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Detection of gaps in the spatial coverage of coral reef monitoring projects in the US Caribbean and Gulf of Mexico

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Abstract: As part of the US Coral Reef Task Force's *National Program to Map, Assess, Inventory, and Monitor US Coral Reef Ecosystems*, a comprehensive survey of projects/programs monitoring coral reef ecosystems and related habitats (i.e., seagrass beds and mangroves) in the US Caribbean and Pacific was undertaken. Information was gathered on a total of 296 monitoring and assessment projects conducted since 1990 in the US Caribbean and the Gulf of Mexico. Substantial gaps in monitoring coverage of US coral reef ecosystems were revealed through geographic information system (GIS) analysis of survey metadata. Although southern Florida contains approximately two-thirds of all marine monitoring projects found in the US Caribbean and Gulf of Mexico, we were unable to identify any ongoing projects that monitor coral reefs along Florida's western coast and off of the Florida Middle Grounds. Additionally, Florida is covered by approximately 1 900 km^2 of mangroves, yet there were only four ongoing projects that monitor this ecosystem, leaving gaps in coverage in the Lower and Middle Keys and along the eastern and western coasts. The Flower Garden Banks National Marine Sanctuary, located offshore of the Texas/Louisiana border, has an integral long-term monitoring program, but lacks a monitoring project that gathers long-term, quantitative data on reef fish abundance and certain water quality parameters. Numerous coral reef monitoring projects in Puerto Rico are concentrated on the island's southwestern coast surrounding La Parguera, while far fewer monitoring projects are conducted along the northern and southeastern coasts and around Vieques Island. In the US Virgin Islands, the paucity of monitoring projects in large areas of St. Croix and St. Thomas contrasts with monitoring activity in three marine protected areas (MPAs), where 66% of the US Virgin Islands' coral reef monitoring sites were found. Only a series of assessments have been conducted at Navassa, a small, uninhabited island located 55 km west of Haiti and 137 km northeast of Jamaica. In order to better understand changes in coral reef communities and to produce a series of biennial reports on the status of US coral reef ecosystems, the National Oceanic and Atmospheric Administration (NOAA) is developing a national coral reef monitoring network. This network has already begun to fill some of these gaps in monitoring coverage through issuing cooperative grants to states and territories to build long-term monitoring capacity.

Key words: Coral reef, monitoring, gap analysis, geographic information system, Caribbean, Gulf of Mexico.

Coral reefs worldwide have been subjected to a variety of anthropogenic and natural threats, which have precipitated the degradation of 11% of all reefs beyond the point of recovery (Wilkinson 2000). An additional 16% of the world's coral reefs were severely impacted by mass coral bleaching associated with the 1997-1998 El Niño/Southern Oscillation (ENSO) event. It is projected that within the next 30 years an additional 32% of the world's reefs are likely to experience significant decline (Wilkinson 2000). In the Carib-

bean, two-thirds of reefs are currently reported to be threatened by human activities, while one -third are classified as being potentially at "high risk" from the expansion of coastal development, inland and marine-based pollution, and overexploitation of reef resources (Bryant *et al.* 1998). Moreover, the increasing frequency of outbreaks of coral diseases (Harvell *et al.* 1999) and mass bleaching events (Hoegh -Guldberg 1999) in the Caribbean and elsewhere may negatively affect the condition of even remote, offshore reefs removed from direct sources of anthropogenic impact.

In the US Caribbean and Gulf of Mexico, which includes reefs located nearshore and offshore of Florida, the Texas/Louisiana border, Puerto Rico, the US Virgin Islands, and Navassa Island, researchers and managers are responding to these heightened threats to reef health through the development of new projects/programs designed to monitor this ecosystem. Monitoring can be used to assess the present condition of a reef; detect temporal changes in its community structure and dynamics; evaluate the importance of multiple physical, chemical, and biological factors for maintaining ecosystem stability or contributing to decline; and determine the effectiveness of management policies that aim to protect and restore reefs. Currently, monitoring projects in the US Caribbean and Gulf of Mexico are disparately conducted by a variety of federal, state, and territorial governmental agencies, academic institutions, non-governmental organizations (NGOs), and environmental consultants. In order to detect gaps in monitoring and to facilitate the development of an integrated national coral reef monitoring network, the National Oceanic and Atmospheric Administration (NOAA) conducted a comprehensive survey inventorying all projects/programs that monitor and assess coral reef ecosystems and related habitats (i.e., seagrass beds and mangroves) in the US Caribbean and Pacific regions.

MATERIALS AND METHODS

As part of the US Coral Reef Task Force's *National Program to Map, Assess, Inventory, and Monitor US Coral Reef Ecosystems*, the US Coral Reef Monitoring Project Survey was designed in July 1999 to collect information on all projects/programs that monitored US coral reef ecosystems between 1990 and 2000. This survey inquired about each monitoring project's methods, parameters sampled, period of record, frequency of sampling, and locations of survey sites. Copies of this survey were sent to principal investigators conducting monitoring projects in Florida, Texas/Louisiana, Puerto Rico, the US Virgin Islands, and Navassa Island (Appendix 1). Participating principal investigators either choose to complete and return the survey directly or to arrange a phone interview during which survey questions could be discussed. Much of the information included here on projects conducted in Florida had been previously gathered through NOAA's 1997 South Florida Ecosystem Survey or as part of the Florida Marine Research Institute (FMRI) metadata collection effort (Florida Geographic Information Board 2002).

