of benthic macroinvertebrates and fishes are thought to be indicators of the ecological health of the Florida Keys marine ecosystem. These include groupers, queen conch and spiny lobster. Monitoring of the population dynamics of these “indicator” species is critical to understanding the effects of management actions, such as marine zoning and fisheries restrictions. Identification of sentinel species or physiological processes that may serve as early-warning mechanisms of ecosystem change is essential. Sentinel species may be more sensitive to water quality changes than those that can be detected by standard water quality monitoring. For example, changes in water quality may result in changes in physiological responses, such as gonad development and larval viability of queen conch or synthesis of proteins in corals. Studies on the genetics of sentinel species may provide important information on the sensitivity of species to environmental perturbations and recovery of viable populations following environmental threats.

SCIENCE NEEDS

This science plan is divided into the following categories: Physical Oceanography, Water Quality, Coral Reef Communities, Hardbottom Communities, Seagrass Communities, Algal Communities, Mangrove Communities, Fish Communities, Queen Conch, Spiny Lobster, and Benthic Invertebrates. Management objectives and associated research and monitoring needs are described for each category. High-priority needs are highlighted in bold lettering. The science plan is consistent with the recommendations of the FKNMS Science Advisory Panel and has been reviewed and approved by the FKNMS Technical Advisory Committee. Requests for proposals will be published by the U.S. EPA, NOAA, Florida DEP, and other organizations. Research and monitoring projects in high-priority topical areas will receive due consideration as funding for research becomes available.

PHYSICAL OCEANOGRAPHY

The Florida Keys are a hydrologically open system and receive waters from a variety of sources, including Florida Bay, the Gulf of Mexico, and the Florida Current. Both large-scale flow patterns and local bathymetry influence water movements in the Keys. Water flow is essential in maintaining good water quality. Current and tidal patterns in the Keys are complex because of the geology and topography above and below the surface of the water, including the juxtaposition of flats, channels, and mangrove islands. Wind is a very important forcing function that controls current direction and speed (Smith and Pitts, 1998). Flow is generally from the Gulf of Mexico through the tidal passes between the Keys to the Atlantic Ocean. However, there are regular and seasonally pronounced reversals of that overall flow pattern, as well as gyres that contribute to retention of water masses and planktonic larvae. Timing, strength, and direction of flow patterns are critical to distribution of pollutants and larval dispersal from areas within and outside the FKNMS.

Management Objectives and Associated Monitoring and Research Needs

- *Management Objective:* Improve our understanding of how regional and local water circulation patterns influence water quality in the Florida Keys. Completion of this objective requires improved knowledge of both circulation patterns and nutrient concentrations to determine loadings.
    - ***Monitoring Need (High Priority):*** **Maintain or expand the existing SEAKEYS network of monitoring buoys to provide a long-term data set of physical oceanographic parameters.** Continuation of this data set will provide a long-term record that can be correlated with other observations within the FKNMS.
    - ***Research Need (High Priority):*** **Develop an internal circulation model for the FKNMS that will interface with other models and will tie together local, regional, and larger-scale patterns.** Development of this model is essential to understand and predict the fate and effect of nutrients and larval transport.
    - *Research Need:* Correlate existing water circulation monitoring projects with remote sensing. Use of remote sensing may provide a cost-effective way of tracking circulation patterns and validating model predictions.

- *Management Objective:* Determine the influence of local and regional currents on recruitment, growth, and survival of Keys marine species. Completion of this objective is critical in determining the size and locations of possible ecological reserves and other fully protected zones in the future.
    - ***Research Need (High Priority):*** **Develop predictive larval recruitment, dispersal, and connectivity models that include sources, sinks, larval concentrations, and larval behaviors.** This information will be useful in determining the size and location of managed areas.

- *Management Objective:* Apply knowledge of physical oceanographic processes to gain insight into biological processes, such as coral bleaching. Knowledge of sea temperature and currents are required for predictive modeling of biological processes.

WATER QUALITY

Congress recognized that maintenance of waters low in nutrients and turbidity is critical to the survival of natural biological communities in the Florida Keys. Congress directed the U.S. Environmental Protection Agency and the State of Florida, in conjunction with NOAA, to develop a Water Quality Protection Program (WQPP) for the Sanctuary to "recommend priority corrective actions and compliance schedules addressing point and non point sources of pollution to restore and maintain the chemical, physical, and biological integrity of the Sanctuary, including restoration and maintenance of a balanced, indigenous population of corals, shellfish, fish and wildlife, and recreational activities in and on the water" (Florida Keys National Marine Sanctuary and Protection Act of 1990). The strategies recommended in the WQPP are described in the Water Quality Protection Program Document (U.S. EPA, 1996). Causes of water quality problems in the Keys and their potential solutions are discussed in "Water Quality Concerns in the Florida Keys: Sources, Effects, and Solutions" (U.S. EPA, 1999).

Wastewater and stormwater contribute to nutrient loading of nearshore waters of the Florida Keys. The relative contributions of known sources of nutrients and other pollutants are summarized in U.S. EPA (1999) and the Monroe County Sanitary Wastewater Master Plan and Stormwater Master Plan. It is thought that if land-based and live-aboard vessel-generated sources of nutrients are maintained or are increased, they could result in changes of ecosystem structure and function that cascade from nearshore to waters throughout the Sanctuary. Other waters that impinge upon the Florida Keys represent additional sources of nutrient loading to the Sanctuary. These include waters from Florida Bay, the Gulf of Mexico, and the Florida Current.

