



**STATUS OF REEF RESOURCES OF NAVASSA ISLAND:
NOV 2002**

EDITED BY

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CRUISE REPORT NOV 2002

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Chapter 1. EXECUTIVE SUMMARY

This report provides a descriptive summary of activities and results for the NOAA-Fisheries sponsored expedition to Navassa Island conducted 28 October – 12 November 2002. This expedition was intended to provide an intensive baseline assessment of the composition and condition of local benthic and fish assemblages. This study distinguishes itself from previous expeditions that mainly focused on quantifying taxonomic diversity. To reveal the temporal dynamics of Navassa's bottom communities, permanent monitoring stations (3 sites) and settlement tiles were installed (2 sites). It is intended to re-visit and re-survey these during future expeditions to Navassa.

This report document is divided into chapters focusing on the description of abundance and distributional patterns in local biota (i.e. benthic community structure, habitat types, crustose coralline algae, fish and plankton assemblages). In addition some chapters deal with biological processes that are believed to be important in Navassa waters (i.e. fish trophic structure, the effect of coral predation by snails). One chapter summarizes an initial overview of potential impacts of local fishing activities on Navassa's reefs. This report does not represent final, polished scientific products, but rather a timely documentation of our findings and some potential implications.

Benthic communities show live coral cover ranging from 3% on sparse hardbottom communities on the north shelf of the island to over 40% on some deep patch reefs. Shallow shelf and spur and groove habitats average almost 20% live coral cover. Macroalgal cover is high in some habitats (especially deeper sites >15 m). The brown alga *Lobophora variegata* dominates the algal community at nearly all our sites. Compared to data obtained during a prior survey in April 2000, algal cover was doubled at one site (25% to 50% cover) in 2002 but similar at the other two re-sampled sites. It is not clear, however, if this increase might be attributed to seasonal effects (fall vs. spring). Otherwise, little change in benthic community structure was observed in the sites that were sampled in both surveys. Elkhorn coral, *Acropora palmata*, is increasing in abundance compared to the Apr 2000 observations whereas staghorn coral, *A. cervicornis*, remains rare and in poor condition. Current threats to live coral include predation by the snail, *Coralliophila abbreviata*, invasion by the eroding sponge, *Clinoa* sp. and the presence of an unidentified disease affecting mainly brain corals (*Diploria* spp and *Colpophyllia natans*). Densities of coral juveniles are similar to other areas in the Northern Caribbean (e.g., United States Virgin Islands, Florida Keys, Jamaica). The crustose coralline algal flora is characteristic of one that is highly grazed. Extended depth distributions were observed across diverse groups including elkhorn coral, benthic foraminifera, and crustose coralline algae with shallow water species were observed at much greater depths than typically observed in the Caribbean. This pattern is seemingly attributable to consistently clear waters surrounding Navassa.

The reef fish assemblages are numerically dominated by planktivores and small sizes dominate population structure of all species. Large grouper and snapper species are extremely rare in Navassa's fish community. In 110 stationary visual survey samples covering a wide range of habitat types, only 12 individuals of larger grouper species (Graysby, Red Hind, Yellowmouth, Yellowedge, and Tiger) were observed and no Nassau grouper were observed. Average size and density of grouper, snapper and parrotfishes were substantially less in the more extensive 2002 survey than observed in 2000 at a subset of shallower habitats. Thirty-four new fish species were found that had not been previously reported from Navassa. This is mainly due

the more extensive diving activities during our 2002 expedition that allowed the sampling of more habitat types for longer periods of time.

Preliminary surveys of plankton communities around Navassa suggest biomass is substantially low compared to other islands in the Caribbean. This may be due to Navassa's isolated positioning in an oligotrophic sea. Benthic foraminifera showed typical abundance and distribution patterns for Caribbean assemblages with minor levels of sub-lethal bleaching indicating possible light or temperature stress. Population structure (size structure and sex ratio) of the corallivorous snail, *Coralliophila abbreviata*, are similar to that observed in other Caribbean areas. Snails resident on different coral host species display substantial variation in size structure and sex ratio.

Fishing activity by transient Haitians is ongoing at Navassa. We observed ~ 4 boats fishing at a time, though none were present for more than 3 days during our observation. Several qualitative changes in fishery methods were observed compared to the April 2000 observations. Sizes of captured fish were smaller and novel fishing practices such as harvest of conch and juvenile sea turtles with nets (not observed in April 2000) were observed. The use of a novel gear type and exploitation of novel species suggest that serial overfishing is occurring at Navassa.

Island biogeographic theory predicts that islands like Navassa, being small and isolated, show reduced species diversity. This prediction is most clearly born out in the fish assemblage, as qualitative habitat limitation appears to restrict the diversity in some common Caribbean groups. For example grunts are nearly absent as their juvenile life phase requires mangrove habitats that are absent at Navassa. The fact that Navassa is small and, subject to high physical disturbance in the form of hurricanes (2 hurricanes passed in 2002) suggests that its communities will show strong temporal variation. In other words, Navassa communities are poorly sustained by local recruitment and therefore highly susceptible to episodic disturbance or recruitment events. The interpretation of "snapshot" surveys of reef condition, such as provided by the current report, is therefore problematic. Subsequent periodic surveys must be undertaken at Navassa in order to draw meaningful conclusions regarding temporal patterns reef condition.



Expedition Vessel, R/V Coral Reef II

ACKNOWLEDGMENTS:

This expedition was made possible by funding from the NOAA-Fisheries coral reef initiative, with cooperation from the U.S. Fish and Wildlife Service (USFWS), Caribbean Islands National Wildlife Refuge. Work was conducted under Navassa Island National Wildlife Refuge Special Use Permit # 41529-2002-10. Participation by USFWS personnel as well as investigators from Princeton University and University of Maine is greatly appreciated and greatly enhanced the productivity of the expedition. LTJG G. Mark Miller, David McClellan, Charles Fasano and Jack Javech of the Southeast Fisheries Science Center are due thanks for their diligence above and beyond the call of duty in logistic support, particularly to enable the NITROX diving support that allowed us to enjoy so much productive bottom time. Jack Javech assisted with photo formatting and Carlos Rivero assisted with ArcView set-up of the expedition results. Last, but not furthest from least, logistical support from John G. Shedd Aquarium and, specifically, the crew of the R/V Coral Reef II made the trip feasible and enjoyable. We are in their debt – Thanks Capt John, Capt Lou, and Charles!



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- | | |
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Chapter 2: History and Status of Navassa Island

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Navassa Island and a 12-mile radius of marine habitat became the 517 th National Wildlife Refuge on April 22, 1999. Navassa is one of nine National Wildlife Refuges administered by the US Fish and Wildlife Service as part of the Caribbean Islands National Wildlife Refuge Complex.

The island is located in the Jamaica Passage approximately 55 km southwest of Haiti's Cap des Irois and 136 km east northeast of Morant Point, Jamaica. Navassa rests on a submarine ridge averaging 700 meters in depth formed by the extension of the Haitian Peninsula de la Hotte. The approximately 5.2 square km island supports several thousand nesting Brown and Red-footed boobies and four extant endemic reptile species. Although the island has undergone extensive disturbance a surprisingly intact evergreen dry forest exists along the southern slopes and across the upper plateau.

Navassa Island was claimed by the U.S. in 1837 a year after the passage of the Guano Act. The Civil War was fought before the Navassa Phosphate Company of Baltimore brought to the island 140-180 African American contract laborers from Maryland. These former slaves working under very harsh conditions removed about one million tons of phosphorite from the island. Harsh conditions led to a rebellion in 1889 in which five supervisors died in the fighting. Mining continued at a much reduced rate and was abandoned before the Spanish-American War of 1898 forced the company to evacuate the island.

Due to the opening of the Panama Canal, in 1917 the U.S. built a lighthouse on the island. The still standing 162 foot lighthouse was the first poured concrete lighthouse built by the U.S. Lighthouse Service. Located on the southeastern uplands it reaches 395 feet above sea level. The U.S. Lighthouse Service installed an automatic beacon in 1929. The U.S. Navy set up an observation post for the duration of World War II. Except for visiting Haitian fishermen the island has not been inhabited since.

The refuge complex will begin Comprehensive Conservation Planning in 2004. Congress has directed the Service to produce a fifteen year conservation plan with public input and participation for each of its refuges. Navassa Island NWR will be included with the other eight refuges in the Caribbean Islands complex. The refuge manager would like to see the annual

expeditions to the island continue with our partners, including The Ocean Conservancy, NOAA, USGS, Shedd Aquarium and the American Museum of Natural History, all of which have all made major contributions. Much biological information has been compiled to date on both marine and terrestrial systems.

The Service will continue to monitor the large seabird colonies on the island and document use by resident and migratory songbirds. An extensive flora has been compiled for the island and several long term vegetation monitoring plots have been established. The artesanal fishing pressure by Haitian fishermen and other nationals that enter refuge waters with fishing trawlers needs to be monitored more closely and debate continues on its extent. Long term trends will be assessed with the help of NOAA as permanent transects have been established around the island.

The harvest of young seabirds and endangered hawksbill sea turtles along with the frequent fires started by visiting fishermen are all immediate management concerns. Fire has a detrimental effect on the island's forest habitat. This forest cover is important for migratory song birds and resident nesting sea birds such as the red-footed booby. Opening dialogue with the Haitian conservation community may be a necessary step to ensure the conservation of the tremendous fish and wildlife resources of Navassa Island National Wildlife Refuge.

Chapter 3. Benthic Habitats and Community Structure

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Abstract: Benthic habitats around Navassa were stratified into eight types based on depth and topography. Quantitative assessments of benthic community structure were conducted for most of the habitat strata. In most cases, in situ point intercept transects were employed. In some cases where bottom time was limiting, 1 m² digital still photo quadrats were used to estimate percent cover of benthic groups.

Scleractinian coral cover ranged from 3 % in sparse hardbottom habitats on the deep terrace to > 40% on some terrace patch reefs along the west coast. These deeper habitats had not been previously quantified. Macroalgae, predominantly *Lobophora variegata* and *Dictyota* spp. were observed at high abundance (45-60%) in most habitats – less in sharp-edged spur and groove habitat (~20%). Sponges are also substantial components of benthic communities with up to 25% cover. Gorgonians were patchily abundant and dominated by larger size classes. Overall coral condition in shallow habitats is good with very low incidence of disease (0% of 985 colonies surveyed in shallow habitats) though substantial disease was observed on brain corals (*Diploria* spp. and *Colpophyllia natans*) in deeper habitats (~ 40%).

