NURC/UNCW Highlighted Science Results

Note: This document is an excerpt from the center's certification self-study report

NOAA Strategic Goals

One NOAA strategic plan existed during this certification period, "NOAA Strategic Plan: A Vision for 2005[14]." NOAA's mission is "to describe and predict changes in the Earth's environment, and conserve and manage wisely the Nation's coastal and marine resources to ensure sustainable economic opportunities." Objectives and actions are divided into two "missions" and seven "inter-related goals":

Environmental Assessment and Prediction Mission:

- Advance Short-Term Warning and Forecast Services
- Implement Seasonal to Interannual Climate Forecasts
- Predict and Assess Decadal to Centennial Change [DCC]
- Promote Safe Navigation

Environmental Stewardship Mission:

- Build Sustainable Fisheries [BSH]
- Recover Protected Species [RPS]
- Sustain Healthy Coasts. [SHC]

NURP research projects fall under the goals with bracketed acronyms above. Every research project in the NURP MIS is assigned to one of these goals.

South Atlantic Bight and Gulf of Mexico (SAB/GOM) Projects

Regional Research Priorities:

Based largely on recommendations from the center's 1995 certification panel, the NURC 1996 Annual Report included a strategic plan for 1997-2001 with regional research priorities. These priority objectives were chosen based on external input from various sources, for example, regional NOAA programs and offices, ad hoc planning meetings (e.g., Gulf RMRP, 1995; SACRMRP, 1994; COBIA, 1991), and NURP science guidance documents[15] produced each year by the NURP headquarters. NOAA's new strategic plan now under review includes a new "matrix management" element entitled "Ocean Exploration" [OE]. This element supports discovery-based science, for example, exploration and understanding of new ecological systems, bioprospecting for new products from the sea, and description and preservation of marine cultural heritage. Since 1995, center proposal solicitations have included some subset of these priorities, and they continue to be NOAA priorities in 2003:

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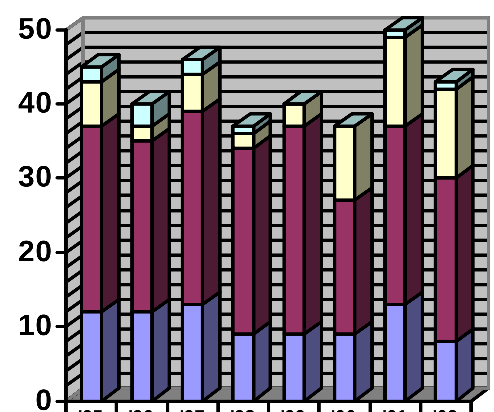
[14] http://www.osp.noaa.gov/docs/NOAA_current_Strategic_Plan.pdf

[15] http://www.nurp.noaa.gov/Attachments/2003_20SCIGUID.pdf

- Conserve coastal ecosystems through understanding of the cross- and along-shelf flux of materials, e.g., beach sands and dredge materials, and the impacts of these materials on coastal ecosystems such as “live bottom” reefs [SHC, BSF]
- Conserve coastal resources through understanding of the extent and impacts of point and non-point sources of pollution (contaminants and nutrients) on coastal resources, for example, hypoxia associated with the Mississippi River plume [BSF, SHC]
- Promote the wise use of pelagic fisheries through understanding of distribution and migration patterns of adults, and the distribution, recruitment processes, and mortality of post-larval stages and definition of essential fish habitat for pelagic species, e.g., Gulf Stream fronts and eddies, and *Sargassum* mats [BSF, RPS]
- Promote the wise use of reef fish populations that are declining due to environmental degradation and overfishing through habitat characterization, ecological research, and conservation science [BSF, SHC]
- Improve the efficiency of fishing techniques, provide faster, more accurate stock and habitat assessments, and reduce the negative effects of fishing activity on the environment through studies that document impacts and evaluate alternative methods [BSF, SHC, RPS]
- Build improved models of the ocean carbon cycle and global climate, and promote understanding of ocean biodiversity through studies of the ecology, geology, and geochemistry of cold seeps and hydrate deposits at the seafloor [OE, DCC, SHC]
- Provide better predictions of future climate and environmental changes through paleoceanographic studies of submerged continental margin settings, with emphasis on eustatic sea level history and regional/global climate variability since the late Pleistocene. [DCC]

SAB/GOM Research Accomplishments:

From 1995-2002, the center supported a total of 334 projects, an average of just over 40 per year; over half were conducted in the Florida Keys, 25 percent in the SAB region and 16 percent in the GOM region (Figure 5.3). SAB/GOM research projects from 1995-2002 addressed all of the priority objectives; Doc. #014 on the report CD is a table of all projects supported and the related NOAA research category.



	'95	'96	'97	'98	'99	'00	'01	'02
Other	2	3	2	1	0	0	1	1
GOM	6	2	5	2	3	10	12	12
FLK	25	23	26	25	28	18	24	22
SAB	12	12	13	9	9	9	13	8

Year

Figure 5.3. Center projects by year and region.