In order to facilitate analysis of the information gathered by this survey, an ArcView geographic information system (GIS) was developed. This GIS pinpoints the precise locations of monitoring sites and links them to a database containing information on each project conducted at the site. A second GIS, which presents users with several maps that show the density of projects monitoring specific parameter categories, was created to display information on the nearly 200 projects conducted in South Florida. These two GIS products will be available to the public over the internet via the NOAA Biogeography Program website (http://biogeo.nos.noaa.gov).

Gaps in the spatial coverage of monitoring initiatives were identified through comparing the geographic location of sampling stations displayed in this GIS with maps of the distribution of coral reef, seagrass, and mangrove habitats. Maps used in this analysis were produced by the NOAA Coral Health and Monitoring Program (2002), NOAA National Oceanographic Data Center (2002), and UNEP World Conservation Monitoring Centre (2002) with most of the information on the extent of the coral reefs originally derived from UNEP/IUCN (1988) and recently updated by Spalding *et al.* (2001). For the Florida Keys,

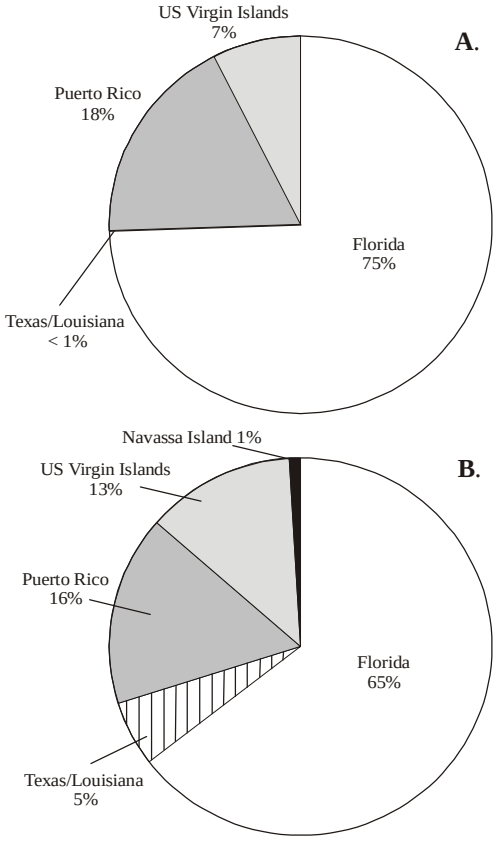

Fig. 1. Pie charts comparing the extent of coral reefs (A) and the distribution of coral reef monitoring projects/programs in the US Caribbean and Gulf of Mexico (B). Data on extent of coral reefs from FMRI/NOAA 1998, Ault *et al.2001,* Florida Fish and Wildlife Conservation Commission 2001, Kendall *et al.* 2001, and S. Gittings pers. comm. No good estimates of the area covered by coral reefs around Navassa Island are currently available (Miller 2002).

US Virgin Islands, and Puerto Rico, these sources were supplemented by digital benthic habitat maps developed by FMRI/NOAA (1998) and Kendall *et al.* (2001).

Each individual reef area depicted on these maps, which did not contain a site monitoring any one of five parameter categories (i.e., corals, reef fish and marine invertebrates, seagrass beds, mangroves, and water quality), was classified as possessing a gap in monitoring for the particular category. In coastal zones characterized by continuous reefs, gaps in coverage were considered to exist in any subarea where there was a reef tract greater than ~10 km in length that did not contain a single monitoring station. Additionally, some reefs were categorized as containing gaps, due to the fact that all projects conducted there were either historical, only assessed sites on a sole occasion, or did not collect data that could be used to evaluate temporal changes in the abundance of reef organisms (i.e., percent benthic cover for corals, seagrass, and algae, density of reef fish and marine invertebrates).

The results of this survey and its accompanying GIS were reviewed for accuracy and completeness by the researchers and marine resource managers that form the US Coral Reef Task Force's Coral Reef Assessment and Monitoring Working Group.

RESULTS

Information was gathered on a total of 296 monitoring projects/programs that have been conducted in the US Caribbean and Gulf of Mexico since 1990. Of these, 180 (61%) projects were ongoing and 116 (39%) projects were historical. Scleractinian corals and gorgonians were monitored directly by 42% of these projects, while remaining monitoring initiatives principally examined other reef organisms, physical, chemical, and oceanographic parameters, associated ecosystems, such as seagrass beds and mangrove forests, and/or watershed land-use patterns. Metadata were collected from 192 monitoring projects conducted in Florida, 48 projects in Puerto Rico, 37 projects in the US Virgin Islands, 16 projects offshore of the Texas/Louisiana border, and three projects on Navassa Island. Respectively, projects from each of these areas represent 65%, 16%, 13%, 5%, and 1% of the total number of US Caribbean and Gulf of Mexico monitoring projects inventoried (Fig. 1). On a regional level, the distribution of coral reef monitoring projects in each area is not consistently proportional to the extent of coral reef habitat within the given area.