Introduction:

Navassa Island is a small, uninhabited, oceanic island ~ 50 km off the southwest tip of Haiti. It is under jurisdiction of the US Fish and Wildlife Service as one component of the Caribbean Islands National Wildlife Refuge. Based on some preliminary quantitative surveys in 2000, and because of its isolated and uninhabited status, Navassa has been suggested to provide a relatively pristine end member for reef status in the Caribbean (Miller and Gerstner 2002). However, there is substantial but unquantified activity at Navassa by migrant Haitian fishers and their impact has been suggested to be substantial (Collette et al. 2003) or potentially rapidly increasing (Miller and Gerstner 2002).

Navassa's morphology resembles a wedding cake and thus lacks typical Caribbean patterns of reef zonation. The dolomite island is surrounded by cliffs. For most of the island's

circumference, these cliffs reach straight down to ~ 25m depth where a submarine terrace slopes out gradually. In some areas, these cliffs are highly eroded and undercut, often with large chunks having fallen off that now rest on the terrace forming huge boulders. In limited areas around the northwest point and at Lulu Bay, the island has small shoulders of shallow reef habitat (10-15m). Previous quantitative surveys had been confined to these relatively shallow habitats (<25 m). Mangroves and sandy beaches are completely lacking around Navassa while seagrass habitats are extremely limited.

Thus, Navassa reefs may provide a valuable reference site for Caribbean coral reef structure and function. However, to fulfill this role, additional quantitative information on the range of habitats, the status of benthic and fish assemblages, and the intensity of fishing activity is required to apply such comparisons meaningfully. The use of NITROX scuba during an expedition in Nov 2002 has allowed progress toward this goal - classification and quantitative description of a much wider range of habitats, including more habitats around the ~ 30m terrace. The classification of habitat types based on depth and topography as well as the quantitative description of benthic community structure is described in the current paper. Quantitative fish community structure (Chapters 4 and 5) and qualitative observations on fishing activities (Chapter 10) are described separately.

Methods

Habitat Types

Specific habitat types encountered around Navassa Island were classified by depth and gross topography/geomorphology. Reference was made to habitat classification schemes described for reef habitats in the Florida Keys and Dry Tortugas (Franklin et al., 2003) but, as described above, additional habitat types were encountered at Navassa that are not present in other areas (and conversely, many 'typical' reef habitat types are not present at Navassa).

Benthic community structure

Sampling to quantify benthic community composition was accomplished for most of the identified habitat types at multiple sites per habitat type (see map, Figure 1). In situ line intercept transects were sampled at shallower sites where bottom time was adequate. Four 15-m transects were placed haphazardly within each site/habitat and the benthic organism or substrate

type underneath was recorded every 15 cm, yielding 100 points per transect. Thus the number of intersection points occupied by a given benthic group provided a direct estimate of percent cover. Scleractinian corals and macroalgae were recorded to species or genus, other groups such as sponges were recorded collectively.

At additional deeper sites around the terrace (patch reefs and a sloping dropoff offshore of the southwest coast), 1m² quadrats were haphazardly placed and photographed with a housed digital still camera (3 Megapixel Sony Cybershot DSC-P5; n=9-15 quadrats per site). A random array of 50 dots was superimposed on the computer image for each quadrat and the organism or substrate under each dot was recorded. Four close-up photographs of each quadrat were also taken and referred to when the identity of the substrate under a given point was not clear from the full quadrat picture. For each substrate type, the coverage by these fifty points was multiplied by two to estimate percent cover.

Bray-Curtis similarity was calculated amongst all surveyed sites via PRIMER software (PRIMER-E Ltd, Plymouth Marine Lab, Plymouth UK) followed by group-average linkage clustering to examine the congruence of this benthic community classification with the a priori assigned habitat types.

Gorgonians

Holaxonian gorgonians were identified and measured by size class at four sites. Encrusting gorgonians (*Briarium* sp., *Erythropodium* sp.) were not common and were not included. Gorgonians within four 8 meter long by 1 meter wide transects were recorded at each site. Where densities were very low (East Side), haphazard identifications of gorgonians encountered outside of the transects were made in the general area. Size frequency information was taken for gorgonians at all sites, however, only two sites (Northwest Point and Southeast Point on the wall) had sufficient numbers to make size frequency comparisons. Size frequency information from the West Pinnacles site was from a vertical wall within 20 meters of the 4 benthic transects. On the vertical walls, size frequencies and densities were recorded within two 10 meter long by 1 meter wide horizontal transects. Additionally, gorgonian species were noted during a brief dive in the shallow shelf of Lulu Bay. The species list represents what was seen during the transect studies and some brief inspections of the area, and does not represent a

comprehensive species list for Navassa. The primary effort was to record density and population structure, and characterize the sites.

Coral Condition

At a subset of shallow sites where *in situ* transects were performed, quantitative data was also obtained on the condition of coral colonies. Each colony >4cm diameter within a 0.5 m wide band along either side of 10 m length of two of the transects was identified (to species or genus) and examined for various conditions including bleaching, disease, predation, and overgrowth/competitive interactions. Hence a variable number of colonies was examined at each site according to the colony density at that site.

Results

Habitat Types

At least seven benthic habitat types were distinguished in the coastal region around Navassa Island (Table 1). This habitat classification is based on that devised by Franklin et al. (2003) for reef habitats in the Dry Tortugas. Benthic community characterization was conducted for all but two of these habitat types. Additional habitats encountered at Navassa that were not described by Franklin et al. (2003) include vertical wall, sharp-edge spur and groove, calves, and boulder/avalanche.

Benthic Community Structure

The percent cover by the dominant benthic groups for all sites is given in Figure 2. Macroalgae (predominantly *Lobophora variegata* and *Dictyota* spp.) is the dominant benthic group overall. However, at several sites of different habitat types (e.g. shallow shelf at Lulu Bay and several of the deep patch reefs), live coral cover was equal or greater than the cover of macroalgae. Live coral cover was highest (up to 46%) at several deep sites (25-30m) including patch reefs and one site on the deep southwest dropoff. In shallower habitats (10-20m), live coral cover was in the range of 10-20%. Live coral less than 10% (co-incident with extremely high macroalgal cover) was observed in sites with apparently intense disturbance regimes, including the east coast, apparently scoured deep hardbottom habitats, and the “avalanche zone”

observed at the North Shore. Sponges comprised a substantial cover (10-20 %) at most sites. *Neofibrilaria nolitange* was the dominant sponge taxa across habitats.

For the subset of sites with high coral cover, the relative composition of the coral community is given in Figure 3. The dominant coral taxa at these sites were *Montastraea* spp., *Agaricia* spp. and *Porites porites*. Overall, *Agaricia* spp. was the dominant component of the coral community in shallower sites.

The dendrogram for the clustering of all these sites is given in Figure 4. There is good congruence with the *a priori* habitat types assigned to each site (Table 1) with major clusters consisting of shallow shelf/SESG sites, Calves sites, deep sites with low coral cover (hardbottom, avalanche, other), and deep sites with high coral cover (deep patch reef and slope sites).

Gorgonians

Gorgonian densities (Figure 5) at the sites sampled (from 15 to 20 meters in depth) were relatively low (ranging from 0 to about 6 m²), but highly variable or patchy. The highest density occurred in transects in a vertical wall habitat within 20 meters of the West Pinnacles transects (Calves habitat) where gorgonian densities were very low. These observations were largely representative of the nearshore, shallower sites, and do not reflect gorgonian abundances on the deeper, moderate relief hardgrounds and patch reefs on the insular shelf around Navassa.

Species composition at the sites examined (Table 2) was typical of Caribbean shallow water gorgonians. The northwest site, was heavily dominated by *Gorgonia ventalina*, consistent with similar habitats in Puerto Rico with high energy, but relatively low sediment (bedload) movement (Yoshioka and Yoshioka, 1989). While densities were extremely low at the east site, species composition was not notably different from the other sites examined. The east site, characterized by large blocks that have calved off the island edge, was very similar to algal and sponge dominated hardgrounds off the high wave energy north coast of Puerto Rico. *Iciligorgia schrammi*, a gorgonian typically found at the slope breaks on offshore, deeper reefs with very clear water and high currents was seen at all sites (usually along vertical walls or slope breaks) except the northwest station and the shallow waters in Lulu Bay.

The population size structure at Northwest Point (Sharp-Edged Spur and Groove habitat, Figure 6) was remarkable for the paucity of small colonies. The large *Gorgonia ventalina*

colonies that dominated this site appeared to be extremely healthy, with most of the population being large enough to assume sexual maturity (generally over 20-25 cm). The West Pinnacles Wall site (Figure 7) was more varied with respect to species composition and size classes, however, it was heavily dominated by large *Pseudopterogorgia bipinnata* and *Muriceopsis flavida*. The smaller size classes were mostly *Eunicea succinea*, a species that tends to be smaller.

Coral condition

The relative incidence of various coral conditions for a subset of shallow and mid-depth sites (10-25 m) is given in Table 3. A total of 985 colonies were examined for conditions. The most common condition was algal overgrowth (where coral tissue was clearly affected) and the incidence of this condition was strongly correlated with overall macroalgal abundance (percent cover) among sites ($r^2=0.55$, Figure 8). A weaker relationship was found between sponge cover and incidence of sponge overgrowth damage on corals (Figure 8). Just over 4% of colonies on average displayed the effects of predation by snails, fire worms, or fish (Table 2). No colonies in this sample were observed with active disease although substantial impact of disease on brain corals (*Diploria* spp. and *Colpophyllia natans*) was observed in deeper sites.