This discussion of accomplishments will focus on two major regional initiatives: *Carbonate Reef Ecosystems* and *Hydrocarbon Seeps*. These were chosen for several reasons, including:

- Uniqueness of the issues to the southeast U.S. region
- Global national, and regional relevance to NOAA's mission
- Unique leadership role of NURC based on capabilities of the center and regional science community.

Carbonate Reef Ecosystems:

The entire southeast coastal region from North Carolina to Texas is in the coastal plains geological province of the United States. Gently sloping plains generally grade seaward into a wide continental shelf largely composed of carbonate substrate with varying sediment veneer. In some areas, limestone provides a base for reef or bioherm formation (e.g., Flower Garden Banks, Florida Keys and Oculina Banks). Bands of exposed rock and reef formation often mark past stands of sea level. "Live bottom," rock covered with dense growth of sessile invertebrates and algae, often forms on exposed rock areas and changes in response to movement of the sediment veneer (Figure 5.4). Tropical and sub-tropical cyclones originate offshore and commonly transit through the region, creating intense periods of physical disturbance that, along with the underlying geology and physiography, control distribution of reef communities.

Figure 5.4. Gag grouper at base of temperate "live bottom" reef off North Carolina—community structure changes over months to years scales based on many factors, such as storms and temperature regime (NURC/UNCW).

Although reef habitats are less than 20 percent of the shelf, they support over 70 percent of the region's offshore fisheries. Important reef and pelagic fisheries are declining and overfished. Seasonal closures, quotas, and gear restrictions alone have not effectively reversed these trends. Just since 1995, both the South Atlantic and Gulf of Mexico Fisheries Management Councils have established new offshore Marine Protected Areas closed to most fishing in order to restore both stocks and essential fish habitat. Many more are now being considered on the mid-to outer shelf, in water depths below 50 meters (Figure 5.5). However, especially for the offshore reefs, there is not enough data in most areas to determine how they may work, where to locate them, how large they should be, what they should contain, or how long they need to work. Undersea science and technologies are necessary for addressing these questions, especially in physically complex environments.

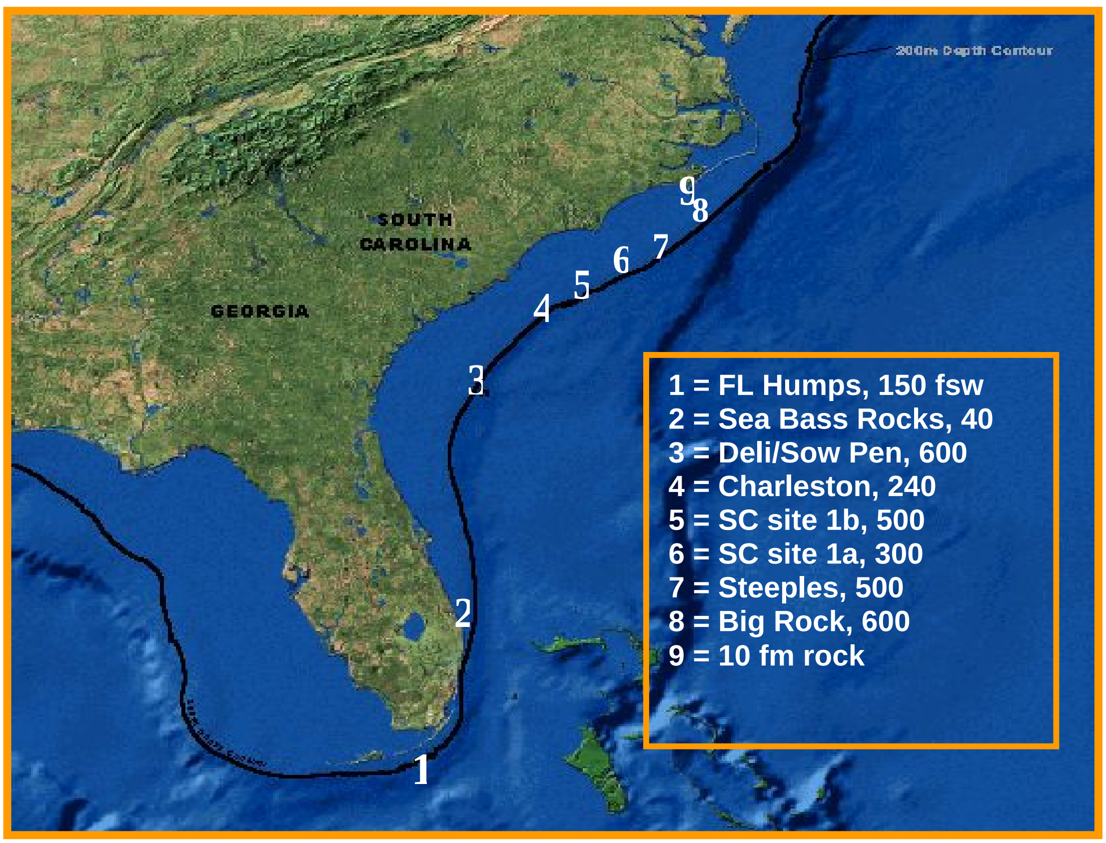


Figure 5.5. Locations of nominated MPAs in the S. Atlantic Bight now being considered by the SAFMC - most are near the shelf edge in more than 50 m of water depth.

