The State of Coral Reef Ecosystems of Navassa Island

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INTRODUCTION AND SETTING

Navassa is a small (4.64 km^2), uninhabited, oceanic island approximately 50 km off the southwest tip of Haiti (Figure 4.1) under the jurisdiction of the U.S. Fish and Wildlife Service. The island is a raised dolomite plateau ringed by vertical cliffs that descend to a sloping submarine terrace at an approximate depth of 25 m, with coral reef development primarily on small nearshore ledges and shelves. Navassa's oceanic position in the Windward Passage exposes it to substantial physical energy, with the eastern coastline exposed to persistent swells and regular storms and hurricanes. Both geomorphology and exposure have resulted in an absence of shallow-water inshore fish nursery habitats (e.g., mangroves, sandy beaches and seagrasses) that are found on other islands in the region. The local and regional oceanography around Navassa is poorly characterized, but detailed geology is provided in Miller et al. (in press).

Status of reef resources and threats have been documented by Miller and Gerstner (2002), Miller (2003) and Miller et al. (2005) from data collected during expeditions in 2000 and 2002. These assessments reported relatively healthy coral conditions and reef fish assemblages which, though dominated by small planktivores, still compared favorably with other Caribbean locations. Substantial fishing activity by transient Haitians was also reported.
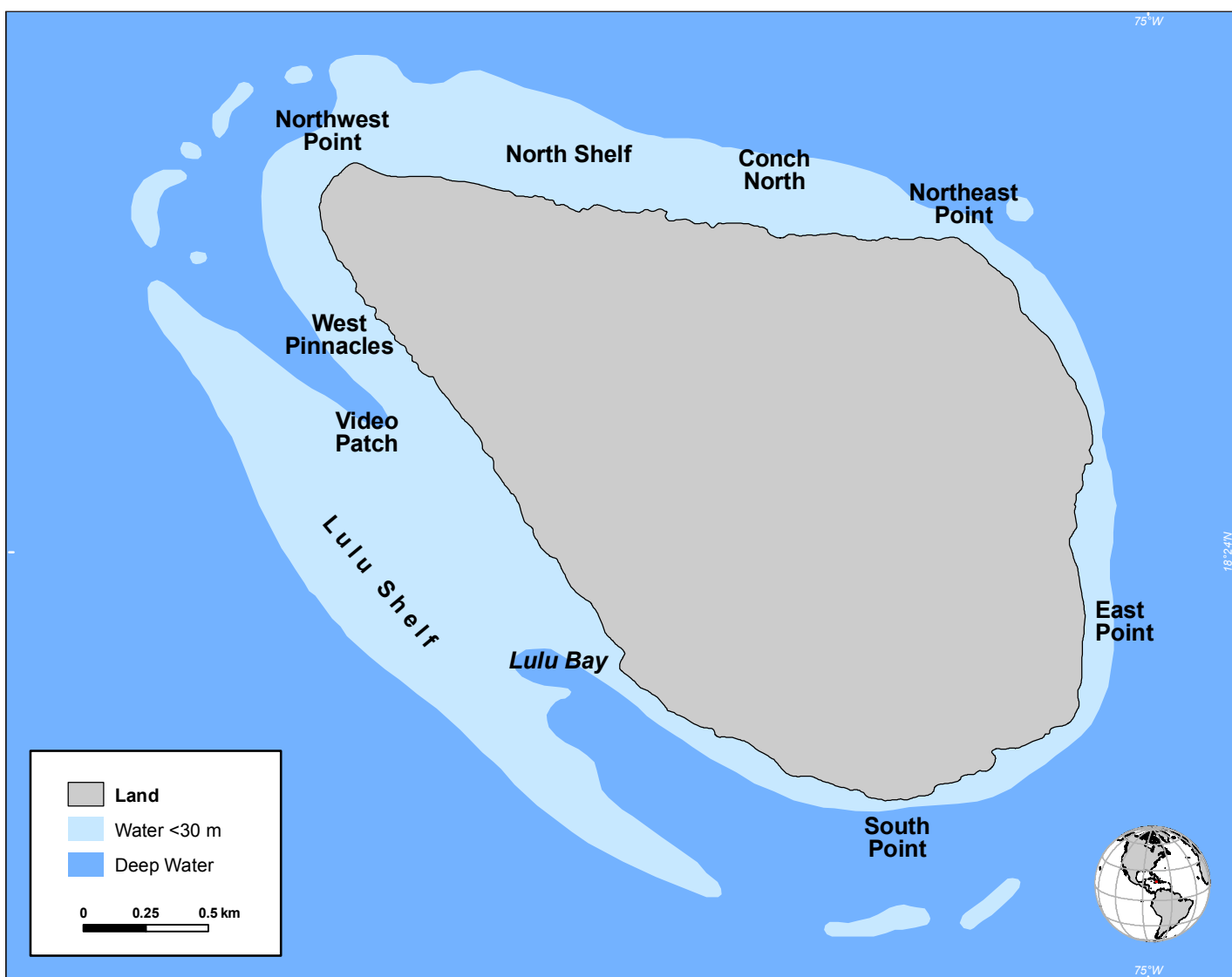

Figure 4.1. A map of Navassa Island showing locations mentioned in the chapter. Map: K. Buja.

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ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching
No suitable historic observations are available to determine past occurrence or potential trends in coral bleaching at Navassa, particularly through the 2005 Caribbean event. Observations in April 2006 indicated that bleaching was not extensive (G. Piniak, pers. obs.). Miller et al. (2005) suggested that the relatively deep and exposed (i.e., high water flow) position of most of the coral reefs surrounding Navassa reduced exposure to elevated sea surface temperatures (SST). However extensive, and in some places, severe coral bleaching was observed at Navassa in November 2006, when little new bleaching had been reported in the Caribbean and no predictions of bleaching (bleaching alerts) had been issued based on satellite temperature records. In fact, observed bleaching prevalence was greater at deep sites (20-30 m) than at shallow (7-10 m) sites. *In situ* temperature data was collected at a range of depths around Navassa from April to November 2006 providing potentially useful data that can contribute to the future development of accurate bleaching predictions for corals in deeper water (20-30 m). Please see the Water Quality and Benthic Habitats sections of this chapter for more information on elevated SST and coral bleaching.

Diseases
Until 2004, coral diseases at Navassa were rarely seen (Miller et al., 2005). During the November 2004 expedition, however, a severe coral disease event was observed (Miller and Williams, 2007; see Benthic Habitat section). This disease event appeared to have developed following hurricanes Charley and Ivan that affected Navassa in 2004. No sampling for pathogen identification was possible, but disease signs were consistent with a white-plague type disease. Isolated observations of disease on *Acropora palmata* (low prevalence) and *A. cervicornis* (much higher prevalence given this species' rarity at Navassa) were also made (Williams and Miller, pers. obs.)