Florida: The continental United States' only emergent reefs are found in the Florida Keys between the area south of Miami and the

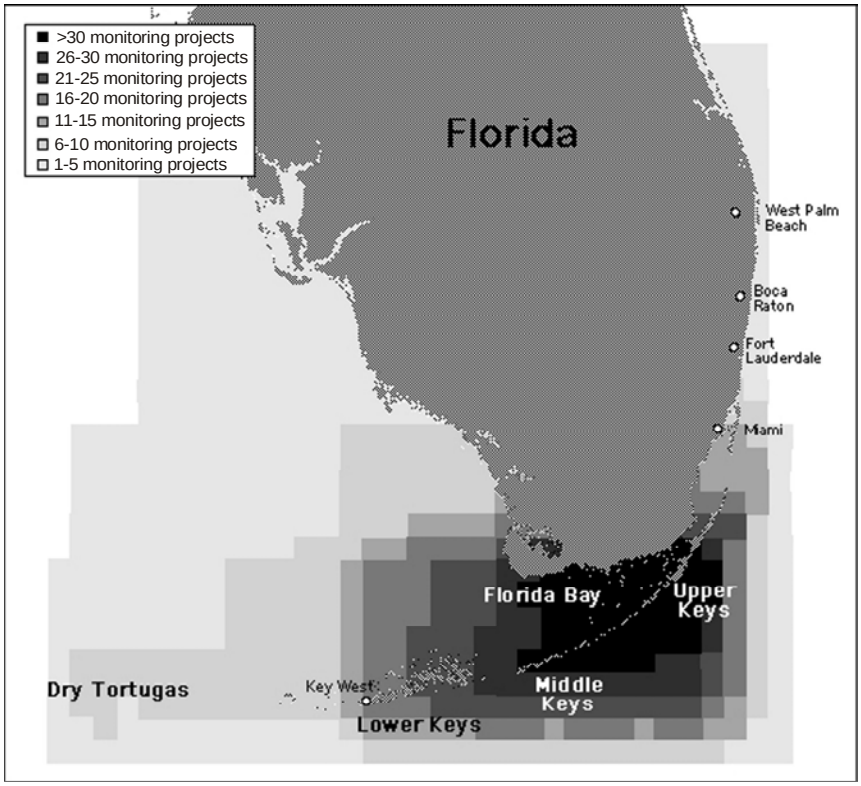

Fig. 2. Map depicting the density of coral reef monitoring and assessment projects in South Florida.

Dry Tortugas. With the exception of this reef tract's northernmost extent, coral reefs in this area are protected by the Florida Keys National Marine Sanctuary (FKNMS). Between Miami and Vero Beach, there exists a series of discontinuous reefs that run parallel to the shoreline. The Oculina Bank Habitat Area of Particular Concern, which protects deep-water reefs, is located slightly further to the north, offshore of Brevard County. Along Florida's western coast, coral reef development is also discontinuous. According to maps produced by the NOAA National Oceanographic Data Center (2002), coral reefs occur at Marco Island, Sanibel Island, Captiva Island, Gasparilla Island, Crystal River, St. John's Pass, Clearwater, Anclote Key, and Hog Island along Florida's western coast. The Florida Middle Grounds, located 137 km south of Appalachicola and 129 km northwest of Tarpon Springs, consist of a series of submerged reef pinnacles.

Based on recent benthic habitat mapping data (FMRI/NOAA 1998, Ault *et al.* 2001, Florida Fish and Wildlife Conservation Commission 2001), Florida contains approximately 75% of the coral reefs in the US Caribbean and 65% of this region's coral reef monitoring projects. Despite the fact that 107 ongoing and 85 historical monitoring projects have been conducted in Florida, gaps in coverage of geographic areas and parameter sets still exist due to the uneven distribution of monitoring sites within the state (Fig. 2). Florida Bay and the Upper Keys have by far the highest density of monitoring projects compared to other areas of Florida. For instance, the Upper Florida Keys have almost twice as many ongoing coral monitoring projects as the Lower Keys and 3.5 times as many projects as the Dry Tortugas. While some historical monitoring has been conducted, ongoing projects monitoring corals are completely absent at the Florida Middle Grounds and along much of the western coast.

There is only one ongoing coral reef monitoring project on Florida's eastern coast north of Biscayne Bay.

Reef fish and marine invertebrates are monitored by 42% of the ongoing projects conducted in Florida. As is the case with the state's coral reef monitoring projects, the greatest number of monitoring, research, and assessment initiatives investigating these organisms are found in Florida Bay and the Upper Keys. At reef sites along both Florida's eastern and western coasts, relatively few species of marine invertebrates are being assessed, constituting a gap in monitoring. Of the species of marine invertebrates that are monitored in these areas, the spiny lobster, *Panulirus argus* (Latreillle, 1804), is surveyed across the widest geographic area, reflecting its importance as a commercially targeted species. Similarly, projects monitoring reef fish along Florida's eastern and western coasts are also somewhat scarce. The sole project monitoring reef fish on the western coast concentrates primarily on analyzing mercury levels in samples of fish tissue and does not assess the abundance of species in this area. Although several studies monitor reef fish in Biscayne Bay off of Florida's southeastern coast, the density of reef fish monitoring projects decreases traveling northward, leaving gaps in coverage at all reefs north of St. Lucie County.

Another domain in which the uneven, geographical distribution of Florida's monitoring projects can be observed is water quality sampling. Almost half of the monitoring projects in Florida sample physical and chemical parameters, making it the most widely assessed parameter category. However, monitoring efforts have not necessarily focused on the parts of the state where water quality is of most concern. Of the 46 ongoing projects that assess physical and chemical parameters in the Florida Keys, the Lower, Middle, and Upper Keys are sampled by 37%, 54%, and 93% of these monitoring initiatives, respectively. This demonstrates that, although the Lower and Middle Keys have higher levels of nutrient concentrations (Jones and Boyer 2001), they are not necessarily the most intensely monitored. Despite the fact that increasing urbanization on south Florida's eastern coast has precipitated many anthropogenic impacts that diminish water quality (i.e., sedimentation, turbidity, etc.) in coral reef areas (Causey *et al.* 2002), only two ongoing projects are sampling the area north of Fort Lauderdale, making this one of the least densely monitored zones.

