Expedition Report

2003 Joint Ocean Conservancy - CORALINA
Rapid Ecological Assessment of the Northern Banks of the Archipelago of San Andrés and Old Providence

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Dennis Heinemann[1]
Richard Appeldoorn[2]
Craig Dahlgren[3]
Pilar Herrón[4]
Martha Prada[5]
Juan Sánchez [6]

[1]The Ocean Conservancy, Washington, DC
[2]University of Puerto Rico, Mayagüez, PR
[3]Caribbean Marine Research Center, Lee Stocking Island, Bahamas
[4] Corporation for the Sustainable Development of the Archipelago of San Andrés, Old Providence and Santa Catalina – CORALINA, San Andrés Island, Colombia
[5]PO Box 75, San Andrés Island, Colombia
[6]National Institute of Water & Atmospheric Research, Wellington, New Zealand

Summary

In April and May of 2003, The Ocean Conservancy and CORALINA (The Corporation for the Sustainable Development of the Archipelago of San Andrés, Old Providence & Santa Catalina) conducted a three-week rapid ecological assessment of Quitasueño, Serrana and Roncador. The latter are oceanic banks in the northern part of the Archipelago of San Andrés and Old Providence, which is located in the southwestern Caribbean Sea. The key objectives of the Expedition were to 1) characterize the reef substrate and benthic communities, 2) assess the health of the corals, 3) characterize fish populations and communities, 4) assess the abundance and age structure on the conch populations, and 5) assess the apparent impacts of fishing on fish, conch and lobster populations.

During the expedition, 20 researchers working in three teams – benthic, fish and conch – surveyed 118 reef sites (benthic and fish teams working together) and 151 conch sites. Key findings from the Expedition were:

- In general, the diversity of corals, octocorals and fishes was high on the banks, and compared favorably with some of the best areas in the Caribbean.

- Live coral cover on Quitasueño was very good (18-50%), but much lower on Serrana (3-52%) and Roncador (4-41%).
- Numerous reefs dominated by the red-listed *Acropora palmata* were found on Serrana and Roncador, but no significant concentrations of *A. cervicornis*, another red-listed acroporid, were found on any of the banks.
- Sea urchins critical to reef health had a patchy distribution, being common in some locations but absent from others.
- Many areas had high coverages of opportunistic algae (up to 60% on Quitasueño and Serrana), perhaps indicative of poor reef health.
- Coral disease was generally low, but a significant outbreak of what appeared to be white plague disease affecting a large number of species in one small area on Serrana was discovered.
- The density, size and biomass of groupers on the banks were very low compared to the least fished areas in the Caribbean, suggesting a history of perhaps intense, undocumented fishing for reef fish on the northern banks.
- Several red-listed fish species (e.g. goliath and Nassau grouper, and cubera snapper) were never or rarely seen during the Expedition, although fore-reef habitats were not sampled on Serrana and Roncador because of weather constraints.
- Lobsters, sharks and turtles were encountered in very low numbers, suggesting a history of intense impacts of fishing on these species.
- Conch population densities varied tremendously among the three banks, being among the highest in the Caribbean on Serrana, but near the lowest on Quitasueño.
- The conch population was so low on Quitasueño that a long-term closure of the fishery is recommended.
- Conch were abundant enough on Serrana to support moderate levels of fishing, but it appears that Roncador could support only low levels of fishing.
- It was clear from the benthic, fish and conch analyses that the three banks are distinct and should be treated separately for the purposes of management and protection.

Based on the findings of the Expedition (Sánchez *et al.* 2003, Dahlgren *et al.* 2003, and Appeldoorn *et al.* 2003) and spatial analyses of the data conducted at a recent workshop, recommendations are made here for the zoning of the MPA encompassing the northern banks. Multiple areas that would protect the diversity of species and habitats, special features and habitats, areas with higher abundances of key species, and areas important to conch settlement, production and spawning are proposed for protection from fishing and other extractive activities. Because analyses and considerations of possibilities for exchanges among the banks lead to the conclusion that the banks are well differentiated ecological units, the zoning recommendations made here are done so for each bank independently.

Introduction

The Archipelago of San Andrés and Old Providence is located in the southwestern Caribbean (Figure 1). The Archipelago is Colombia's only oceanic department. One of the most isolated island regions in the Americas, the Archipelago includes 3 small inhabited islands - San Andrés and the island pair of Old Providence and Santa Catalina, as well as several uninhabited cays and coral banks, with a total insular area of 57 km^2 and a marine area (EEZ) of around 350,000 km^2 (Figure 2). The Exclusive Economic Zone surrounding this archipelago includes nearly 10% of the Caribbean Sea. The island of San Andrés lies approximately 130 miles east of Nicaragua, 450 miles south of Grand Cayman Island, and 500 miles west-northwest of Cartagena, Colombia (Figure 1).

San Andrés has an area of 27 km^2 and an estimated population of over 80,000. The majority are immigrants from mainland Colombia, who have come during the last 25 years. Native islanders, who are descended from early settlers, have a culture defined by an Anglo-puritan/African heritage, Protestantism, and English as a mother tongue. The estimated population density is the highest of any oceanic island in the Americas, nearly 3,000 inhabitants per km^2, with most of that population concentrated at the north end of the island. In contrast, Old Providence – Santa Catalina (18 km^2), with only 4,200 inhabitants and a population density of just 525 inhabitants per km^2, is one of the least environmentally and culturally degraded spots in the Caribbean.

Fishing in the Archipelago is conducted by residents, vessels from the Colombian mainland, and vessels from other countries in the region, but contracted by Colombian companies. Many habitats around the islands have been impacted by pollution, nutrient enrichment and sedimentation, and invertebrate and fish populations throughout the Archipelago show signs of overfishing (CORALINA 2000a, 2000b, Dahlgren 2003, Friedlander et al. in prep). Scientific surveys and fishermen interviews have identified shallow-water lobsters, conch, and large parrotfishes, groupers and snappers as the most over-fished components of the Archipelago's reefs, although the picture varies among banks. In addition, fishermen reported that spawning aggregations of various groupers have been depleted by fishing in many cases (Friedlander et al. in press).

Although little studied, the region is defined as a center of high to very high marine endemism. In addition, the western Caribbean has been identified as a major site of coral and fish diversity and is considered a global biodiversity "hot spot". The oceanic reefs of the Archipelago make up one of the most extensive and productive reef systems in the Western Hemisphere and include 2 barrier reefs surrounding the main islands of San Andrés and Old Providence, 5 large atolls, and other less well defined coral banks (Figure 2) that extend for more than 500 km along the Nicaraguan rise (Geister and Diaz 1997). The Archipelago's reef formations are particularly complex because of the open oceanic location and adaptation to heavy wave action. Previous studies have identified 57 species of coral and 273 species of fish representing 54 families. A number of coral, fish, and turtles are listed on the IUCN Red List. Important commercial species include queen conch, spiny lobster and spotted spiny lobster, and popular food fish like snappers and groupers.

In 2000, the Archipelago was declared the Seaflower Biosphere Reserve by UNESCO's Man and the Biosphere Program. In the same year, CORALINA, the Corporation for the Sustainable Development of the Archipelago of San Andrés, Old Providence & Santa Catalina, initiated a four-year GEF-funded project to establish a system of multiple-use marine protected areas (MPAs) within the reserve. The MPA project aims to conserve the Archipelago's globally important sites of biodiversity and ensure sustainable use of coastal and marine resources. The

Ocean Conservancy and Island Resources Foundation were brought into the project as technical partners at the planning stage.

Stakeholders have provided input on a plan to establish a network of MPAs within the Seaflower Biosphere Reserve. Current plans propose the establishment of three MPAs: 1) around San Andrés and the southern cays, 2) around Old Providence and Santa Catalina, and 3) around the northern cays, including reef and deep-water habitats. All combined the proposed MPAs will cover over 40,000 km^2. Five zoning categories are planned for the MPAs: 1) no-entry, where use is restricted to research and monitoring, 2) no-take, allowing a variety of non-extractive uses, 3) artisanal fishing, for use by traditional fishers only, 4) special use, for areas identified during MPA planning, particularly where a high potential for conflicts exists, like ports, marinas, or heavily used recreation areas, and 5) general use, where basic restrictions apply to protect water quality and preserve MPA system integrity. To effectively establish these zones and design the system of MPAs, biological, socioeconomic, and historical information was required for the Archipelago. This information is being collected through a variety of mechanisms including expeditions, biological and socioeconomic surveys, stakeholder interviews, and social mapping. The Ocean Conservancy has assisted CORALINA in several of these processes, most prominently by conducting scientific expeditions to assess the state and condition of the Archipelago's marine ecosystems.

The Ocean Conservancy assembled and led two earlier marine research expeditions to the Archipelago to gather ecological information essential to the effective design and management of the system of MPAs. In August 2000, research teams made up of experts in the field of fisheries and coral habitat assessment, joined by marine biologists from CORALINA, conducted a twelve-day expedition in the coastal and marine waters surrounding the islands of Old Providence and Santa Catalina, north of San Andrés (Friedlander *et al.* 2003a). In December 2000, the researchers again traveled to the Archipelago, this time for a seven-day expedition in the San Andrés coastal waters (Friedlander *et al.* 2003b).