Tropical Storms
Several named storms have passed near Navassa in recent years (Figure 4.2), including Ernesto (2006), Dennis (2005), Charley (2004), and Ivan (2004). Unfortunately, the wide spacing of observations makes it difficult to attribute observed reef changes directly to storms. However, following Charley and Ivan in 2004, some obvious physical damage (e.g., toppled hard and soft coral colonies) and sand movement was observed.

Coastal Development and Runoff
Navassa is uninhabited, except for the temporary presence of transient Haitian fishers. There has been no change in terrestrial activity.

Coastal Pollution
No information about coastal pollution sources from neighboring islands that have the potential to impact Navassa is available.

Figure 4.2. Map of Navassa Island showing the path and intensity of major storm events between 2002-2007. Map: K. Buja. Source: http://maps.csc.noaa.gov/hurricanes/.

Tourism and Recreation
There is no tourism or recreational use at Navassa. A Special Use permit from the U.S. Fish and Wildlife Service is required for entry.

Fishing
Despite its status as a National Wildlife Refuge, fisheries at Navassa are effectively unmanaged as regulations are not well publicized and enforcement is not feasible in this remote location. Fishing activities by migrant Haitian artisanal fishermen have been ongoing since at least the 1970s. Miller et al. (2007) perceived an escalation of fishing effort based on observation of the use of novel and more destructive gear types including net fishing (first observed in 2002), which allowed exploitation and bycatch of previously unexploited species such as queen conch (*Strombus gigas*) and Hawksbill sea turtles (*Eretmochelys imbricata*; Wiener, 2005).
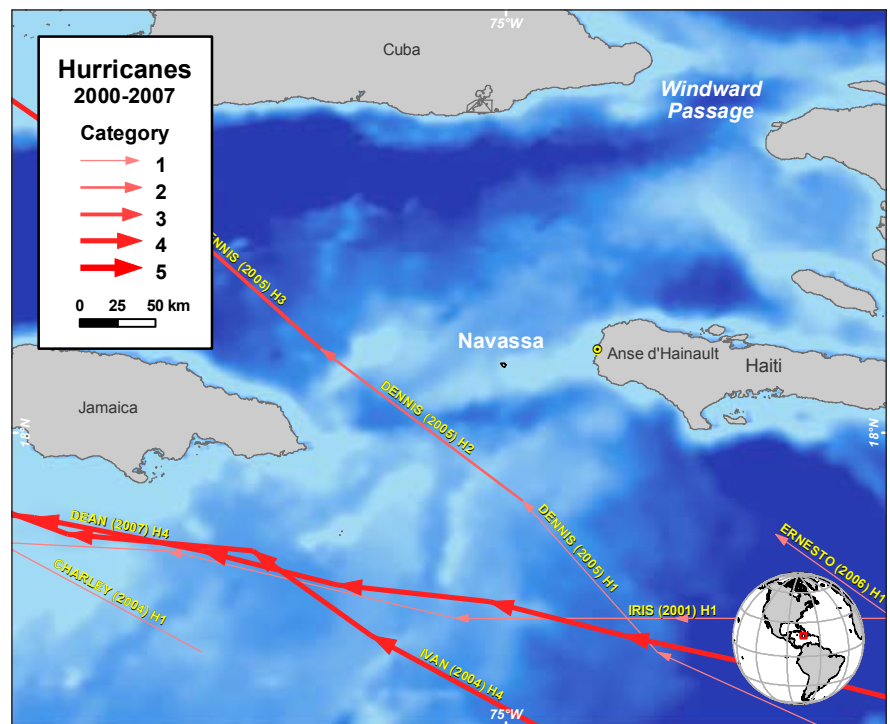
The National Oceanic and Atmospheric Administration's (NOAA) Southeast Fishery Science Center (SEFSC) has recently conducted a sociocultural characterization of Haitian fishing communities that exploit the waters surrounding Navassa (Wiener, 2005; Miller et al., 2007). This study included extensive interviews of fishers both on site in Navassa and in southwest Haiti, as well as limited quantification of landings from three individual boat-trips. Results of the fisher interviews conducted between November 2004 and June 2005 also indicated that capital for boats, traps and fuel was the primary limitation on current fishing effort. Similarly, the harsh living conditions on Navassa were the only factor preventing permanent settlement of the islands as socioeconomic conditions in Haiti continue to be dismal.

Unexpectedly, the most recent observations in April and November of 2006 revealed a reduction in fishing activity when compared with 2004. A total of 175 fixed gear buoys (marking an unknown ratio of traps and nets combined) were mapped in 2004 (Miller et al., 2007), whereas many fewer traps were being actively fished in April and November 2006 (Table 4.1). Other measures of fishing effort appear to have peaked in 2004 and abated in 2006. Particularly notable was the lack of net fishing in 2006. All of the fishers present in 2006 were from a single Haitian village, Anse d'Hainault, and those interviewed indicated that this village had not previously participated in net fishing. It is not clear if this apparent relaxation of fishing effort has resulted from a form of self-management, poorer yields (interviewees indicated that the fishing was very poor in 2006) or other external factors such as high fuel prices.

Table 4.1. Trends in apparent fishing effort by transient Haitians on the Navassa shelf. Source: Miller et al., 2004; Wiener, 2005; Piniak et al., 2006.

MEASURE OF FISHING EFFORT					GEAR IN USE		
Date of observation	Duration of observation (d)	Total # gear buoys/traps	Mean boats/day	Mean fishers/day	Traps	Hook and Line	Nets
November 2002	11	NA	2	9.7*	X	X	X
November 2004	13	175	4.4	22	X	X	X
April 2006	10	7	0.7	2.8	X	X	-
November 2006	11	34	4	15.9	X	X	-
* Observations in 2002 were less complete; data are extrapolations based on reported average of five fishers per boat.							

Additionally, Haitian commercial fishing operations and international trawlers purportedly from the Dominican Republic and Jamaica are suspected of targeting pelagic fish species within the Navassa National Wildlife Refuge's (NNWR) 12 nautical mile territorial sea.

Trade in Coral and Live Reef Species
This threat does not have a major impact on Navassa's reefs.

Ships, Boats and Groundings
This threat does not have a major impact on Navassa's reefs.

Marine Debris
Marine debris from recent fishing activities and historical uses was described by Miller et al. (2005).

Aquatic Invasive Species
Invasive species have not been observed at Navassa to date.

Security Training Activities
No military activities occur at Navassa.

Offshore Oil and Gas Exploration
No oil and gas exploration activities occur at Navassa.

CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

Monitoring of the coral reefs of Navassa is now conducted biennially by NOAA-Fisheries and partners, with support from the NOAA Coral Reef Conservation Program. Cruises took place in November 2002, 2004 and 2006 to conduct underwater visual censuses of fish, habitat mapping (including single-beam acoustics), and benthic community assessments. Complementary data sets including multibeam bathymetry, temperature records, additional habitat assessments and sampling for trophic analysis via stable isotopes (Piniak et al., 2006) were obtained during an additional cruise in April 2006 conducted by NOAA's National Centers for Coastal Ocean Science (NCCOS), Center for Coastal Fisheries and Habitat Research (CCFHR). Monitoring locations for both groups are shown in Figure 4.3.
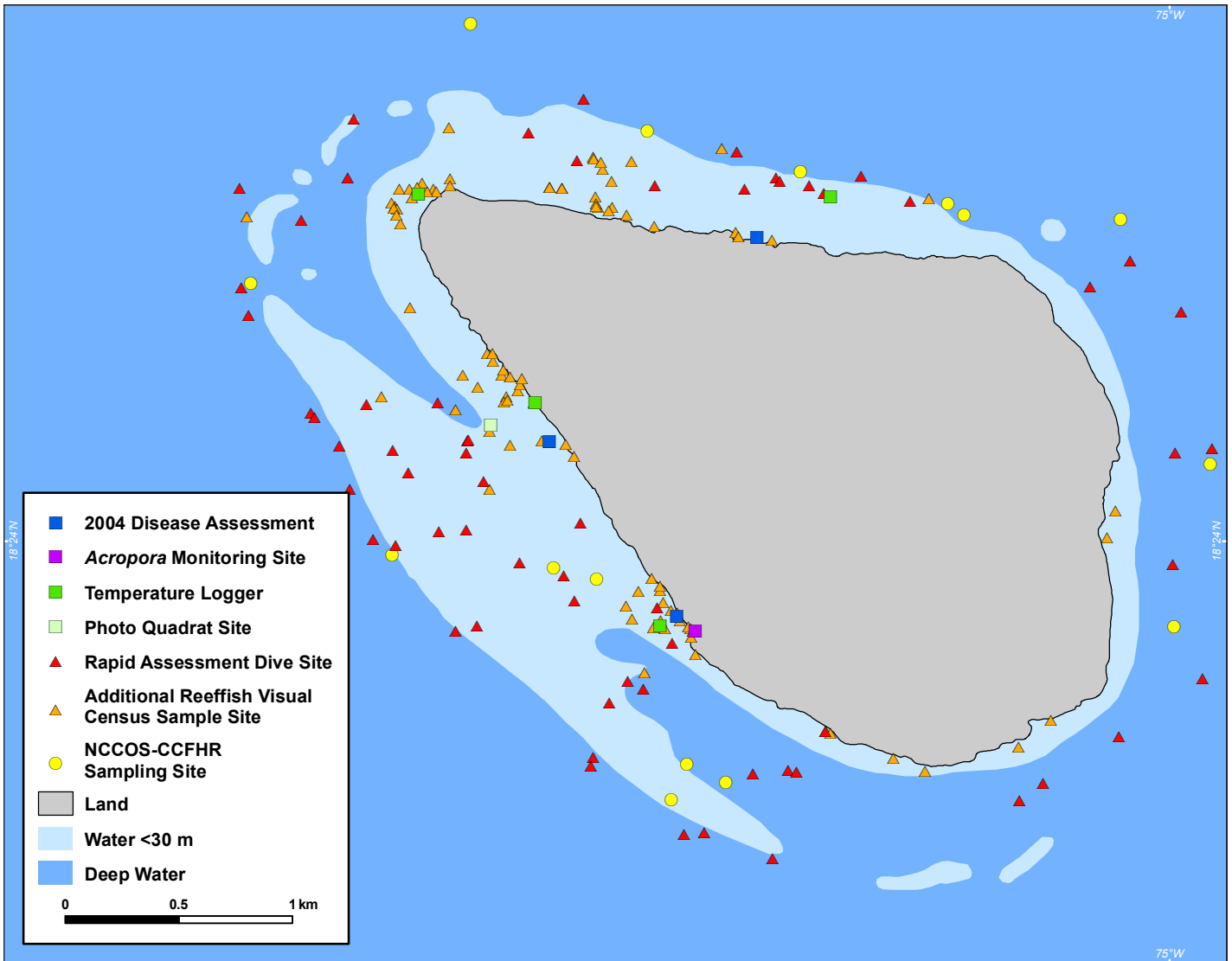

Figure 4.3. Monitoring locations sampled by NOAA/SEFSC and NOAA/NCCOS. Map: K. Buja.

WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

Since April 2006, temperature has been regularly measured at Navassa using an array of temperature loggers deployed at five sites at depths between 11 and 28 m. Hourly data was retrieved from these sensors in November 2006 and is summarized in Figure 4.4. Currently, temperature is the only water quality parameter being measured at Navassa.
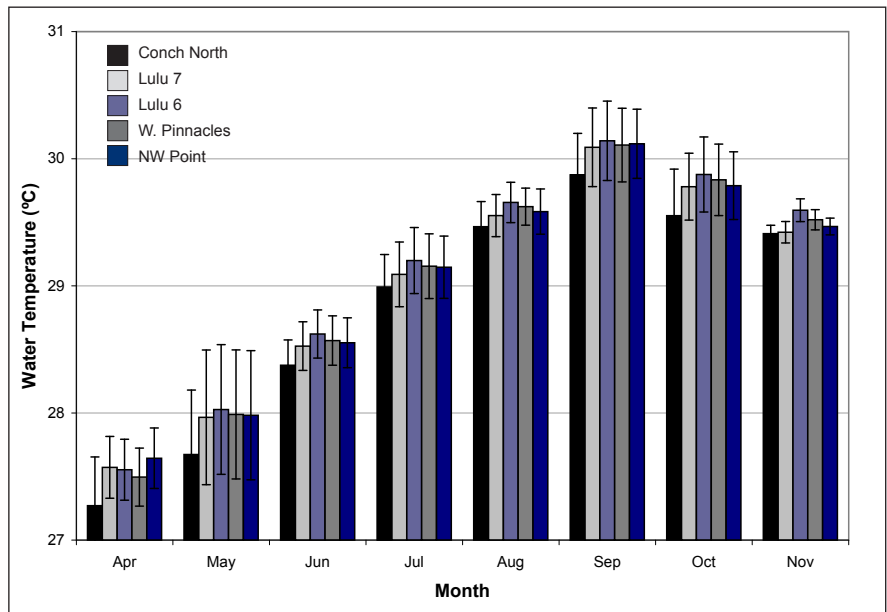

Figure 4.4. Monthly mean (± 1 SD) of hourly temperature readings from five sites around Navassa in 2006. Sites are: Conch North (28 m depth), Lulu Bay 7 (15 m depth), Lulu Bay 6 (26 m depth), West Pinnacles (26 m depth), and Northwest Point (11 m depth). This period of time preceded the observation of a severe coral bleaching event at Navassa in November 2006. Source: Piniak et al., unpub. data.

BENTHIC HABITATS

Benthic Characterization (SEFSC 2002–2006)

Methods

Given the relatively deep depths and limited sampling effort available for reef assessment at Navassa (about 10 days every two years), a hybrid sampling approach has been adopted. Standard *in situ* line intercept transects (15 m transect, sampled at 15 cm intervals, n=2-4) were used to estimate the percent cover of primary community components (scleractinian corals, macroalgae, octocorals, sponges) at four, relatively shallow (7-22 m) fixed sites every two years. Additionally, haphazard photoquadrats were collected from a distinct set of Rapid Assessment Dive (RAD) sites (22-32 m depth) distributed throughout the shelf. Photoquadrats (n=4-10) were analyzed using a standard point count method applied by Coral Point Count (CPCe) software. To enhance comparability between years, data are presented only for reef RAD sites along the southwest portion of the shelf.