Discussion





The greatest contribution of this expedition was the characterization of deeper habitats (20-30m) made possible by the implementation of NITROX mixed gas diving. Many of the deep patch reefs, particularly had high relief and had very high coral cover. The deep (20-30m) flats amongst these patch reefs harbor an interesting sand bottom gorgonian-sponge community. Despite the depth, the Navassa terrace receives ample light and water motion due to seemingly characteristic high energy and high water clarity. Representatives of both taxa reach extremely large sizes. The presence of large, healthy gorgonian colonies with very few recruit (< 5 cm) colonies suggests that poor recruitment success (either failure to settle, or post-settlement survival) rather than larval availability/reproduction is a limiting factor. This is consistent with other studies (Yoshioka 1997). Fireworms (*Hermodice carunculata*), a major grazer on gorgonians, were very common on Navassa. The geology of the sites selected (tops of limestone blocks, vertical walls) makes burial from bedload movement an unlikely cause of mortality. It is





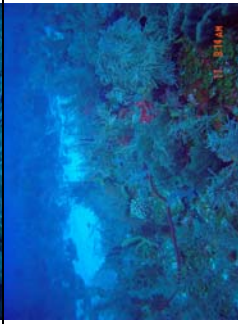
also the case that many taxa from diverse kingdoms appear at deeper depths at Navassa than noted in other areas of the Caribbean (e.g. *Acropora palmata*, App.2; benthic foraminifera, Chapter 8; crustose coralline algae, Chapter 6).

Three of the sites surveyed on the current expedition are comparable to data collected in April 2000. The Lulu Bay and Northwest Point sites appear reasonably similar in benthic community composition while the West Pinnacles site shows some substantial variation, notably higher macroalgal cover and lower live coral cover (Figure 2). It is plausible that this increase in macroalgal cover is a seasonal pattern; generally higher macroalgal standing stock would be expected in the autumn (following the summer growing season) than in spring (following likely winter storms and scouring). Unfortunately, with only two snapshots, it is impossible to tell if this increase represents a trend toward increased dominance of macroalgae (i.e. “phase shift” Done 1992) as has been observed at many Caribbean reef sites, (e.g. Hughes 1994, McClanahan & Muthiga 1998) as a manifestation of reef degradation. Extensive cover of *Lobophora variegata*, as was observed particularly at the deeper Navassa sites, is likely inhibitory to coral recruitment.

It appears that Tropical Storm Lili (with 40-45 kt winds) passed at least near Navassa approximately one month prior to our observations. While it is not clear whether this particular storm had much influence, it is clear that high physical disturbance is a common phenomenon and greatly influences Navassa reef structure as evidenced by the large boulders or “calves” (up to 15m diameter) which have broken off the cliffs and fallen into the shallow reef areas. The benthic communities in the most disturbed areas (the east coast) consist mostly of macro-algae, crustose coralline algae and gorgonians.

Table 1: Habitat types at Navassa classified by depth and gross topography; different communities could occur with these habitat types based on other environmental factors (e.g. exposure). * indicates habitat types where quantitative benthic community structure was not sampled.

Code	Habitat Type	Depth (m)	Description	Typical locations	
SESG	Sharp-Edged Spur and Groove	5-12	Eroded substrate forming sharp ribs (2 m tall at 5-10 m spacing) running perpendicular to shore	Northwest Pt North Shelf	
SL	Shallow ledge	7-10	“Shoulders” in wall that provide shallow habitat lacking SESG	Lulu Bay, East side	
CLV	“Calves” ^{1,2}	15-25	Huge boulders (e.g. the size of a house) broken off from the cliff face and resting on the terrace	West Side East Side Southeast Pt	
AVL	Boulders/avalanche	10-15	0.5-1 m diameter boulder zone appearing as “avalanche” flow from shore	North Shelf	

WALL	Vertical Wall*	0-20	Cliff face surrounding the island			
WB	Wall base*	25	Complex habitat at the edge between the cliff and the terrace. Often smaller boulders	West Side North Side		
SR	Sand/Rubble	20-30	Flat terrace area interstitial to hardbottom and patch reefs	West Side		
LRHB	Deep, low-relief hardbottom	25-35	Low relief continuous habitat along the terrace dominated by octocorals (<i>Pseudopterogorgia</i> spp)			
DP	Deep Patch Reef	25-30	Often well-developed constructional reefs scattered throughout the terrace, at least on north and southwest sides. Surrounded by sand. Often with high coral cover and 2m or more topographic relief			
MRHB	Deep, medium profile reef	>30	Dropoff along southwest coast with relict spur and groove formation. Sand grooves 8-10m wide with 1 m tall reef spurs. High abundance of soft corals <i>Pseudopterogorgia</i> (spp)	West Wall North slope		

¹ Clarke 1988; ² Franklin et al. 2003

Table 2. Gorgonian species recorded by site

<i>Species</i>	NW Pt	East Side	SE Pt	West Pinnacles (Calves and Wall habitats)	Lulu Bay
<i>Plexaura homomalla</i>	X		X		
<i>Plexaura flexuosa</i>	X	X	X	X	X
<i>Pseudoplexaura porosa</i>			X		
<i>Pseudoplexaura</i> sp. (w-f)*		X	X	X	
<i>Pseudopterogorgia acerosa</i>	X	X	X		X
<i>Pseudopterogorgia americana</i>		X	X		X
<i>Pseudopterogorgia americana</i> **	X	X	X	X	X
<i>Pseudopterogorgia bipinnata</i>			X	X	X
<i>Eunicea succinea</i>	X		X	X	X
<i>Eunicea mammosa</i>			X		
<i>Eunicea fusca</i>			X		
<i>Eunicea tourneforti</i>		X			
<i>Eunicea tourneforti</i> f. <i>atra</i>				X	
<i>Eunicea</i> sp. 7 ⁺			X		
<i>Gorgonia ventalina</i>	X	X	X	X	X
<i>Gorgonia mariae</i>					X
<i>Pterogorgia citrina</i>			X		
<i>Pterogorgia anceps</i>					X
<i>Muriceopsis flavida</i>	X	X	X	X	
<i>Muricea muricata</i>	X		X	X	X
<i>Plexaurella dichotoma</i>		X	X		
<i>Plexaurella grisea</i>			X		
<i>Iciligorgia schrammi</i>		X	X	X	
Total species	8	10	19	10	10
Depth	12m – 15m	12m- 21m	18m- 22m	18m-21m (calves) 13m (wall)	9m - 21m

* *Pseudoplexaura flagellosa* or *wagneriana*

** *Pseudopterogorgia americana* different morph where the exterior is not very slimy (may be different variety or sub-species, spicules consistent with other *P. americana*)

+ *Eunicea* sp. 7 small *Eunicea* found commonly in Puerto Rico, but does not conform precisely to described species. Small, branching at right angles, very friable, breaks very easily and re-attaches to bottom, eventually forming clonal colony groups.

Table 3: Percent of scleractinian coral colonies (>4 cm diameter) surveyed at subset of shallow sites ($\leq 20\text{m}$) that displayed various conditions. Overgrowth was designated only in cases where visible tissue damage was evident on the colony margins. “Snails” indicates the presence of corallivorous snail *Coralliophila abbreviata*, “other predation” includes fishes and the fireworm, *Hermodice carunculata*; the only bleaching observed was mild (pale or splotchy appearance).

SITE	Habitat Type	# colonies surveyed	% with snails	% with other predation	% with algal overgrowth	% with sponge overgrowth	% with coral overgrowth	% with disease	% with bleaching/discoloration
NW Pt	SESG	185	0.5	1.6	5.4	1.6	0	0	2.2
North shelf	SESG	201	2.5	0	10.4	5.0	2.0	0	1.5
Lulu Bay	Shallow shelf	177	5.6	0	6.8	4.5	2.8	0	1.7
East Side	Calves	69	4.3	2.9	27.5	8.7	1.4	0	1.4
SE	Calves	179	2.8	0.6	7.8	4.5	2.2	0	1.7
West side	Calves	174	4.0	0	14.9	4.6	0	0	4.0
TOT/MEAN		985	3.28	0.85	12.1	4.82	1.4	0	2.08

