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CORAL REEFS OF MISKITUS CAYS, NICARAGUA

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Abstract: The Miskitus Cays, on the Caribbean coast of Nicaragua, consist of eighty mangrove and two sand and gravel cays, surrounded by seagrass beds, octocoral gardens, patch reefs, reef crests, extended algae platforms, short reef walls, and two marginal reefs around the sand cays. Seventy sites were inspected and eighteen sites were selected for rapid assessments in order to determine the status of the coral reefs. Linear transects and the intercept point methods were used to determine the relative benthic cover, and the density, size and health of coral colonies was estimated following the AGRRA protocol. Water was highly turbid due to the shallowness of the reefs and high wave energy. Northwest reefs, closer to the Coco river mouth, were affected by terrestrial sediments and were overgrown by algae whereas storm damage was evident in the eastern reef crest fronts. In total, 39 stony coral species were found and 12 new species were reported for Cayos Miskitus. Mean live coral cover was high (43.4%), but it was still lower than the algae cover (54.2%). Mean coral diameter (59.7 cm) and height (4.2 cm) were high but total mortality (27.9%), bleaching (4%) and diseases (3%) were low. Reefs of Nicaragua are in the best condition of the Caribbean region of Central America but good management of the fisheries, the marine reserve, and the Coco river basin are urgent to maintain reef quality.

Introduction

The Caribbean shoreline of Nicaragua is about 463 km long with a broad continental shelf where coral reefs grow, especially in the north section (Murray et al. 1982, Hallock et al. 1988). The coast is divided into the Autonomous North Atlantic Region (RAAN) and the Autonomous South Atlantic Region (RAAS); the RAAN is mainly inhabited by the Miskitus indigenous people (USAID 1996).

Coral reefs of the Caribbean coast of Latin America are described in Cortés (2003). The Miskitus Cays Biological Reserve, created in 1991, is located 50 km from the coast, northeast from Puerto Cabezas inside the RAAN. It has a radius of 40 km around Major Miskitu Cay (14°23'N-82°46'W) totaling 50,000 ha, and a coastal and marine belt 20 km wide between Wounta and Gracias a Dios Cape. The total area of the reserve is 765,867 ha (Jameson 1996). The marine ecosystem consists of eighty mangrove and two sand and gravel cays, surrounded by a mosaic of shallow interconnected marine habitats (Alevizon 1993, Jameson 1996). The communities in the north littoral of Nicaragua, mainly Sandy Bay and Puerto Cabezas, use the area of this marine reserve for artisan fishing. Fishing for shrimp and finfish is done close to the coast, whereas lobster, shark and turtle fishing is concentrated around the cays (Harrington and Gallucci 1996, USAID 1996, Maradiaga 1998).

The first scientific study in Miskitus Cays was on algae and seagrass (Phillips et al. 1982), followed by Ogden and Gladfelter (1983) and Marshall (1984). Between 1993 and 1995 the "Ministerio del Ambiente y los Recursos Naturales de Nicaragua (MARENA)", the Caribbean Conservation Corporation (CCC) and the United States Agency for International Development (USAID) developed a preliminary management plan for the reserve where a general description of coral reefs, seagrasses and lagoons was provided. Alevizon (1993) provided qualitative descriptions of these coral reefs and their fishing resources and Jameson (1996) reported 27 coral species from this system. There are no quantitative studies in this section of the Caribbean coast of Nicaragua, although the coral reefs of Corn Island in the RAAS have been widely studied (reviewed in Ryan and Zapata 2003).

The main objective of this study was to quantitatively assess the coral reef status in Miskitus Cays in comparison with other reefs in the Caribbean coast of Central America, providing baseline data that can be used for future research and monitoring.

Materials and Methods

A rapid reef assessment was conducted in August 2001 inside the 50,000 ha around the Major Miskitu Cay (14°23'N-82°46'W; Figure 1) in order to diagnose the status of its coral reefs in terms of reef substrate cover, coral colony density, and health. In total, seventy sites recorded with GPS were inspected by snorkeling for 15 min to determine habitat type and coral species richness. These sites were assessed and distributed as follows: four to the north, seventeen to the northeast, two to the east, six to the southeast, three to the south, three to the southeast, ten to the west, and twenty five to the northwest. Of these, eighteen sites were selected for SCUBA diving and evaluation with linear transects. These were distributed as follows: one to the north, five to the northeast, one to the east, one to the southeast, three to the south, two to the southwest, two to the west, and three to the northwest. We report the site names used by the local fishermen.

Coral reefs are very shallow in this area, so three 10 m long linear transects parallel to the depth contour and separated by 5 m each were evaluated in each site at a depth between 1 and 5 m. In sites with distinguishable reef crests (crashing waves), transects were done at the base of the crest. Generally, there were no reef platforms associated with these reef crests. Reef crest complexity was estimated in Creole Bar, Toro Cay and Witties by following the contour of the bottom with a chain (Rogers et al. 1994). In sites consisting of reef patches or reef spurs, transects were done over these formations.