In the early 1990s, the center launched a major initiative to understand the ecology of temperate and sub-tropical "live bottom" reefs. S. Riggs and colleagues showed that not all exposed rock is suitable substrate for "live bottom" formation—some hardbottom (e.g., Miocene mudstones) evident on acoustic surveys may be too friable, while others may not be high enough above the surrounding bottom and shifting sand veneer (Figure 5.6) (Riggs et al. 1998). They described how sand and reef interact, seasonal to interannual stability of reef communities, and how long it takes to re-establish a productive "live bottom" community following significant disturbance events (Renaud et al. 1999). They demonstrated that the soft substrate around reefs is an important component of the reef ecosystem, providing food for many reef species in what is known as the "halo effect" (Dahlgren et al. 1999). M. Hay's research teams looked closer at the fine-scale processes that control "live bottom" community structure on the same reefs, for example predation and competition (Miller and Hay, 1998). All this information is necessary to help answer the questions regarding which reefs are in fact EFH, and are relevant to considerations of MPA placement and monitoring.

NURC projects have been the first to document both the effectiveness and shortcomings of new MPAs off the southeast. Although the southeast is somewhat fortunate compared to other areas of the world in that heavy trawling and dredging gear are rare, there are exceptions. Most notably, the Oculina Habitat Area of Particular Concern (OHAPC) off northern Florida, which has been severely impacted by scallop dragging and shrimp trawling—an estimated 90 percent of the ivory tree coral banks have been destroyed. And, although closed since 1994, illegal trawling continues. With minimal support given the size of the reserve and difficult study conditions at 100 meters under the Gulf Stream, NOAA, NURC and academic partners have struggled to expose the plight of the Banks to the public and restore damaged reefs. Beginning in 1995, C. Grimes and partners began revisiting dive sites in the reserve first explored in the 1970s. Their initial results showed that vast areas of former healthy (live coral cover) bioherm were now vast beds of coral rubble (Koenig et al. 2000). A 2001 submersible expedition, Islands in the Stream, doubled the amount of previous data and conclusively confirmed the widespread devastation and continued illegal trawling. C. Koenig subsequently presented results to the SAFMC, who in turn proposed to: 1) continue the closure beyond 2004, 2) install Vessel Monitoring Systems on local trawlers, and 3) expand the mapping and research effort in and outside the OHAPC.