The primary goals of these expedition were to 1) prioritize sites for marine surveys, based on existing research gaps, 2) train CORALINA researchers in methods of data collection and evaluation, especially of coral condition and fish identification, 3) collect primary information on the current status of fish (abundance and distribution) and seafloor habitats (emphasizing corals), and 4) use these data to supplement baseline information about these coastal waters, evaluating how this information can be applied to MPA zoning and management for Old Providence and San Andrés. A key outcome of this work was scientific recommendations for the placement of 'no-take' zones around these two inhabited islands (Appeldoorn *et al.* in press, Friedlander *et al.* 2003a,b). This information is being added to socioeconomic information and input from fishermen and other stakeholders to finalize the objectives and zoning plans for the MPAs.

In September 2002, The Ocean Conservancy provided support and technical advice for a similar expedition to the keys and atolls south of San Andrés –Albuquerque and Courtown (Figure 2). These areas are of critical importance to local, artisanal fishermen, but are suffering from overfishing and other impacts. The team again gathered critical information about the status of corals and fish in the areas and worked directly with local fishermen to take advantage of their knowledge (Caldas *et al.* 2002).

In the spring of 2003 TOC led its third expedition in the Archipelago, this time to three of the remote northern banks – Quitasueño (also called Queena, located 70 km NNE of Providence), Serrana (located 150 km NE of Providence), and Roncador (located 150 km E of Providence and 210 km NE of San Andrés) (Figure 2). The goals of this Expedition were similar to those of the earlier expeditions – to provide an ecological characterization of the benthos and fish communities as part of the MPA-design process. In addition, the 2003 Expedition focused on the economically important conch populations on these banks – collecting the data required to perform an assessment of the populations and their ability to sustain fishing.

Due to their remoteness, these northern atolls and banks have been little studied. Acquiring better information about the distribution and status of the their key habitats and resources was essential to ensure the design of an effective Marine Protected Area within the Archipelago. The expedition spent three weeks in the northern banks gathering information similar to that obtained in earlier expeditions on the status and health of the reef ecosystem. A team of 28 scientists and support personnel from The Ocean Conservancy, CORALINA, and other institutions participated in the expedition. The scientists worked in three teams – benthic, fish and conch. The teams were lead, respectively, by Drs Juan Armando Sánchez, Craig Dahlgren and Richard Appeldoorn. The results of their work are contained in the accompanying team reports. The Fish and Benthic teams worked together at almost all of their stations, and they will be referred to jointly as the Reef Team. The Reef Team always worked independently of the Conch Team, although in some cases they sampled adjacent sites. This report provides a description of the expedition plan and a summary of the findings of the three teams. The detailed findings are contained in the team reports (Sánchez *et al*. 2003, Dahlgren *et al.* 2003, Appeldoorn *et al.* 2003).

The Northern Banks

The Archipelago of San Andrés and Old Providence consists of a number of oceanic islands, atolls, coral-reef banks and a portion of the Nicaraguan Rise, surrounded by water 500-2500m deep. The area of the northern banks and cays is one of the most remote parts of the western Caribbean, being at its closest over 120 miles from the nearest continental land mass (Nicaragua) and 50-140 miles from the islands of Old Providence and San Andrés. The oceanic nature and remoteness of the banks means that they are different from coastal coral-reef habitats in the region. All three banks are characterized by a barrier reef on the windward, eastern, border, extensive lagoons that slope from quite shallow immediately behind the barrier reef, to deeper platforms and slopes on the leeward (western) margin. General descriptions of the geomorphology of the northern banks and their general biological characteristics can be found in the team reports and references cited therein.

Quitasueño is the largest atoll in the Archipelago (1,320 km^2; Figure 3). Including shelf areas, it is over 60 km long, varies in width from 10 to 20 km, and has a windward barrier reef that extends north-south for more than 40 km. There are very few breaks in the barrier reef. Although it has no land area, the bank is very shallow in parts, with some patch reefs being exposed at low tide. This bank is one of the least studied areas in the Archipelago even though the conch and lobster beds have traditionally been regarded as among the most productive in the southwestern Caribbean.

Serrana is a large, roughly triangular-shaped bank approximately 36 km long and 15 km wide (320 km^2) including the insular shelf (Figure 4). The barrier reef stretches from the northern peak of the bank all the way around to the southwestern corner. Important passages are found on the north and south sides of the eastern tip, and further west along the southeaster barrier reef. There are several small cays scattered around the perimeter of the bank. The lagoon is extensive and has a diversity of habitat types.

Roncador, an elongated atoll approximately 15 km long by 7 km wide, is by far the smallest of the three banks (50 km^2; Figure 5). There is a prominent cay at the northern tip, and like Quitasueño, Roncador is oriented north-south with a barrier reef running the length of the windward (east side). Unlike Quitasueño and Serrana, the barrier reef is unbroken by any passages.

Expedition Plan

The Benthic Team’s objectives were 1) to characterize the reef substrate and benthic communities, including scleractinian corals, octocorals, other invertebrates and algae, across a range of habitats on each bank, 2) determine the status of keystone urchin species, and 3) assess the prevalence of coral diseases. The objectives of the Fish Team were to characterize the fish populations and communities across a range of habitats on each bank. The characterization consisted of three elements, 1) fish-species diversity, 2) abundances of each species, and 3) the distribution, abundance and size structure of key species. The Conch Team had two main objectives: 1) to assess the abundance and age structure on the conch populations on each bank, and the capacity for those populations to sustain fishing, and 2) to characterize the populations relative to the geomorphology and habitats on each bank.

The number of sites sampled was roughly proportional to the size of the bank and its habitat complexity. The Reef Team sampled 48 sites on Quitasueño, 48 sites on Serrana, and 22 sites on Roncador; on one day the Fish Team sampled an extra 4 sites on Serrana, while the Benthic Team investigated an outbreak of coral disease in another area of the bank. The Conch Team sampled 65 sites on Quitasueño, 69 sites on Serrana, and 27 sites on Roncador.

The criteria used to select sampling stations stemmed from each team’s objectives. On each bank several habitats were chosen for sampling based on those identified by Díaz *et al.* 2000 from a survey of the northern banks conducted by the Instituto de de Investigaciones Marinas y Costeras (INVEMAR). Using the habitats maps from Díaz *et al.* 2000 and depth the Reef Team identified five sampling strata: 1) elkhorn coral (*Acropora palmata*) reefs, 2) lagoonal patch reefs, 3) leeward-margin reefs, 4) shallow fore-reefs, and 5) deep fore-reefs. Sites were selected haphazardly within each stratum, and an effort was made to sample enough sites in each stratum for one or more parts of each reef to proved a thorough characterization of the benthos and fish. However, because of constraints imposed by the weather, the scarcity of some habitats and difficulties in getting the research vessels to all parts of the banks, some strata were undersampled (e.g. fore-reef habitats on Serrana and Roncador, and *Acropora palmata* habitats on Quitasueño; see Table 1 in Dahlgren *et al.* 2003).

A wide range of habitats was sampled by the Reef Team on Quitasueño, although no Acropora reefs were visited due to their rarity and small size on that bank. Because of bad weather fore-reef sites could not be sampled on Serrana and Roncador, although two leeward sites classified by Díaz *et al.* (2000) as 'mixed coral', which was typically a fore-reef habitat, were visited on Serrana. Several *Acropora palmata* reefs on Serrana, and one on Roncador, were included in the surveys on those banks.

The Conch Team identified different strata on each bank for sampling, based on the distribution of habitats on each bank and their accessibility. Three habitats (strata) were sampled on Quitasueño and Roncador (Tables 2 and 6), although they were not the same habitats. Stations were haphazardly selected within strata, or often within strata along transect lines running across several strata (e.g. from back reef to leeward terrace), or parallel to the barrier reef moving away from or toward a geomorphic feature (e.g. the end of the barrier reef or a channel through the barrier reef).

The Research Platforms

The primary research platform was the *M/V Spree*, based in Freeport, Texas. The *Spree* is a 100' live-aboard dive boat, with considerable experience in supporting scientific dive expeditions, recently having conducted a large-scale survey of fish in the Florida Keys run by NOAA and the University of Miami. She was crewed by her Captain, Frank Wasson, the Second Captain, Orlando Pinzón Trejos, the Dive Master, Melanie Wasson, the Dive Safety Officer, John Embesi, and the Cook, Sharon Kerr. With a beam of 22 ft and a draft of 7 ft, excellent dive operation facilities, dual props, three main engines, a cruising speed of 13 kts, a range of 700 nm, large fresh water tanks, and berthing for 24 research personnel, the *Spree* provided an ideal platform from which to conduct the expedition. The *Spree* provided scuba tanks, supplemented by some from Coralina, dive weights, and filled all tanks with Nitrox or air on demand throughout the dive operations. The rest of the dive gear was provided by the divers, Coralina or The Ocean Conservancy.