Along the 10 m transects, the point intercept method was used to record the relative substrate cover every 25 cm (Nadon and Stirling 2006). Corals were identified after Humann (1993), and the AGRRA protocol (Lang 2003) was used to describe adult coral colonies longer than 25 cm, including their diameter (cm), height (cm), old and recent mortality, and presence of diseases. Analysis of Variance (ANOVA) followed by Bonferroni pairwise comparisons were used to compare the relative substrate cover (%) and coral colonies density (# colonies/10 m) among sites after $\log_{10}$ transformation of the data to aid in meeting the normality and homogeneity of variance assumptions.

Results

Description of the reef habitats

The Miskitus Cays reef system is shallow (< 5 m) and consists of a series of mangrove cays (10 %), two sand and coralline gravel cays surrounded by a mosaic of extensive seagrass beds (73%) and algae, several octocoral gardens, patch reefs, and reef crests (17%) oriented from north to south. The reef system extends up to 20 km from the cays, and water visibility was low (5 to 10 m).

Seagrasses were dominated by *Thalassia testudinum* and/or *Syringodium filiforme* in sandy substrate, and they were found mainly around the mangrove cays and to both sides of the reef crests. Octocoral gardens, in sand patches or rocky bottoms, were dominated by *Pseudopterogorgia americana, Plexaura flexuosa, Gorgonia ventalina*, and some disperse colonies of live coral like *Diploria strigosa, Siderastrea siderea,* and *Porites astreoides*.

Reef crests had a mean complexity index of 1.84 at a depth between 1 to 5 m. Reef crests were formed mainly by *Acropora palmata*, most of which were dead, and *Millepora complanata*. Other dominant species were *Montastraea faveolata, S. siderea, D. strigosa, P. asteroides, Agaricia agaricites,* and *Agaracia tenuifolia*.

The windward base of the reef was up to 5 m deep and several reef bases were dominated by gardens of *Acropora cervicornis*, *Acropora prolifera* and big colonies (up to 2 m wide and high) of *M. faveolata*. In some sectors, the reef crests were adjacent to wide shallow platforms of flat carbonate rock covered by fleshy non-coralline algae, especially *Dictyota* spp., *Padina* spp., *Galaxaura comans, Sargassum natans, Asparagopsis taxiformis, Turbinaria turbinata* and *Stypopodium zonale*, with a few disperse coral colonies of *P. astreoides, D. strigosa,* and *S. siderea*. In other sectors, the reef fronts consisted of sand with seagrass beds or octocoral gardens also with low coral cover. In some reefs there were also deep walls (50 m) covered by a great diversity of reef organisms, small coral colonies and big octocorals and antipatharians, and in a few cases spurs and grooves were found at the base of these walls. Some of these crests presented an edge relatively close to the crest, with a small wall down to 16 m maximum, with complex caverns and great diversity, adjacent to sand and in some cases the seagrass *Halophila baillonis*. In the leeward side of the reef crests the substrate was usually covered by dead coral gravel, algae, octocorals and disperse colonies of

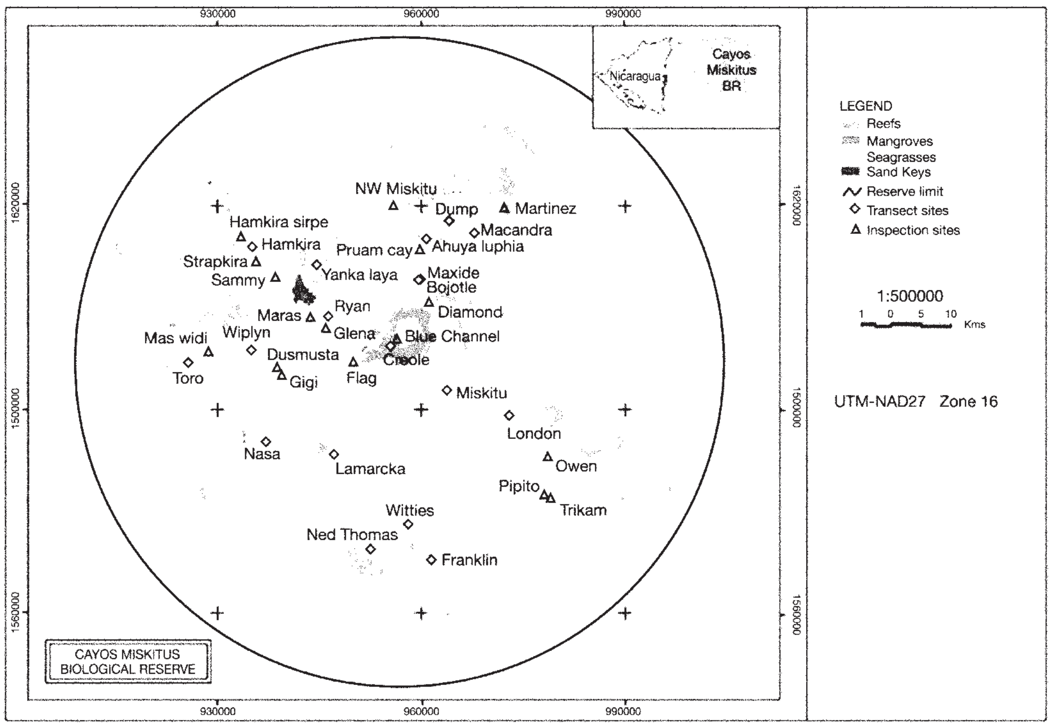

Figure 1.
Map of Miskitus Cays, Nicaragua. Transect sites have quantitative information whereas inspection sites have qualitative information (Modified from Valerio 2001). + = latitude and longitude grid points.