Results and Discussion

Mean percent cover of fixed sites and deeper RAD sites are shown in Figures 4.5 and 4.6. Macroalgae (predominantly *Lobophora variegata*) comprised the dominant benthic group overall, with values around 40% cover common and values over 70% observed on occasion (Figures 4.5 and 4.6; mean ±1 SD for 2006 fixed sites, 54.4 ±17.3% SD). Declines in coral cover have occurred, but only at deeper sites (i.e., Video Patch and RAD sites) where coral cover had initially been very high and both 2004 disease and 2006 bleaching were observed at greater prevalence. Mean coral cover ±1 SD for southwest shelf RAD sites in 2002 was 39.9 ±8.0% SD but had dropped to 11.1 ±6.4% SD by 2006 (Figure 4.6). Meanwhile, live coral cover at the shallow fixed sites at NW Point and Lulu Bay have remained fairly steady in the range of 10-15% and 20-25%, respectively (Figure 4.5). Coral cover losses observed through 2006 likely resulted from disease and hurricane impacts (particularly during 2004). Ongoing coral mortality is anticipated given the severe bleaching status of corals observed in 2006.
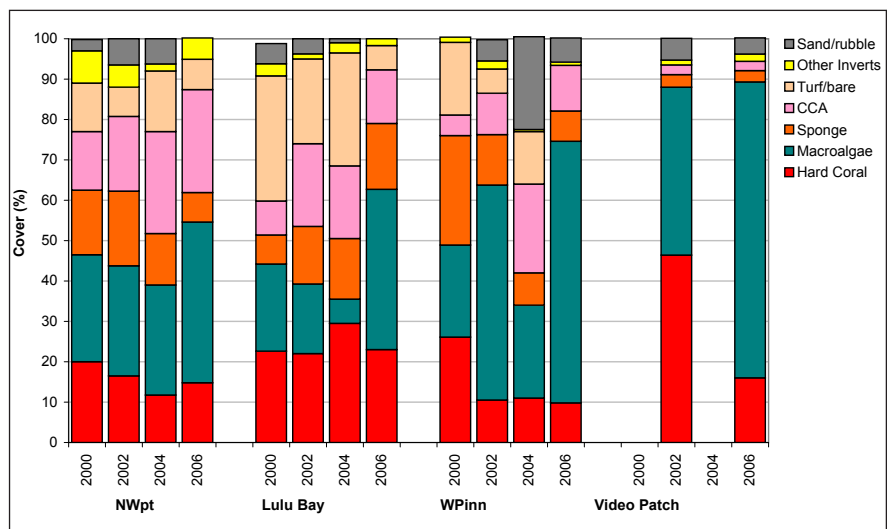

Figure 4.5. Percent cover of fixed sites sampled via in situ *point-intercept transects over time. NW Point, approximately 10 m; Lulu Bay: 7-10 m; West Pinnacles, 22 m; Video Patch: approximately 30 m, not sampled in 2000 or 2004. Source: Miller and Gerstner, 2002; Miller et al., 2003; Miller et al., unpub. data.*

Benthic Characterization (NCCOS 2006)
Methods
The habitat characterizations on the April 2006 cruise focused on the deeper portions of the inner shelf (30-34 m). Sites were randomly selected from the appropriate depth range; each site consisted of three replicate transects deployed in random directions. A site therefore incorporated a mixture of habitat types (both reef and non-reef). Due to differences in techniques, these data are not strictly comparable to the SEFSC data. Three 30 m visual fish transects were conducted at each site (data not reported) and benthic photoquadrats were collected at each meter along the transect and analyzed using standard point count methods within CPCe software.

Results and Discussion
Mean percent cover for the NCCOS sites are given in Figure 4.7. Macroalgae were the dominant benthic biota, comprising 36% of the total benthic cover around Navassa. *Lobophora variegata* was by far the most abundant macroalga (maximum 34%). *Halimeda* sp. and *Dictyota* sp. were secondary components of the algal community. Coral cover ranged from 1-7%; this underestimates typical cover measurements because mixed habitat types (including non-reef areas) were surveyed at each site. The primary components of the coral communities were the species that make up the *Montastraea annularis* species complex (referred to as *Montastraea* spp.), *Siderastrea siderea*, *Porites astreoides* and *P. porites*. Coral cover was lowest on the eastern coast, which had high proportions of rock (36%) and rubble (15%); uncolonized substrate on the north and south coasts was primarily sand.
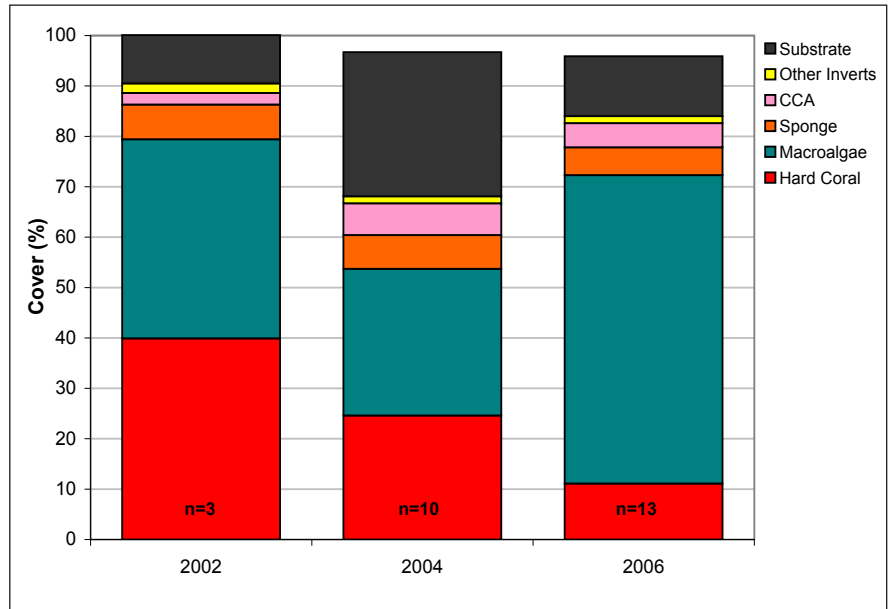