The *Spree* could not get safely into water less than 10-15 feet deep. Therefore, we used a second boat to access shallow water areas. A 33-ft artisanal fishing boat from Old Providence, the *Anglonamar 2*, accompanied us on the Expedition. The *Anglonamar* was used primarily to take the Conch Team into the shallow-water habitats that they needed to survey. On occasion the Fish and Benthic Teams used the *Anglonamar* to get to inaccessible sites. The *Anglonamar* was operated by her Owner/Captain, Antonio Archbold, and two crewmembers.

Research Teams

The benthic team was lead by Dr Juan Armando Sánchez, then a Postdoctoral Fellow with the Smithsonian Institute in Washington, D.C. Dr Sánchez had considerable experience in the Archipelago, having been involved in the INVEMAR surveys of the Archipelago (Díaz *et al.* 2000) and two of the previous Ocean Conservancy / CORALINA expeditions (Friedlander *et al.*

in press, Friedlander *et al.* in prep.). The other members of the Benthic Team, with their affiliations at the time of the Expedition, were Alison Acosta (Smithsonian Institution, Washington, D.C.), Paula Andrea Castillo (INVEMAR, Santa Marta), Pilar Adriana Herrón (CORALINA, San Andrés Isla), Juan Camilo Martinez (CORALINA, San Andrés Isla), Phanor Hernando Montoya (INVEMAR, Santa Marta), Carlos Andres Orozco (Universidad del Valle, Cali), and Valeria Pizarro (CORALINA, San Andrés Isla).

The Fish Team was lead by Dr Craig Dahlgren, Director of Science with the Caribbean Marine Research Center in the Bahamas. The others members of the team, with their affiliations at the time of the Expedition, were Enrique Arboleda (INVEMAR, Santa Marta), Kevin L. Buch (Caribbean Marine Research Center, Bahamas), Juan Pablo Caldas (Universidad Nacional de Colombia, San Andrés Isla), Luis Santiago Posada (CORALINA, Old Providence Island), and Martha Cecilia Prada (CORALINA, San Andrés Isla).

The Benthic and Fish Team worked together forming the Reef Team. The Reef Team operated in two units of seven divers each, 4 from the Benthic Team and 3 from the Fish Team.

The Conch Team was lead by Dr Richard Appeldoorn, Professor at the University of Puerto Rico, Mayagüez. Dr Appeldoorn was involved in the Ocean Conservancy / CORALINA expeditions around Old Providence – Santa Catalina and San Andrés. The other members of the team, with their affiliations at the time of the Expedition, were Leonidas Felipe Cabeza, (Felipe's Diving, Old Providence Island), Robert Glazer (Florida Marine Research Institute), Erick Castro Gonzalez (Secretaría de Agricultura y Pesca, Gobernación del Departamento Archipiélago San Andrés y Providencia, San Andrés Isla), Leonardo Arango López (Jorge Tadeo Lozano University in Bogotá), and Giovanna Peñaloza (CORALINA, Old Providence Island). The Conch Team operated in three units of two divers each.

Dive Operations

All sampling was carried out while SCUBA diving used compressed Nitrox, although mechanical problems with a compressor forced the used of compressed air for a couple of days. Diving operations were conducted differently on the two research platforms. Nitrox (mostly EAN32%) was used to increase the bottom time and safety margin available to the divers, so as to increase the number of sites that could be sampled per day. Tanks were filled and maintained by the Dive Master.

The *Spree* focused on placing the Reef Team on reef-habitat sites, while the *Anglonamar* operated independently, placing the Conch Team on various soft-bottom habitats favored by conch. On a couple of days the teams traded boats, with the Conch Team using the *Spree* and the *Anglonamar* taking the Reef Team. The Spree used a 'live-boating' technique to put the two Reef Team units (7 divers each), alternately on separate dive sites. While one unit was down on a dive, the other would be in its 'surface interval' recovering from the last dive and waiting for the next. While a dive unit was down the Spree would stand off awaiting their return to the surface. Because the Spree never had to anchor for dropping off or picking up divers, she was able to move quickly from site to site, increasing the number of sites that could be sampled per day. Each Reef Team unit typically sampled 3-4 sites per day or 6-8 sites per day for the Reef

Team as a whole. Details of the sampling methods used are provided in the Benthic and Fish Team reports (Sánchez *et al.* 2003, Dahlgren *et al.* 2003). Dive operations were supervised by the Dive Safety Officer, with assistance from the Dive Master

Each morning tanks, gear and supplies were transferred from the *Spree* to the *Anglonamar* for the Conch Team, although on occasion the Reef Team used the *Anglonamar*. Sites were then sampled with the three Conch Team units alternating as they went from site to site, which enabled them to sample 9-12 sites per day; 3-4 dives per person per day. The Conch Team was able to sample more sites per day because their protocol called for less time spent down on each dive, on the average. Details of the sampling methods used are provided in the Conch Team report (Appeldoorn *et al.* 2003).

Team Findings, Conclusions and Recommendations

The following three sections summarize the findings of the Benthic, Fish and Conch Teams as described in Sánchez *et al.* 2003, Dahlgren *et al.* 2003, and Appeldoorn *et al.* 2003; refer to those reports for details, data, tables and figures.

<u>Benthic Team</u>

The Benthic Team identified 46 species of reef-building corals and 38 species of octocorals across the range of sites and banks sampled. The diversity of reef-building corals was similar to that of other well-developed reef systems in the region. Octocoral species diversity would have been higher if extractive sampling had been used, as many species could not be distinguished from each other visually, and so were recorded only to genus. The Octocoral community on the northern banks was similar to that of Old Providence Island, where more extensive sampling has identified 44 species, the highest octocoral species diversity in the western Caribbean (Sánchez *et al.* 1998). The highest diversity sites were on wave-protected, mid-depth habitats on the leeward zones of the banks. In many cases, almost all coral and octocoral species encountered on the Expedition could be found on very small areas of leeward-terrace reefs.

The most abundant and widespread species in the benthic communities of the northern banks, as is the case elsewhere in the Archipelago (Sanchez *et al.* 1997 1998, Friedlander *et al.* 2003a, Friedlander *et al.* 2003b) were several *Montastraea* species of reef-building corals, the octocoral *Pseudopterogorgia bipinnata*, and the fleshy macroalgae *Lobophora variegate*.

Habitats

Multivariate analysis was used to identify benthic habitats. The major contrasts that were recognized were between relatively shallow and deep habitats, or protected and exposed habitats. Although there was some correspondence between the habitats identified in this study and those identified by Díaz *et al.* 2000, there were considerable differences, suggesting that the characteristics of the benthic communities could not be completely discerned from the old, black and white, aerial photographs available to the latter study, and ground truthed only at a small number of sites. For example, based on benthic characteristics, at the broadest scale, two major clusters of sites were identified on Quitasueño, but sites associated with the first cluster type occurred within three of the Díaz *et al.* habitats.

Cluster I occurred mostly at shallow, lagoon sites with medium to high rugosity and density of *Diadema*, but lower densities/coverages of *E. viridis*, sponges and octocorals. Cluster II occurred mostly on medium to deep leeward and fore-reef sites, with the opposite biological characteristics to Cluster I. In addition, Cluster I sites had high coverages of two *Montastraea* species (*M. faveolata*, *M. annularis*), while Cluster II sites were notable for their relatively high coverage of the algae *Dictyota* and the coral *Siderastraea siderea*. Sub-clusters were readily apparent within each of the two major clusters. At some level of resolution, these clusters may correspond to habitats that might be identified by an ecological analysis. Some of the higher resolution clusters were more closely matched to the Díaz *et al.* habitats. For example, on Quitasueño, all of the sites in Cluster E occurred in Díaz's 'mixed coral' habitat. However, the reverse was not true, as many 'mixed coral' sites were in other clusters (see Figure 2 in Sánchez *et al.* 2003).

Live Coral Cover

Live coral cover varied widely among sites, habitats and banks. Mean live coral cover on Quitasueño was 33% (range 18-51%), which was much higher than on Serrana or Roncador, with means of 19% and 17%, respectively. However, the range of values on the latter two banks, 3%-52%, was even wider than for Quitasueño. The habitats were not sampled in the same proportions on the different banks. For example, fore-reef habitats on Serrana and Roncador largely were not sampled due to weather constraints, and the edge of leeward terrace was not sampled on Quitasueño, because of the size of the bank. Thus, the mean differences in live coral cover among the banks may have been due in part to the uneven sampling. Differences in live coral coverage among habitats were not consistent on the three banks, making generalizations difficult. Live coral coverages on Quitasueño compared well with the best areas in the Caribbean, but Serrana and Roncador had coverages more similar to that seen over most of the Caribbean, which has suffered a significant decline in live coral coverage over the last few decades (Gardner *et al.* 2003).

As elsewhere in the Caribbean, the effects of the loss of urchins and herbivorous fishes, dieases and hurricanes are presumed to have had an impact of the condition of the reefs in the Archipelago (Zea *et al.* 1998, Sanchez *et al.* 1998). Major impacts have been a decline in live coral cover, the loss of particular corals (e.g. *Acropora* spp.), and the proliferation of algae. Many parts of the northern banks, especially Serrana and Roncador, were found to have very high coverages of opportunistic algae (e.g. *Lobophora* and *Dictyota*). Interestingly, the highest densities of the urchins *Diadema antillarum* and *Echinometra viridis*, which may exert a strong influence on algal growth, were encountered on Quitasueño bank. As pointed out by Dahlgren *et al.* 2003, the habitat maps of Díaz *et al.* 2003 indicated the presence of a few *Acropora cervicornis* reefs, however none were found on the Expedition; one large area of *cervicornis* rubble was found on Roncador.