TABLE 1. *Damage by site and coral species (see Figure 1). Sites not listed had no damage. Codes: Black Spot Disease (BSD), White Band Disease (WBD), White Plague (WP), Black Band Disease (BBD) and White Spots (WS). Tumors = neoplasm; Damselfish chimneys = produced by damselfish bites.*

Sampling site	***Coral species (Damage)***
Bojotle Kira	*Siderastrea siderea* (BSD) *Montastraea faveolata* (BSD) *Acropora cervicornis* (WBD)
Ahuya Luphia	*Siderastrea siderea* (WP, BSD) *Acropora cervicornis* (WBD)
Martínez reef	*Siderastrea siderea* (BSD)
Dump	*Siderastrea siderea* (BSD)
Macandra	*Diploria strigosa* (Tumours) *Acropora palmata* (Damselfish chimneys)
Hamkira	*Acropora palmata* (Damselfish chimneys) *Acropora cervicornis* (WBD) *Montastraea faveolata* (BBD)
Wiplyn	*Siderastrea siderea* (BBD) *Acropora prolifera* (WBD) *Diploria strigosa* (WP)
Gigi	*Montastraea franksi* (BSD) *Montastraea faveolata* (BSD) *Siderastrea siderea* (WP, WS) *Colpophyllia. natans* (BBD)
Dusmusta	*Diploria strigosa* (BBD, Tumours, WP) *Diploria clivosa* (BBD) *Acropora palmata* (WBD) *Montastraea faveolata* (BBD)
Lamarcka reef	*Acropora palmata* (WBD)
Nasa reef	*Acropora cervicornis* (WBD) *Siderastrea siderea* (BSD) *Diploria strigosa* (BBD)
Witties	*Acropora cervicornis* (WBD) *Siderastrea siderea* (BSD)
Creole Bar	*Montastraea faveolata* (WP, BBD) *Siderastrea siderea* (BBD) *Colpophyllia natans* (BSD) *Montastraea annularis* (BSD)
Toro Cay	*Acropora cervicornis* (WBD) *Acropora palmata* (Damselfish chimneys)
Franklin reef	*Diploria strigosa* (BBD)
Ned Thomas	*Acropora prolifera* (WBD) *Siderastrea siderea* (BSD) *Acropora palmata* (Damselfish chimneys)
Yanka Laya	*Acropora palmata* (Tumours)

the corals *Siderastrea* spp., *Diploria* spp., and *Porites* spp.

Circular patch reefs, ranging from 20 to 100 m in diameter, were dispersed around the islands and were < 10 m deep. These reefs were also surrounded by sand patches and seagrass beds. There are a great number of patch reefs in the area around the cays, especially to the north near Ahuya Luphia and Bojotle Kira, to the northeast near Morrison Dennis cays (MARAS), and near Sammy, Strap Kira and Hamkira cays. Finally, there were two marginal reefs around the two sand cays in the northeast Hamkira and Hamkira sirpe. In these reefs, it was also possible to find healthy gardens of *A. palmata, A. prolifera,* and *A. cervicornis*.

In the west (Toro Cay, Glena Bar) and northwest (Sammy, reef patches around Hamkira) areas, significant suspended sediment was present which reduced water visibility. In this sector and some parts of Nasa and Gigi in the southwest, several reef patches were covered by a thick mat of the green algae, *Chaetomorpha gracilis,* and most coral colonies were dead. In Toro Cay and Glena Bar to the west, there was also a high cover of the cyanobacteria, *Schizotrix* spp.

Based on qualitative observations, diseased coral colonies were found in 24% of the inspected sites (Table 1). This is especially true at Wiplyn, Dusmusta and Gigi (the west), at Nasa reef (southwest), at Ned Thomas (south), at Creole Bar (north), and at Ahuya and Bojotle Kira (northeast). The most frequent disease in Miskitus cays was Black Band Disease (BBD) in colonies of *M. faveolata, S. siderea, Colpophyllia natans,* and *Diploria* spp. Furthermore, there was a great incidence of Black Spot Disease (BSD) in colonies of *S. siderea*, White Band Disease (WBD) in colonies of *Acropora* spp. and White Plague (WP) in colonies of *S. siderea, D. strigosa,* and *M. faveolata.*

Composition, richness, density and status of coral colonies

Thirty nine scleractinian coral species were found at Miskitus Cay (Table 2), similar to what has been found in other reefs from the southern Caribbean coast of Central America (Table 3). The richest sites were those in which the reef crest was associated with a vertical complex and/or deep wall (Table 4). These deep wall systems were Creole Bar, North West Miskitu reef, and Macandra and Witties in the south. Nassa reef in the southeast also exhibited high coral species richness but had a short wall down to 10 m deep. Finally, the patch reefs of Ahuya Luphia were also rich due to their 3 to 8 m high depth. The poorest sites in coral species richness were the patch reefs located in carbonate rock platforms covered with fleshy macro-algae such as Martínez reef, Owen shoal and Flag Reef. The poorest reef crest sites were Yanka laya, Ryan and Sammy in the northwest, Mas Widi in the west, Trikam rock in the southeast and Maxide and Dump in the northeast.