A long-term surface water quality monitoring program was established in the FKNMS in 1995. That monitoring program is designed to provide a long-term data base on the status and trends of standard water quality parameters, including temperature, salinity, turbidity, dissolved oxygen, chlorophyll a, nutrients, organic carbon, and alkaline phosphatase activity. Surface water quality monitoring stations were selected using a stratified random design within nine geographic segments (Klein and Orlando, 1994). Stations were located randomly within EMAP grid cells and along transects extending from nearshore to offshore. Surface and bottom samples are taken quarterly at approximately 150 fixed station locations. Incorporating the monitoring needs identified below would enhance the current water quality monitoring program:

Management Objectives and Associated Monitoring and Research Needs

- <u>*Management Objective:* Quantify the relative importance of natural and anthropogenic nutrient and other pollutant loadings to Sanctuary waters from local, subregional (south Florida), and regional (Gulf of Mexico) sources.</u> Upwelling events may be a significant source of nutrients to Sanctuary waters, particularly at the reef tract. Other sources include nutrients generated in the Keys in stormwater and wastewater, and nutrients from other locales that are brought to the Keys by prevailing currents. Wet-fall (rain) and dry-fall may also be a significant source of nutrients to waters of the Sanctuary.

- *Monitoring Need:* Design a more frequent sampling program. More frequent samples would result in greater statistical rigor in spatial and temporal (seasonal and inter-annual) comparisons.
- ***Monitoring Need (High Priority):*** **Regularly scheduled samples should be supplemented with samples timed to include episodic episodes, such as rainfalls, major storms, and upwellings to quantify the impacts of those events on water quality parameters in the Sanctuary.**
- *Monitoring Need:* Add additional stations outside the Sanctuary boundary to the north. Additional stations located in the Gulf of Mexico north of the Keys would allow a more accurate assessment of the nutrient loadings from distant sources to the north (e.g. Mississippi River).
- *Monitoring Need:* There is a continuing need to eliminate redundancy among existing water quality sampling stations. Such analysis may result in a reduction of stations while retaining the continuity of the data.
- *Monitoring Need:* Add groundwater monitoring at select locations to continually assess the impact of injected wastewater and stormwater on groundwater quality. Injected water may rapidly mix with surface water in areas with preferential flow paths. Comparisons of groundwater and surface water data may help identify areas where injection wells are not functioning properly and the cumulative impact of many wells in some geographic areas.
- ***Monitoring Need (High Priority):*** **Inter-laboratory comparisons of split samples and standards are essential to assure the comparability of data from samples taken in the FKNMS and analyzed at different laboratories.** Also, this may be important in comparing the Keys data sets with data sets from different geographic areas.
- *Monitoring Need:* Quantify nutrient loading from rain. Wet fall and dry fall of nutrients have been found to be a significant source of nutrient loading in other coastal ecosystems (e.g. Tampa Bay).
- ***Research Need (High Priority):*** **Develop a nutrient-loading model for the FKNMS ecosystem.** There is currently enough information to prepare a first-order nutrient-loading model. However, several sources of nutrients remain to be quantified (e.g. injection wells).
- *Research Need:* Quantify the organic and nutrient loading from seagrass and algae wrack that accumulates along shorelines and in canals and other confined water bodies. The sources of this organic material are the extensive seagrass communities that are located to the north of the Keys and the loading is variable and possibly seasonal.
- *Research Need:* Quantify loadings from Florida Bay and the Gulf of Mexico into waters surrounding the Florida Keys. The Florida Keys are part of the much larger south Florida region that is the focus of the Comprehensive Everglades Restoration Plan. That plan includes re-engineering the entire water management network in south Florida. Restoration decisions on the mainland have the potential to affect waters in the FKNMS. Modeling is required to assure that changes in the quality, quantity, timing and distribution of water to Everglades National Park and Florida Bay do not represent an additional source of nutrients and other pollutants to the FKNMS.

- ***Research Need (High Priority):*** **Investigate methods of improving water quality in Keys canals.** Water quality in many canal systems is enriched by nutrients from stormwater, wastewater, and other sources. Water quality in canals is also a function of canal depth, length, and geometry. Physical improvements, such as culverts, flushing channels, filling, and sloping, may improve canal water quality.

- *Management Objective:* Eliminate or reduce the impact of anthropogenic nutrients, human pathogens, and other pollutants on biological communities and public health. Important and manageable sources of anthropogenic pollutants are from wastewater and stormwater generated in the Florida Keys. These sources have been quantified and methods to reduce or eliminate them are discussed in the "Monroe County Sanitary Wastewater Management Plan" (CH2M Hill, 2000) and the "Monroe County Stormwater Management Master Plan" (Camp, Dresser, and McKee, 2001).
    - ***Research Need (High Priority):*** **Quantify the geochemical changes in wastewater injected into disposal wells as it passes through limestone.** Preliminary evidence shows sequestering of phosphorus and some denitrification. However, rates and long-term events require further quantification to estimate flux and total loading of nutrients into surface waters from injected wastewater. This includes modeling of groundwater flow and nutrient dynamics.
    - *Research Need:* Investigate how far from a pollutant source changes in biological community structure can be detected. Sources include surface waters from enriched canals and groundwater that has received wastewater. Community responses could include changes in species composition or productivity of benthic diatoms, macroalgae, and/or seagrasses, as well as faunal changes.
    - *Research Need:* Develop thresholds and target levels for nutrients and other pollutants that may be harmful to various components of the FKNMS ecosystem. Research in this area may lead to the development of sensitive bioindicators that may allow accurate predictions of community responses. Queen conch is a good candidate since reproductive success may be linked with water quality (Robert Glazer, personal communication).
    - ***Research Need (High Priority):*** **Assess the effects of mosquito spray and other toxicants on non-target living resources.** Preliminary evidence has shown that sprayed chemicals or their breakdown products occur in surface waters at concentrations that may be harmful to non-target species. The effect of sprays and larvicides on non-target organisms should be quantified, particularly in areas that are sprayed many times during the mosquito season and in protected areas adjacent to sprayed areas.
    - *Research Need:* Determine the role of turbidity and other non-nutrient factors in limiting Sanctuary biological resources. Assessment of seasonal and geographic patterns in turbidity may help explain distribution patterns of seagrasses, corals, and other organisms and could lead to the development of a narrative water quality standard.
    - ***Research Need:*** **Assess the risk of poorly functional wastewater collection and treatment systems on public health.** Live viruses were found in canals receiving wastewater from onsite wastewater systems. Rain events have resulted in beach closures due to bacterial contamination. Public health risk should be assessed by quantifying