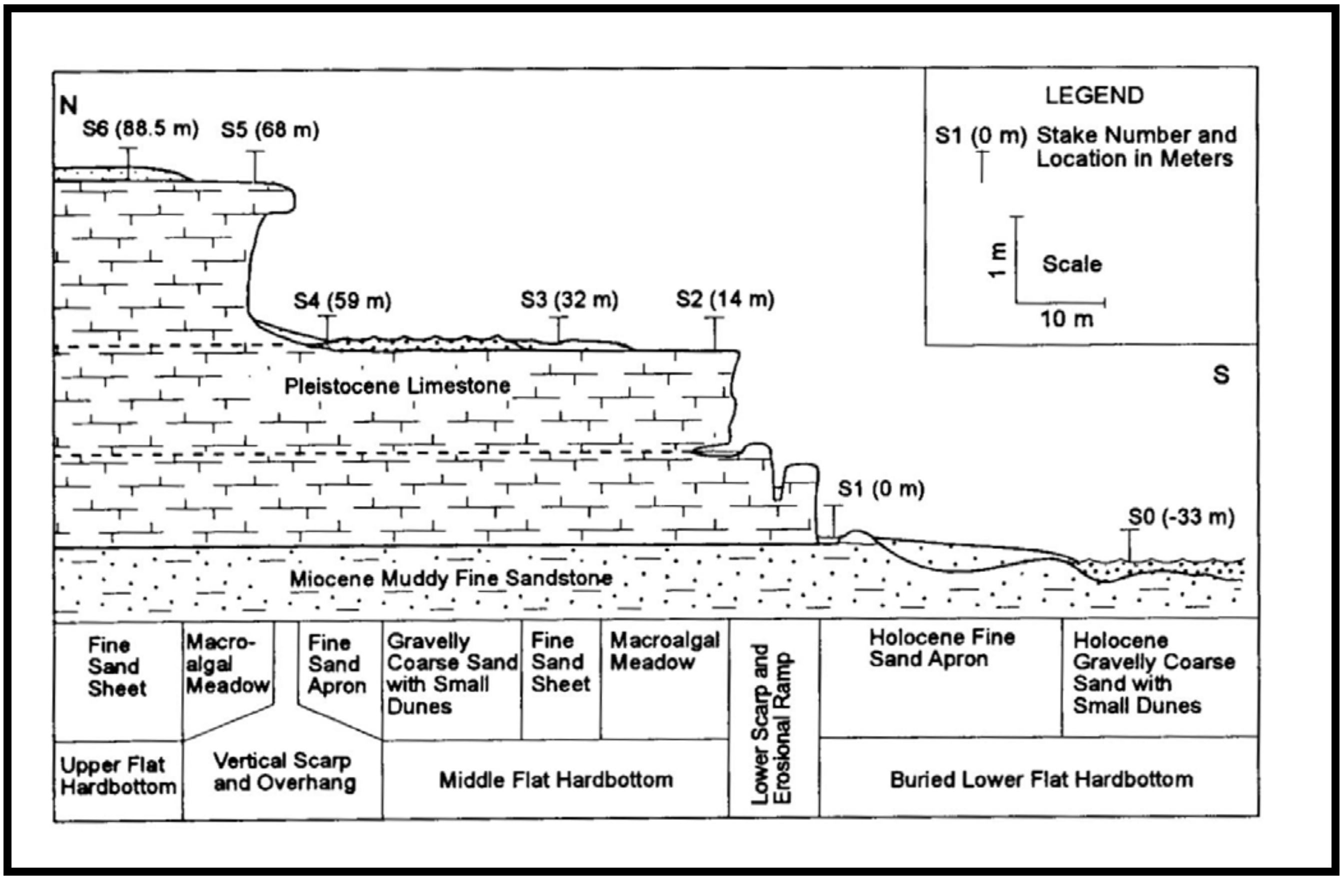


Figure 5.6. Cross-section of temperate "live bottom" reef off North Carolina; Pleistocene hardpan supports dense growth, whereas underlying Miocene mudstone, which also outcrops in places, does not (from Riggs et al. 1998).

Habitat characterizations, as required by the Magnuson-Stevens Sustainable Fisheries Act amendments of 1996 for defining and managing EFH, are woefully lacking in most areas of the mid- to outer continental shelf. Acoustic technologies are now commonly used for habitat mapping. Similarly, acoustic systems have been tested as replacements for traditional trawl assessments used for most fish stocks. Center projects provided ground-truthing for these surveys, revealed potential uses and limitations, and tested new approaches. The center is partnering with several programs to develop habitat maps and monitor changes, especially in offshore areas that require NURC technologies and expertise. For example, M. Fonseca and colleagues from the NOAA/NCCOS Beaufort Lab have used center ROVs to survey off the Dry Tortugas and on the West Florida Shelf. Their preliminary data from the Tortugas Ecological Reserve (TER) suggest that "benthic habitats surrounding the coral reefs of the TER are the source of a significant amount of primary production ultimately fueling fish production throughout the TER and thus, downstream throughout the range of larval fish dispersal. Therefore, the status and influence of the previously neglected, non-reef habitat (comprising over 70 percent of the TER) appears to be intimately tied to the health of the coral reef community proper" (Fonseca, 2001, unpub. annual report[16]).

During C. Grimes' 1995 project, the center compared a Fishery Acoustic System (FAS) to submersible observations and showed that the system does not effectively census reef fish (Grimes, unpub. data). A planned demonstration of a laser-line scan system was thwarted during the same project, however, in 2001, the center co-sponsored a west coast field program with an LLSS; results suggested that these systems provide imaging details of the low relief sediments such as sand waves and ripples, rock outcrops, and attached sessile forms. More development is needed to make the systems more affordable and efficient for large-scale surveys (Yoklavich, unpub. data[17]).

With funding from NOAA Fisheries, the center is developing an Oculina GIS (CD on hand at meeting) that will include past submersible dives, ROV dives, acoustic surveys, including a center-led multibeam survey in 2002, and transect data (Halls and Manning, in press). Such syntheses are necessary to communicate results to managers and the public, and are just as important a product and metric of center performance as the scientific literature.