Coral colony density was significantly different among sites ($F_{17,36}$ = 2.17, p = 0.025). Sites with densities between 1 and 10 colonies per 10 m were patch reefs such as, Bojotle Kira and Ahuya Luphia in the north, and Ryan, one of the most deteriorated reef crests in the northwest and Maxide to the northeast. Density was > 16 colonies in Macandra and Creole bar to the north, Franklin reef and Ned Thomas in the south, Nasa reef and Toro cay in the southwest, and Hamkira and Yanka Laya in the northwest (Table 5).

The dominant (> 35%) coral species in most of the reef crests were *A. palmata* and *M. faveolata* with exception of the

TABLE 2. *List of marine invertebrates observed in Miskitus Cays, Nicaragua coral reefs in August 2001.*

SPONGES (Phylum Porifera, Class Demospongiae)
Callyspongia plicifera
Ircinia strobilina
Diplastrella megastellata
Agelas confiera
Cliona sp.

MILLEPORINES (Phylum Cnidaria, Class Hydrozoa, Order Milleporina)
Millepora alcicornis
Millepora complanata

ANEMONES (Phylum Cnidaria, Class Anthozoa, Order Actinaria)
Stichodactyla helianthus
Condylactis gigantea
Bartholomea annulata

ZOANTHIDS (Phylum Cnidaria, Class Anthozoa, Order Zoanthidea)
Palythoa caribaeorum
Zoanthus pulchelus

SCLERACTINIANS (Phylum Cnidaria, Class Anthozoa, Order Scleractinia)
Acropora cervicornis
Acropora palmata
Acropora prolifera
Porites porites
Porites astreoides
Oculina diffusa
Madracis mirabilis
Madracis decactis
Stephanocoenia michelinii
Montastraea annularis
Montastraea faveolata
Montastraea franksi
Montastraea cavernosa
Dichocoenia stokesii
Favia fragum
Siderastrea siderea
Siderastrea radians
Solenastrea bournoni
Solenastrea hyades
Diploria strigosa
Diploria clivosa
Colpophyllia natans
Meandrina meandrites
Manicina areolata
Leptoseris cucullata
Agaricia grahamae
Agaricia agaricites
Agaricia tenuifolia
Mycetophyllia danaana
Mycetophyllia lamarckiana
Mycetophyllia aliciae
Mycetophyllia ferox
Isophyllastrea rigida
Scolymia cubensis
Scolymia lacera
Mussa angulosa
Eusmilia fastigiata

CTENOPHORES (Phylum Ctenophora, Class Tentaculata)
Leucothea multicornis
Ocyropsis crystallina

SEA CUCUMBERS (Phylum Echinodermata, Class Holothuroidea)
Isostichopus badionotus
Holothuria mexicana

SEA URCHIN (Phylum Echinodermata, Class Echinoidea)
Echinometra viridis
Echinometra lucunter
Diadema antillarum
Meoma ventricosa

SEA STARS (Phylum Echinodermata, Class Asteroidea)
Oreaster reticulatus
Linckia guildingii
Asterina folium

TUNICATES (Phylum Chordata, Class Ascidiacea)
Clavelina puertosecensis

sites where the majority of *A. palmata* colonies were dead such as Witties, where *P. astreoides* (45%) dominated. Wiplyn was dominated by *D. strigosa* (40%) and *A. prolifera* (40%), Toro Cay was dominated by *A. tenuifolia* (48%), the fringing reef of Hamkira was dominated by *A. cervicornis* (42%), and Ryan crest and Bojotle Kira reef patches were dominated by *S. siderea* (30% and 50%, respectively). Only in the spurs of Creole Bar and the deep reef patches of Ahuya Luphia was *M. annularis* abundant (33% and 20%, respectively). *Montastraea faveolata* was especially abundant in Nasa reef (76%), *D. strigosa* in London reef (100%), and *A. palmata* in Yanka Laya (79%). The fire coral, *Millepora complanata,* was also common in these reefs and it contributed to the construction of the reef crests.

In general, the mean diameter and height of coral colonies was high in Yanka Laya, Toro Cay, Nasa reef and Lamarcka. The lowest mean diameter was found in London reef. The mean height was also higher in Maxide and Lamarcka (Table 6). The largest colonies of *A. palmata* (> 80 cm) were found in Miskitu reef, Maxide, Ned Thomas, Lamarcka, Hamkira and Yanka Laya, whereas relatively small colonies (diameter < 50 cm) were noted in Ryan. The colonies of *D. strigosa* were larger (> 50 cm) on average in Franklin reef, Macandra and Bolotle Kira, whereas those of *M. faveolata* > 1 m diameter were found in Macandra and Ryan. *Siderastea siderea* was larger (50 cm) in Wiplyn and Ryan (Table 7) than other areas. Overall, the mean diameter and height of coral colonies for all the reef system of Miskitus Cays was high (59.7 cm and 46.2 cm, respectively).