infectious disease and indicator organisms and conducting public health surveys. This includes an assessment of the viability of viruses outside human hosts (e.g. coral mucus, bivalves).

- *Management Objective:* Develop methods for rapidly and accurately determining if the ecosystem is responding to changes in water quality conditions. Identify sentinel species or conditions so problems can be identified and corrected before they become chronic.

CORAL REEF COMMUNITIES

The FKNMS includes 1,400 km^2 of coral reefs in several distinct habitats (Turgeon et al., 2002). Human activities, such as boat and ship groundings, accumulation of debris, and improper anchoring cause extensive damage to reefs. In addition, a range of anthropogenic and natural stresses affect reef-building corals and associated organisms. The collective effects of damage and stresses are manifested as decreases in coral cover and species diversity and increases in coral diseases and coral bleaching in the Sanctuary (Jaap et al., 2000).

FKNMS coral reefs are monitored by four projects. The Water Quality Protection Program's Coral Reef Monitoring Project (CRMP; Florida Marine Research Institute) examines status and trends of a number of parameters at fixed stations throughout the Sanctuary. A Rapid Assessment Project (National Undersea Research Center, University of North Carolina at Wilmington) examines randomly selected sites across a range of reef types both inside and outside fully protected zones. A Coral Reef Ecosystem Processes Project (Florida Institute of Oceanography) monitors changes in ecological processes associated with full protection at the two largest zones. Finally, a U.S. Environmental Protection Agency Coral Disease Monitoring Program conducts an annual survey of coral diseases in the Sanctuary. In addition to these monitoring projects, many independent investigations are being conducted on coral biology and ecology.

An important finding of the existing CRMP monitoring project is a marked decline in live reef-building corals between 1996 and 2000. This trend is alarming because corals are major contributors to the framework of coral reefs and reefs grow only when the rate of accretion exceeds the rate of erosion. Continued monitoring of coral reefs clearly is necessary and there is a critical need for research to investigate causes of coral decline and to identify and evaluate possible corrective actions.

Management Objectives and Associated Monitoring and Research Needs

- *Management Objective:* Determine the causes of coral reef decline. Coral reefs in the FKNMS are losing live coral cover at an alarming rate. Several causes of the losses are known, such as disease, bleaching, abrasion, parrotfish bites, and macroalgal overgrowth; however, the relative importance of these causative agents and how much of the losses are driven by anthropogenic factors that may be ameliorated by management actions are not known. Natural resource managers need to be able to reduce factors that are responsible for reef decline and enhance those that stimulate recruitment. It is also important to improve our understanding of the interactions between natural and anthropogenic factors, e.g. seasonal variation in water conditions and light, ENSO events, and long-term environmental variation. Natural resource managers require this information to make informed decisions.

- ***Research Need (High Priority)*: Determine direct and indirect causes of coral decline with emphasis on cause and effect.** Process-oriented research is required to separate natural variation in community composition from anthropogenic changes.
- *Research Need:* Quantify the effects of coral bleaching on coral survival. There is a general relationship between severity of bleaching events and coral mortality. However, more information is needed on intra- and interspecific differences in sensitivity to bleaching, habitat-related differences, and synergistic effects, including possible genetic factors.
- *Research Need:* Conduct studies on coral pathology and epizoology with an emphasis on cause and effect. More information is needed on coral immune systems and how they may be compromised by environmental stresses, whether a number of purported coral diseases meet Koch's criteria, how diseases spread, and whether there are ways to prevent coral diseases.
- *Research Need:* Identify sentinel species indicative of coral reef decline. Sentinel species are species other than corals that have clear physiological, behavioral, reproductive, or other reactions to the types of environmental conditions that stress corals. These reactions should occur before environmental conditions reach levels that are deleterious to corals. Examples may include echinoderms, sea anemones, and small crustaceans, such as amphipods or stomatopods.
- *Research Need:* Integrate current coral monitoring techniques with water quality monitoring data to develop water quality thresholds for corals. We need to determine whether there are correlations between water quality parameters and a range of parameters associated with coral condition, including species composition, incidence of disease, *Diadema* abundance, and *Acropora* spp. abundance.

- *Management Objective:* Identify corrective actions that are required to enhance coral recruitment and growth and prevent future causes of degradation. Coral recruitment rates in the FKNMS are comparable to rates that have been measured elsewhere in the Caribbean, which are lower than those in the Indo-Pacific (S. Robbie Smith, personal communication). A significant factor in successful coral recruitment is the availability of suitable substratum, i.e. stable, dead coral without macroalgal growth and encrusted with coralline algae. Prior to the *Diadema antillarum* die-off of 1983, an abundance of such substratum was generated by the grazing activities of this urchin. Natural resource managers need information about the most effective and efficient ways to act to restore suitable habitat for coral recruitment.
  - *Research Need:* Study the relationship between *Diadema antillarum* and corals with an emphasis on the possible enhancement of coral recruitment and growth as a result of *Diadema* transplantation. There may be an optimal density of *Diadema* for maximum coral recruitment (Sammarco, 1980).