As in most other areas of the US Caribbean and Gulf of Mexico, this survey found that a surprisingly small number of projects monitor seagrass beds and mangrove forests. Although Florida's approximately 1 900 km^2 of mangroves (Florida Department of Environmental Protection 2002) is the most extensive in the US Caribbean, it only has four ongoing projects that monitor this ecosystem. This leaves significant gaps in mangrove monitoring in the Lower and Middle Keys and along both Florida's eastern and western coasts. Information was gathered on 18 ongoing projects assessing the condition of seagrasses in Florida, indicating that this form of monitoring is slightly more widespread. However, assessments of this habitat are still underrepresented, since in many areas of the Florida Keys seagrass is the dominant type (i.e., ≥50% cover) of benthic habitat (FMRI/NOAA 1998). Furthermore, the semi-continuous area covered by seagrass in south Florida is currently the largest documented seagrass community in the world (it should be noted that the extent of seagrass beds has not yet been estimated in many parts of the world) (Fourqurean *et al.* 2001).

Texas/Louisiana: The northernmost coral reefs on the North American continental shelf are located 198 km south of the Texas/Louisiana border in the northern Gulf of Mexico in the Flower Garden Banks National Marine Sanctuary (FGBNMS). Although there are fewer projects here than in other areas of the US Caribbean and Gulf of Mexico, monitoring in this sanctuary does include a commendable long-term program, which uses quantitative methods that are comparable with other regional coral reef monitoring programs. This monitoring program, jointly coordinated by NOAA and Minerals Management Service (MMS), surveys percent benthic cover, coral species diversity and evenness, coral growth rates, percent coral affected by bleaching or diseases, abundance of sponges, sea urchins,

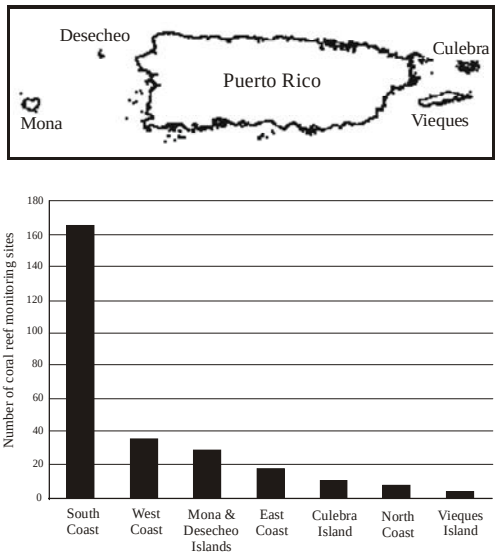

Fig. 3. Geographic locations and numbers of coral reef monitoring sites for sub-regions of Puerto Rico. Black dots on map represent individual monitoring sites.

and micromollusks, contaminants (i.e., PAHs, PCBs, and pesticides), light attenuation, and sea surface temperature (G. Schmahl pers. comm.). Other monitoring, assessment, and research projects in the FGBNMS supplement this program by conducting surveys of diverse organisms, including reef fish, sharks, rays, marine mammals, birds, sea turtles, cephalopods, crustaceans, gnasthomulids, macroalgae, and cyanobacteria. While monitoring sites are clustered around certain areas within the sanctuary's boundaries, this reflects the relatively small section of these banks that are shallow enough to support a living coral reef and the locations of mooring buoys where research vessels are allowed to dock.

Nevertheless, due to FGBNMS's remote location and lack of available research vessels, monitoring is somewhat sporadic at these reefs, as is evidenced by the fact that 36% of FGBNMS's ongoing projects conduct sampling on an "opportunistic" basis. Also, despite anecdotal reports of declines in the abundance of targeted species (Schmahl 2002), the sanctuary's sole long-term project monitoring reef fish only collects abundance data using four logarithmic categories, which are may not be specific enough to detect significant temporal changes in fish abundance. However, this gap may be partially filled through the scheduled resumption in 2001 of monitoring through the SEAMAP Reef Fish Survey. Recent reports of increased algal abundance in the sanctuary (Schmahl 2002) also suggest that an additional component sampling levels of nutrients should be added to FGBNMS's monitoring initiatives.

Puerto Rico: Located at the easternmost extent of the Greater Antilles, the main island of Puerto Rico is surrounded by large areas of fringing, barrier, and patch reefs on its western, eastern, and southern coasts. The northern coast of this island possesses less extensive reefs, with two-thirds of this area dominated by hard ground and reef rock habitats with low to very low coral cover (Matos *et al.* 2002). Digital benthic habitat maps delineating the location of coral reefs, seagrass beds, mangroves, and soft sediment communities in Puerto Rico have recently been developed by NOAA's National Centers for Coastal Ocean Science (Kendall *et al.* 2001). The detailed habitat information contained in these maps can be used by scientists conducting coral reef monitoring projects to measure changes in habitat distribution over time, help select the locations of monitoring stations stratified by habitat type, and determine species habitat utilization patterns (Monaco *et al.* 2001).

The density of coral reef monitoring sites throughout Puerto Rico varies greatly with some geographic areas receiving high levels of attention and others being largely overlooked by ongoing monitoring initiatives (Fig. 3). With 48.5% of all coral reef monitoring and assessment sites located on the southwestern coast of Puerto Rico, La Parguera and its surrounding area are intensively studied and contain numerous long-term data sets that assess the condition of coral reef and seagrass habitats, investigate processes affecting community structure, and evaluate the extent of natural and anthropogenic impacts on marine organisms. Overall, La Parguera possesses a total of 28 monitoring, mapping, assessment, and research projects that survey corals at 131 sites, reef fish at 118 sites, seagrass at 115 sites, marine invertebrates at 33 sites, algae at

23 sites, and physical and chemical parameters at 15 sites. Puerto Rico's western coast, the next most densely assessed area in the Commonwealth, has been monitored by 16 ongoing and four historical projects with its oldest data set dating back to 1975. While monitoring sites are evenly dispersed throughout this coast, many reefs covering extensive expanses are monitored at only one or two sites.