Recent mortality was 3.2%, old mortality was 25.7% and total mortality 28.9%. The ratio between live and dead coral was high (3.9, Table 6). Recent mortality of coral colonies was highest in Witties (24%), while old mortality was highest in Nasa reef (54%), followed by Ned Thomas (49%) and Bojotle Kira (49%) (Table 6). Total mortal-

TABLE 3. *Comparison of stony coral species richness in the Central American Caribbean coast.*

Country	*Site*	*Reference*	*# Coral species*
Panamá	Bocas del Toro	Guzmán 1998	32
Costa Rica	Cahuita	Cortés 1996-1997	41
	Manzanillo	Cortés 1996-1997	32
Nicaragua	Miskitu Cays	This study	39
	Corn Island	Ryan and Zapata 2003	25
Honduras	Cayos Cochinos	Guzmán 1998	56
	Roatán	Siirila 1992, Villeda et al. 1997	47
Guatemala	Punta Manabique	Fonseca 2003	29
Belize	Carrie Bow Cay	Cairns 1982	44

ity was highest in Nasa reef (54%) followed by Bojotle Kira (50%). The ratio between live and dead colonies was highest in Hamkira and lowest in Nasa reef. Bleaching was highest in Ahuya Luphia (20%) and Creole Bar (19%). Mean bleaching for Miskitus Cays was 4% (Table 6) and in only 6 of 18 sites (33%) was there evidence of bleaching, and it was always partial. I found disease in only 28% of the sites (5 of 18 sites) and in 26% of the coral species (10 of 39 species). The highest incidence of disease was found in Wiplyn (40%) and mean disease incidence overall was 3% (Table 6). There was not evident damage by anchors, but damage by storms was great, since colonies of *A. palmata* were fragmented and dead, especially in all the reef fronts and mainly in the ones to the east of Miskitus Cays.

Relative substrate cover analysis

There was a significant difference among sites and low variability within each site on coral live cover ($F_{17,36}$ = 2.399, p = 0.01) and algae ($F_{17,36}$ = 2.238, p = 0.02). The sites with higher live coral cover (> 50%) than the algae cover were the reef crests of Dump in the north, Franklin reef and Ned Thomas in the south, Lamarcka and Nasa reef in the southwest, and Hamkira and Yanka Laya in the northwest. The other sites had higher algae cover than live coral cover. The patch reefs of Bojotle Kira were the sites with less live coral cover and higher algae cover, followed by the reef patches of Ahuya Luphia, and the reef crest of Ryan. However, only the patches of Bojotle Kira had significantly lower coral cover than all other sites after Bonferroni pairwise comparisons (p < 0.05). Moreover, in Ahuya Luphia, the bottom consisted mainly of sandy material within the colonies, whereas in Ryan it consisted mainly of mud. Mean live coral cover for Miskitus Cays was high (43.4%), but lower than the algae cover (54.2%). In all sites, the percentage of non-coralline algae was higher than the percentage of coralline algae. In Miskitu reef (or Farrel reef) in the east, London reef in the southeast, Witties in the south and Wiplyn in the west a higher dead coral cover with algae than live coral cover was found (Table 8).

TABLE 4. *Number of coral species ranked by site from August 2001 collections.*

Site	***Physical Attribute***	***# coral species***
Creole Bar-Blue Channel	Reef Crest/Deep Wall	31
Macandra	Short Wall	29
Witties	Reef Crest/Short Wall	29
Ahuya Luphia	Patch Reef	28
NW reef	Deep Wall	27
Nassa	Reef Crest/Short Wall	25
Ned Thomas	Reef Crest	20
Franklin reef	Reef Crest/Deep Wall	17
Hamkira	Fringing Reef	17
Gigi	Reef Crest	16
Toro cay	Reef Crest/Short Wall	16
Hamkira sirpe	Fringing Reef	16
London reef	Reef Crest	15
Wiplyn	Reef Crest	15
Bojotle Kira	Patch Reef	14
Lamarcka	Reef Crest	14
Dusmusta	Reef Crest	14
Miskitu reef - Farrel reef	Reef Crest	13
Glena Bar	Reef Crest	13
Maxide	Reef Crest	11
Dump	Reef Crest	11
Sammy	Reef Crest	11
Ryan	Reef Crest	11
Yanka Laya	Reef Crest	8
Mass Widi	Reef Crest	7
Martínez reef	Patch reef	7
Flag reef	Patch reef	7
Owen shoal	Patch reef	5
Trikam rock	Reef crest	3

TABLE 5. *Density (mean ± standard deviation) of coral colonies (n=3) by site along transects from August 2001 collections.*

Site	**Density (Colonies/10 m transect)**
Maxide*	4.0 ± 1.0
Bojotle Kira*	4.7 ± 2.5
Ryan	10.0 ± 7.8
London reef	11.7 ± 6.4
Ahuya Luphia*	13.7 ± 5.5
Dump	13.7 ± 7.0
Miskitu reef	14.0 ± 5.6
Wiplyn	14.7 ± 9.0
Lamarcka	15.0 ± 1.7
Witties	15.7 ± 1.5
Toro cay	16.7 ± 7.1
Creole Bar	17.7 ± 1.2
Ned Thomas	18.3 ± 5.0
Macandra	18.3 ± 5.7
Nasa reef	18.7 ± 2.3
Hamkira	20.0 ± 11.4
Franklin reef	20.7 ± 6.0
Yanka Laya	21.3 ± 4.0

* Counted only colonies with a diameter > 25 cm.