- *Research Need:* Investigate the negative effects of contaminants in the ocean surface layer on coral spawn and larvae. Some contaminants may occur at higher concentrations near the air-water interface than deeper in the water column. Coral spawn and larvae may be exposed to these contaminants and detrimentally affected by them, possibly resulting in lower recruitment rates.

- *Management Objective:* Restore and speed up the recovery of coral reef areas that have been degraded. Natural resource managers need to know the full range of options to enhance reef restoration. This includes restoration techniques after catastrophic events, such as vessel groundings, as well as techniques to reverse more gradual loss of live coral from anthropogenic causes.
  - *Research Need:* Continue the development of reef restoration techniques with an emphasis on transplantation of hardy specimens, genetic variability, cultured corals, and coral plugs to damaged areas. Field experiments are necessary to test alternative approaches to reef restoration.

- *Management Objective:* Assess and eliminate redundancy in the current coral reef monitoring programs. Natural resource managers and principal investigators need to discuss sampling designs and monitoring techniques to optimize this component of the research and monitoring program, i.e. discuss management needs with respect to spatial considerations, monitoring frequency, precision, and habitat stratification.
  - ***Monitoring Need (High Priority)*: Develop a refined coral monitoring program using existing data and assessment techniques.** We need to create a more focused long-term coral-monitoring program using the information we have accumulated since the establishment of the existing monitoring programs. We need to assess the ability of the existing long-term monitoring sites to detect the impacts resulting from the Comprehensive Everglades Restoration Plan. Where available and appropriate, satellite imagery should be used to help identify essential sites. The program needs to assess the ratio of monitoring sites according to habitat types to determine if all habitat types are appropriately represented. The Sanctuary will host a workshop to discuss actions required to fulfill this need.
  - *Monitoring Need:* Conduct broad surveys of coral cover. In addition to monitoring long-term stations, there is a strong need for periodic, synoptic "snap shots" of coral reefs throughout FKNMS. These surveys need to include all forms of coral reef habitats: deep fore reef, shallow fore reef including spur-and-groove formations, mid-channel patch reefs, and nearshore patch reefs.

HARDBOTTOM COMMUNITIES

Hardbottom communities are defined here in the sense of live bottom habitat of Jaap (1984). They are characterized by their shallow depth (1-4 m), low topographic relief (< 0.5 m), and a sessile community comprised of various species of gorgonians, sponges, algae, and eurytopic scleractinian corals (Chiappone, 1996b). The relative proportions of these groups vary under different environmental conditions. The other two hardbottom habitats of Jaap (1984; patch and bank reefs) are considered in the section on coral reefs.

There is a need for research on the functional significance of hardbottom communities. Despite their spatial extent, potentially high productivity, and potential role as nursery habitat, much remains to be learned about the ecology of hardbottom communities.

FKNMS hardbottom communities are monitored by two projects. The Coral Reef Monitoring Project examines status and trends of a number of parameters at seven fixed sites. The Rapid Assessment Project examined randomly selected sites in hardbottom communities both inside and outside fully protected zones in 1999 and 2000.

Management Objectives and Associated Monitoring and Research Needs

- *Management Objective:* Determine functional significance of hardbottom communities in FKNMS, including a characterization of sponge communities. The ecology and functional significance of hardbottom communities are poorly understood. Sponges, gorgonians, and corals provide physical structure for a diverse and abundant community of mobile animals. Investigations of the ecology and functional significance of hardbottom communities are required to improve our understanding of how to best manage natural resources associated with this habitat.
    - *Monitoring Need:* Develop a refined hardbottom community monitoring program based upon existing data and assessment techniques.
    - *Research Need:* Determine the functional significance of hardbottom communities in the FKNMS ecosystem. Basic ecological studies including food web and life history observations are required to meet this need.
    - *Research Need:* Assess the role of hardbottom communities in the life cycles of reef fishes. There is limited information about the utilization of hardbottom habitats by reef fishes during different stages of their life cycles. Research is needed on fish ecology in this habitat to define inshore-offshore fish movements.
    - *Research Need:* Assess the effects of water quality on hardbottom communities. Research is required to determine water quality thresholds that produce changes in community structure.

- *Management Objective:* Understand the history and ecological dynamics of hardbottom communities in the FKNMS environment and determine the role of hardbottom communities in predicting changes in reef communities. The evolution of hardbottom habitats and the ecology of associated communities are poorly understood. Natural resource managers need to know whether changes in hardbottom communities are indicators of future changes in coral reef communities.
    - *Research Need:* Investigate the history and ecological dynamics of hardbottom communities on a geologic time scale. It is not understood why hardbottom communities are a distinct community type and whether they will evolve to become coral reefs in the

long term. There may be environmental or ecological factors that prevent the density or growth of corals to attain reef-forming levels. Alternatively, there may be centuries-scale processes in the dynamics of patch reef formation and hardbottom communities may be an initial stage in these dynamics.

- *Management Objective:* Reduce anthropogenic impacts on hardbottom communities through the continued marking of hardbottom locations and boundaries. Many hardbottom communities occur in very shallow water and thus are particularly susceptible to damage from boating, anchoring, lobster and stone crab traps, and other anthropogenic impacts.