Benthic Transects and Photo Quadrats

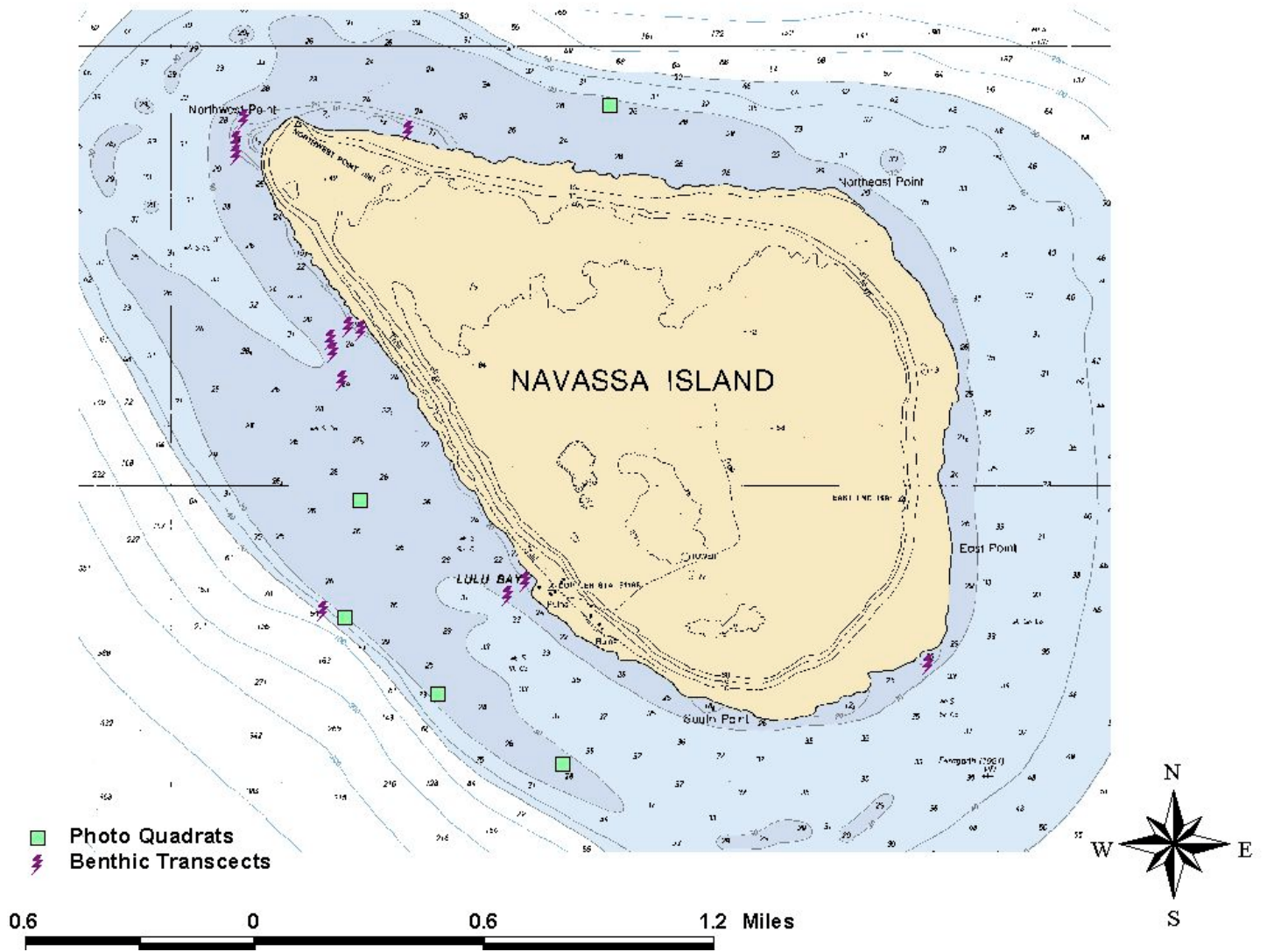
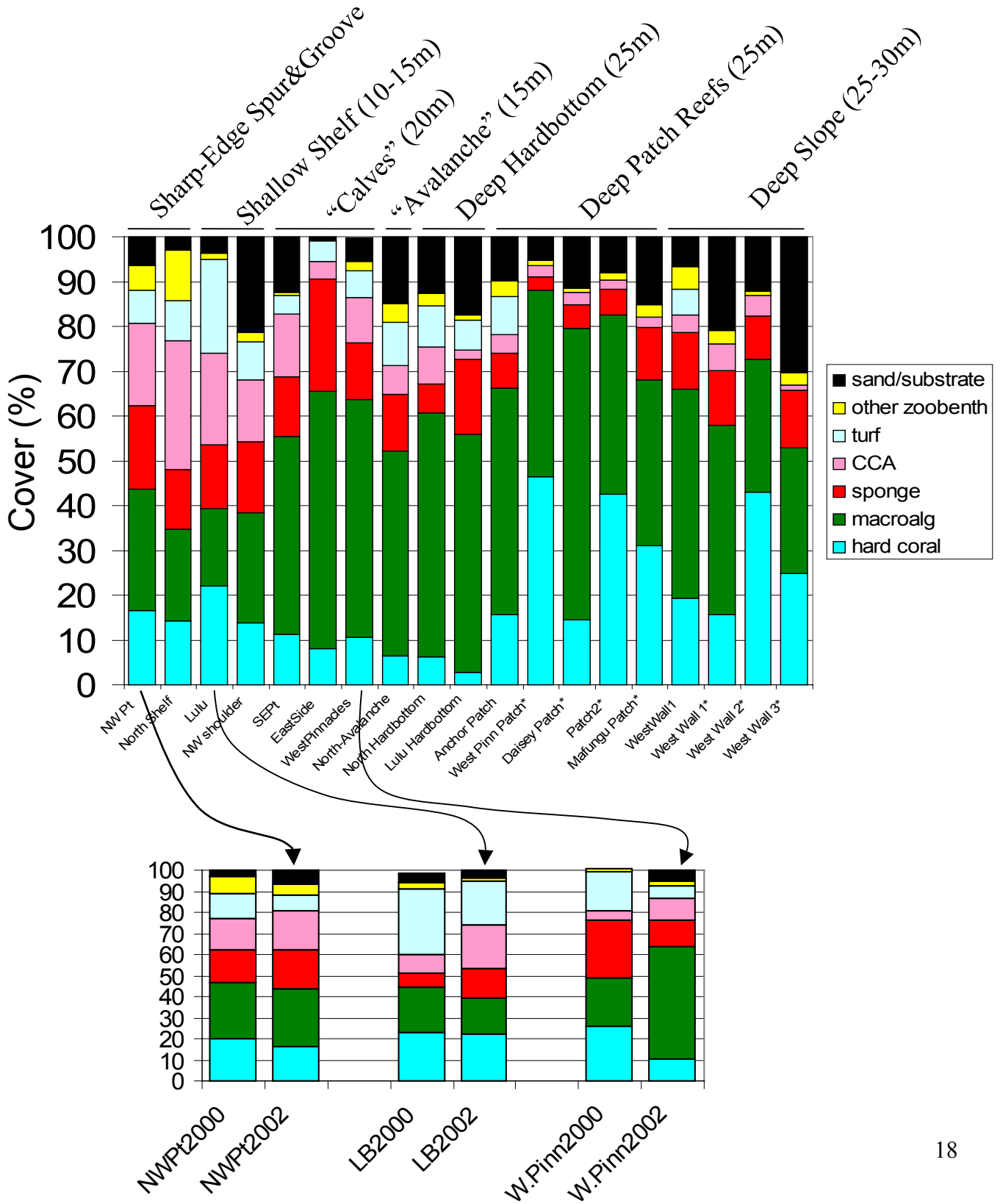


Figure 1: Location of *in situ* benthic transect sampling and photo quadrat sampling (deeper sites) used to quantify benthic community structure.

Figure 2: Community composition for all sites surveyed at Navassa, Nov 2002. Sites along the bottom axis with asterisk were surveyed by haphazard photo quadrats (n=8-15), others were surveyed *in situ* via point intercept transects (n=2-4 per site). Algal turfs were not resolvable from photographs. CCA indicates crustose coralline algae. Categories along the top axis indicate *a priori* habitat type classified according to depth and topography. Lower panel shows comparison with sites that were surveyed in April 2000.