Hydrocarbon Seeps:

The Gulf of Mexico produces more offshore oil and gas than any other region of the nation. However, not all the oil and gas beneath the gulf stays locked under the Louanne Salt Sheet until drawn out by wells; at least a super tanker full of crude oil enters the Gulf of Mexico via natural seepage each year (MacDonald et al., 1993). Gas and oil in various forms seep and vent into the water column, thus, affecting the ocean carbon cycle, ocean ecosystem, and atmospheric levels of carbon dioxide and methane, the major greenhouse gases. In 1986, dredge samples collected during a Minerals Management Service (MMS) survey brought up chemosynthetic tubeworms and bivalves similar to the animals discovered at hydrothermal vents a decade earlier. The next year, NURC initiated a research submersible program that carried pioneers to deep-sea Hydrocarbon Seeps and Vents (HSV) of the gulf. This initiative continues today and has changed fundamental views of invertebrate biology, deep-sea productivity, and the ocean carbon cycle. One form of seafloor carbon reserve, gas hydrates, may one day be the nation's number one fuel source, or the cause of dramatic climate change. While much of the center-sponsored pioneering work was conducted in 1995 and earlier, the center continues to support HSV research, largely through partnerships with other programs now actively supporting HSV research, such as OE, NSF, MMS, and the Department of Energy (DOE).

Shepard (2001) summarized findings from NURC HSV studies in the Gulf (Doc. #015 on CD). HSV communities, like hydrothermal vent (HTV) communities are oases of life and support unusually high concentrations of biomass with generally lower diversity than the

[16] http://shrimp.bea.nmfs.gov/~mfonseca/reports.html
[17] http://oceanexplorer.noaa.gov/projects/laser01/laserlinescan.html

background slope fauna (Carney, 1994). Clams (Vesicomyid and Lucinid) and Pogonophoran tubeworms with symbiotic bacteria that utilize sulfide from below and oxygen from the water column above are common in soft substrate. Epifaunal species including the Bathymodiolid mussels and Vestimentiferan tubeworms occupy hard substrata (Figure 5.7). The tubeworms grow roots that provide a firm anchor and collect sulfide from deep in the sediments (Julian et al., 1999). The worms are the oldest known colonial, marine animals, living more than 250 years (Berquist et al. 2000).

Figure 5.7. Slope species like spider crabs are attracted to seep oases-- chemosynthetic seep communities dominated by cold seep mussels and tubeworms that provide physically complex habitat and food (J. Brooks).

An intriguing question regarding life with sulfide is how chemosynthetic fauna use both oxygen and sulfide, since sulfide spontaneously oxidizes in the presence of oxygen (Childress, 1995). NURC studies revealed a significant difference between HTV and HSV communities. HTV tubeworms get their sulfide from the venting fluids through their plumes extended from the anterior end of their tubes (Arp et al. 1985). Nix et al. (1995) used an *in situ* water sampling probe used to collect discrete samples from precise locations in and around HSV tubeworm bushes and found that there is minimal evidence of sulfide anywhere near the anterior end and plume of the worms. They used a similar sampler adapted for interstitial sediment collections and noted very high sulfide concentrations. Julian et al. (1999) describe how the worms physiologically deliver sulfide via "roots" and oxygen via their plumes to their endosymbionts.

Gas hydrates exposed at the seafloor are common at seep sites below 500 meters (MacDonald et al. 1994). They are of particular interest in the Gulf for several reasons including: 1) their stability range, which now overlaps with new slope oil and gas prospects, 2) their impact as a geohazard on oil and gas development activities, 3) their role as a source of hydrocarbons for HSV communities and the surrounding slope, and 4) their proximity to the seafloor in the Gulf, as opposed to many other areas where they are deeply buried beneath sediments. Their extent and exposure in the Gulf has provided a natural laboratory setting for the collection and observation of hydrates using submersibles (MacDonald et al. 1994; Sassen et al. 2001). MacDonald et al. (2000) report on monitoring of an exposed gas hydrate lobe at Bush Hill in the Green Canyon area of the northern Gulf. They deployed a "bubbleometer" device over an observed gas leak in the bed, in conjunction with a thermistor probe to measure interstitial temperature profiles above and in the substrate. Their results showed that a 1^{o} C temperature change may shut the leak on and off. Samples collected by the HOV in insulated containers survived the ride from the seafloor to the cold room and have allowed precise characterizations of hydrate chemistry (Sassen and MacDonald, 1997). This research suggests that while outcrops are transiently unstable, most hydrate in the gulf is currently stable, increasing in volume, and likely sequestering greenhouse gases.

In 1997, an HSV episode occurred that was beyond imagination and turned out to be one of the great discoveries of the decade. Scientists working at Bush Hill revisited a known exposed hydrate lobe to monitor its condition and collect hydrate samples. Along the way, they discovered a new species of worm, living and thriving directly on the hydrate. The scientists coined the new species "ice worms," later known by the binomial, *Hesiocaeca methanicola* (Desbruyeres and Toulmond, 1998) (Figure 5.8). The density of ice worms approached 2500 m^{-2}, all burrowed into a hydrate lobe. Collections of the worms and hydrate suggest that the worms may be grazing on bacteria that feed on hydrocarbons in the ice (Fisher et al. 2000), an exciting proposition in light of recent evidence of other ice-covered worlds in the Solar System. During a 2002 submersible expedition where we partnered with OE (they covered ship and submersible costs and the center covered subcontract funding to the PIs), P. Sobecky and J. Montoya probed the same hydrate mounds to further understand the hydrate bed biotope[18]. The primary goal of their on-going research funded largely by NSF is to define the microbial communities and processes in brine and gas hydrate environments and to understand how the microbiota affect, and are affected by, the geochemistry of the system. Preliminary results indicate that bacteria and archaea, sometimes in close associations, inhabit the hydrates and may provide food for other bed inhabitants besides the ice worms, such as shrimp (Sobecky, unpub. data; see dispatches from the expedition[19]).