- *Management Objective:* Examine the effects of commercial sponging on hardbottom communities in the FKNMS. The ecological significance of commercial sponge species is not well understood. Natural resource managers need scientific evidence about the ecological roles of commercial sponge species to assess management options.
  - *Research Need:* Quantify the habitat value of commercial sponges and assess the impact of harvesting on habitat and water quality. A large number of marine species utilize sponges as habitat. Information is needed on the relative contributions of commercial and non-commercial sponges as habitat. Natural resource managers need research findings on impacts of the commercial sponge fishery on habitat provided by sponges.

- *Management Objective:* Ameliorate existing damage to hardbottom communities. Studies are required to determine the most effective approaches toward restoring damaged hardbottom communities.

SEAGRASS COMMUNITIES

In addition to the extensive coral reef and hardbottom resources found in the Florida Keys, the region contains one of the largest seagrass habitats in the world. This seagrass community performs many significant functions, including maintaining water clarity, stabilizing sediments, providing habitat and foraging grounds for fish and shellfish, and supplying a nursery area for recreationally and commercially important species.

Of the approximately 52 species of marine seagrasses that exist worldwide, seven are found in Florida waters. Three of these species are widespread and comprise the majority of the Florida Keys seagrass community: shoal grass (*Halodule wrightii*), turtle grass (*Thalassia testudinum*), and manatee grass (*Syringodium filiforme*). Some seagrass sites are monitored quarterly and others annually by the Water Quality Protection Program's Seagrass Monitoring Project. This project has gathered and evaluated over four years of spatially extensive data on seagrass status and trends in the Sanctuary.

Seagrasses are a valuable resource of the FKNMS, and are being impacted at an alarming rate. Boat propellers have permanently damaged over 121 km^2 of seagrasses (Turgeon et al., 2002). Dredge-and-fill projects and degraded water quality can also result in seagrass declines in some areas. Long-term monitoring is required to assess impacts of activities of the Comprehensive Everglades Restoration Plan on seagrass communities. The environmental and economic significance of seagrasses to the Florida Keys necessitates responsive management, timely assessment, and when possible, biological restoration of this important marine resource.

Management Objectives and Associated Monitoring and Research Needs

- *Management Objective:* Identify the status and trends of local seagrass populations. An emphasis should be placed on determining the effects of seagrass loss or gains on the Sanctuary ecosystem.
    - ***Monitoring Need (High Priority):*** **Maintain status and trends monitoring of seagrasses to track seagrass loss and recruitment Sanctuary-wide.** The development and use of remote-sensing techniques for seagrass monitoring should be explored to increase cost-effectiveness. Currently, over four years of data have been gathered on seagrass status and trends through quarterly and annual monitoring. As recommended, monitoring at permanent monitoring sites has been reduced to once every three years. Pulse amplitude modulated (PAM) fluorometry has recently been developed as a technique for assessing the physiological condition of seagrasses and macroalgae. As suggested, PAM was added to the Seagrass Monitoring Project in FY2001.

- *Management Objective:* Determine the influence of seagrasses on the homeostasis of local communities. This objective includes identifying the extent that seagrasses serve as indicators of local and regional water quality changes.

- *Management Objective:* Reduce anthropogenic impacts to seagrass beds and ameliorate existing damage that continues to occur. This management objective is closely linked to public outreach and education efforts by the Sanctuary and other organizations.
    - *Monitoring Need:* Continue to assess impacts to seagrasses in the Sanctuary. Monitoring is required to quantify anthropogenic impacts. Collaboration with the Seagrass Outreach Partnership, the Sanctuary's Education and Outreach programs, and other agencies and educational organizations must continue to properly and effectively communicate the value of seagrasses to all Sanctuary users. An evaluation of current education tools would be appropriate after those tools have been in place for a year or more.
    - ***Research Need (High Priority):*** **Develop and evaluate new restoration techniques.** Continued restoration research is needed to stem the increasing frequency of injury to seagrasses. Additionally, an evaluation of existing seagrass restoration techniques with regards to feasibility, cost, and success is needed.

- *Management Objective:* Assess the linkage between seagrass diversity, distribution, and abundance and water quality parameters. Identification of thresholds in water quality parameters will provide important nutrient- and turbidity-loading targets for resource managers.

- ***Research Need (High Priority):* Assess the correlation between water quality and seagrass distribution.** This priority research need is driven by the Water Quality Protection Program's seagrass and water quality monitoring efforts, which share some common sampling locations and timing. A preliminary multivariate comparison of these data sets has been made, but more detailed analyses are required to conclusively develop relationships between these two important parameters in the Sanctuary.

ALGAL COMMUNITIES

Benthic macroalgae are a diverse and widely distributed component of the Florida Keys ecosystem. Phytoplankton concentrations are generally low in tropical marine waters. However, marked increases in macroalgal and phytoplankton biomass and productivity (blooms) can be detrimental to seagrass, coral reef, and hard bottom communities. Phytoplankton blooms can reduce light penetration and adversely affect growth and survival of seagrasses, corals, sponges, and other important ecosystem components. Benthic algal blooms can smother seagrasses and hard bottom communities and prevent larval settlement of corals and other reef organisms. Blooms have been related to increases in nutrient availability. Phytoplankton and macroalgae respond rapidly to increases in nutrient availability, initially by uptake and storage, then by increased growth. Macroalgal growth is more related to internal tissue nutrients than to nutrients in the external medium (Hanisak, 1999).