Discussion

Miskitus Cays show a great diversity of interconnected marine habitats and resources which give shelter to reef species of great commercial value like turtles, dolphins, sharks, reef fishes, lobsters and queen conchs which are the base of the economy of the local fishing communities (Ryan et al. 1998). Most of the Miskitus Cay coral reef system is < 30 m deep, with high wave energy and low visibility that creates an environment dominated by seagrasses, octocoral gardens, coral reef patches, and reef crests built mainly by *Acropora* spp. and *Millepora* spp. Both coral species are known as the main reef crest builders in the Caribbean (Kramer and Kramer 2000). This high species richness and great cover of *A. palmata, A. prolifera* and *A. cervicornis* in some reefs of Miskitus Cays suggests a quality habitat complex unknown

TABLE 6. *General characterization of coral colonies in August 2001 by site. sd = standard deviation.*

Site	Diameter, cm ($\bar{x}$ ± sd)	Diameter, cm ($\bar{x}$ ± sd)	Recent mortality (%) ± sd	Old mortality (%) ± sd	Total mortality (%) ± sd	Ratio Live:Dead	% Bleached	% Disease
Macandra	59.4 ± 37.8	49.4 ± 31.4	0.0	24.6 ± 29.2	24.6 ± 29.2	3.1	0.0	0.0
Maxide	93.3 ± 87.0	65.6 ± 59.6	0.0	26.1 ± 36.5	26.1 ± 36.5	2.8	0.0	0.0
Dump	62.5 ± 39.6	52.9 ± 30.6	0.0	34.3 ± 24.7	34.3 ± 24.7	7.3	0.0	0.0
Bojotle	54.4 ± 30.2	35.6 ± 19.7	1.0 ± 1.8	49.4 ± 33.3	50.4 ± 35.1	1.0	12.5	0.0
Ahuya	40.0 ± 23.2	23.4 ± 34.6	8.0 ± 17.9	8.0 ± 12.5	16.0 ± 30.4	5.3	20.0	0.0
Creole	49.8 ± 25.4	43.1 ± 23.4	12.6 ± 24.9	16.6 ± 25.5	29.2 ± 50.4	2.4	19.0	0.0
Miskitu	63.3 ± 44.5	35.0 ± 28.3	0.0	13.3 ± 30.3	13.3 ± 30.3	6.5	0.0	0.0
London	30.0 ± 0.0	50.0 ± 0.0	0.0	25.0 ± 0.0	25.0 ± 0.0	3.0	0.0	0.0
Witties	45.0 ± 24.4	33.4	24.1	20.5 ± 30.6	44.6 ± 32.1	3.7	9.1	4.5
Franklin	55.9 ± 26.8	42.5 ± 27.3	0.0	31.8 ± 27.5	31.8 ± 27.5	2.1	0.0	0.0
Ned Thomas	60.8 ± 36.8	51.7 ± 31.4	0.1 ± 0.4	49.5 ± 31.1	49.6 ± 31.5	1.0	3.8	0.0
Lamarcka	67.7 ± 36.7	57.5 ± 37.4	4.5 ± 16.6	20.8 ± 23.9	25.3 ± 40.5	2.9	0.0	4.6
Nasa	67.8 ± 30.5	51.6 ± 29.1	0.0	54.2 ± 37.8	54.2 ± 37.8	0.8	0.0	0.0
Wiplyn	54.0 ± 27.9	38.0 ± 13.0	4.0 ± 6.5	7.0 ± 11.0	11.0 ± 17.5	8.1	0.0	40.0
Toro	75.2 ± 50.6	52.6 ± 25.3	2.4 ± 5.8	23.9 ± 26.9	26.3 ± 32.8	2.8	14.3	4.8
Hamkira	46.0 ± 24.3	36.7 ± 18.3	0.0	8.3 ± 19.4	8.3 ± 19.4	11.1	0.0	0.0
Yanka Laya	84.2 ± 36.3	69.5 ± 34.4	0.0	20.8 ± 23.6	20.8 ± 23.6	3.8	0.0	0.0
Ryan	66.0 ± 35.3	42.0 ± 25.8	0.0	29.2 ± 33.5	29.2 ± 33.5	2.4	0.0	0.0
$\bar{x}$, all Cayos Miskitus	**59.7**	**46.2**	**3.2**	**25.7**	**28.9**	**3.9**	**4.0**	**3.0**

in much of the Caribbean and is very important in terms of conservation. These very fragile species have been intensively destroyed in other reefs of the Caribbean by hurricanes, anchoring and diving (Precht et al. 2002).