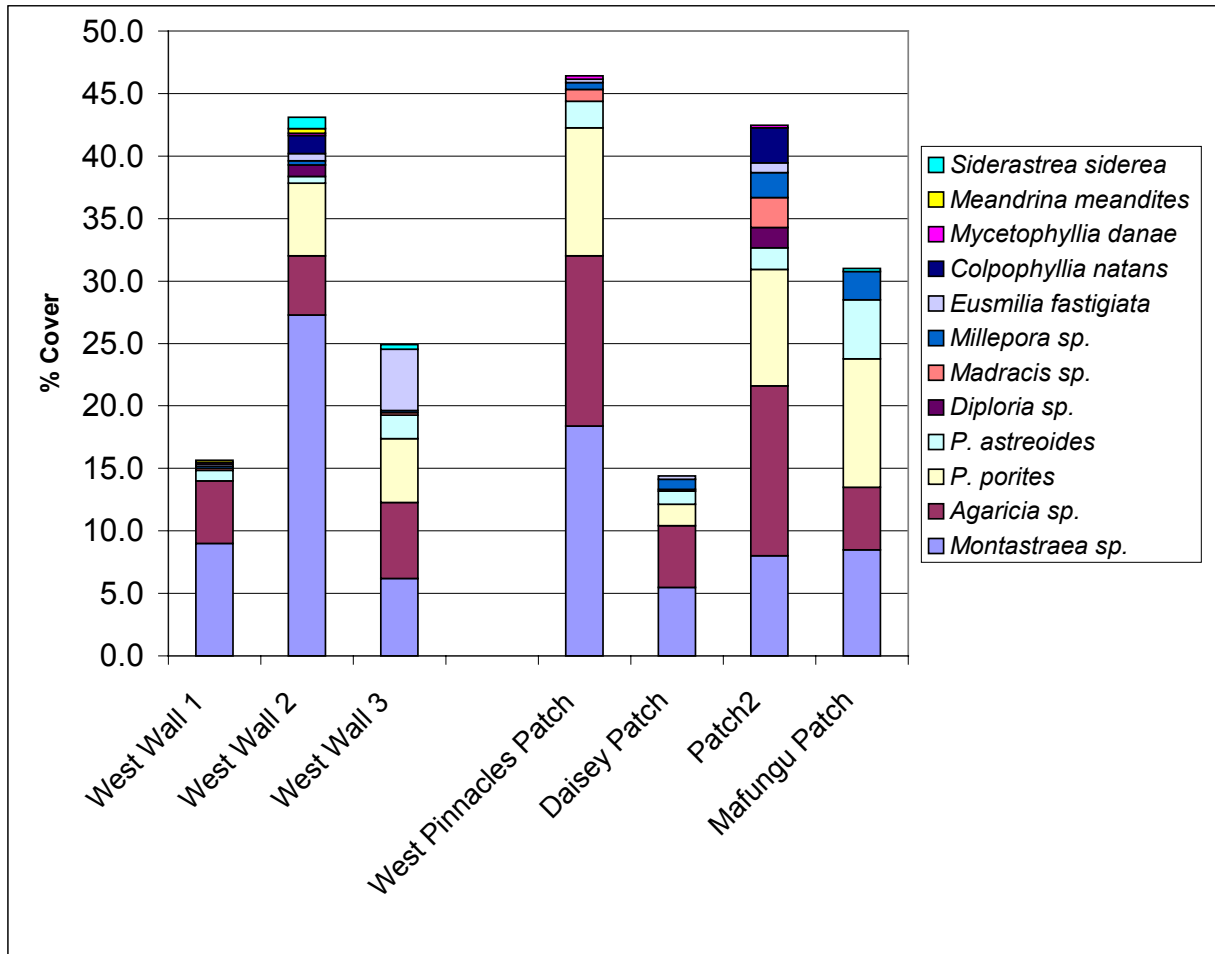


Figure 3: Coral species composition for deeper sites (>25m) sampled via photo

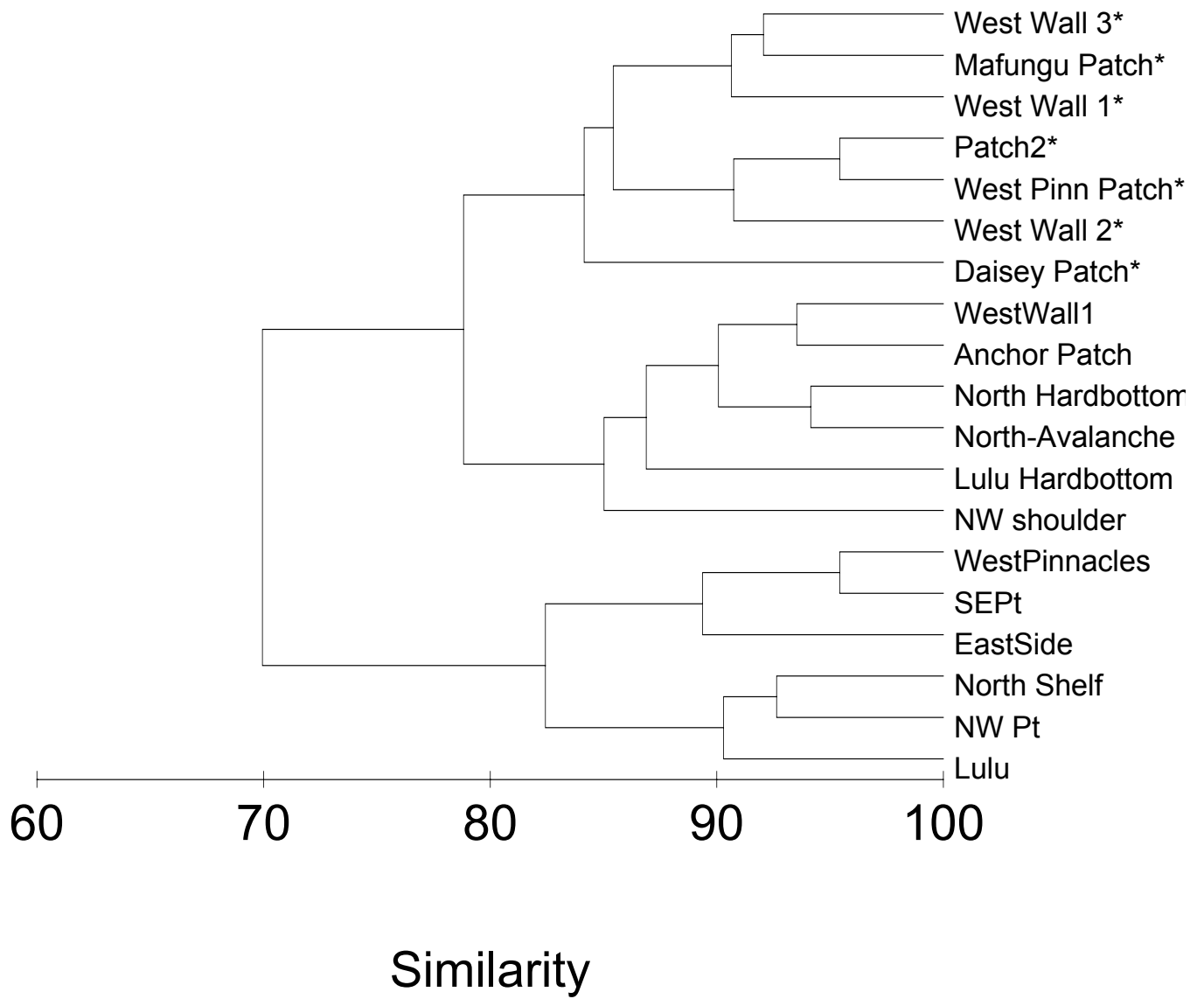


Figure 4: Dendrogram based on Bray-Curtis similarity matrix for benthic community structure of all Navassa sites. Note good concordance of clustering with *a priori* habitat classification given in Table 1.

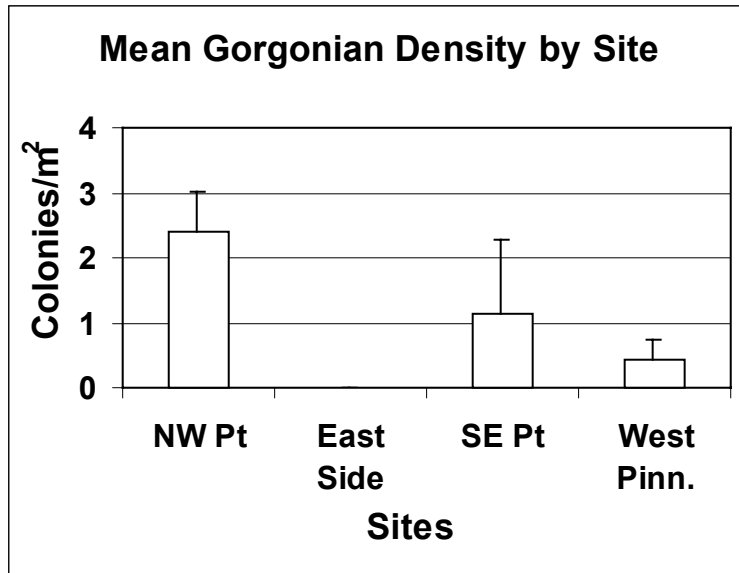


Figure 5. Mean density of gorgonians by site: Northwest Point, East Side, Southeast Point, and West Pinnacles. N=4 transects for each.

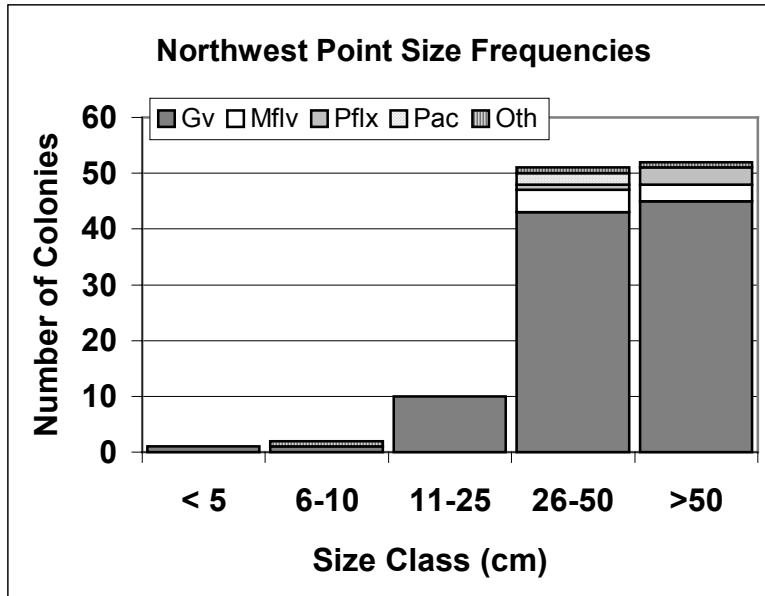


Figure 6. Size frequency distributions of gorgonians at Northwest Point. *Gorgonia ventalina* (Gv), *Muriceopsis flavida* (Mflv), *Plexaura flexuosa* (Pflx), *Pseudopterogorgia acerosa* (Pac), Other (Oth). Other consisted of *Muricea muricata*, *Eunicea succinea*, and *Plexaura homomalla*. N = 116

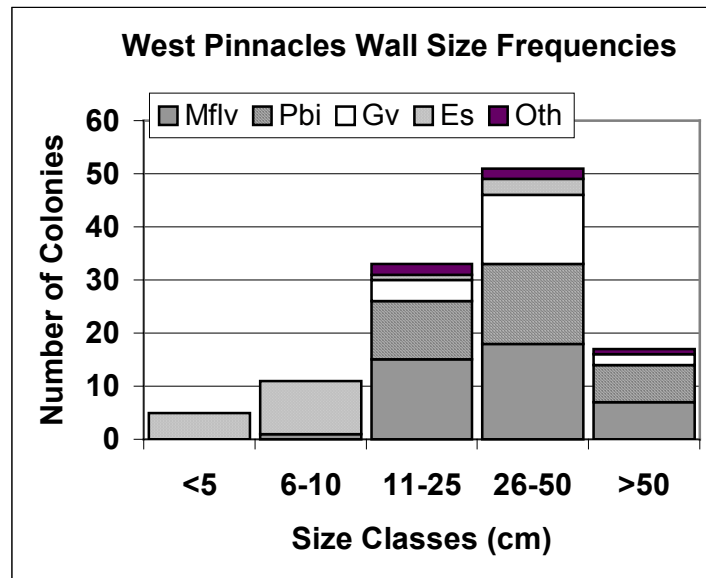


Figure 7. Size frequency distributions of gorgonian colonies in a 20 m by 1 m horizontal transect along a vertical wall near the West Pinnacles site. Other colonies were *Muricea muricata* and *Plexaura flexuosa*. N = 117.

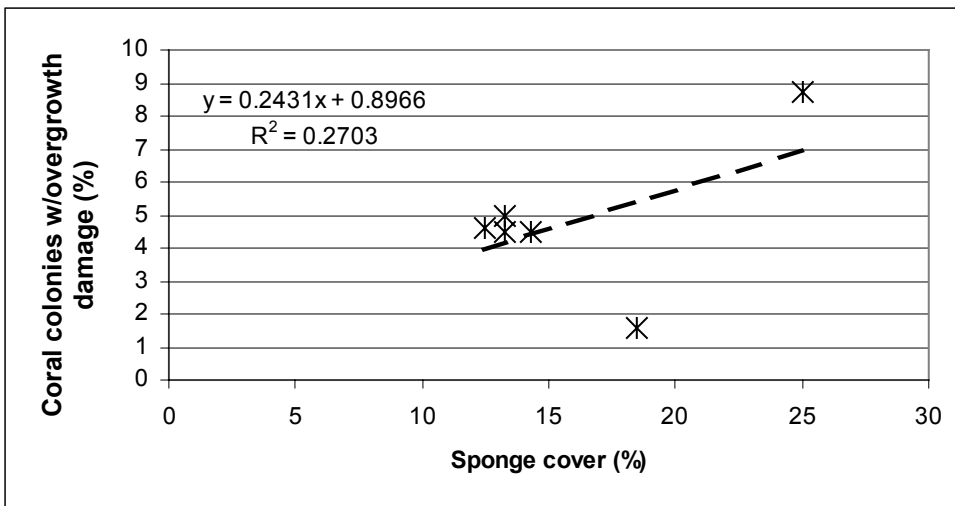
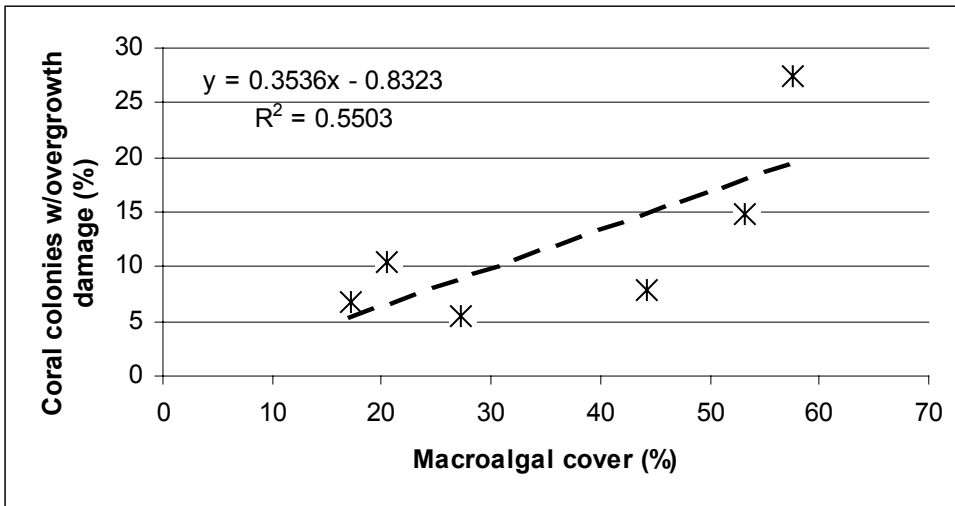


Figure 8: Relationship of macroalgal abundance (upper panel) and sponge abundance (lower panel) with the incidence of coral colonies displaying damage from competitive overgrowth by these groups. Each point represents one of six sites where coral condition was quantified along the *in situ* transects.