Several studies have related anthropogenic increases in nutrient availability with declining ecological health of tropical ecosystems (Bell, 1991; Lapointe and O'Connell, 1989). Coral reefs with elevated nutrient concentrations generally have higher standing crops of phytoplankton and benthic macroalgae than reefs in nutrient-poor water (Hatcher, 1990). Phytoplankton and most reef macroalgae acquire nutrients directly from surrounding waters, not sediments, and are probably integrating nutrient availability at shorter temporal scales than seagrasses. Thus, the standing crop of phytoplankton and macroalgae may be important indicators of nutrient variations associated with seasonal changes, inter-annual variability, and stochastic events (Hanisak, 1999).

Perhaps the most documented case of nutrient impacts on coral reefs is Kaneohe Bay (Hawaii), where a green alga (*Dicytosphaeria cavernosa*) bloomed and overgrew coral reefs in response to sewage discharge. When the sewage was diverted, the bloom subsided and the reefs began to recover (Maragos et al., 1985). Coastal phytoplankton blooms have been directly related to natural and anthropogenic sources of nutrients (Nixon, 1995). Canal and nearshore waters of the Florida Keys have consistently higher chlorophyll a concentrations than waters farther from shore (Brand, 1997). Persistent phytoplankton blooms in north-central Florida Bay are thought to be a result of nutrients released to the water column from seagrass die-off and sediment resuspension (Fourqurean and Robblee, 1999).

Seawater nutrient concentrations are often too ephemeral or too low to routinely be used as parameters to detect natural or anthropogenic sources in nearshore reef environments (Hanisak, 1999). Because macroalgae respond quickly to changes in environmental conditions and changes in other important components of the marine community, such as the loss of benthic grazers (e.g. *Diadema*), studies on macroalgae in the Florida Keys may provide important indicators and thresholds of community changes.

Management Objective and Associated Monitoring and Research Needs

- *Management Objective:* Understand the dynamics of algal communities in response to natural and anthropogenic environmental changes. Because of their sensitivity to low nutrient levels and their rapid response to changes in environmental conditions, phytoplankton and benthic algae may provide an important "early warning" system to more widespread and chronic community changes.
    - *Monitoring Need:* Include measurement of species composition and productivity of benthic algae in seagrass and coral reef/hard bottom monitoring programs. Changes in benthic algal community structure may be an important indicator of future changes in other community components.
    - *Research Need:* Investigate the dynamics of algal communities in response to environmental changes. Field and laboratory experiments are required to quantify thresholds of change of benthic macroalgae, epiphytes, fleshy and calcareous algae, and phytoplankton.
    - *Research Need:* Develop a model to predict biological community responses to natural and anthropogenic stresses.

MANGROVE COMMUNITIES

Mangrove communities contribute to the overall health of Florida's coastal environments. Mangroves trap and cycle various organic materials, chemical elements, and important nutrients from terrestrial and aquatic ecosystems. Mangrove roots act as physical traps for sediments and attachment surfaces for many marine organisms. Fish and invertebrates find food and nursery habitat among mangrove roots. Furthermore, coastal communities gain shelter, flood protection, and shoreline stabilization from mangroves.

Worldwide, more than 50 species of mangroves exist, including the red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), and white mangrove (*Laguncularia racemosa*) in South Florida. Florida's mangroves are sensitive to extreme temperature and salinity fluctuations. Water temperature, tidal fluctuations, and soil also affect mangrove growth and distribution (Lugo and Snedaker, 1974).

A healthy mangrove community in the FKNMS is critical to stabilizing shorelines, sustaining economically important fisheries, providing nesting and roosting sites for birds, and maintaining the character and beauty of the Florida Keys. Mangrove resources are vast and the trusteeship for these important communities is shared between the Sanctuary and the Florida Department of Environmental Protection (FDEP).

Management Objectives and Associated Monitoring and Research Needs

- *Management Objective:* Continue to protect mangrove resources with an emphasis on the removal and elimination of invasive exotics.

- *Management Objective:* Restore mangrove shorelines in appropriate locations. In consultation with the FDEP, the identification of key areas for mangrove restoration projects should be determined.
    - *Monitoring Need:* Assess historic shoreline conditions using aerial photography. Changes to and the existing extent of mangrove vegetation in the Florida Keys can be ascertained by comparing historic with recent aerial photography.
    - *Monitoring Need:* Evaluate these data and develop priority restoration plans for mangroves in the Sanctuary.

FISH COMMUNITIES

Fish stocks in the FKNMS are under steadily increasing fishing pressure. The Florida Keys has had a recreational and commercial fishing community for many years. However, the number of anglers has increased markedly in recent years and the development of new technologies, such as radar, GPS, and fathometers, has increased the efficiency of fishers. A large number of reef fish species are overfished and the average size of groupers and most snapper species is decreasing because of the removal of fish that reach the minimum size limits (Ault et al. 1998).

Consideration of geographic and temporal zoning as a tool to ensure the protection and conservation of resources within the FKNMS is mandated under Section 7(a)(2) of the Florida Keys National Marine Sanctuary and Protection Act. While this type of marine zoning has been used successfully world wide to protect a variety of sensitive marine resources from overuse, and has been effectively used to separate conflicting visitor uses, an effective research and monitoring program is needed to ensure that zone type, number, and size meet the needs of ecosystem management. The research and monitoring program need not be static, and should be continually evaluated by managers and independent panels. Through the continued evaluation and modification of research and monitoring protocols, management practices can be modified to meet the changing needs of both the marine ecosystem and resource users. In this way, the FKNMS will continue to effectively manage the marine resources of the Florida Keys and will continue to assist other agencies with fisheries management.