Figure 4.6. Percent cover of southwest coast reef RAD sites (haphazardly selected each year) as determined from point counts of haphazardly-placed 1 m² photoquadrats (4-10 photoquadrats per site). Algal turfs are poorly resolved from photographs so they are included with pavement, rubble, and sand called "substrate". N given in each bar represents the number of sites (southwest patch reefs only) sampled in that year. Source: Miller et al., 2003 and Miller et al., unpub. data.
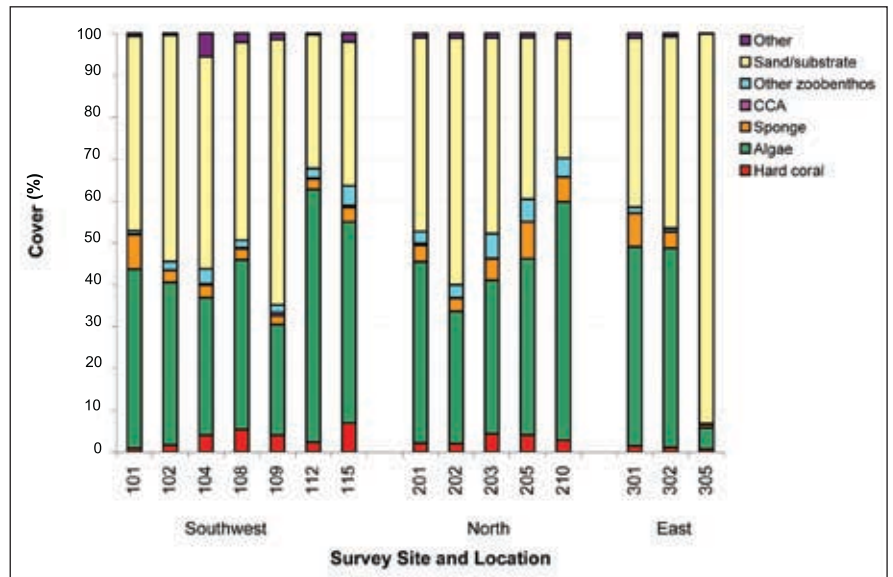

Figure 4.7. Community composition characteristics for all sites surveyed at Navassa by NCCOS in April 2006. All sites were surveyed in situ *using benthic photo transects (n=31 photos per 30 m transect, n=3 transects per site). Sites (numbers along the x-axis) were all 30-34 m depth and stratified by location (southwest, north or east coasts). Benthic cover types are grouped by NOAA Fisheries categories, but are not strictly comparable due to differences in methodology. Source: Piniak et al., in prep.

Disease Characterization (SEFSC–2004)
Methods
Haphazardly placed transects (n=3-7) were sampled at five sites around the island to examine spatial variation in disease prevalence upon observation of high coral disease occurrence in November 2004. Transect size was either 1 x 7.5 m or 0.5 x 10 m. Each colony within the transect was scored for species, size category (small <15 cm diameter; medium 15-40 cm; large >40 cm) and disease state was scored as either "active" disease signs, "recent mortality" or unaffected. Prevalence of both active and recently diseased states were expressed as proportion of total colonies in each disease state. Prevalence was also calculated for certain subsets of colonies, namely large colonies (>40 cm), and *Montastraea* spp. for comparison to the coral community as a whole. Further detail on the methodology employed can be found in Miller and Williams (2007).

Results and Discussion
Over 15 species of scleractinians were observed with "white disease" signs (Miller and Williams, 2007; Figure 4.8). Total prevalence (percent) of colonies with active disease signs at the sites sampled via haphazard transects ranged from zero at NW Point to over 15% at site A, with an additional 20% of colonies at that site displaying recent mortality (Table 4.2). Disease prevalence was substantially higher among large colonies and among *Montastraea* spp. colonies, with a majority of *Montastraea* spp. colonies affected by disease at one site (Table 4.2). The ensuing loss of large colonies is expected to affect coral community structure over a long time span.

Figure 4.8. Photo of pillar coral, Dendrogyra cylindrical*, suffering rapid tissue loss consistent with white-plague type disease in November 2004. White areas of the colony are recently dead (skeleton); only the gray areas still have live tissue. Photo: NOAA SEFSC.*

Table 4.2. Prevalence of active disease signs and recent mortality consistent with disease. Replicate transects were pooled from each site to indicate prevalence amongst all colonies compared to large colonies and Montastraea *spp. colonies. No colony size information was collected at Site A. Locations are given in Figure 1. Source: Miller and Williams, 2007.*

SITE	TOTAL COLONIES			COLONIES >40 cm DIAMETER			*MONTASTRAEA* spp. COLONIES		
	N	% active disease	% recent mortality	N	% active disease	% recent mortality	N	% active disease	% recent mortality
A	79	15	19	NA	NA	NA	19	36.8	21.1
B	360	6.9	7	22	31.8	0	44	25	2.3
Video Patch	267	3.4	2.6	64	14	10.9	28	21.4	7.1
NW Pt	137	0	0	6	0	0	5	0	0
C	300	1.5	0	10	10	0	20	0	0

Bleaching Characterization (SEFSC–2006)
Methods
A widespread and fairly severe coral bleaching event was encountered during the November 2006 cruise. Several rapid assessment techniques were utilized to document the extent (spatial patterns, species affected and severity) of coral bleaching at Navassa. Using a belt transect (10 x 1 m) at seven sites ranging in depth from 7-27 m, all colonies greater than 4 cm diameter were identified to species or genus and colonies were ranked by size class and degree of bleaching (normal, pale, mottled or completely bleached white). These categories were subsequently pooled for the current presentation. Between two and six transects were sampled at each of the seven sites.

In order to get a more representative view, scientists also performed RADs at an additional eight sites ranging in depth from 27-37 m. In these cases, no transect was laid out and a subset of common hermatypic coral species (limited to *Diploria strigosa*, *D. labyrinthiformes*, *Montastraea cavernosa*, *M. faveolata*, *M. annularis*, *M. franksi* and *Colpophillia natans*) were scored for bleaching state as described above. A haphazard compass heading and a 1 m length PVC pole was used to delineate an area for sampling. Although the total area sampled (hence colony density) cannot be determined from this data set, the use of the heading and a 1 m guide minimized bias in 'choosing' colonies to record. Bleaching prevalence (percent of colonies affected) for the sampled species was recorded.

Results and Discussion
Overall prevalence of coral bleaching at the various sites ranged from approximately 15-78% of colonies when all species were pooled (Figure 4.9). Shallow sites (<10 m) were less affected than deeper sites (>20 m) and fringes of bleached colonies that were overgrown by macroalgae (commonly *Lobophora variegata*) were normally pigmented. This suggests that the interaction between the severity of bleaching and differences in light levels may be complex. The most impacted coral taxa were *Agaricia* spp. and *Montastraea spp.*(*M. faveolata* was greatly dominant in this group). *Siderastraea siderea*, *Diploria* spp. (predominantly *D. strigosa*) and *Porites porites* were intermediately affected. Least impacted were *P. astreoides* and *M. cavernosa*.