Site Characteristics

Comparisons of the site characteristics among the three banks uncovered a number of differences. As mentioned above, live coral cover was much higher on Quitasueño, although there was little difference in the number of coral species among the banks (somewhat higher on Quitasueño). The density of octocorals was much higher on Roncador than on the other two banks, and the number of octocoral species was lower on Serrana than on the other two. The coverage of upright sponges was considerably greater on Quitasueño than on the other two banks. And, the coverage of opportunistic algae was much higher on Serrana and Roncador, than on Quitasueño.

Coral diseases, especially white plague, were most common on Serrana. White plague disease was most prevalent in the lagoonal habitats on Serrana Bank, especially in the semi-enclosed basins at the northern and eastern ends of the bank. A sizeable outbreak of white plague at the northern end of Serrana sampled on two occasions during the Expedition, may have been related to outbreaks observed elsewhere in the western Caribbean at roughly the same time; see Sánchez *et al.* 2003 for details. White plague and other problems, such as bleaching and dark spots, were observed at a number of sites spread across all three banks.

In general, Roncador and Serrana stations were more similar to each other than those on Quitasueño. It is not certain what the differences among the banks mean, but it is clear that they have differentiated, which suggests that they cannot be viewed as replicates of each other and must be managed and protected separately.

Special Areas and Species

Sánchez *et al.* (2003) defined areas with high coral abundance and diversity as those with live coral cover greater than 32%, density of octocorals greater than 0.6 colonies/m^2, and more than 16 species of corals and 4 species of octocorals. Using these criteria they identified several clusters of sites with high coral abundance and diversity (see Table 8 in Sánchez *et al.* 2003), which may deserve special consideration when considering the zoning of the MPA. They noted that most of these areas were found on Quitasueño. However, an area was found in the lagoon and leeward margin of Roncador that had the highest gorgonian density yet recorded in the Colombian Caribbean (up to 22 colonies/m^2) and a high coverage of corals (42%). In general, the areas of high coral and octocoral abundance and diversity occurred in the *Montastraea* or 'mixed corals' habitats of Díaz *et al.* (2000), and were distributed across the leeward terraces, lagoonal basins, and fore-reef terrace on Quitasueño (this habitat was largely unsampled on the other banks).

Some species were given special consideration because of their rarity or vulnerability to environmental stresses. Sánchez *et al.* (2003) noted the mass mortalities suffered by the sea fans (*Gorgonia ventalina* and *G. flabellum*) within the region, and that they are scarce elsewhere in the Archipelago (Sánchez *et al.* 1997, Zea *et al.* 1998, Sanchez *et al.* 1998). Earlier surveys found that the fore-reef terraces of Serrana and Roncador appeared to be unaffected by the sea fan mortality and had some of the highest abundances recorded in the region. Unfortunately, weather prevented the Expedition from reaching those areas. Nonetheless, those habitats warrant special consideration and further examination based on the previous findings. In some parts of Colombia, harvesting of octocorals for use in handicrafts has extirpated local populations. Because the practice of using octocoral axes in native handicrafts occurs in the Archipelago, attention should be paid to the extent and potential impact of this practice. For this reason and because of the potential importance of octocorals to the pharmaceutical industry, areas of high octocoral abundance and diversity should be considered for protection.

Two areas with a high diversity and abundance of reefs in small areas were found in the lagoonal basins at the eastern and northern ends of Serrana bank. These areas were characterized by an extensive reticulated network of *Montastraea* patch reefs, as well as healthy *Acropora palmata* reefs (sometimes co-occurring with *A. cervicornis* and *Porites furcata*). As noted earlier, one of these areas was also the site of an outbreak of white plague disease affecting a large number of coral species and a large portion of the coral tissue. Thus, these areas may also require further examination and special consideration in the zoning process. As well, similar areas on Quitasueño and Roncador that received relatively little sampling may warrant further examination.

<u>Fish Team</u>

The Fish Team surveys recorded 190 species of fish from 43 families, representing 80% of the total fish fauna known from the Archipelago. One new species for the Archipelago, the reef butterfly fish (*Chaetodon sedentarius*), was recorded at two sites, one on the shallow fore-reef of Quitasueño and another on a shallow patch reef on Serrana. The most abundant fishes recorded on the Expedition were the wrasses *Thalassoma bifasciatum* and *Halichoeres garnoti*, the parrotfishes *Sparisoma viride* and *Sparisoma aurofrenatum*, and several damselfishes (Pomacentridae). Overall, fish species richness and diversity on the northern banks were high compared to other areas of the Archipelago and Caribbean.

The reef-associated fish community of Quitasueño, Serrana, and Roncador had a high species richness and diversity compared to other parts of the San Andres Archipelago and other parts of the Caribbean where similar techniques have been used to survey fish.

Biodiversity

A number of differences were found in community composition among habitats and banks. Fish species richness and diversity on lagoonal patch reefs were significantly lower on Roncador than on the other banks, but on the leeward margin the lowest species richness occurred on Quitasueño. The only cluster of sites with high species richness and diversity on Quitasueño was found near the southern end of the bank in back-reef and lagoonal habitats. In contrast, some of the sites with the lowest species richness were found on the adjacent fore-reef at the south end. In general, however, no small-scale biodiversity ‘hotspots’ were identified on any of the banks, making it difficult to identify particular spots for protection.

On Serrana, the highest species richness occurred along the leeward margin and on lagoonal patch reefs. *Acropora palmata* reefs had the lowest species richness and diversity.

Because of the lower sampling effort expended on Roncador and the constraints imposed by high winds, the only comparison possible was between lagoonal patch and leeward-margin reefs. The latter reefs had the highest species number. No geographic sections of the reef had higher species richness or diversity than others.

Community Composition

Community analysis using multivariate techniques identified sampling stations most similar to each other, and the clusters of those sites that were maximally differentiated. Five of seven clusters of lagoonal patch reefs were composed of sites from the same bank, suggesting a high degree of differentiation between banks, for this habitat at least, as well as differences within banks. Within the clusters covering more than one bank, sites from the same bank tended to cluster together, perhaps indicating that inter-bank differences were more important than intra-bank differences.

Leeward-margin reefs separated into two distinct clusters, one composed of sites from Quitasueño and the other from Serrana and Roncador. This pattern may have reflected actual differences between the banks, but may have been affected by sampling bias. The leeward-margin sites sampled on Roncador and Serrana were placed at or close to the dropoff with high-relief wall features, but those on Quitasueño were placed on leeward terrace some distance from the dropoff. In contrast, the several *Acropora palmata* reef sites on Serrana, and the one on Roncador, were very similar to each other.

The two fore-reef sites on Serrana were considerably different from those on Quitasueño, and there was some differentiation of the shallow and deep fore-reef sites within Quitasueño. In addition, there was some evidence that proximity to the channels through the barrier reef, which connect fore-reef with back-reef and lagoonal habitats, had an effect on the degree of differentiation of fore-reef sites.

Trophic Groups

The differences in community composition illuminated by multivariate analysis were related to composition at the trophic-group level. For example, benthic carnivores were most abundant on leeward-margin and lagoonal patch reefs, herbivorous fishes were least common in fore reef habitats (at least on Quitasueño), and *Acropora palmata* reefs were recognizable by having a different representation of planktivores, generalist carnivores, omnivores and spongivores. Large differences were detected for some groups among banks, but the differences were not consistent across habitats.

In general, lower trophic-level groups (for example, herbivores, planktivores and omnivores) dominated the northern banks, at least for the shallow depths (less than 30m) sampled on the Expedition. Although this is not an uncommon phenomenon, the low abundance of higher trophic level fishes, e.g. piscivores and carnivores (including sharks and barracudas) may be indicative of overfishing.

Differences in community composition among habitats within banks also were idiomatic, although comparisons were complicated by the uneven sampling of different habitats on the three banks.

On Quitasueño, the trophic-group composition was similar and the most even on leeward-margin and lagoonal patch reefs. Most trophic groups were also well represented on the deep fore-reef, although generalist carnivores and planktivores were much more common than on the former two habitats. However, shallow fore-reef sites showed a very different composition from any of the other habitats, being dominated by benthic carnivores, planktivores and herbivores, with the other trophic groups almost being absent.

On Serrana, the two shallow fore-reef sites had a very similar trophic-group composition to the same habitat on Quitasueño. However, the compositions on leeward-margin and lagoonal patch reefs were different from those on Quitasueño. Most of the trophic groups were well represented on the leeward-margin reefs, but unlike Quitasueño over 50% of the fish were planktivores. Lagoonal patch reefs had lower numbers of benthic carnivores and herbivores, but higher numbers of planktivores. The *Acropora palmata* habitats were dominated by benthic carnivores, herbivores and planktivores, with most other groups being under-represented or almost absent.