In contrast, monitoring along Puerto Rico's northern and southeastern coasts is characterized by substantial gaps in geographical coverage. Corals and reef fish are only being monitored on an ongoing basis at two sites along the entire northern coast. Although short-term, historical assessments of reef condition have been conducted at a few additional sites, six out of the ten reefs along this coast, which are included on the NOAA Coral Health and Monitoring Program (2002) map, have not yet had a baseline characterization. Similarly, this survey was unable to identify any historical or ongoing projects monitoring corals, reef fish, marine invertebrates, seagrass, or mangroves along the southeastern coast between Puerto Arroyo and Puerto Yabucoa. To a certain extent, the paucity of monitoring projects along the northern coast may reflect the fact that coral reefs are not as widespread in this area. However, the geographic distribution of reefs cannot completely explain the lack of monitoring along Puerto Rico's southeastern coast, where fringing reefs are more developed (UNEP/IUCN 1988, Kendall *et al.* 2001, ICLARM-World Fish Center 2002).

Gaps in monitoring and assessment were also evaluated for four offshore islands, which are part of the Commonwealth of Puerto Rico. Mona and Desecheo are small, uninhabited islands designated as nature reserves, which are located 70 km and 22 km west of Puerto Rico, respectively. With a total of 14 ongoing projects, corals have been surveyed at 29 sites around these two islands. While monitoring coverage is fairly good, it is necessary to note that seagrass habitats on Mona and water quality on both islands have not been fully assessed. Located approximately 22 km east of Puerto Rico, Vieques Island has been sparsely monitored and, as of the year 2000, possessed only a single sampling station devoted to surveying reef fish and corals on an ongoing basis. To recognize the true extent of this gap in coverage, it should be noted that the 68 km^2 of coral reef habitat on Vieques is comparable to the combined 64 km^2 of coral reef habitat found on St. Thomas and St. John in the US Virgin Islands (Kendall *et al*. 2001). Together, these two islands possess a total of 61 coral reef monitoring sites. Culebra Island, which is located 18 km north of Vieques and 32 km east of Puerto Rico, contains 11 coral and 19 reef fish monitoring sites, most of which are situated along the island's western coast, surrounding the recently established Luis Peña Marine Reserve. However, maps of the island's coral reefs (UNEP/IUCN 1988, Kendall *et al*. 2001, ICLARM-World Fish Center 2002) report that the most extensive reef on Culebra are found on its eastern side, suggesting the existence of a potential geographic gap in monitoring.

A few of the previously mentioned gaps may soon be filled through the development of the Puerto Rico Department of Natural and Environmental Resource's new territorial monitoring network. Although this represents a positive step towards building monitoring capacity, in most parts of Puerto Rico the lack of historical data sets and scarcity of long-term monitoring projects that have continuously collected data for more than five years may complicate efforts to identify temporal changes in community structure. Another area of concern is that, aside from some monitoring work conducted in two southern Puerto Rican bays (i.e., La Parguera and Guayanilla Bay), the ongoing projects and programs that were inventoried did not assess seagrass and mangrove habitats in most areas of Puerto Rico.

US Virgin Islands: The US Virgin Islands consist of St. Thomas and St. John, which are respectively located approximately 58 km and 87 km east of Puerto Rico, and St. Croix, which is positioned 62 km further to the south. As in Puerto Rico, the development of digital benthic habitat maps characterizing the US Virgin Islands' coral reef ecosystems has recently been completed by NOAA's National Centers for Coastal Ocean Science. Through allowing researchers to easily select appropri-

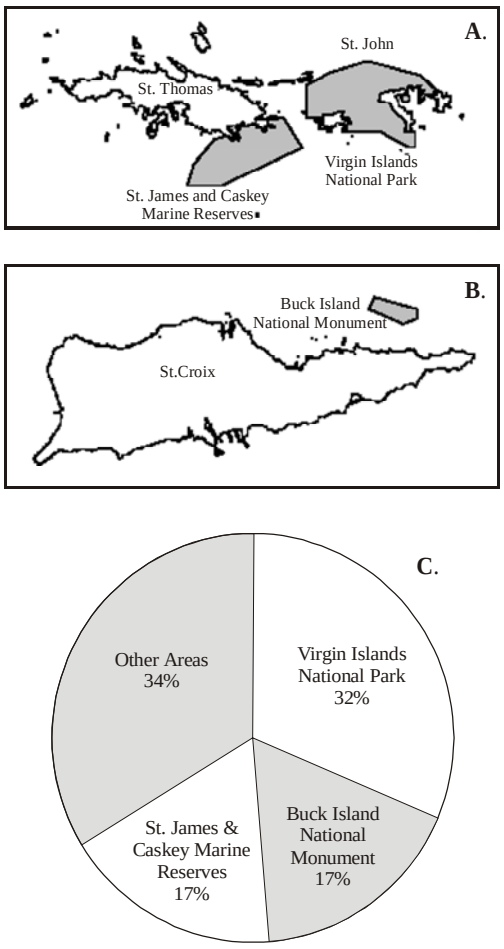

Fig. 4. Maps of coral reef monitoring sites in selected US Virgin Islands MPAs (A and B). The black dots on the maps represent individual monitoring sites. Pie chart showing the percentage of coral reef monitoring sites present in US Virgin Island MPAs and others areas (C).

ate locations for monitoring stations stratified by habitat type, these maps will enhance both ongoing and future monitoring initiatives (Monaco *et al.* 2001). For example, mapping data are already being utilized to evaluate the optimal level of monitoring effort needed to detect changes in fish populations in two US Virgin Island MPAs.