Chapter 4: Reef Fish Abundance, Biomass, Species Composition, and Habitat Characterization of Navassa Island

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Introduction

A limited reef fish survey of Navassa Island, a unique tropical marine environment, was conducted by two members of the Reef Resources Team, Protected Resources and Biodiversity Division, Southeast Fisheries Science Center (SEFSC), National Marine Fisheries Service (NMFS), National Oceanographic and Atmospheric Administration (NOAA). At random sites based on vessel location, Reef Fish Visual Censusing (RVC) surveys censused the fish fauna, collected habitat information, and photo-documented habitat and fish assemblages. This fishery independent sampling and habitat characterization method has been used extensively in the Florida Keys National Marine Sanctuary, Dry Tortugas National Park, and Biscayne National Park to provide baseline information and multispecies stock assessments of reef fishes (Ault et al. 1998, 2001, 2002). The method can be used both for large scale expeditions or small scale surveys. Information from this survey could be used to provide guidance and identify priorities for developing comprehensive Management Plans for Navassa Island, part of the Caribbean Islands National Wildlife Refuge (see Chapter 2). Despite its remoteness, Navassa is considered a fragile marine ecosystem threatened by overfishing and habitat degradation (see Chapter 10).

A total of 20,901 fishes representing 111 species (45 families) were recorded from the 110 RVC samples (Figure 1). This preliminary analysis of the data is necessary to get a snapshot of the study area.

Methods

Data were collected using a stationary point sampling technique (Bohnsack and Bannerot 1986) which utilizes standard visual sampling methods. The stationary sampling technique is based on censuses taken at random points using open-circuit SCUBA. Because of the greater depths surveyed at Navassa, 36% Nitrox was used to maximize bottom time and increase the number of samples being taken. Slates with underwater paper were used to record observations

(Figure 2). Human and DeLoach (2002) provided invaluable assistance in species identification. Species names used are according to Robins et al. (1991) and W. Richards (pers. comm.).

At each point divers recorded all species observed in five minutes within an imaginary cylinder extending from the surface to the bottom within a radius of 7.5 meters (24.6 feet) from the observer. New species are recorded while rotating in one direction and scanning the field of view. No quantitative data are recorded during the first five minutes with the exception of a few species in moving schools that are counted when first observed in the sampling cylinder. These species are unlikely to remain in the sampling area for later counting.

After recording species for five minutes, divers next record quantitative data for these species while ignoring all other observed species. The estimated number of individuals and the minimum, maximum, and mean estimated length for each species are recorded using a standard methodology. Divers systematically work up the list from the bottom to top to avoid overlooking a species and to avoid bias caused by a tendency to count each species when it is particularly conspicuous or abundant. This procedure forces actual counts for each species to be made at random times although delayed after the initial observation. For many species only a few individuals appeared within the sampling cylinder during the initial five-minute listing period. Data for these individuals are recorded from memory. Species that are always present are counted, one at a time, after the 5 minute listing period by starting at one point on the underwater horizon and rotating 360 degrees, counting all individuals of that species until the entire area is scanned. When large schools were present, fish were counted by 10's, 20's, or 50's, or even 100's. Fish fork lengths (average, max, and min for each species) were estimated in centimeters by comparing fishes to a ruler attached perpendicular to the end of a scaled PVC rod. New species to the sample, which include the rare or cryptic species, observed after the initial 5 minutes are also recorded, along with estimates of length for selected species, to expand the species list composition. An underwater digital camera was used to record unknown species, as well as document fish assemblages. Water temperature and visibility, presence or absence of fishing gear and artifacts, and numbers of marine turtles, spiny lobster *Panilurus argus*, queen conch *Strombus gigas*, and long spined urchin *Diadema antillarum* are recorded if present in the sample area.

Hard-bottom community classification for each survey area was recorded following the protocol developed for the Florida Keys and Dry Tortugas¹ (Franklin et al. 2003) although depths are generally greater in Navassa. For Navassa we were able to follow their classifications for five habitats (see Chapter 3): low relief hard-bottom (LRHB), medium profile reefs (MRHB), patch reefs (DP), sand/rubble (SR), rocky outcrops (CLV, calves, chunks or pinnacles). In addition, five new habitat classifications were added: wall base (WB), wall (WALL), ledge (SL), avalanche zone (AVL), and sharp-edged spur and groove (SESG).

Habitat characterizations for the area contained within each sample were taken to facilitate the collection of quantitative habitat information concurrently with assessments of reef fish species composition, abundance, and size². Underwater digital cameras were utilized to record habitat characteristics for each sample, usually taken after the completion of a fish census (see Chapter 3). Five essential habitat elements useful for interpretation of reef fish survey data are:

- 1) Minimum and maximum depth of the survey area, providing a measure of substratum slope,
- 2) Amplitude of substratum relief, recorded as the maximum vertical relief of both hard- and soft-bottom components of the substratum,
- 3) Estimated surface relief coverage using five different categories ranging from <0.2m to <1.5m, which sums to 100%,
- 4) Abiotic footprint, recorded as the percentage of three substratum types (hard-bottom, sand, rubble), and
- 5) Biotic cover, recorded as the relative coverage of benthic life forms in sand and hard-bottom substrata.

Data are computerized using the RVC program, developed by NOAA\NMFS\SEFSC and the Rosenstiel School of Marine and Atmospheric Science (RSMAS), University of Miami. Summary statistics were obtained using a bio-analysis program developed to obtain species

¹ Chiappone M, Swanson D, and Miller S (2002, Unpubl.). Florida Keys and Dry Tortugas hard-bottom community classification. 14 p.

² Smith, S, Ault J, Meester G, Bohnsack J, McClellan D, Harper D, Chiappone M, Swanson D, Miller S. (2002, Unpubl.). Habitat characterization for reef fish censuses in the Florida Keys, May 2002, 3 p.

composition, sample frequencies, mean abundance, standard deviations, sample frequency ranges, fish lengths, and biomass estimates. Numerical classification techniques (cluster analysis) are used to compare similarity based upon species assemblages (mean species abundance) for sites and habitats, measured by the Bray-Curtis index. Similarity relationships are depicted using dendrograms generated by a normal sorting strategy. Because of the small sample size, all species are included, even rare species seen in only one or two samples.

Results and Discussion

Reef Fish Composition

Navassa is an unusual area to conduct reef fish surveys because of the consistent clarity of the water (>35m underwater visibility) and deep sample depths encountered (mean = 26.6m, range = 4.3m - 35.7m). One hundred ten stationary samples were collected from 56 sites (Figure 1), and because of depth and bottom time constraints, only one (n=2) or two (n=54) samples could be taken per site. Statistical descriptions of individual species observed are provided in Table 1. Descriptive statistics include the total number of observed individuals; frequency and percent occurrence; mean abundance, standard deviation, and range; mean, minimum, and maximum observed length; and estimated total biomass for each species.

A total of 20,901 fishes representing 110 (and one unidentified) species (45 families) were recorded from the 110 RVC samples. An additional 34 (and 3 unidentified) species were observed: 1) after the five minute period species were recorded during the RVC sample, 2) from video stations and fish counts (see Chapter 5), or 3) observed independently. A phylogenic listing and trophic level classification of species observed during the expedition is given in Appendix 3. We added an additional 35 fish species to the 237 Navassa Island fish species reported by Collette et al. (2003).

The most abundant fish species, comprising 59.1% of the total number, were the blue chromis *Chromis cyanea* (n=4,912), creole wrasse *Clepticus parrai* (n=3,050), bluehead wrasse *Thalassoma bifasciatum* (n=2,950), and bicolor damselfish *Stegastes partitus* (n=1,449). Species with the highest frequency of occurrence seen from all the samples were the blue tang *Acanthurus coeruleus* (88.2%), followed by the princess parrotfish *Scarus taeniopterus* (86.4%),

redband parrotfish *Sparisoma aurofrenatum* (86.4%), bluehead wrasse (86.4%), bicolor damselfish (86.4%), and black durgon *Melichthys niger* (80.9%).

Biomass

Biomass estimates (Table 1) were derived for all species using length-to-weight comparisons summarized by Bohnsack and Harper (1988). The great barracuda *Sphyraena barracuda* was observed in 23.6% of the samples and comprised 27.3% of total biomass (54 fish, 306.9 kg). Biomass estimates for the next highest ranked species as percent of total biomass were the black durgon (88.2 kg, 7.8%), Bermuda chub *Kyphosus sectatrix* (87.5 kg, 7.7%), ocean triggerfish *Cantherhines sufflamen* (63.2 kg, 5.6%), and schoolmaster snapper *Lutjanus apodus* (63.0 kg, 5.6%). The average fish community biomass for RVC samples was 57.9 g/m², comparable to the 48.2 g/m² calculated by Sandin (Chapter 5), and less than the Florida Keys (71.9 g/m², Bohnsack et al. 1999). Miller and Gerstner (2002) reported an estimate of 13,719 g/m² suggesting an unexploited reef fish community, but the sampling method employed was the Atlantic and Gulf Rapid Reef Assessment (AGRRA) and sites favored larger reef fishes, especially the groupers. Biomass across all habitats in SE Florida waters was dominated by the piscivores and macroinvertivores. (Bohnsack et al. 1999). By comparison, the planktivores replaced the macroinvertivores in second place in Navassa, mainly because of the scarcity of grunts (family Haemulidae) (Figure 3a,b).