Miskitus Cays has high coral richness (39 species) similar to other sites in the Caribbean (reviewed in Fonseca 2003, Ryan and Zapata 2003). The reef crest complexity index (1.84) found at depths < 5 m is also high, suggesting high reef complexity. Recent and total mortality in Miskitus Cays was lower (3.2 and 27.6%, respectively) than in other shallow reefs from the Mesoamerican Reef System (18 and 49%, respectively); however, mean bleaching and disease incidences were similar (Kramer and Kramer 2000). Several diseases known to be widespread throughout the wider Caribbean (Green and Bruckner 2000) were also found in Miskitus Cays, and the BBD showed the highest frequency (Kramer and Kramer 2000). Dark Spot Disease was most common on massive *Siderastrea* and *Montastraea* (Bruckner 2001), and the WBD was found in *Acropora* as expected. White Band Disease is thought to be a major factor in the decline of elkhorn and staghorn corals in the wider Caribbean (Aronson and Pre-

TABLE 7. *Mean diameter (cm) of dominant coral colonies in August 2001 by site.*

Site	Siderastrea siderea	Montastraea annularis	Montastraea faveolata	Diploria strigosa	Acropora palmata
Macandra	38.3	–	116.7	50.0	58.3
Maxide	–	–	–	27.5	88.0
Dump	30.0	–	51.4	30.0	75.4
Bojotle	38.8	–	76.7	50.0	–
Ahuya	25.0	40.0	52.5	–	–
Creole	37.5	45.0	73.6	–	–
Miskitu	25.0	–	–	–	103.3
London	–	–	–	30.0	–
Witties	–	–	–	35.0	75.0
Franklin	48.3	–	–	56.0	78.1
Ned Thomas	40.0	–	70.0	–	84.1
Lamarcka	13.6	–	45.0	25.0	83.8
Nasa	30.0	–	74.5	25.0	80.0
Wiplyn	60.0	–	–	40.0	–
Toro	–	–	55.0	–	62.5
Hamkira	40.0	–	55.0	26.7	98.8
Yanka Laya	–	–	60.0	–	92.3
Ryan	55.0	–	110.0	–	50.0

cht 2001), causing major changes in the composition and structure of reefs (Green and Bruckner 2000).

The highest incidence of disease was found in Wiplyn, and may be related to its proximity to MARAS, the largest human settlement in the area where people are discharging waste water and solids directly into the sea. The incidence and prevalence of diseases may also increase when corals are stressed by sedimentation, hurricanes, nutrients, toxic chemicals and warmer-than-normal temperatures (Richardson 1998), as is evidenced by the imports from Hurricane Mitch in 1998 (Kramer and Kramer 2000), and other earlier events (Jameson 1996). Jameson (1996) did not find corals with active diseases, although he observed low levels of bleaching and anchor damage. In this study, no anchor damage was found because the highest reef development occurs in the crests and boats do not anchor directly over them. However, even though large coral colonies within reef crests are dispersed it would be better if mooring buoys were installed in diving and fishing sites to protect the coral colonies. Finally, in 1995 and 1998, late summer temperature increased from 29.5 to 31.1°C throughout the Caribbean, and this coincided with several bleaching reports (Guzmán and Guevara 1998, McField 1999). Apparently, shallow reefs experienced catastrophic losses due to the initial bleaching but now show minimal signs of remnant bleaching (Kramer and Kramer 2000). The coral reef in the Miskitus Cays appear to have recovered because observed mortality was low.

Most of the Miskitus reef system is in good health, especially in the south and southwest sections. The sites in best condition within the Miskitus Cays Biological Reserve are Nasa reef in the southwest, the protected side of the fringing reef around Hamkira and Yanka Laya in the northwest, and to a lesser extent Lamarcka in the southwest, Franklin reef and Ned Thomas in the south, and Creole Bar-Blue Channel in the North. Blue Channel is a potential site for reef fishes' reproductive aggregations. The most deteriorated sites, with non-coralline algae overgrowth and diseases, are those in the west-northwest, especially Ryan, North West reef, Toro Cay, Gigi and Glena Bar and some reef patches around Hamkira and Sammy. This appears to be due to sediments, and associated nutrients and pesticides coming from the deforested mangroves of MARAS and the runoff of Coco River.

The mean live coral cover for Miskitus Cays is relatively high (43%) compared to other continental Caribbean coral reefs (Table 9), with 7 sites having higher live coral (>50%) than algae cover. However, most sites had lower coral cover than algae cover. The percentage of non-coralline algae was higher than the percentage of coralline algae (Table 9) as is typical of the Caribbean region due to a combination of hurricanes, bleaching, diseases, eutrophication, and low herbivory rates as a consequence of over fishing and *Diadema* mass mortality (Goreau et al. 1998, Hayes and Goreau 1998, Kramer and Kramer 2000). The most diverse and structurally complex coral reefs reported for the Central American coast were Belize, Honduras and Panama (Cortés 1997). However, Miskitus Cays has a great development of

TABLE 8. *Relative coverage of benthic substrate (n = 3; "-" = no data) by site in August 2001.*