With only one historical and six ongoing projects, St. Thomas is the least monitored of all the US Virgin Islands. The majority of its monitoring sites are located around the south-eastern coast within the St. James and Caskey Marine Reserves. Excluding these two marine protected areas (MPAs) and a few offshore cays and islands, there are no sites where ongoing monitoring projects are surveying corals, reef fish, and water quality on St. Thomas, although limited baseline data for these parameter categories exist. Even in areas with ongoing monitoring initiatives, the onset of data collection has been relatively recent (i.e., within the last two to six years) for most projects. The lack of comparable historical data could potentially hinder efforts to detect long-term temporal changes in coral reef community structure.

With approximately two-thirds of its landmass and surrounding waters covered by the Virgin Islands National Park (ICLARM-World Fish Center 2002), St. John has a total of 23 monitoring projects, of which 15 are ongoing (Fig. 4). (In January 2001, an Executive Order issued by President Clinton established the US Virgin Island Coral Reef National Monument, which designates much of the area to the south of St. John as a MPA covering 51.4 km^2. As a result, a higher percentage of St. John's surrounding waters are now protected for conservation purposes). According to the results of this survey, as many ongoing monitoring projects are conducted on St. John as the other US Virgin Islands combined. Using quantitative methods, these projects gather data on percent benthic cover, coral growth rates, incidence of coral disease and bleaching, coral and fish recruitment, reef fish abundance and size, essential fish habitat (EFH), seagrass density and community structure, as well as multiple physical and chemical parameters. Long-term data collection has been consistent with several ongoing projects dating back 12-14 years. While monitoring sites are fairly well dispersed throughout St. John, a significant geographical gap in coverage exists along the island's eastern coast in one of the few marine areas excluded from the Virgin Islands National Park. Other smaller geographical gaps in coral and reef fish monitoring are located at Reef Bay, Rendezvous Bay, Brown Bay, and Mennebeck Bay.

In comparison with neighboring St. Thomas and St. John, St. Croix's eight historical and

nine ongoing projects represent an intermediate level of monitoring activity. In many areas of this island, sites where historical coral monitoring projects and assessments were conducted outnumber stations with ongoing sampling. Furthermore, coral reefs are not monitored at any sites along St. Croix 's southern and western coasts. This contrasts dramatically with monitoring at Buck Island National Monument, located offshore of the northeastern coast of St. Croix. The long-term monitoring program at this MPA has been annually gathering data on the condition of coral reefs from 15 sampling stations since 1977. While there have been several short-term, historical projects assessing and researching St. Croix's fish population, the two ongoing projects surveying reef fish on this island rely primarily on data collected by volunteers and do not use a precise method to monitor reef fish abundance. As on St. Thomas, there is no ongoing project that monitors water quality on St. Croix.

At the territorial level, a few trends in monitoring exist throughout the US Virgin Islands. First, the paucity of projects assessing seagrass, mangroves, and marine invertebrates, including commercially and recreationally valuable species, is characteristic of monitoring throughout this area. Second, a high proportion of monitoring sites are found within the boundaries of areas designated as MPAs. Overall, 66% of the US Virgin Islands' coral reef monitoring sites are located within the Virgin Islands National Park, Buck Island National Monument, and St. James and Caskey Marine Reserves (Fig. 4). Together, these three MPAs protect approximately 11% of the coral reef habitat within the US Virgin Islands (based on the area covered by coral reef habitat in Virgin Islands National Park and Buck Island National Monument prior to the expansion of their boundaries in January 2001).

Navassa Island: In 2001, a National Wildlife Refuge to be administered by the US Fish and Wildlife Service was established at Navassa, a small, uninhabited island located 55 km west of Haiti and 137 km northeast of Jamaica (Miller 2002). Although no monitoring has yet been conducted at Navassa Island, a series of baseline assessments have been undertaken. In 1998, the National Marine Fisheries Service (NMFS) assessed coastal sharks and other incidental fish at five sites around Navassa. At three additional sites, CTD measurements were taken and underwater video cameras were deployed to investigate habitat diversity and species composition of reefs. In 1999, a second expedition to this island also led by NMFS collected voucher specimens and developed a comprehensive list of 219 fish species inhabiting the waters around Navassa (B. Collette pers. comm.). Between 1998-2000, the Ocean Conservancy spearheaded annual expeditions to Navassa, which have assessed corals, reef fish, echinoderms, mollusks, crustaceans, marine algae, and contaminants.

With each new expedition to Navassa Island, knowledge of its natural resources has become more complete and the survey data collected has become progressively more quantitative. However, due to the limited amount of time that researchers have spent on the island, sampling has not yet been conducted along all areas of the coastline, in particular habitat types, at certain depth ranges, and during different seasons. Also, little to no information has been gathered on water quality and the effect that subsistence fishers from Haiti have on Navassa's coral reef resources.

DISCUSSION

With the exception of Navassa Island, all areas of the US Caribbean and Gulf of Mexico possess one or more long-term monitoring projects that assess the condition of coral reef ecosystems and their associated marine organisms. The distribution of monitoring sites within each region tends to be highly uneven, resulting in sizable geographical gaps in coverage. Overall, the most substantial gaps in monitoring include the western coast of Florida, the Florida Middle Grounds, Navassa Island, Vieques Island, the northern and southeastern coasts of Puerto Rico, and several nearshore areas of St. Thomas in the US Virgin Islands. Virtually, all regions of the US Caribbean are characterized by a scarcity of

projects monitoring seagrass beds and mangrove forests. This is a critical gap in knowledge, since these ecosystems filter contaminants, protect coastal shorelines from erosion, provide valuable habitat for reef fish and other species, and in many areas are being rapidly destroyed (Ellison and Farnsworth 1996, Short and Wyllie-Echeverria 1996, Barbier 2000, Scott *et al.* 2000, Spalding *et al*. 2001).