On Roncador, the trophic-group composition on lagoonal patch reefs was quite similar to that on Quitasueño. In contrast, the leeward-margin reefs were very similar to those on Serrana. The single *A. palmata* site was similar to those on Serrana, but with many fewer benthic carnivores and more planktivores

Focal Species

Groupers – Because of the economic importance of some fish species (e.g. groupers; Family: Serranidae), their patterns of distribution and abundance were examined where permitted by the data. Overall, the three most abundant groupers were the coney (*Cephalopholis fulvus*; 43% of all groupers), the graysby (*C. cruentatus*; 29%), and the red hind (*Epinephelus guttatus*; 19%). The graysby was seen at over half of all sites, making it the most widespread grouper. In terms of biomass, the pattern was similar but large-bodies species, such as *E. guttatus* and the tiger grouper (*Mycteroperca tigris*) accounted for a significant proportion of the biomass (32% and 13%, respectively).

Differences in grouper densities and biomass did occur amongst banks within habitat types. For example, grouper densities and biomass in lagoonal patch reefs were greatest on Serrana, with Quitasueño and Roncador showing little difference. In contrast, densities on leeward-margin reefs were much higher on Roncador than either of the other banks, which did not differ from each other.

For all three banks combined, there were not any differences amongst habitats in abundance, but leeward-margin reefs had the highest grouper biomass. Lagoonal patch reefs and shallow fore-reefs had intermediate grouper biomass, and deep fore-reef and *Acropora palmata* reefs had much lower biomasses.

Differences in biomass were contributed by differences in abundance, but also by the mean size of individuals, perhaps indicating the influence of processes such as fishing and recruitment. Comparisons of the sizes amongst banks of the three most common groupers did not reveal consistent patterns. Coney were largest on lagoonal patch reefs, leeward-margin reefs and on Roncador. On the other hand, graysby on lagoonal patch reefs were significantly larger on Serrana and Quitasueño, but no other significant differences were found. Finally, the red hind showed another pattern, with no significant differences except that Quitasueño had smaller individuals that the other banks, apparently because the mean size on shallow fore-reef sites was low.

In general, the density and biomass of groupers on the banks were low compared to areas elsewhere in the Caribbean that are protected or experience a low fishing pressure, which may indicate that populations of groupers are overfished on the northern banks. This possibility is supported by the fact that the smaller species tended to be the most common.

Parrotfishes – The parrotfishes *Sparisoma viride* (stoplight) and *S. aurofrenatum* (redband) were abundant on all three banks, but displayed significant differences between habitats. Stoplight parrotfish were most common on *A. palmata* and lagoonal patch reefs. Interestingly, the mean size of *S. viride* showed the complementary pattern – smallest in those two habitats. Redband parrotfish showed another pattern, with higher biomasses occurring on lagoonal patch than *A. palmata* reefs; the other habitats were intermediate. Biomass differences also occurred between banks for this species but not in the same manner for lagoonal patch reefs and leeward-margin reefs, and appeared to be due to size differences.

Hamlets – The northern banks displayed a high diversity of hamlet species (genus *Hypoplectrus*) and color morphs, making the region an area of special concern for the conservation of this group.

Red Listed species – Several red-listed species are known to have occurred in the Archipelago. On the Expedition, the goliath grouper (*Epinephelus itajara*) and cubera snapper (*Lutjanus cyanopterus*) were never observed, and the Nassau grouper (*E. striatus*) was seen just once on Quitasueño. The absence or near absence of these species could be an indication of poor habitat quality and/or overfishing. Likewise the rainbow parrotfish (*Scarus guacamaia*) was seen just once on Serrana. Queen triggerfish (*Balistes vetula*), however, were the most common of the triggerfish seen on the Expedition, which may be a result of low spearfishing pressure and, perhaps, the importance of the Archipelago to this species. Hogfish (*Lachnolaimus maximus*), another spear-fishing species, was found at a number of sites on all three banks. Sharks, a group sensitive to fishing pressure, were widely observed, but all but two sightings involved a single species, the nurse shark (*Ginglymostoma cirratum*).

Given the intensity of sampling effort on the Expedition, lobster (*P. argus* and *P. guttatus*) densities appeared to be very low, possibly indicating intense fishing pressure, at least in the shallow habitats sampled. As well, very few sea turtles were encountered, which may also be due to overfishing. It has been reported that foreign shark longliners have caught sea turtles for use as bait.

Conch Team

Queen conch (*Strombus gigas*) is an important fisheries species in the Archipelago, but since the large increases in industrial fishing in the late 1970s, the populations have declined significantly. Comparison of the age structure on the northern banks with that from areas with known histories of exploitation, supports a hypothesis that these populations have experienced considerable fishing pressure possibly over a long period of time. Intense fishing pressure on Quitasueño has resulted in seasonal closures of the fishery.

Quitasueño

In general, queen conch densities were low throughout Quitasueño, and comparable of those typical of overfished regions that can at most support very low levels of fishing (Figure 6). Despite the presence of apparently suitable habitat, conch were not found across a large part of the leeward deep terrace and central lagoon (see Figure 4 in Appeldoorn *et al.* 2003). The highest densities encountered were in back reef areas. Juveniles were absent from the central and southern parts of the bank. Although adult conch were fairly large, the densities of small conch were very low, which may be indicative of poor recruitment recently. Only one instance, by a single individual, of spawning was recorded, but it was early in the year for spawning. Quitasueño may be capable of conch production, but at a greatly reduced capacity relative to optimally sustainable yield levels. It is possible that further declines in the population could produce a long-term collapse.

Serrana

The characteristics of the conch population on Serrana were in general quite different. Although few conch were encountered in center of the bank or on the leeward slope, very high densities were found in the area of sandy substrates along the southwest margin of the bank, and in the channel running between two cuts in the southern barrier reef. The former area was populated mostly by adults, and the latter by juveniles. Adult conch on Serrana, although more abundant, were smaller on the average than those on Quitasueño. Also there was evidence of consistent recruitment of juveniles to the adult class, and a full range of ages in the population. Spawning was observed on two high-density sites. Overall, the densities of conch on Serrana were about 25 times those on Quitasueño, and similar to those recorded from unexploited areas or areas with very little fishing activity. Although, sampling biases may have inflated the densities estimates somewhat, it appears that the bank may be able to sustain moderate levels of fishing.

Roncador

Conch densities on Roncador were fairly even across the different habitats of the bank. The greatest densities occurred in sand area amongst the leeward slope reefs. Very few conch on Roncador were juveniles. Spawning was observed in two locations, one of which had a large aggregation of adults with many conch spawning. Overall densities on the bank were intermediate compared to those on the other banks, and characteristic of regions that already support fisheries.

Recommendations

Consideration of the age structure of conch on the banks suggests that there is little connectivity between the populations on the three banks, and, therefore, that the populations on the three banks will have to be managed separately.

Because of the very low abundance of conch on Quitasueño, their absence from large areas of the bank, and the very low densities of juveniles, closure of the bank to conch fishing should be strongly considered. Experience with populations of conch elsewhere suggests that given these characteristics it could take over 10 years for the population to recover.

The establishment of marine reserves, at least in part for the management and protection of conch, can be accomplished through the use of a few general principles. Because back-reef terrace and adjacent lagoonal areas are known to be the most important nursery areas, these habitats should be well represented in any reserve design. Adjacent or contiguous areas stretching across the lagoonal basin to the leeward margin of the banks should be included to provide access to spawning habitat. Because currents and eddies moving around the ends and through cuts in the barrier reefs are expected to be important for the recruitment of larvae, these and adjacent areas should be included in the reserve design. Ribbon reefs should also be included in the reserves, as this habitat is important as a site of settlement and juvenile development. On Serrana, the large abundance of adult and juvenile conch on the deep sand terrace on the western side of the bank may warrant protection. Finally, on Roncador, consideration should be given to including those areas where significant spawning activity was encountered.

Zoning Recommendations

The MPAs proposed for the Archipelago will include three areas. The northernmost of the three areas will include the northern banks of Quitasueño, Serrana and Roncador, as well as other areas. Within each MPA as many as five different types of zones will be established: 1) 'no-entry', where use is restricted to research and monitoring, 2) 'no-take', allowing a variety of non-extractive uses, 3) 'artisanal fishing', for use by traditional fishers only, 4) 'special use', for areas identified during MPA planning, particularly where a high potential for conflicts exists, like ports, marinas, or heavily used recreation areas, and 5) 'general use', where basic restrictions apply to protect water quality and preserve MPA system integrity. It is important to recognize that the first two types of zones ('no-entry' and 'no-take') are intended to be permanent closures to all restricted activities. With respect to fishing, they would apply to all forms of fishing and to fishing of all species. In particular, these zones should not be confused with fisheries closures, which are typically short lived (e.g. seasonal) and focused on one or few species or gear types. Based on the findings from the Expedition we are able to make recommendations regarding the zoning of the northern banks and adjacent waters. These recommendations almost exclusively reflect a consideration of the environmental, ecological and resource-based characteristics of these areas. For the most part, we did not take into account, except in a peripheral and non-quantitative fashion, considerations of other factors such as the type of fishing taking place on and around the northern banks, the distribution and intensity of fishing effort, the socioeconomic impact of closing areas on local, regional, national or international stakeholders, or on issues associated with management, surveillance, compliance or enforcement. Because one main purpose of the MPAs is to protect and restore the environments, habitats, communities and resources of the areas, and because there is not sufficiently precise scientific information to specific different levels of protection (e.g. no-entry versus no-take versus artisanal only), here we will make recommendations for the areas that should receive conservation protection, which are assumed to be at least no-take. With the inclusion of additional data, the remaining open areas could be partitioned between the ‘artisanal’ and ‘general’ categories, and parts of the ‘no-take’ areas could be designated as ‘no-entry’.