Qualitatively, the intensity of bleaching appeared to increase over the 11 days of observation. Some bleached colonies were clearly undergoing partial mortality, but it was not possible to differentiate causality related to bleaching versus disease as both often co-occurred in colonies (Figure 4.10).
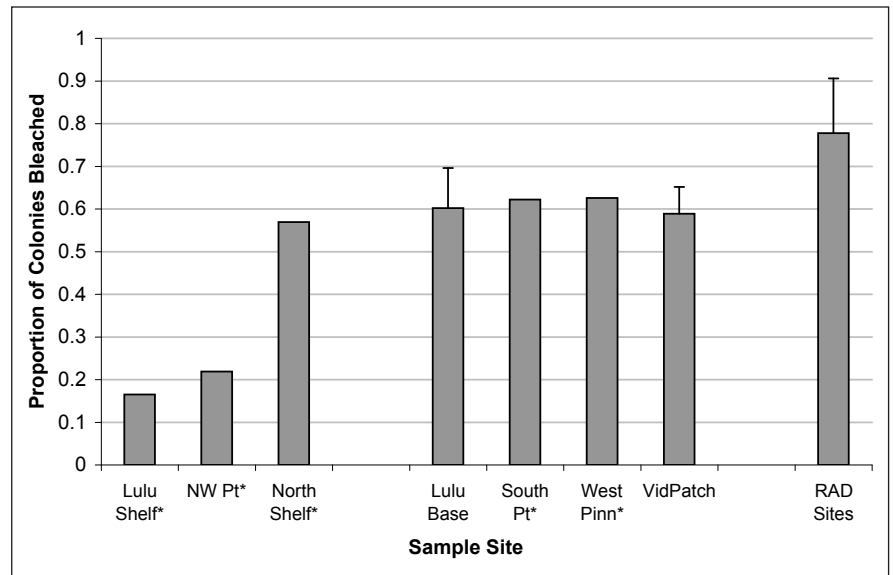

Figure 4.9. Mean plus ±1 SD bleaching prevalence. Sites with asterisks show no variance estimate since only two transects were sampled. The error bars shown for the other sites indicated ±1 SD for n=5 or 6 transects (or six sites for RAD sites). These means pool all degrees of coral bleaching and all species sampled (see text for details). The first three sites are shallow shelf habitats (7-10 m depth). The second set of four sites range from 20-27 m depth. The last bar (RAD sites) is the mean of prevalence scored for a subset of coral species in one rapid assessment dive at each of six sites ranging from 27-37 m. Source: Miller and Williams, unpub. data.
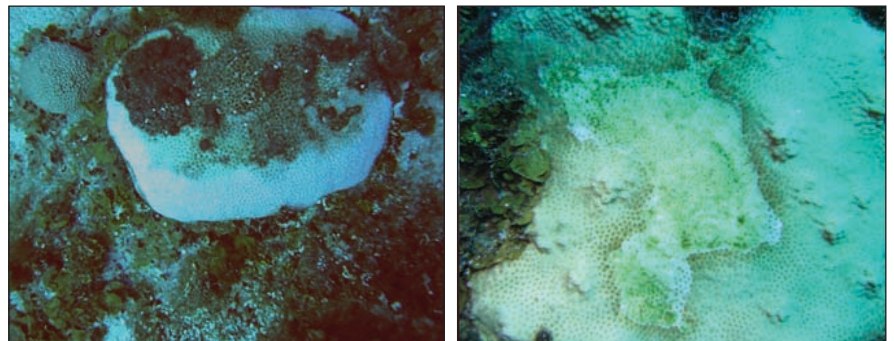

Figure 4.10. Photos showing bleached coral with partial mortality. Left: Bleached Siderastraea siderea *that appears to have endured multiple recent (estimated 6-18 months) partial mortality events. Note small unbleached conspecific to the left. Right: Moderately bleached* Montastraea *spp. with current mortality possibly from simultaneous disease. Photos: NOAA SEFSC.*

Status of Acroporids (SEFSC–2002-2006)

Methods

A. palmata habitat is mostly confined to the shallow shelf areas around Lulu Bay and Northwest Point and around the cliff along much of the southwest and north coasts. Only qualitative observations on *Acropora* spp. abundance were made in 2002. In 2004, minimal surveys were made along confined sections of the coast. However, in 2006, following the Endangered Species Act listing of these species, targeted abundance sampling and demographic monitoring were established. We quantified the spatial extent and location of *A. palmata* colonies along the entire north and southwest coasts using snorkeler observations and a handheld Global Positioning System to mark the position of each colony encountered. Approximately 6.8 km of the estimated 9 km of coastline was surveyed for *A. palmata*. In addition, a total of 77 *A. palmata* colonies in five permanently marked plots (three around Northwest Point and two near Lulu Bay) were tagged, assessed, photographed, and biopsied for genotyping according to protocols developed and applied in the Florida Keys (Williams et al., 2006). Future surveys will reveal the recruitment and survivorship of the population at Navassa.

Results and Discussion

In stark contrast to other coral species in the area, the majority of *A. palmata* colonies observed appeared healthy with recent mortality observed only occasionally. A total of 1,800 colonies were mapped over 6.8 km of the Navassa coast. Although rough seas prevented surveys along the east coast of the island, heavy swells along this windward coast seem to limit coral development, and few *Acropora* spp. colonies were expected to occur in this area. In contrast, the 1998 expedition to the island (Littler et al., 1999) reported approximately one dozen *A. palmata* colonies confined to Lulu Bay based on casual observation. While targeted surveys of *A. palmata* were not conducted in 1998, it appears that the population has increased, with our 2006 survey counting more than 100 colonies in Lulu bay, and observations of portions of the wall that were paved with encrusting *A. palmata*.

In contrast to *A. palmata*, *A. cervicornis* remains extremely rare at Navassa. A total of only five small colonies were observed in over 250 person dives during the November 2006 cruise. One of these colonies clearly displayed tissue sloughing, a sign of disease, as has been observed in the Florida Keys (Williams and Miller, 2005).

Mapping

Directed efforts at mapping Navassa's benthic habitats began in 2004 with single beam acoustic work and benthic community characterization by scientists from the University of Miami's Rosenstiel School of Marine and Atmospheric Science (RSMAS). Multibeam mapping of the Navassa shelf was conducted in April 2006 by NCCOS-CCFHR in partnership with Solmar Hydro from approximately the 20 m contour out to 12 nm (about 22 km) from the island. A digital elevation model based on Light Detection and Ranging (LiDAR) data acquired in 1999 and multibeam bathymetry was used to calculate slope. Figure 4.11 shows the result when these two output layers were combined.