Figure 5.8. Ice worm, Hesiocaeca methanicola, borrowed in exposed gas hydrate discovered by C. Fisher in a Gulf of Mexico at 800 m depth (picture by I. MacDonald).

5.1.3.3 Florida Keys Projects

All of the problems that threaten the environmental integrity of coastal ecosystems nationwide are concentrated in the Florida Keys (Precht and Miller 2003, Turgeon et al. 2002, NOAA 1996). Further, global threats related to atmospheric and ocean warming, and regional threats related to pollution and harvesting, have created a complicated set of interacting factors that make management of coastal resources in the Florida Keys especially challenging. In response to these and other factors (especially major vessel groundings) the Florida Keys National Marine Sanctuary (FKNMS) was established in 1990 to protect and conserve the nationally and economically ($1.2 billion is spent

[18] http://hydrate.eas.gatech.edu/gthydrates/lexen.html
[19] http://www.at-sea.org/missions/extremes/preview.html

annually in the Keys) significant resources of the region, including critical coral reef habitats (Causey et al. 2000).

When the sanctuary was designated, Congress also directed the U.S. Environmental Protection Agency and the State of Florida to work with the sanctuary to prepare and implement a water quality protection program. Thus, all of the parties with potential jurisdictional responsibilities worked together from the start both on the sanctuary management plan and the water quality protection plan. It was against this backdrop, starting in 1990 when NOAA transferred Aquarius and approximately $2 million to UNCW, that center operations expanded in Florida. The ultimate decision to operate Aquarius in the Florida Keys, however, was based on an extensive programmatic review (Simmons 1991) that identified significant research opportunities that were needed to support management of coastal resources in the sanctuary.

Recently, the sanctuary program developed a Comprehensive Research Plan (CRP) and a conceptual model to help summarize the current state of knowledge regarding the Florida Keys ecosystem, and to help prioritize research needed to monitor the structure and function of the system (Keller 2002). The model identifies forcing functions, and highlights the importance of regional circulation patterns, global warming, and fishing. Stresses that are linked to forcing functions, such as temperature, water quality, and harvesting, are then linked to the biotic components of the system. The report acknowledges that to meet the goal of effective management a thorough understanding – at multiple spatial scales – of interactions among forcing functions, stressors, and biotic components is needed. The following discussion, therefore, identifies a subset of center research results in the Florida Keys that match up with priority research needs identified in the CRP. Only a small subset of all publications that appeared since our last review in 1995 are referenced. Examples are provided of significant result and to highlight important themes. Some material is referenced that is in preparation, to highlight the results of significant work not yet published or a result of long-term monitoring.

Physical Oceanography

Water movement through the Keys is dominated offshore by the Florida Current, but complex interactions with Florida Bay and Gulf of Mexico waters are common, especially close to shore where depths are shallow, tidal and wind influences are strong, and flats and channels are common. High priority research needs relate to developing circulation models to understand how regional and local patterns influence water quality, nutrient dynamics, and larval transport. The latter objective is considered critical to help determine the size and location of MPAs in the region.

<u>Accomplishments</u>

Two projects have contributed substantially to our understanding of nearshore and offshore oceanographic processes in the Keys. Oceanography is not a typical undersea research theme, but the center helped deploy equipment over a period of many years, using diving, to support studies of nearshore currents (Smith and Pitts 2002, Pitts 2001, Smith 1998). Results reveal an unusually dynamic system affected largely by wind and tides that couples the gulf and Atlantic sides of the Keys. The gulf and Florida Bay linkages have taken on more significance related to water quality issues in Florida Bay and potential effects due to Everglades restoration. The second project is related to a long-term effort of the center's to maintain oceanographic sampling equipment at Conch Reef, the Aquarius site. Over 12 years of data are available including temperature, salinity, current speed and direction, and tides. One publication is in manuscript form that documents long-term averages and a net nearshore to offshore flow pattern along the bottom (Lee et al. in prep.). Results from this sampling program also led to development of a major research effort, supported over many years by the center, that is contributing important new information about upwelling and nutrient dynamics in the Florida Keys, with significant implications for reef systems worldwide (Leichter et al. 1996, Leichter and Miller 1999). Results related to nutrient dynamics from Leichter's work are presented in the next section under Water Quality.