We clearly recognize that these zoning recommendations are not unique nor optimal, in the sense of being the product of a quantitative optimization procedure. A different weighting of the perceived benefits and costs, and tradeoffs of protecting one component over another, may have produced different zoning recommendations. We consider these recommendations to be the options identified by the authors as ‘most favororable’ given the factors we considered.

Principles

In selecting areas to recommend for no-take protection, we applied a number of principles and specific criteria. Three principles generally accepted as being key to the success of a multiple-zoned MPA or network of MPAs are that the areas are representative, sustainable and replicated.

<u>Representativeness</u> – Areas that are representative will contain a reasonably complete, and proportional, cross-section of the diversity of geomorphological zones, habitats, communities and species found in the area being considered for protection. Of course, because of the normal distributional patterns of these elements of natural environments it is not possible to capture a completely representative sample within any one area or set of sub-areas. Some elements will be left out – for example it will usually be impossible to include all species found in the region, unless one is perhaps considering only a particular small group of organisms. In addition, given that no areas are completely homogeneous and because biological distributions are dynamic, it is not possible to capture the elements precisely in amounts proportional to their actual occurrence in the region. Nonetheless, representativeness is an ideal against which the quality of a protected area can be assessed. Often protected areas are selected so as to maximize the number of elements (e.g. species or habitats) that they contain.

<u>Sustainability</u> – Areas selected for protection should be large enough alone or in aggregate so that the protected populations will persist indefinitely. First areas must be of sufficient size to provide the habitats (e.g. nursery areas, hiding places, spawning sites) and resources (e.g. prey species) required by the species being protected. Second, areas must be large enough to contain populations large enough to persist in the face of environmental uncertainty, various stresses, and genetic drift. Third, reproduction in some species may be dependent on the population size or density being large. At very low population sizes or

densities reproductive performance may fail or decline disproportionately, a phenomenon known as the 'Allee Effect' (Allee 1931). For example, spawning activity may be disproportionately low, perhaps because encounter rates are too low (mates may be difficult to find), inter-individual distances are too large in the case of sessile or limited-mobility species with external fertilization, densities are too low for sufficient social interaction to occur, or sex ratios are too skewed. In addition, there must be a source of recruits to the population if it is going to persist. If there is not an external source of recruits, e.g. another reef system, then the populations in the protected area must be self-sustaining, retaining enough recruits from its own reproduction to replace the normal losses to mortality.

Replication – Because large-scale environmental and human impacts can lead to the extirpation of local populations, it is important to create multiple representative areas that each alone, or together as a network, are sustainable. A critical habitat or endangered species that was protected in just one area could be lost to a single event such as a hurricane or oil spill, which would be less likely to happen if they occurred in more than one protected area.

Thus, in proposing zones for protection we tried to place the zones where they would protect as much of the habitat and species diversity as possible, to ensure that they were not too small, and to ensure that as many elements as possible were contained in more than one zone. In addition, we used other criteria in the selection process.

- *Geomorphology*. Where possible we placed zones across the breadth of a bank from windward fore-reef to leeward terrace or drop-off. This was done to include a broad range of geomorphological features on, and adjacent to, the banks.
- *Deep water*. Although all of our sampling was conducted on the bank platforms above a depth of 100ft, we have included deep-water portions off the bank, roughly to a depth of 300m (1000ft). These portions were included because it is known from other studies in the Caribbean, and fisheries information from the Archipelago, that habitats and species occur in deep water that are not found in the shallow water where we sampled.
- *Size and Boundaries*. Because of the remoteness of the northern banks, and the fact that many fishermen would not have the most sophisticated electronics, only rectangular-shaped zones oriented east-west and north-south were selected.
- *Diversity*. In general, selecting zones that meet the 'representativeness' principle was achieved by drawing boundaries so that most of the habitat and fish-community types, which were identified by multivariate analyses of the benthic and fish data collected at each station, were included.
- *Hot spots*. Relatively small areas with especially high abundances of important species (e.g. economically important, endangered or vulnerable), or diversity of species or habitats were included whenever possible.
- *Special Sites*. When special or unique sites or features were located they were included in zones proposed for protection when possible. Examples of such features are nursery habitats, reef-building species (e.g. *Acropora* or *Montastraea*), seagrass meadows, and larval settlement habitats.
- *Conch Production*. Areas in which there are high densities of juvenile conch, indicating good settlement, and/or high densities of adults, indicating good conditions for survival

and growth, are considered to be critical to the viability of conch populations. Some areas of high juvenile and/or adult density were included to ensure that a basis for continuous production was protected.

- *Conch Spawning.* An effort was made to include areas in which conch spawning was observed, which may or may not have been coincident with conch production areas. Because the Expedition was conducted very early in the conch-spawning season, any amount of spawning was considered to be potentially important.
- *Ends.* Experience elsewhere, as well as the data from this cruise, has demonstrated that the ends of the barriers reefs of oceanic banks and atolls are especially important, often containing a high diversity of species and habitats, significant abundances of important species, as well as being areas of settlement of conch and other pelagic larvae, which are swept around the ends of the reef by eddies and deposited on back-reef or lagoonal habitats. Therefore, both ends of the barrier reefs of all three banks were included in proposed 'no-take' zones.
- *Cuts*. Many studies have also shown cuts (channels) through barriers reefs to be important areas for the exchange of nutrient water between the lagoon and fore-reef, settlement of pelagic larvae (including conch), and for the movement of individuals. No cuts occur along the relatively short barrier reef on Roncador, but several can be found on the other two barrier reefs, and we tried to include at least one on each bank in a 'no-take' zone.

Statistical analyses of the benthic, fish and conch data showed clearly that each bank was different, and that they could not be considered replicates of each other. Sites within the same zone or 'INVEMAR habitat' (Díaz *et al.* 2000) were usually more similar within banks that between banks. Therefore, the selection of potential protected zones using the principles and criteria just described was carried out independently on each bank.

Zone Selection

We started the process of selecting candidate zones with a consideration of the aggregations of benthic and fish sites identified by cluster analyses (Sánchez *et al*. 2003, Dahlgren *et al.* 2003). These clusters of sites can be interpreted as benthic habitats and fish communities, although they may not show a close correspondence to such structures identified by other processes (e.g. the INVEMAR habitats, Díaz *et al.* 2000). They provide one possible classification of the variation in benthic or fish-community characteristics, and can be used to describe and partition the biodiversity found on the banks. The zones suggested for protection by this first step were then modified as required based on a consideration of the other criteria described above (e.g. hot spots, special sites, conch production areas, etc.).

Each option for the placement of 'no-take' zones is presented in a single figure. A single option may contain several areas that would receive 'no-take' status. The remaining parts of a bank would be placed in the other zone types, probably a combination of 'general use' and 'artisanal fishing' zones, but those choices would be made at subsequent steps in the zoning process using a combination of the data presented here, fishing data and socio-economic data. The boundaries of the recommended 'no-take' zones have been placed only roughly. The final placement would need to take into account issues associated with their use by fishermen, and surveillance and enforcement agencies.

Quitasueño – One option for protection of the resources of Quitasueño is composed of three 'no-take' zones, one at each end and another in the middle (Figure 7). Other designs, may meet the same criteria, but this was simplest of several that were examined. The features that would be protected by this design are as follows:

- *Geomorphological and special sites* on Quitasueño of interest are the ends of, and cuts in, the barrier reef (Figure 7), the *Acropora palmata* reefs (red habitat on Figures 3 & 7; many of which are in the distinct 'ribbon' formation), the highly unusual stations 4 and 22 (Figure 8), and seagrass habitats encountered around station 22 and at a back-reef site (36) near the center of the bank (Figure 8). Each of these features was included in one or more of the proposed 'no-take' zones.
- *The diversity* of benthic habitats and fish communities is displayed in Figure 8. Cluster analysis of the benthic coverage information for corals, other invertebrates, and algae for Quitasueño identified six major groups of sites that can be interpreted as sharing particular, unique combinations of benthic characteristics and, therefore, can be treated as separate benthic habitats (Figures 2 and 6 in Sánchez *et al.* 2003). Station 22, a leeward-margin reef site, did not group with any of the other clusters. The similar analysis of the fish data identified five major groups of sites on Quitasueño, which can be interpreted as separate fish communities (Figure 7 in Dahlgren *et al.* 2003). Two clusters were composed mostly of sites on the fore-reef, one cluster was composed exclusively of lagoonal patch-reefs, and two others contained sites from lagoonal patch reefs and leeward-margin reefs. One site on the fore-reef (Q4) and another site on a leeward-margin reef (Q22) were not sufficiently similar to any other sites to be included in any of these clusters. The benthic and fish clusters are combined in Figure 8 to create 16 'benthos-fish associations', including the unique combinations at stations 4 and 22. Some fish clusters were associated with just two benthic clusters (e.g. the gray, green and blue circles), whereas one fish cluster (dark yellow) was widely spread, being associated with five of six benthic clusters. As described above, it is immediately apparent that the ends of the bank are areas of a high diversity of associations (Figure 8). Five of six of the sites at the far north end of the bank had different benthic-fish associations, and three of the next four sites to the south were different from those. At the south end, eight of ten sites were different. Combined, the extreme ends of the bank contain 11 of the 16 habitat-fish associations, and including the next four stations from the north end, added 3 more combinations. The final two combinations occurred in the center of the bank. The proposed 'no-take' zones, in total, capture the full diversity of benthos-fish associations found on the bank.
- *Hot spots* were discovered from an examination of both the benthic and fish data. Figure 9 shows the fish-species diversity on the bank, and reveals a distinct difference between the north and south ends of the bank. All of the highest fish-diversity sites occurred on the southern half of the bank, several at the south end and others in back-reef and fore-reef sites north along the barrier reef. Likewise, an examination of live coral cover, coral species richness, octocoral density, and octocoral species richness revealed that the sites immediately north of the south end contained some of the highest quality benthic habitats

(Figure 10). Therefore, the northern boundary of the southern-most protected zone was placed far enough north to encompass some of these sites. Finally, mapping the distribution of commercially important groupers and snappers (Figure 11) confirmed that the ends and back-reef habitats were important areas for fish.

- *Conch production areas* were found in two locations on the bank (Figure 12; taken from Appeldoorn *et al.* 2003) – at the northern end and in back-reef habitats near the cuts in the north-central part of the barrier reef. The former areas were included in the northernmost no-take zone, and the latter partially included in the mid-bank 'no-take' area. The southern end contained sites with relatively high densities of juveniles, indicating the presence of important settlement areas, and reinforcing the importance of the 'no-take' zone placed at the southern end.

Thus, the three zones together were chosen to capture the range of benthic-habitat and fish-community diversity found on the bank. In addition, each of the 'no-take' zones captured specific features:

- Northern 'No-take' Zone
  - High diversity of benthic-habitat/fish-community associations
  - *Acropora* ribbon and patch reefs
  - Conch production areas
  - Station 22
  - Some relatively good areas for snappers and groupers
- Mid-bank 'No-take' Zone
  - Barrier reef cuts
  - Leeward margin with steep wall habitat
  - Conch production areas
  - Seagrass habitat around Station 36
  - Back-reef sites with relatively high densities of snappers
  - Presence of some lobster
- Southern 'No-take' Zone
  - High diversity of benthic-habitat/fish-community associations
  - *Acropora* ribbon reefs
  - Conch settlement area
  - Station 4
  - High reef-quality area (as measured by coral, octocoral and fish abundance and species diversity)

While this option would protect many of the features, habitats and areas of conservation importance on the bank, it does leave some elements outside the proposed 'no-take' zones. Examples of elements excluded from proposed design were:

- the cut in the barrier reef in the southern half of the bank;
- a portion of the area of high benthos-fish association diversity in the north;
- a portion of the area of high reef quality in the south; and
- an area with a very high diversity of hamlets, which fell between the northern and central zones.

Serrana – Option 1 for the protection of the resources of Serrana is composed of four 'no-take' zones (Figure 13). The features that would be protected by this design are as follows:

- *Geomorphological and special sites* on Serrana shown in Figure 13 are the ends of the barrier reef at the southwest corner and northern peak of the bank, the cuts in the barrier reef on the south and north sides, and the channel running between the two cuts on the south side. Critical habitats are the large areas of *Montastraea* reefs, the numerous *Acropora* patch reefs between the two cuts on the north and south sides of the eastern end, and the *Acropora* ribbon reefs in the north central part of the lagoon and in the northern peak of the bank. Two conch stations within the proposed south-central 'no-take' zone, which were in the 'algal mat' habitat of Díaz *et al.* 2000 (Figure 3), were reported to have high densities of larval fish, indicating that the 'algal mat' habitat may be important as larval-fish settlement habitat. For that reason, a portion of the 'algal mat' habitat was included in the south-central 'no-take' zone. Finally, the two patches of 'encrusting coral' habitat (Díaz *et al.* 2000), a fore-reef habitat (Figure 3), along the leeward margin of the bank, are highly unusual, and, therefore, candidates for protection.
- *The diversity* of benthic habitats and fish communities is displayed in Figure 14. Cluster analysis of the benthic coverage information for corals, other invertebrates, and algae for Serrana identified 5 major clusters of sites (Figures 3 and 18 in Sánchez *et al.* 2003). Station 1, a shallow-water site adjacent to the southeast cay at the end of the barrier reef, was most like the sites in one subset of clusters but different enough that it was not joined with any of them. The similar analysis of the fish data identified five major groups of sites or fish communities on Serrana (Figure 16 in Dahlgren *et al.* 2003). The largest cluster of sites was composed solely of lagoonal patch reefs, another cluster was made up of the leeward-margin reefs sites, two other clusters included all of the *Acropora palmata* reefs, and the final cluster was composed of a mixture of lagoonal patch reefs and the only two shallow fore-reef sites surveyed on Serrana. One lagoonal site (station 6) was dissimilar from all other sites. The benthic and fish clusters are combined in Figure 14 to create 13 'benthos-fish' associations, including the unique combinations at stations 1 and 6. Some associations were confined to one habitat or geographic part of the bank. For instance, all of the blue-circle/green-triangle associations were found along the leeward margin, or all of the pink-circle/green-triangle associations occurred on lagoonal patch reefs at the eastern end of the bank. Other associations (e.g. pink-circle/blue-triangle) were found spread around the bank. The INVEMAR habitat maps (Figure 13; Díaz *et al.* 2000) suggested a high degree of habitat diversity in and around the lagoonal basin at the northern peak of the bank. The benthos-fish associations confirmed this pattern (four associations out of six sites), but not to the degree seen at the barrier-reef ends on Quitasueño. Overall, the diversity of benthos-fish associations is captured by the four 'no-take' zones in aggregate – all but one of the associations occurs within or immediately adjacent to the proposed 'no-take' zones.
- *Hot spots* were discovered from an examination of fish data; none were found in the benthic data. A generally higher species diversity was recorded on the western half of the bank (Figure 15). Most of the highest fish-diversity sites occurred on southwestern part of the bank or just to the south of the basin at the northern peak; the former, but not the latter was captured in proposed 'no-take' zones. As on Quitasueño, no sites had significant numbers of groupers (Figure 16). Larger numbers of snappers were found at

some sites. The largest concentrations of snappers were recorded at the eastern end of the lagoon and along the leeward margin, with some of these areas captured within two of the proposed ‘no-take’ zones.
- *A conch production area* was found in the southwest quadrant of the bank, and an important conch settlement area was discovered around the south-central cut and in the channel between the two southern cuts in the barrier reef (Figure 17; taken from Appeldoorn *et al.* 2003). Both zones were included in proposed ‘no-take’ zones.

These four ‘no-take’ zones together were chosen to capture the range of benthic-habitat and fish-community diversity found on the bank, and, in addition, the individual zones captured the following specific features:

- Northern peak ‘No-take’ Zone
  - Barrier reef end
  - Moderate diversity of benthic-habitat/fish-community associations
  - *Acropora* ribbon reefs
  - *Montastraea* reefs
  - Some of the few areas with lobsters
- Eastern basin ‘No-take’ Zone
  - Barrier reef cut
  - *Acropora* ribbon reefs
  - *Montastraea* reefs
  - Some of the few areas with lobsters
- Southern cut and channel ‘No-take’ Zone
  - Barrier reef cut and channel between cuts
  - Conch settlement area
  - Larval fish habitat
- Southwestern ‘No-take’ Zone
  - Barrier reef end
  - Conch production area
  - Unusual sites (stations 1 and 6)
  - Hot spots for snapper
  - Special habitat - ‘encrusting corals’ on the leeward margin

This option was designed to protect as many features, habitats and areas of conservation importance as possible. However, because of the size and complexity of the bank, it was not possible to include all of the important elements. Examples of elements excluded from the proposed design were:

- one of the three major cuts in the barrier reef;
- a broad area of sand and patch-reef habitats in the northwestern part of the bank that had relatively high densities of conch, patch reefs with high fish-species diversity, and was one of the only places where many lobster were recorded; and
- much of the ‘algal-mat’ habitat that may be an important settlement habitat for larval fish.