Management Objectives and Associated Monitoring and Research Needs

- *Management Objective:* Maintain a healthy and diverse fish community. Effective management will ensure that healthy and robust fishery stocks are maintained for future generations.
    - ***Monitoring Need (High Priority):* Continually evaluate and optimize existing status and trends monitoring.** The current monitoring program for the FKNMS is effective,

but does duplicate efforts in some areas. The FKNMS should evaluate current monitoring efforts to reduce redundancy and create a more streamlined and optimized program without compromising the statistical design of the sampling program.

  - *Research Need:* Examine the effects of habitat degradation and loss of coral on local fish community structure and stability. Research should focus on the effects that habitat degradation and loss of living coral have on the structure and stability of local fish populations.

- *Management Objective:* Give more attention to and gain a better understanding of the role, diversity, and ecological significance of non-food fish species in the community; include biogeographic distribution in order to be more predictive of responses to protection. The existing monitoring program for lobster, snapper, grouper, and other commercially important fish species needs to be maintained. However, more attention should be given to non-food fish species. Emphasis should be given to understanding life histories and population dynamics of a wide range of non-target reef fish species and their biogeographic distribution patterns. This understanding will allow managers to evaluate and make better predictions about of the results of different management practices.
  - *Monitoring Need:* Examine bycatch and incidental catch in alternative fisheries. The effects of bycatch on non-target reef fish populations are not well understood. As the monitoring program is evaluated, additional studies are needed to ascertain these effects.

- *Management Objective:* Assess the effectiveness of SPAs and other management tools used in the preservation of both target and non-target species. Management is an ongoing process. While many of the management objectives of the FKNMS will remain constant, new situations and conflicts may develop which necessitate further management action. It is essential that the science plan for the FKNMS remain adaptive and able to address new questions as they arise. Only through continued research and monitoring will the management practices of the FKNMS continue to evolve to compensate for the ever-changing needs of ecosystem and resource users.
  - ***Monitoring Need (High Priority):* Monitor the effects of new artificial reefs, including the Spiegel Grove, on local fish communities.** In recent years the use of artificial reefs has been explored as a possible supplement to dwindling natural reef environments. While shipwrecks are often hailed as an effective reef-building material, there has been little monitoring concerning the effectiveness of existing artificial reefs in the FKNMS. Monitoring efforts need to be focused on the effects of artificial reefs on fish abundance and distribution.
  - ***Research Need (High Priority):* Create an ecosystem model for reef fish communities in the FKNMS to predict cascading effects of zoning on reef fishes.** This type of model will enable managers to predict shifts in local communities and to anticipate changes in the Florida Keys ecosystem as historical levels of larger, top predators are restored. Ecosystem models of this type are also important in the continued evaluation of the size and distribution of management zones and will be used as a tool to continually evaluate the effectiveness of the management program.

QUEEN CONCH

Queen conch (*Strombus gigas*) once were abundant in the Florida Keys, but are now a threatened and protected species in Florida (Chiappone and Sluka, 1996). A 1987-1988 survey of nearly 544 hectares found an average density of less than 3 individuals per hectare, mostly juveniles (Berg et al., 1994). This density was one-tenth of the density reported for the Bahamas. More recent surveys show that queen conch density has decreased substantially since then (Robert Glazer, personal communication).

Management Objectives and Associated Monitoring and Research Needs

- *Management Objective:* Assess the effectiveness of current management actions and restore queen conch populations to historic levels. A commercial fishery for queen conch was developed in the Keys in the 1960's (Chiappone and Sluka, 1996). By the 1980's, queen conch had become so scarce that a prohibition on harvesting was issued in 1985. Despite 15 years of protection, queen conch numbers remain relatively low (Robert Glazer, personal communication), suggesting that additional management actions are required.
    - ***Monitoring Need (High Priority):* Continue current status and trends monitoring of queen conch.**
    - ***Research Need (High Priority):* Determine limiting factors to conch reproduction and survival.** Research is needed to isolate and identify the environmental factor(s) that control queen conch reproduction. Further research is needed on settlement of larvae and survival of juvenile queen conch.

- *Management Objective:* Ascertain the role of queen conch in predicting changes in the coral reef community and determine the role of the larger ecosystem in their recovery. Queen conchs are not reproducing in nearshore habitats in contrast to successful spawning aggregations in offshore areas. Reproduction can be switched on or off by reciprocal transplants, indicating that environmental factors are involved (Robert Glazer, personal communication). This effect on queen conch reproduction may be evident in other species, although no signs, reproductive or otherwise, have yet been documented.

SPINY LOBSTER

Spiny lobster (*Panulirus argus*) support an important commercial and recreational fishery in the Florida Keys. The fishery is considered overexploited and overcapitalized (Chiappone and Sluka, 1996), and the Florida Fish and Wildlife Conservation Commission has approved reductions in the total number of trap licenses in recent years. Management of the fishery is complicated by the long duration of the larval stages and the associated uncertainty about stock origins. The life cycle and habits of spiny lobster are relatively well known; less attention has been given to lobster feeding habits and associated ecological effects on benthic communities.

Management Objectives and Associated Monitoring and Research Needs

- *Management Objective:* Continue to assist current fisheries managers where appropriate.
  - ***Monitoring Need (High Priority):*** **Continue current spiny lobster status and trends monitoring, including zone monitoring.**
  - *Research Need:* Investigate the impact of lobster fishing gear on the FKNMS environment. Research is needed on the degree to which lobster fishing gear impacts various FKNMS habitats and possible gear modifications to ameliorate any negative effects.