Water Quality

Concern about declining water quality is the number one environmental issue in the Florida Keys. The biggest concern related to water quality is that sewage disposal practices are affecting the offshore coral reefs. Concern is based on the potential effects caused by 25,000 septic systems, 7,000 cesspits, and 900 shallow-injection wells, all of which are constructed in carbonate rock and sediment with high porosity and flow rates. Water quality dominates environmental issues in the Keys, but related to the condition of offshore reefs is just one factor among many that affects the way the reefs function and look (Hughes et al. 1999, Precht and Miller 2003).

High priority research needs include identification of sources and quantification of nutrient and pollutant loadings, particularly along the reef tract and also related to episodic events such as after major storms, upwelling, and from wastewater injected into shallow injection wells. Results are needed for developing a first-order nutrient loading model. While there are human health concerns related to water pollution (from poorly functioning disposal systems), there is also a large gap in assessing how far offshore nutrient enrichment effects can be detected as changes to community structure; development of bio-indicators is viewed as a major research objective.

<u>Accomplishments</u>

One of the first regional projects to investigate nutrient pollution in the Keys documented gradients in water and sediment chemistry, with nitrogen higher close to shore and a phosphorus signal offshore (Szmant and Forrester, 1996). This was an important paper because it suggested that nutrient pollution was not reaching the offshore reefs, and based on simple modeling determined that nitrogen and phosphorus delivered to the offshore reefs from natural sources (currents and upwelling) exceeded by many orders of magnitude what could be delivered from sewage contamination. These results remain controversial in the Keys, but are supported by the long-term FIO monitoring program (Boyer and Jones 2002) that the center supports with logistical help and equipment (autoanalyzer owned by the center that broadly supports funded projects), and work that quantified the frequency of upwelling events, and concentrations of nutrients and plankton in the upwelled water (Leichter et al. 1998, 2003). The latter citation by Leichter (2003) is especially relevant because it models offshore nutrient dynamics and quantifies upwelling as a source of nutrients to the offshore reefs that is orders of magnitude more significant than potential input from sewage and stormwater.

Taking another approach to assess nitrogen and phosphorus inputs at the ecosystem level, the elemental composition of seagrasses were quantified throughout the sanctuary over an eight year period (Fourqurean and Zieman 2002); results suggest gradients in nutrient input where nearshore nitrogen loading could influence offshore, N-limited seagrass beds, but not nearshore, P-limited grassbeds. The Environmental Protection Agency used preliminary results from this study to help design their Keyswide monitoring program that is part of the sanctuary's water quality protection program. Finally, an experimental program that developed a new and innovative way of manipulating nutrients and distinguishing the affects of herbivores on the reef also documented that offshore concentrations of nitrogen and phosphorus had little affect on the composition of algal communities (M. Miller et al. 1999), further supporting the idea that the condition of offshore reefs in the Keys are affected by multiple factors – not just water quality.

Coral Reef Communities

Coral decline in the Keys is unambiguous. Not surprisingly, a high priority research need is to determine the direct and indirect causes of coral decline, especially related to disease, bleaching, and algal overgrowth, and the relative impact of these stressors.

Accomplishments

Coral Reef Ecology

While corals are a focus of many researchers in the Keys, the center has directed research to other elements of community structure too. For example, the importance of parrotfish predation on sponges was discovered in a series of experiments (Pawlik and Dunlap 1996, Pawlik 1997, Dunlap and Pawlik 1998) that documented the selectivity of sponge-eating fishes – where many palatable species are found only under cryptic conditions on the reef. When combined with new data on chemical defense, these results have completely altered our view of sponge ecology on Florida and Caribbean reefs (Pawlik 1998). These results have interesting management implications because "indirect effects" or linkages between sponge-eating fish and the benthos, due to the loss of certain predators or herbivores, may alter the ecology of reef sponges to permit the growth of otherwise cryptic species, some of which may more effectively compete for space with corals. At least a dozen other publications (for example: Assmann et al. 2000, Lindall et al. 2000) resulted from work on sponges to understand the chemical defenses of reef invertebrates against predatory fishes and novel assay systems were used to identify and isolate the responsible metabolites – some of which are being tested for their pharmacological potential.

Two other research groups (Hay and Lindquist) are also conducting work related to chemical ecology, addressing how organisms use secondary metabolites (a) to ward off consumers (Lindquist and Hay 1966, Cetrulo and Hay 2000, Hay 2001, Bullard and Hay 2002), thus affecting who eats who, food web structure, and energy flow on reefs, or (b) to gain defensive or aggressive traits by stealing these chemical abilities from other organisms or by building mutualistic relationships with other organisms (Cronin et al. 1995, Stachowicz and Hay 1996). It is becoming apparent that chemical signaling underlies many of the basic processes affecting reef structure and that chemically mediated interactions determine much of the biodiversity and ecosystems processes affecting marine communities (Hay and Fenical 1996).