Trophic levels

Species recorded during the RVC samples were analyzed to compare trophic levels of the species around Navassa (Figure 3a,b). Of the species observed from all samples, 14,942 (71.5%) individuals and 16.7% of biomass were considered primarily planktivores (Figure 3a,b). Planktivores comprised 44.2% of numbers and 5.1% of biomass in SE Florida waters for comparison. Four planktivores (blue chromis, creole wrasse, bluehead wrasse, and bicolor damselfish), comprised 59.1% of the total number, and also were the most abundant species. Copepods comprise two-thirds of available plankton (see Chapter 5).

Herbivores in Navassa comprised the second largest trophic level with 16.7% of total numbers and 20.9% of total biomass (Figure 3a,b), compared to 17.3% of numbers and 21.2% of

biomass in SE Florida waters. The Bermuda chub (86.5kg, 17.3%) was the major contributor. Parrotfishes (Scaridae), surgeonfishes (Acanthuridae), and damselfishes (Pomacentridae) are the other prevalent families which make up this trophic level. The artesinal fish trap fishery (see Chapter 10) captures many of these fishes, which reduces their total number. Algal cover was extremely high in some Navassa habitats (see Chapter 3, Figure 4), probably due to the lack of urchins and other herbivores.

Grunts (Haemulidae), a family commonly seen in SE Florida waters (Bohnsack et al. 1999), were conspicuously absent from these surveys. Only 23 individuals of 3 species, primarily macroinvertivores, comprised only 0.2% of the total biomass. All macroinvertivores only comprised 4.0% of total biomass (Figure 3b), compared to 24.7% of the biomass in SE Florida waters. Grunts and some smaller snappers primarily feed on macroinvertebrates at night in grass beds and sand flats close to reefs. These habitats were notably absent from Navassa waters (see Chapter 3).

Even though only 729 (3.5%) fishes were primarily piscivores, they comprised 48.4% of the total biomass (Figure 3a,b). The pattern of predator dominance is classic for coral reef communities. In SE Florida waters, 8.5% of reef fishes are piscivores and make up 41.8% of the total biomass (Bohnsack et al. 1999). In Navassa, the top predator species as a percentage of total biomass were the great barracuda (27.3%), bar jack *Carangoides ruber* (5.6%), schoolmaster snapper *Lutjanus apodus* (4.5%), and dog snapper *L. jocu* (2.0%). Sea basses (family Serranidae), were mostly comprised of smaller species such as the hamlets *Hypoplectrus* (11 species, 55 individuals). The most common grouper species seen (frequency-of-occurrence) were the graysby *Cephalopholis cruentatus* (80.0%), coney *C. fulvus* (45.5%), and tiger grouper *Myteroperca tigris* (3.6%). Only 2 red hind *E. guttatus* were observed during the surveys. No Nassau grouper *E. striatus*, although common in Little Cayman, BWI, were observed² (Whaylen et al. 2002). Only 12 large grouper species were counted in the surveys (2.2% of total biomass). Snappers (family Lutjanidae) were also not frequently observed during the surveys, and only 109 commercially important snappers were counted (8.6% of total biomass). Frequency-of-occurrence were, for schoolmaster snapper (28.2%), yellowtail snapper *Ocyurus chrysurus*

² Eklund AM, Schull J, McClellan DB, Collins A, Judge M, Feeley M (In prep.). Nassau grouper distribution and habitat characteristics at Little Cayman, BWI, December 2002. NOAA/NMFS/SEFSC/PRD Rpt. 02/03-1.

(10.9%), and dog snapper (6.4%). The hogfish *Lachnolaimus maximus*, a wrasse (family Labridae), was completely absent perhaps because habitats, such as grass beds and mangroves flats that are utilized by these fishes, especially during their early life history stages, are absent in these waters (see Chapter 3).

Habitat and fish ecology

Habitat analyses showing sampling effort, mean number of species, and mean fish abundance by site and habitat are shown in Table 2. The mean number of fish observed per sample was 190 (range 51 to 599) and the mean number of species per sample was 20 (range 7 - 30), over all sites and habitats. The medium relief hard-bottom habitat had the highest species richness and total numbers of individuals of all the areas. The North slope area, a medium relief hard-bottom habitat, had the highest species count and abundance. The sand/rubble area on the North Shelf had the lowest number of species and individuals, and although only one sample was taken, other observations support this conclusion. The ledge and wall samples had the next lowest species richness, while the wall had the lowest abundance. The East side of the island, primarily calves, ledges, and wall habitat, had the lowest total species and numbers.

Percent coverage of bottom habitat type is shown in Figure 4. The highest live coral coverage is found in the DP habitat (23.6%), followed by MRHB (16.9%), SL (16.7%), and WB (11.7%). Macroalgae cover is highest in the WB (42.1%) and CLV (40.8%) habitats. Octocorals dominate in WALL (21.7%) habitat. Algal turf/bare rock are the dominant cover in the LRHB (64.0%) and SESG (52.7%) habitats. Sponge cover, encrusting and others, comprised about 10% of all habitats. Chapter 3 describes bottom type coverage as recorded by the coral team. Coverage from RVC surveys approximated the coverage found by that method. Octocoral coverage was estimated with the RVC protocol, as seen from a fishes view, therefore much higher coverage is recorded than using basal attachment coverage.

Habitat appears to define these reef fish assemblages. The more diverse and complex the habitat, the higher the abundance and diversity of the species complex (see Chapter 7). Differences between sites were obvious. Normal cluster analysis demonstrated a strong similarity between three groups of study sites and two groups of habitats, when mean abundance for all fishes and all samples were analyzed (Figure 5a,b). The East and SE sides of the island along

with NW Point shows similarity, probably due to the similar habitats (wall bases, calves, ledges and low relief hard-bottom habitats) encountered. These sites are also the areas with the strongest currents, winds, and erosion. The West side, North shelf, and Lulu Bay samples show strong similarity, probably due to the presence of patch reef and medium profile reef habitats. The West and North slope sites, which are medium profile reef habitats, show similarity and also cluster with group 2. This pattern is also shown when analyzed by habitats. The patch reefs, medium profile reefs, low-relief hard-bottom and wall base habitats are similar and the walls, ledges, calves, and sharp-edged spur and groove habitats are grouped together. Sand/rubble areas are completely dissimilar to all other habitats.

Size composition

Mean lengths of selected species were analyzed to obtain sizes of reef fishes available for fishing (Figure 6, Chapter 10). Fish traps and small hooks were used by the artesinal fishers. Small fishes (<12cm) were not able to be captured and were not included in the analysis. The great barracuda had a mean length of 87.3 cm, larger in size than those (68.8 cm) found in SE Florida waters (Bohnsack et al. 1999). Grunts, groupers, and parrotfishes all had a mean size less than 19 cm. Jacks, dominated by the bar jack, had a mean size of 26.4 cm. Snappers, dominated by the schoolmaster, had a mean size of 34.3 cm. These sizes are also smaller than those seen in the SE Florida waters.

Other species

Long spined urchins, *Diadema antillarum* (n = 18), considered relatively abundant in Navassa waters from previous reports³ (Littler et al. 1998, Miller and Gerstner 2002), queen conch, *Strombus gigas* (n = 8), and spiny lobster *Panulirus argus* (n = 2), were rarely observed during RVC samples (see Chapter 10). The Caribbean wide pandemic nearly exterminated *D. antillarum* in 1983. Queen conch is found throughout the Caribbean and is an economically important food species. It has come under increasing fishing effort as export markets have

³ Hendler, G (2000, Unpubl). Preliminary report: Navassa Island. 7 p.

developed⁴. Individuals seen were large, mature individuals located in the deeper waters of Navassa. The spiny lobsters observed were large, and egg-bearing females were observed being harvested by artesinal fishers.

Numerous species including the bicolor damselfish and blackbar soldierfish *Myripristis jacobus* were infested with one or two isopods.

Summary

Reef fish censuses conducted during this cruise demonstrate the complexity and abundance of the reef fish fauna associated with Navassa Island. Previous reports on the reef fish fauna of Navassa used numerous sampling methods making comparisons over time somewhat complicated and not directly comparable. A number of sampling methods were utilized during the 1977 survey which mainly targeted pelagics⁵. Video and bottom longline collections were used in 1998 (Grace et al. 2000). Methods included nets, longlines, and rotenone collections during the 1999 Expedition (Collete et al. 2003). The AGRRA visual transect method was used during the 2000 expedition (Miller and Gerstner 2002). Collette et al. (2003) reported 237 fish species are known from Navassa, while cruise reports of earlier years reported only 72 species. Among the 145 species observed during this cruise, an additional 34 new species can be added to the species list of Navassa fishes, increasing the total known documented species to 273.

To conduct stock assessments, a more robust statistical analysis of the fish community needs to be undertaken. Preliminary analyses provided here are important to begin to answer questions, identify habitat and ecosystem dynamics, describe preliminary statistics, and provide a baseline species list. A more robust sampling design would be necessary to answer population and stock assessment questions (Ault et al. 2001, 2002). Shifting baselines, because of the unregulated artesinal fishery, are an obstacle to any future assessments.

This survey, along with previous surveys, provides a baseline of species composition around Navassa Island. Ecosystem information from as many habitats as possible were obtained in the limited time and space available, but more intense sampling is necessary to better

⁴ Caribbean Fishery Management Council. (1999, Unpubl.) Queen conch stock assessment and management workshop. Belize City, Belize. 15-22 March 1999. 105 p.

⁵ Miller GC (1977, Unpubl.). Cruise results for Oregon II 77-08 (80), Navassa Island resource assesment survey. 12 p. NMFS, SEFSC, Miami, FL.

understand the whole system. Snapper and grouper considered common in the 1970's and 1990's, were rare during our study and preliminary analysis suggests serial overfishing is occurring (see Chapter 10).