In order to fill some of these gaps and develop a national coral reef monitoring network, NOAA issued in 2000 cooperative and continuing grants to island groups designed to build long-term monitoring capacity. The programs developed under this source of funding are already beginning to have a positive impact on regional monitoring initiatives. In Puerto Rico, the first territory-wide monitoring program, which surveys corals, reef fishes, motile invertebrates, and water quality at 13 sites, was established through one of these grants. Also, a baseline assessment of coral reef and seagrass communities on Vieques Island, sponsored by a second grant, is simultaneously filling a significant gap in coverage and preparing for the eventual transfer of land from the US Navy to the control of the Puerto Rican government. Recognizing that intensive monitoring in the US Virgin Islands is only occurring at a limited number of sites, another grant issued under this program extends monitoring to new areas in order to gather data on baseline conditions at potential sites to be established as MPAs. Using another source of funding from NOAA, reef fish surveys are being conducted in Broward County, Florida across a 25 km stretch of shoreline using multiple visual-techniques (Causey *et al.* 2002). This recently initiated project aims to establish a baseline for the eastern coast of Florida, which has received comparatively less monitoring attention than other areas of the state, such as FKNMS and Florida Bay. As the *National Program to Map, Assess, Inventory, and Monitor US Coral Reef Ecosystems* expands, NOAA plans to continue its efforts to fill gaps in coral reef monitoring.

Coral reef assessment and monitoring activities should ideally be incorporated into a management framework, in which the data generated by monitoring programs are used to direct efforts to conserve and restore coral reef ecosystems. As a prerequisite for the integration of monitoring into this type of management framework, it is necessary to conduct thorough baseline assessments, which evaluate species diversity and abundance, current environmental conditions, and the ecological processes that drive coral reef community dynamics. Preferably, this baseline characterization should be supplemented by studies identifying current levels of anthropogenic activities affecting reefs and a socioeconomic assessment examining resource use patterns, stakeholder characteristics and perceptions of coral reef resources, and the market and non-market economic value of these resources (Bunce *et al*. 2000). The information provided by such a socioeconomic assessment can help guide management decisions through revealing the concerns of the local community and how their interactions with coral reefs may influence the ecosystem's integrity. Another component of a comprehensive baseline characterization is the development of detailed maps that delineate types of benthic habitats. These maps can serve as a tool for evaluating long-term changes in the distribution of benthic habitats (MISWG 1999, Monaco *et al*. 2001). They should also play an important role in the selection of representative sites to be surveyed by long-term monitoring programs.

In the US Caribbean and Gulf of Mexico, some form of baseline information has been acquired for most geographic areas. In addition, there is a general awareness and understanding of how anthropogenic activities are affecting coral reef ecosystems. FKNMS is the only area of the US Caribbean, in which a socioeconomic assessment has been conducted. In comparison with almost every other coral reef ecosystem in the world, the US Caribbean has received the greatest amount of attention in terms of benthic habitat mapping initiatives. Completed mapping work in FKNMS, Puerto Rico, and the US Virgin Islands has delineated approximately 65% of the coral reefs in the US Caribbean region. The majority of reefs in this area that remain to be mapped are located on the eastern and western coasts of the Florida and in the Florida Middle Grounds.

Once a comprehensive baseline has been established, a monitoring program should be

put into place that is designed to meet management needs and evaluate the effects of management actions. The objectives of a management-driven monitoring program may include: 1) the identification of specific "bioregions" which will be incorporated into a system of MPAs (Done 2001); 2) the development of multi-metric indexes of ecological integrity geared towards diagnosing the condition of coral reef ecosystems (Jameson *et al*. 2001); and 3) the creation of "ecological forecasting" models designed to evaluate the potential ecological and socioeconomic impacts of alternative management actions (NOAA 2001). In order to effectively and cost-efficiently accomplish these and other objectives, a multi-tiered monitoring program should be developed that surveys basic parameters at a relatively large number of sites and conducts more in depth monitoring at a smaller number of representative sites. This type of multi-tiered approach to monitoring has been implemented successfully in both developed nations and developing countries, where financial resources to support monitoring may be limited (Hodgson and Wilkinson 2001). A critical characteristic of an integrated monitoring program is that it incorporates various user groups and stakeholders, such as academic institutions, governmental agencies, and non-profit and volunteer organizations. This type of inter-agency cooperation increases the availability of resources for monitoring and provides for enhanced communication between groups conducting research on different aspects of coral reef ecology. It can also incorporate policy-makers and resource managers into the monitoring process, thus, making them more likely to design and/or modify management plans based upon the findings of monitoring data (Done 2001).

While long-term monitoring has been ongoing in many regions of the US Caribbean and Gulf of Mexico, FKNMS is the only area that has developed an integrated, multi-tiered program that seeks to evaluate the effectiveness of Sanctuary regulations. This program incorporates monitoring activities conducted by volunteer groups, academic researchers, and governmental agencies. Regular FKNMS science advisory board meetings help generate an exchange of information between the various groups involved in different aspects of this program. Although the FKNMS monitoring program is undoubtedly the most expensive program in the US Caribbean, the development of other integrated monitoring systems within the region could be implemented relatively easily and inexpensively through the creation of a network that incorporates existing projects currently gathering data in each area.