Results of a slope calculation performed using multibeam data from 20–50 m depths with the Matlab Mapping Toolbox (Version 1.2; Mathworks, Natick, MA), which uses finite differences to compute the gradient of a gridded data set are shown in Figure 4.12A. Single beam acoustic data were acquired as points along track lines, classified, then gridded to 100 m cells using a majority

Figure 4.11. Bathymetric map of Navassa Island and the surrounding coastal area. Source data: Solmar Hydro and NASA.

filter. Figure 4.12B shows the acoustic seabed classification based on the percent of the seabed covered with sediment (patchiness) and the local variability in depth (relief). Information from all sources (IKONOS satellite imagery, multibeam bathymetry, benthic community analysis, drop camera and diver observation) were integrated into the habitat map (Figure 4.12C). Details of map construction are given in Miller et al. (in review).
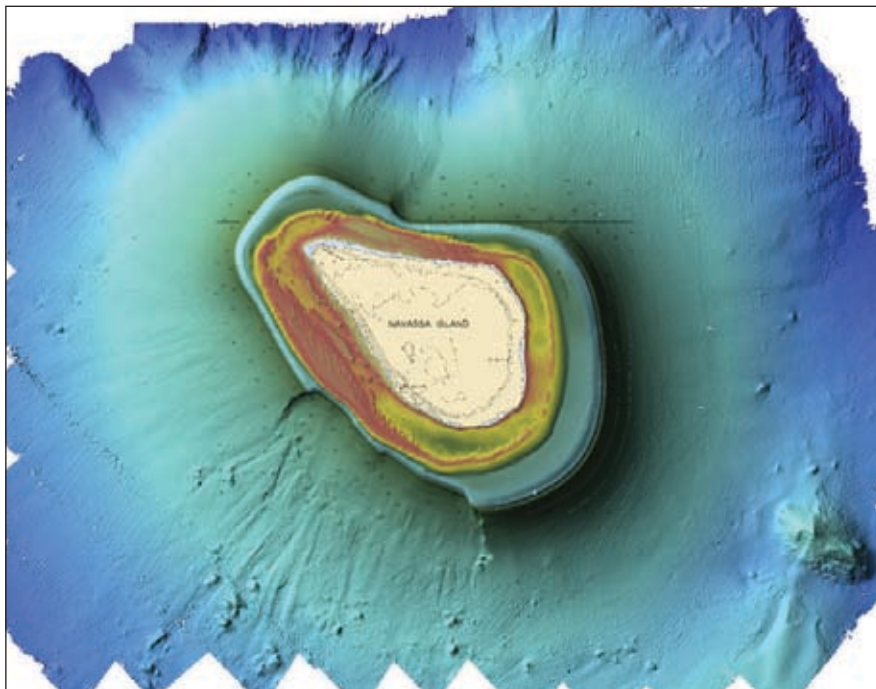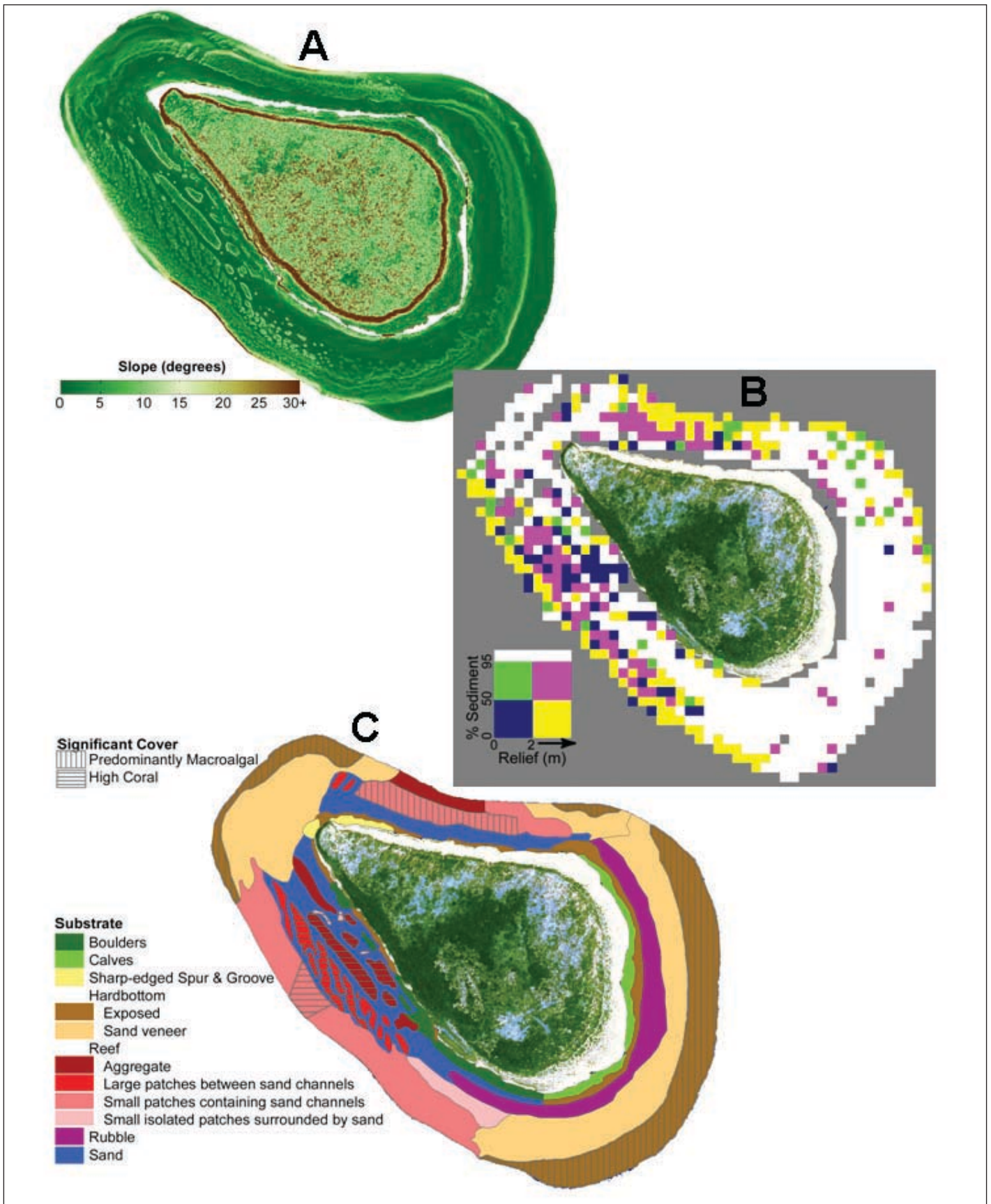
Navassa Island

Figure 4.12. A) Slope for Navassa Island computed from NASA's LiDAR data on land and Simrad XX data from 20-50 m water depth. Values above 30 degrees were clipped to show detail in the range 0-30 degrees. Maximum slope for this data set was 80 degrees. Null values due to lack of data are shown in white encircling the island. B) Acoustic seabed classification based on "patchiness", the percent of the seabed covered with sediment, and "relief", the local variability in depth. Data were acquired as points along track lines, classified, then gridded to 100 m cells using a majority filter. No data is shown as gray. C) Interpreted benthic habitat map based on all available information sources including bathymetry, IKONOS imagery, benthic community classification, and diver/drop camera observations. Sources: A) Solmar Hydro, NASA; B and C) A.Gleason, Univ. of Miami/RSMAS.