- *Management Objective:* Understand the role of spiny lobster in the ecosystem and determine their ecological significance. There is a need for further understanding of spiny lobster feeding habits and rates of consumption as a function of size/age, as well as the use and modification of dens as a function of density.
  - *Research Need:* Assess and evaluate current knowledge concerning the ecological significance of lobster populations in the FKNMS. Further research is needed on the trophic ecology of spiny lobster, habitat modifications, and other aspects of the role of spiny lobster in the FKNMS ecosystem.

OTHER BENTHIC INVERTEBRATES

Few ecological studies have been conducted on the majority of invertebrate phyla in the Florida Keys (Levy et al., 1996). The region contains a high diversity of invertebrates, with over 1,600 species in the six major marine invertebrate phyla (sponges, cnidarians, annelids, mollusks, echinoderms, and arthropods; Levy et al., 1996).

Management Objectives and Associated Monitoring and Research Needs

- *Management Objective:* Determine the functional significance of benthic invertebrates, including bioeroders, in the FKNMS ecosystem. While much study has been devoted to the ecological role of lobster and conch in the FKNMS ecosystem, other benthic invertebrates, many of which are smaller and more cryptic, have received less attention. Benthic invertebrates may play a large role in the overall health of the Florida Keys coral reef ecosystem as a food source for higher trophic levels. Many benthic invertebrates of the reef environment are detritivores, consuming and breaking down the waste products of other reef-dwelling species and thus forming an important link in the nutrient cycle of the reef. Bioerosion has also been demonstrated to be an important role of many reef-dwelling invertebrates. Bioerosion may have a significant impact on the ability of a reef to retain structural integrity during times of extreme physical perturbation.
  - *Research Need:* Investigate the functional significance of abundant macro-invertebrates such as sea biscuits *(Clypeaster rosaceus)*, cushion stars *(Oreaster reticulatus)*, sea cucumbers, and sand dollars. There exist in the FKNMS an abundance of macroinvertebrates other than conch and lobster that have received little attention in the

Research and Monitoring Program to date. These species include herbivores, carnivores, and detritivores that doubtless have an important role in natural nutrient recycling. Without first understanding their role in the ecosystem, it is not possible to determine the effects of environmental change on or proper levels of protection for these various species of macroinvertebrates.

- ***Research Need (High Priority):*** **Investigate the lack of recruitment of *Diadema* to adult populations.** The *Diadema* die-off of 1983 had a deleterious effect on the reef environment of the Florida Keys. Prior to the die-off, *Diadema* served as an important herbivore in the reef ecosystem, helping to maintain the balance between coral and algal populations. Following the loss of this abundant herbivore, coral species were unable to successfully recruit to bare areas created by extreme events including hurricanes and disease outbreaks before algal populations had taken over the site. This has led to a steady process toward algal domination on the reefs of the Florida Keys.

  Since the 1983 die-off, *Diadema* populations have been slow to recover, due in a large part to a lack of recruitment to adult populations. Acroporid corals have also shown limited recruitment success in recent years. The loss of these typically fast-growing and formerly abundant group of coral species has exacerbated problems caused by the *Diadema* die-off. In order to best protect the reefs of the Florida Keys and to facilitate their recovery, it is necessary that we understand factors contributing to the low recruitment rates of these important reef species.

- *Management Objective:* Assess the importance of benthic invertebrates for purposes of bioassessment. Due in part to their small size and brief life spans, many reef invertebrates may react to environmental change more quickly than other reef-dwellers. Thus, certain species may serve as important bioindicators of overall ecosystem change and may serve as sentinel species, alerting researchers and managers to impending threats to overall reef health.
  - ***Research Need (High Priority):*** **Identify appropriate bioindicators of overall reef health and environmental change with an emphasis on echinoderms, smaller benthic invertebrates, such as amphipods and isopods, and other benthic species that respond quickly to environmental change using an approach similar to that taken in the analysis of freshwater lakes and streams (Index of Biological Integrity).** Bioindicators can be important tools to both researchers and resource managers as signals of impending changes in the overall environment. Due in part their small size and brief life spans, many benthic invertebrates of the reef environment respond quickly to changes in their environment and may serve as important bioindicators of overall reef health. If these species are to be useful to resource managers, they first must be identified.

ADDITIONAL OVERARCHING MANAGEMENT OBJECTIVES AND RESEARCH NEEDS

In addition to the management objectives for important Sanctuary habitats and species outlined above, the following overarching objectives and their associated research needs are required.

Management Objectives and Associated Monitoring and Research Needs

- *Management Objective:* Complete the benthic habitat inventory for the Florida Keys National Marine Sanctuary. In 1998, an extensive benthic habitat atlas for the Florida Keys was produced as a result of a six-year, federal-state effort to map the type and extent of bottom communities in the Sanctuary. This project has supported numerous research, monitoring, and management actions. However, information on benthic assemblages in the western portion of the Sanctuary is not contained in the atlas at this time. It is necessary for data on these habitats to be added and a revised, Sanctuary-wide benthic map produced.
  - ***Research Need (High Priority):*** **Use available technologies to fill gaps in the current benthic habitat inventory for the Sanctuary.** Emphasis should be given to the coral reef, seagrass, and soft-bottom communities between Key West and the Tortugas.

- *Management Objective:* Identify performance indicators and thresholds with regard to resource management.
  - *Research Need:* Conduct studies necessary for the identification of valid performance indicators and thresholds with regard to resource management.

- *Management Objective:* Ascertain current use patterns, including diving, boating, and fishing in the FKNMS.
  - *Research Need:* Conduct additional user surveys in the FKNMS to ascertain current use patterns, including diving, boating and fishing in the FKNMS.

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