Option 1 is complex, containing four separate zones, which could make it difficult for the fishermen and the management and enforcement agencies to work with. Therefore, we considered alternate, less complex designs. To provide a clear contrast between Option 1 and simpler designs, we constructed Option 2 (Figure 18). Option 2 simply creates one ‘no-take’ zone on the northern ‘half’ of the bank, while leaving the southern half open. The main advantage of Option 2 is its simplicity. It has disadvantages in that it does not provide protection for the southwestern corner of the bank, or the area around the southern cuts and the channel between them. Values lost would be the conch settlement and production areas in the southern half, some of the diversity of benthos-fish associations, and some of the areas with highest fish-species diversity. Other similar options could be considered (e.g. making the southern, eastern, or western half alone a ‘no-take’ zone), but similarly each would leave important features unprotected.

Roncador – Option 1 for the protection of the resources of Roncador is composed of two ‘no-take’ zones (Figure 19). The features that would be protected by this design are as follows:

- *Geomorphological and special sites* on Roncador shown in Figure 19 are the ends of the barrier reef at northern and southern ends of the bank. Although, the ends of the bank were not sampled because of poor weather, they were included in proposed ‘no-take’ zones based on their importance on the other two banks. Critical habitats are the large area of *Montastraea* reefs in the central part of the lagoon, the numerous *Acropora* patch reefs interspersed with the *Montastraea* reefs, and the *Acropora* ribbon reef in the southern part of the lagoon.
- *The diversity* of benthic habitats and fish communities is displayed in Figure 20. Cluster analysis of the benthic coverage information for corals, other invertebrates, and algae for Roncador identified 3 clusters of sites (Figures 4 and 32 in Sánchez *et al.* 2003). The similar analysis of the fish data also identified three major groups of sites or fish communities on Serrana (Figure 16 in Dahlgren *et al.* 2003). The benthic and fish clusters combined to create seven ‘benthos-fish associations’. Some associations (e.g. yellow – blue, or orange – blue) were associated with one part of the bank, while others were spread widely (e.g. orange – red), and some were represented by just one site (e.g. green – red, or blue – green). As on the other banks the proposed ‘no-take’ zones were selected in part to try to capture the full range of benthos-fish associations – four of the seven are included in the northern zone, and six of the seven are included in the southern zone (two are in common).
- *Hot spots* were found with respect to fish diversity and commercial species. The highest levels of fish-species diversity were found along the leeward margin (Figure 21), portions of which are included in both of the proposed ‘no-take’ zones. Roncador generally had higher densities of large groupers and snappers than the other banks (Figure 22). High grouper densities were generally associated with the leeward margin, whereas high snapper densities occurred widely across the bank.
- A potential *conch production area* was found along the leeward margin of the northern half of the bank, including stations with some very old conch (Figure 23). The highest juvenile densities were found in lagoonal habitats in the central and north-central parts of the bank. Thus, the northern proposed ‘no-take’ zone would protect, at least in part, both conch production and settlement areas.

- Conch spawning aggregations were found at sites within the northern and southern proposed ‘no-take’ zones. These were the largest spawning aggregations seen on any of the banks.

These two ‘no-take’ zones together were chosen to capture the range of benthic-habitat and fish-community diversity found on the bank, and, in addition, the individual zones captured the following specific features:

- Northern ‘No-take’ Zone
  - Barrier reef end
  - Conch production, settlement and spawning areas
  - *Acropora* and *Montastraea* patch reefs
  - Areas with relatively high grouper densities
- Southern ‘No-take’ Zone
  - Barrier reef end
  - Conch spawning area
  - *Acropora* ribbon reefs
  - *Montastraea* patch reefs

It was noted that a number of good sites, with respect to snapper and grouper densities and conch production potential occurred in the unprotected, center of the bank. We also note, because of the small size of Roncador, that the bank cannot sustain much fishing pressure. Finally, the fact that Roncador is ‘upstream’ of Old Providence and San Andrés, with respect to the dispersal of planktonic eggs and larvae, may indicate that it has an important role to play in seeding the reef systems around those islands. For these reasons, we recommend that a second option to be considered for Roncador would be to protect the entire bank by establishing a ‘no-take’ zone covering the entire bank, although perhaps not all of the surrounding deep-water areas.

These options for zoning the northern banks are generally designed to protect as much of biodiversity, habitats and resources of the area. They were proposed primarily from a consideration of the ecological state and condition of the banks, with only a minor consideration given to data and issues associated with fisheries and other socioeconomic issues. It is expected that these concerns will be integrated into the designs as part of an ongoing process of selecting zones for protection on the northern banks.

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Literature Cited

Allee, W.C. 1931. Animal Aggregation: a Study in General Sociology. University of Chicago, Chicago, Illinois.

Appeldoorn, R.S., A. Friedlander, J. Sladek Nowlis and P. Usseglio. 2003. Habitat connectivity in reef fish communities and marine reserve design in Old Providence-Santa Catalina, Colombia. *Gulf and Caribbean Research* 14(2): 61-77.

Appeldoorn, R., L. Arango, F. Cabeza, E. Castro-Gonzalez, R. Glazer, T. Marshak, and G. Peñaloza. 2003. Queen Conch Distribution and Population Assessment of the Northern Banks of the San Andrés Archipelago, Colombia. Unpublished Expedition team report to The Ocean Conservancy and CORALINA. 36pp, including tables and figures.

Caldas, J.P., E. Connolly, M.I. García, J.C. Martínez, C. McCormick, A. Mitchell, C.A. Orozco, and V. Pizarro. 2002. Southern cays expedition: short report on methods and stations description. Report to The Ocean Conservancy. 31 pp. Unpublished report.

CORALINA. 2000a. Seaflower biosphere reserve nomination document. Submitted to UNESCO Man and the Biosphere Program. Executive Summary – English. 13 pp. Unpublished document.

CORALINA. 2000b. Caribbean archipelago biosphere reserve: regional marine protected area system. Global Environment Facility Project Document. World Bank, Washington, DC, USA. Unpublished document. 78 pp.

Dahlgren, C., E. Arboleda, K.L. Buch, J.P. Caldas, S. Posada & M. Prada. 2003. Characterization of reef-fish diversity, community structure, distribution and abundance on three Southwestern Caribbean atolls: Quitasueño, Serrana, and Roncador Banks (Seaflower Biosphere Reserve), Archipelago of San Andrés and Old Providence, Colombia. Unpublished Expedition team report to The Ocean Conservancy and CORALINA. 59pp, including tables and figures.

Díaz, J.M., L.M. Barrios, M.H. Cendales, J. Garzón-Ferreira, J. Geister, M. López-Victoria, G.H. Ospina, F. Parra-Velandia, J. Pinzón, B. Vargas-Angel, F.A. Zapata and S. Zea. 2000. Areas Coralinas de Colombia. *INVEMAR, Serie Publicaciones Especiales* 5: 1-176.

Friedlander A., J. Sladek-Nowlis, J.A. Sánchez, R. Appeldoorn, P. Usseglio, C. McCormick, S. Bejarano, and A. Mitchell-Chui. 2003a. Designing effective marine protected areas in Old Providence and Santa Catalina Islands, San Andrés Archipelago, Colombia, using biological and sociological information. *Conservation Biology* 17: 1769-1784.

Friedlander A., J. Sladek-Nowlis, J.A. Sánchez, R. Appeldoorn, P. Usseglio, C. McCormick, M. Prada, and A. Mitchell-Chui. 2003b. Defining and investigating ecologically relevant habitat types as a basis for MPA zoning in San Andres Island with comparisons to habitats in Old Providence/Santa Catalina, San Andres Archipelago, Colombia. Unpublished report to The Ocean Conservancy and CORALINA.

Gardner, T.A., I.M. Côté, J.A. Gill, A. Grant, and A.R. Watkinson. 2003. Long-term region-wide declines in Caribbean corals. *Sciencexpress* 17 July 2003. 3pp.

Geister, J. and J. M. Diaz. 1997. A field guide to the oceanic barrier reefs and atolls of the Southwestern Caribbean (Archipelago of San Andrés and Providencia, Colombia). *Proceedings, 8th International Coral Reef Symposium, Panama City, Panama, 1997*. Pp. 235-262.

Sánchez, J.A., S. Zea and J.M. Diaz. 1997. Gorgonian communities of two contrasting environments from oceanic Caribbean atolls. *Bulletin of Marine Science* 61: 61-72.

Sánchez, J.A., J.M. Díaz and S. Zea. 1998. Octocoral and black coral distribution patterns on the barrier reef-complex of Providencia island, Southwestern Caribbean. *Caribbean Journal of Science* 34: 250-264.

Sánchez, J.S., V. Pizarro, A.R. Acosta, P.A. Castillo, P. Herron, J.C. Martínez, Phanor Montoya & C. Orozco. 2003. Benthic Species Distribution, Community Structure, and Condition in Three Southwestern Caribbean Atolls: Quitasueño, Serrana, and Roncador Banks (Seaflower Biosphere Reserve), Archipelago of San Andrés and Providencia, Colombia. Unpublished Expedition team report to The Ocean Conservancy and CORALINA. 87pp, including tables and figures.

Zea, S., J. Geister, J. Garzon-Ferreira and J.M. Díaz. 1998. Biotic changes in the reef complex of San Andrés island (Southwestern Caribbean Sea, Colombia) occurring over nearly three decades. *Atoll Research Bulletin* 456: 1-30.