ASSOCIATED BIOLOGICAL COMMUNITIES

Fish Surveys (SEFSC)

Data on reef fish assemblages and other mobile fauna have been collected via a stationary point sampling technique (Bohnsack and Bannerot, 1986; McClellan and Miller, 2003) referred to as Reeffish Visual Census (RVC). The total number of samples and summary results are given in Table 4.3. Sites sampled in 2006 included both stratified random sites (according to habitat map in Figure 4.12C) and targeted RAD sites. In addition to enumerating reef fishes, RVC samples record the presence and abundance of selected mobile macroinvertebrates, including the long-spined sea urchin (*Diadema antillarum)*, queen conch (*Strombas gigas*) and lobster (*Panulirus argus*, not reported here). The abundance of *D. antillarum*, an important grazer, was also noted in benthic transect sampling at fixed sites surveyed by the SEFSC in 2006.

Results and Discussion

There is a clear declining trend in reef fish biomass (Figure 4.13 and Table 4.3) between 2002 and 2006 as determined by the RVC sampling. This trend is most evident in piscivores, herbivores and planktivores (the dominant trophic groups in terms of biomass). Macroinvertivores were the only group which showed a substantial increase in 2006 but this increase was due to squirrelfish only (data not shown), a common family which are preyed upon by piscivores as well as Navassa's human fishers. Fish sizes (mean fork length of individuals >10 cm) also showed a significant decline between 2002 and 2004 for grouper, snapper, triggerfish, parrotfish, jack, surgeonfish and squirrelfish families (Miller et al., 2007).

It should be noted that a more restricted set of habitats was sampled in 2002, particularly high-relief habitats near shore such as wall and wall base/boulder habitats. However, the same declining temporal trends are evident if relatively depauperate, non-reef habitats (e.g., sand/rubble) are excluded from the latter years' samples (data not shown). Hence, it is not likely that the observed decline in fish biomass (Table 4.3) can be explained by differential habitat representation.

On the other hand, abundance of *D. antillarum* has increased over the four year interval. The mean density of urchins from the RVC data (number/sample) increased 400% between 2002 and 2006 (Table 4.3). Benthic transects indicated a November 2006 *D. antillarum* density of 0.16 m^2 + 0.02 % SE (n=11 10 m^2 transects among six sites). Although these densities are nowhere near those that have been shown to correspond with enhanced coral recruitment (i.e., 2-5 per m^2; Carpenter and Edmunds, 2006)], densities are likely approaching this level in certain habitats (e.g., nearshore boulder/

*Table 4.3. Summary of RVC data, including relative abundance of conch and urchins (*D. antillarum*) collected in 2002, 2004 and 2006. Sampling intensity has increased slightly over the study, including a wider range of habitats. Source: McClellan and Miller, 2003; McClellan et al., unpub. data.*

|	2002	2004	2006
# RVC Samples (N)	110	123	150
# census takers	2	3	4
# Fish Species	122	128	139
# Individuals	22,798	41,174	35,633
Density (# indiv/sample)	207	335	238
Total Biomass (g)	1,547,671	1,052,314	1,128,868
Mean Biomass (g/sample)	14,070	8,555	7,526
# Diadema	18	53	99
Mean density (#/sample)	0.16	0.43	0.66
Frequency (proportion of samples occuring)	0.09	0.20	0.22
# Conch	8	247	65
Mean density (#/sample)	0.07	2.01	0.43
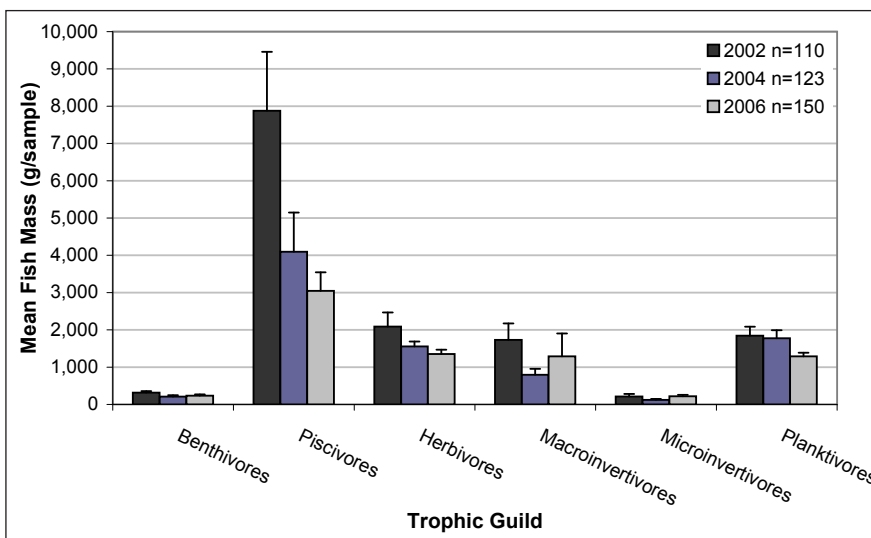
Figure 4.13. Reeffish biomass per sample (mean + 1 SE) by trophic group over a four year interval. Species included in each trophic group provided in McClellan and Miller, 2003. Source: Miller et al., 2007; McClellan et al., unpub. data.

calves habitat on night dive; M. Miller, pers. obs.). The marked increase suggests that recovery of *Diadema* populations is underway at Navassa. Conch are known to be highly aggregative and we observed no clear temporal trend in their abundance (Table 4.3). RVC samples in 2004 encountered several conch aggregations and this yielded higher mean and frequency of occurrence estimates in 2004 (Table 4.3).

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Much valuable information has been gathered about the flora, fauna and threats to the ecology of Navassa. Since the NNWR was established in 1999, it has been faced with a documented increase in threats by foreign nationals, mainly Haitians, conducting commercial and subsistence fishing and hunting activities on the Refuge. Challenges to effective management are related to the island's remote location, an absence of local management presence, and an absence of solid quantitative fishery data. Currently, no practicable mechanism exists whereby the NNWR can efficiently or economically document, manage, or address these threats. Although active management has been limited, work begun by a Haitian non-governmental organization, the Foundation for the Protection of Marine Biodiversity, is beginning to educate local fishers.

Discussions are now underway for developing a strategy to deal with the unauthorized fishing incursions into NNWR via a collaborative conservation effort with federal agency members of the U.S. Coral Reef Task Force, academic institutions and non-governmental conservation organizations. The development of a Navassa NWR collaborative conservation effort will strengthen the National Wildlife Refuge System's natural resource management efforts. It is foreseeable that a similar approach can be employed for other remote, insular U.S. possessions, especially National Wildlife Refuges in the Pacific Ocean.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

It is clear that Navassa reefs, despite their remoteness from many types of local anthropogenic stress, are undergoing rapid change. Both expanded (but possibly stabilized) fishing pressure and disturbances, such as coral bleaching and disease events, are resulting in rapid loss of live coral cover, including loss of large coral colonies, and reductions in the size and abundance of reef fishes. The jurisdictional/management challenges for Navassa, meanwhile, do not abate. The occurrence of severe coral disease and bleaching events in this relatively deep (25-30 m) and remote location support the hypothesis that coral loss in the Caribbean is a regional phenomenon, and effective conservation and management measures to reverse this trend are not obvious.

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