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RESUMEN

La Administración Nacional del Océano y la Atmósfera llevó acabo una encuesta de 296 programas / proyectos que han evaluado y monitoreado desde 1990 los arrecifes coralinos y sus hábitats asociados (i.e., las hierbas marinas y los manglares) en las áreas estadounidenses del Caribe y el Golfo de México. Al analizar los resultados usando un sistema de información geográfica, se encontraron varias brechas substanciales en el alcance de estos proyectos debida a la distribución desigual de sitios donde se monitorean los recursos marinos. Hay

una densidad alta de proyectos que investigan los arrecifes en los Cayos Altos de Florida y La Parguera, Puerto Rico. Mientras que en otras zonas, como la costa oeste de Florida, los Florida Middle Grounds, las costas norteña y sudeste de Puerto Rico, la Isla Vieques, varias partes de St. Thomas y la Isla Navassa, la escasez de los estudios científicos domina. Aunque múltiples proyectos mapean las hierbas marinas y los manglares, estos ecosistemas apenas están monitoreados a lo largo del Caribe estadounidense. Para incrementar el alcance geográfico de estos proyectos, la Administración Nacional del Océano y la Atmósfera ha comenzado a otorgar becas a algunos estados y territorios para que amplíen su capacidad de evaluar la condición de su ambiente costero a largo plazo.

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APENDIX

Regional list of principal investigators whose monitoring and assessment projects were included in the US Coral Reef Monitoring Project Survey. Additional information on the area covered by individual monitoring projects can be accessed by viewing this project's GIS, which will be available on-line at http://www.biogeo.nos. noaa.gov.

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Hay, L. Hefty, J. Hendee, G. Henderson, T. Henwood, G. Hodgson, C. Hopps, H. Hudson, W. Jaap, R. Johnson, R. Jones, B. Keller, C. Kruer, J. Landsberg, B. Lapointe, V.R. Leeworthy, E. Long, J. Lorenz, W. Lyons, J. Macauley, S. Markley, R.E. Matheson, K. Mayo, D. McClellan, B. Mealey, M. Miller, S. Miller, L. Monk, C. Montague, D. Morrison, E. Mueller, L.B. Nye, T. O'Connor, J. Ogden, W.H. Orem, S. Paterson, E. Patino, M. Patterson, J. Paul, W. Perry, K. Peters, E. Phlips, J.W. Porter, K. Rademacher, M. Reaka-Kudla, B. Richards, W. Richards, L. Richardson, M. Robblee, A. Robertson, M. Robson, J. Rose, D. Rumbold, D. Rudnick, D. Rydene, F. Sargent, M. Schmale, T. Schmidt, G. Scott, C. Semmens, J. Serafy, E. Severance, W. Sharp, P. Sheridan, E. Shinn, M. Shirley, R. Skinner, C. Smith, N. Smith, S.R. Smith, T. Smith, S. Snedaker, S. Snow, G. Sprandel, K. Steidinger, J. Stevely, A. Strong, A. Stone, J.T. Streelman, R. Stumpf, P. Swart, A. Szmant, H. Talge, G. Thayer, N. Thompson, C. Tomas, E. Van Vleet, G. Vargo, S. Vargo, C. Weaver, R. Werner, J. Wheaton, B. Williams, T. Wilmers, and K. Yates.

Texas/Louisiana: L. Akins, J. Childs, J. Culbertson, J. DeBose, Q. Dokken, K. Dunton, S. Fredericq, S. Gittings, C. Gledhill, D. Hagman, T. Henwood, E. Hickerson, C. Koenig, L. Miller, C. Pattengill-Semmens, K. Rademacher, M. Scanlin, G. Schmahl, W. Sterrer, T. Shyka, D. Weaver, M. Wicksten, and C. Wilson.

Puerto Rico: A. Aguilar-Perera, L. Akins, N. Aponte, R. Appeldoorn, R. Armstrong, D. Ballantine, B. Berrios, A. Bruckner, C.I. Garcia, J. Garcia, G. Garrison, I. Gill, R. Gonzalez, S. Griffin, K. Hall, J. Hare, E. Hernandez-Delgado, G. Hodgson, J. Holmquist, K. Holtermann, D. Hubbard, A.R. Jimenez, N. Jimenez, J. Marquez, M. Monaco, L. Monk, J. Morelock, M. Nemeth, A. Olivares, A. Ortiz Prosper, J. Rivera, H. Ruiz, A. Sabat, M. Scharer, E. Shinn, J. Timber, L. Velez, V. Vicente, E. Weil, B. Williams, and P. Yoshioka.

US Virgin Islands: A. Adams, L. Akins, D. Ballantine, D. Barry, J. Beets, J. Bythell, B. Devine, J. Ebersole, P.J. Edmunds, A. Friedlander, G. Garrison, I. Gill, Z.M. Hillis-Starr, G. Hodgson, D. Hoffman, D. Hubbard, T. Kelley, B. Kojis, L. MacDonald, I. Mateo, J. Miller, M. Monaco, L. Monk, L. Muehlstein, R. Nemeth, B. Phillips, C. Ramos, J. Rivera, C. Rogers, P. Rothenberger, M. Russell, S. Swearer, M. Taylor, W. Tobias, E. Treml, J. Turner, B. Williams, and L. Whaylen.

Navassa Island: F. Bretos, B. Collette, T. DiBennetto, C. Gertsner, M. Grace, D. Hickey, M. Miller, D. O'Foighel, M. Smith, and R. Wetzer.