Coral Disease

Unfortunately, the most damaging disease to kill corals in Florida and throughout the Caribbean, whiteband disease that affects the branching corals in the genus Acropora, devastated populations long before any research or monitoring programs were in place to document the epidemic in Florida. Since then, additional diseases have emerged and the center supported projects that produced major findings. L. Richardson has emerged as a leading investigator of coral disease, with seminal work related to blackband disease over the last ten years (Richardson 1996, Richardson and Kuta 2003, Richardson 1998, Kuta and Richardson 1996). She was also lead author on a Nature paper that identified the first coral pathogen using Koch’s postulates (Richardson et al. 1998). D. Harvell and K. Kim have also emerged as leading figures in marine disease work related to a fungal pathogen that kills seafans. Results include learning that the fungal growth rate is temperature dependent, with temperatures usually below its growth rate optimum; this means, however, that almost any temperature increase should result in conditions where the pathogen does better (Alker et al. in press). The pathogen is thus a “poster child” for an argument they made in a Science paper about climate links (warming) and diseases (Harvell et al. 1999). Similarly, the correspondence between a killing disease outbreak in a gorgonian and widespread coral bleaching reinforces this point (Harvell et al. 2001). They also have published important results that demonstrates a promising link between disease outbreaks and host resistance (Dube et al. 2002, Kim et al. 2000) and how transmission rates vary across different spatial scales (Jolles et al. 2002).

Coral Bleaching

Coral bleaching is an issue that has local, regional, and global significance, but corals are not the only organisms to bleach on the reef. A long-term program to assess the relevance of bleaching in foraminifera was pioneered in the early 1990s (Hallock et al. 1992) through center-support in Florida and has continued throughout the decade. Forams contain a symbiont (diatoms vs. zooxanthellae found in corals) and are sensitive indicators of environmental change, including light, nutrients, and temperature. Three Ph.D. dissertations were recently completed in Hallock-Muller’s lab that addressed bleaching (Talge 2002), shell-damage as a result of stress (Toler 2002), and the influence of solar radiation (Williams 2002). These studies point to foraminifera as bioindicators for environmental assessment and monitoring programs (Hallock et al. 2003), and possibly as indicators of global change (Hallock 2000).

Specific to coral bleaching, results from one of several groups are highlighted here. In a series of long-term physiological studies, direct evidence was discovered that during bleaching events a specific protein, variably tolerant to temperature in difference strains of zooxanthellae, was lost that is needed for normal photosynthetic function (Warner et al. 2000). This may help explain why some corals show greater or lesser signs of bleaching compared to other corals at the same location. A specific piece of equipment was used in this study, known as a PAM fluorometer, for the first time to non-destructively monitor zooxanthellae function (Warner et al. 1996). Since then the PAM fluorometer was further developed and is now used extensively to conduct in situ physiological work, worldwide. The center supported the fieldwork of Warner and Fitt during these early studies. The same research group also discovered substantial natural and seasonal variation in the density of zooxanthellae in corals, with bleaching resulting at one extreme when host tissue and zooxanthellae densities decrease to levels that can be detected by the eye (Fitt et al. 2000). A main point of this paper is that zooxanthellae usually decrease by at least half, on a seasonal basis, and this decrease is not detectable by the human eye.

Reef Fish Communities

Reef fish in the Florida Keys are overfished, the average size of groupers and most snappers is decreasing, and there is no sign that fishing pressure will abate against steadily increasing fishing pressure and population growth in south Florida. While marine zoning was implemented in 1997, rationale to support the zoning was based largely on the need to separate conflicting visitor uses and not as a fishery management tool. Still, a high priority research need is to maintain and optimize existing fish monitoring programs to evaluate the effects of habitat degradation and to develop ecosystem models to help predict the effects of zoning on reef fishes.

Accomplishments

The center worked closely over the last five years, through peer reviewed projects, with researchers from NOAA's National Marine Fisheries Service in Miami and the Rosensteil School of Marine and Atmospheric Sciences. This is perhaps the most successful partnership effort with a NOAA group, after the sanctuary. Research addresses long-term monitoring and assessment studies that have contributed to a 20-year data base (Bohnsack et al. 1994, Ault et al. 1998). The Ault paper was awarded a U.S. Department of Commerce Certificate of Achievement, and J. Bohsnack received an award for Best Paper by a NOAA scientist as a result of the work. The paper was also named Best Publication 1998 in Fishery Bulletin, Volume 96.

The monitoring program has evolved in recent years to include sophisticated stock assessment methods that use optimized sample design statistics to evaluate fish sizes and community structure inside and outside SPAs and other no-take MPAs in the sanctuary. Three expeditions to the Dry Tortugas provided results that helped managers determine where to place boundaries for the Tortugas Ecological Reserve (Schmidt et al. 1999, Ault et al. 2002a, 2002b).

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