Site	% Live coral	% Dead coral with algae	% Non-coralline algae	% Coralline algae	% Total algae	Sediment	Others	Difference between % live coral and % algae
Macandra	46.3 ± 13.6	17.9 ± 3.7	21.9 ± 17.1	11.4 ± 1.4	51.2 ± 13.6	0.8 ± 1.4	1.6 ± 1.4	-4.9
Maxide	32.5 ± 19.9	25.2 ± 30.1	36.6 ± 47.5	4.9 ± 8.4	66.7 ± 20.7	0.8 ± 1.4	-	-34.2
Dump	64.2 ± 5.1	27.6 ± 15.7	4.1 ± 7.0	0.8 ± 1.4	32.5 ± 7.4	-	3.2 ± 3.7	31.7
Bojotle Kira	13.0 ± 11.0	-	84.6 ± 7.8	-	84.6 ±7.8	-	2.4 ± 4.2	-71.6
Ahuya Luphia	22.8 ± 5.1	2.4 ±0.0	43.9 ± 10.6	19.5 ± 6.4	65.8 ± 8.8	6.5 ± 9.2	4.9 ± 4.9	-43
Creole Bar	42.3 ± 2.8	4.9 ± 4.2	43.1 ± 9.8	7.3 ± 2.4	55.3 ± 3.7	-	2.4 ± 2.4	-13
Miskitu reef	33.3 ± 1.4	66.7 ± 1.4	-	-	66.7 ± 1.4	-	-	-33.4
London reef	44.7 ± 27.0	55.3 ± 27.0	-	-	55.3 ± 27.0	-	-	-10.6
Witties	33.3 ± 7.4	66.7 ± 7.4	-	-	66.7 ± 7.4	-	-	-33.4
Franklin reef	49.6 ± 29.5	41.5 ± 28.8	4.1 ± 7.0	1.6 ± 2.8	47.2 ± 28.3	1.6 ± 2.8	1.6 ± 2.8	2.4
Ned Thomas	62.6 ± 16.2	30.1 ± 11.0	4.9 ± 4.9	1.6 ± 2.8	36.6 ± 16.0	-	0.8 ± 1.4	26
Lamarcka	56.9 ± 17.1	35.0 ± 23.0	4.9 ± 8.4	1.6 ± 2.8	41.5 ± 17.6	-	1.6 ± 2.8	15.4
Nasa reef	59.4 ± 12.0	39.8 ± 13.4	-	0.8 ± 1.4	40.6 ± 12.0	-	-	18.8
Wiplyn	31.7 ± 10.6	68.3 ± 10.6	-	-	68.3 ± 10.6	-	-	-36.6
Toro cay	43.9 ± 11.2	24.4 ± 8.4	16.3 ± 5.1	14.6 ± 8.8	55.3 ± 11.5	0.8 ± 1.4	-	-11.4
Hamkira	56.9 ± 22.7	6.5 ± 6.1	30.1 ± 16.6	1.6 ± 1.4	38.2 ± 18.0	0.8 ± 1.4	4.1 ± 3.7	18.7
Yanka Laya	58.5 ± 23.3	32.5 ± 34.3	8.9 ± 15.5	-	41.5 ± 23.3	-	-	17
Ryan	29.3 ± 22.4	9.8 ± 9.8	52.8 ± 32.4	-	62.6 ± 24.4	7.3 ± 12.7	0.8 ± 1.4	-33.3
Total $\bar{x}$ for Miskitus Cays (n=54)	**43.4 ± 14.8**	**30.8 ± 26.0**	**19.8 ± 27.0**	**3.7 ± 6.4**	**54.2 ± 14.1**	**2.6 ± 2.9**	**2.3 ± 1.4**	**- 10.8**

TABLE 9. *Comparison of mean live coral and algae coverages between Miskitus Cays and other coral reefs of the Central American Caribbean coast.*

Country	Reef name	Reef type	% Live coral	% Algae	Year	Reference
Panamá	Bocas del Toro	Insular	27	21	1999	CARICOMP 1999
Costa Rica	Cahuita	Continental	13	60	1999	CARICOMP 1999
Nicaragua	Great Corn Island	Insular	36	37	1998	CARICOMP 1999
Nicaragua	Cayos Miskitus	Insular	43	54	2001	This study
Honduras	Roatán	Insular	34	38	1997	Fonseca and Radawsky 1997
Guatemala	Punta Manabique	Continental	9	65	2000	Fonseca 2003
Belize	Carrie Bow Cay	Insular	16	65	1997	CARICOMP 1999
Belize	Calabash Cay	Insular	10	58	1997	CARICOMP 1999
México	Puerto Morelos	Continental	1	93	1999	CARICOMP 1999

reef crests, and Miskitus Cays and Corn Island should be considered high quality reefs suited for a high conservation status in the Caribbean because of their high live coral cover and diversity, and low mortality.

Coral reef degradation in the American region is caused mainly by increased influx of terrigenous sediments (Rogers 1986, Ginsburg 1994) primarily due to deforestation, uncontrolled coastal development, and inappropriate agricultural practices (Cortés and Risk 1985). While suspended sediment loads appear to be the greatest human threat to Nicaragua´s reefs (Ryan et al. 1998), unregulated fishing activities have also caused damage. Despite these multiple threats, Nicaragua still lacks a concrete management strategy for its coastal and marine resources due mainly to a general lack of political awareness about the key role that coral reefs play in supporting fisheries and biodiversity, institutional and human capacity gaps and inadequate legislation for reef conservation (Ryan and Zapata 2003). Integrated management of Nicaraguan river basins and coastal-marine reserves is urgent and this can be promoted by extending land-conservation approaches to marine ecosystem biodiversity.

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