Metadata descriptions of the Navassa RVC database, using the FGDC format, will be provided to the SEFSC metadata clearinghouse (www.sefsc.noaa.gov) and data will be integrated into the SEFSC RVC database of RVC samples.

Acknowledgments

Doug Harper, a member of the 1977 Oregon II cruise, provided historical perspectives and editorial suggestions. Jim Bohnsack provided editorial assistance, Carlos Rivero provided Arcview technical assistance, Jack Javech and Charlie Fasano provided logistical support, Veronique Koch searched bibliographic databases and Jennifer Schull provided editorial assistance.

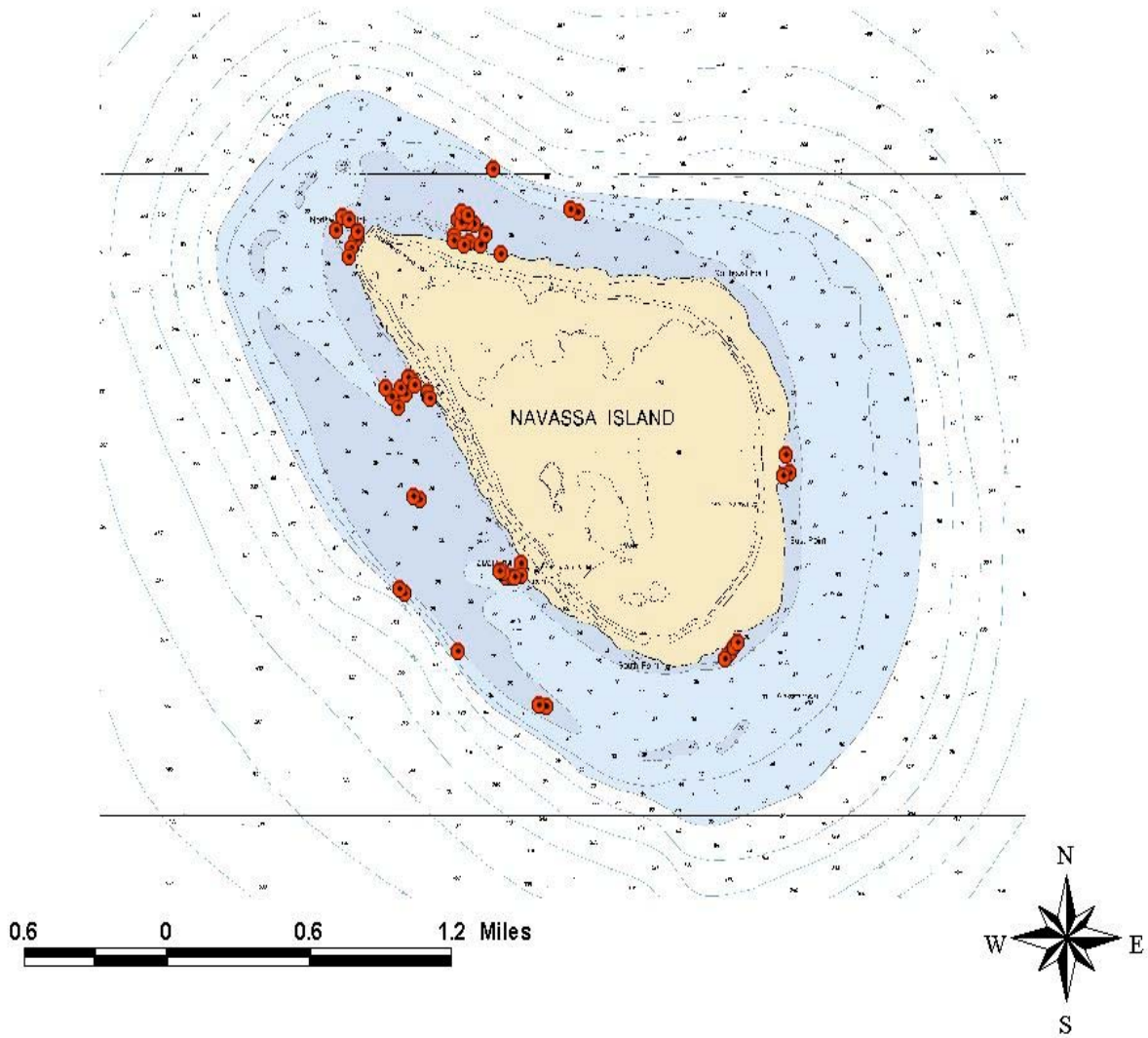


Figure 1. Chart of Navassa Island showing Reef fish Visual Census (RVC) sampling sites censused from October 30 through November 11, 2002.

Diver: McClellan Date: 10/31/02 Field Number: SC Site
 Buddy: Sam Miller Sample Start Time: 1133
 Dive Start Time: 1132 Sample End Time: 1145 Habitat type: Wedge / Ledge
 Dive End Time: 1159 Max Dive Depth: 30 ft
 Station Depth: 28 ft Est. Underwater visibility: 100 ft
 Fishing Gear: _____

Substrate Slope		
Max depth	<u>30</u> ft	
Min depth	<u>10</u> ft	
Max vertical Relief		
Hard substrate	<u>0.3</u> m	
Soft substrate	<u>0.2</u> m	
Surface Relief Coverage %		
	Hard	Soft
< 0.2 m	<u>90</u> %	<u>95</u> %
0.2-0.5 m	<u>10</u> %	<u>5</u> %
0.5-1.0 m	<u> </u> %	<u> </u> %
1.0-1.5 m	<u> </u> %	<u> </u> %
> 1.5 m	<u> </u> %	<u> </u> %
Total	100%	100%

Abiotic Footprint			
SAND	%		
HARD-B	%		
RUBBLE	%		
Total	100%		

Biotic Cover - Dominant Biological Cover %			
SAND		HARDBOTTOM	
"Bare"		Crustose Algae	
Algal Turf (<1cm)		Algal Turf (<1cm)	
Macro Algae		Sarg Macro Algae	<u>69</u>
Sea grass		Live Coral	
Sponge		Octocoral	<u>1</u>
Other 1		Encrust Sponge	<u>30</u>
Other 2		Other 1	
		Other 2	
TOTAL	100%		100%

Species	N	Avg	Min	Max	Species	N	Avg	Min	Max
<u>Can suff</u>	<u>3</u>	<u>37</u>	<u>30</u>	<u>55</u>					
<u>Tur bifa</u>	<u>10</u>	<u>3</u>	<u>3</u>	<u>4</u>					
<u>Epi fulv</u>	<u>10</u>	<u>15</u>	<u>10</u>	<u>20</u>					
<u>Mel nige</u>	<u>28</u>	<u>15</u>	<u>10</u>	<u>20</u>					
<u>Aca coer</u>	<u>5</u>	<u>11</u>	<u>10</u>	<u>12</u>					
<u>Aca bahi</u>	<u>2</u>	<u>10</u>							
<u>SPA VIRI</u>	<u>1</u>	<u>28</u>							
<u>Sparubr</u>	<u>1</u>	<u>32</u>							
<u>Car robe</u>	<u>1</u>	<u>15</u>							
<u>Mic chry</u>	<u>1</u>	<u>10</u>							
<u>Hol tric</u>	<u>1</u>								
<u>Dec macc</u>	<u>1</u>								
<u>Ocy chry</u>	<u>1</u>	<u>30</u>							

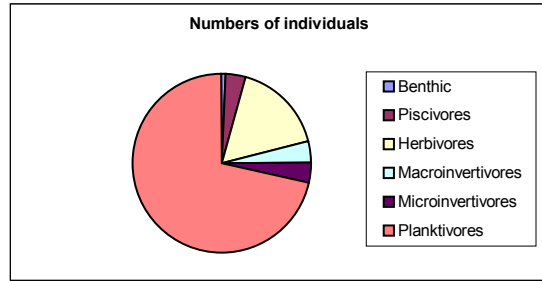
Comments:

 Water temperature - 84°F
 Spiny Lobster # _____ Conch # _____ Diadema # _____

Figure 2. RVC field sheet used during the Navassa Island cruise from October 30 through November 11, 2002. Average, minimum, and maximum fork lengths (cm) are visually estimated via reference to a scaled bar carried by the diver. See text for additional methods.

a) **Sum of numbers**

Trophic level	Total	
Benthic	203	0.97%
Piscivores	729	3.49%
Herbivores	3480	16.65%
Macroinvertivores	828	3.96%
Microinvertivores	719	3.44%
Planktivores	14942	71.49%
Total	20901	100.00%



b) **Sum of biomass**

Trophic level	Total	
Benthic	21139.96	1.88%
Piscivores	544119.5	48.37%
Herbivores	234695.9	20.86%
Macroinvertivores	117185.5	10.42%
Microinvertivores	19589.53	1.74%
Planktivores	188236	16.73%
Total	1124966	100.00%

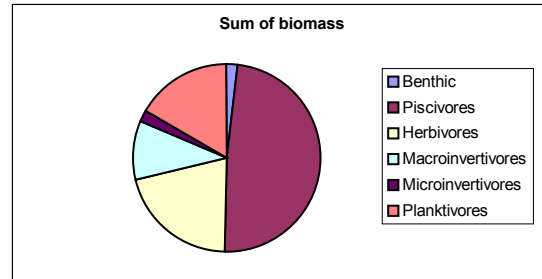


Figure 3. Trophic level comparisons of reef fishes sampled during RVC sampling at Navassa Island from October 30 through November 11, 2002. Biomass given in grams

	SL	LRHB	MRHB	DP	CLV	SESG/AVL	WALL	WB
Algal Turf	35.5	64.0	9.6	8.9	30.2	52.0	34.5	15.8
Live Coral	16.7	3.5	13.9	19.9	6.8	8.5	8.3	8.8
Macro Algae	27.3	5.0	29.1	27.2	36.8	14.7	17.5	31.8
Octocoral	3.2	12.5	18.6	14.3	7.2	13.7	21.7	5.9
Sponge	10.3	15.0	10.9	11.3	9.0	9.4	12.5	10.4
Other	7.0	0.0	0.0	2.9	0.0	1.4	5.5	2.8
Sand/rubble	0.0	0.0	17.9	15.4	10.0	0.3	0.0	24.4

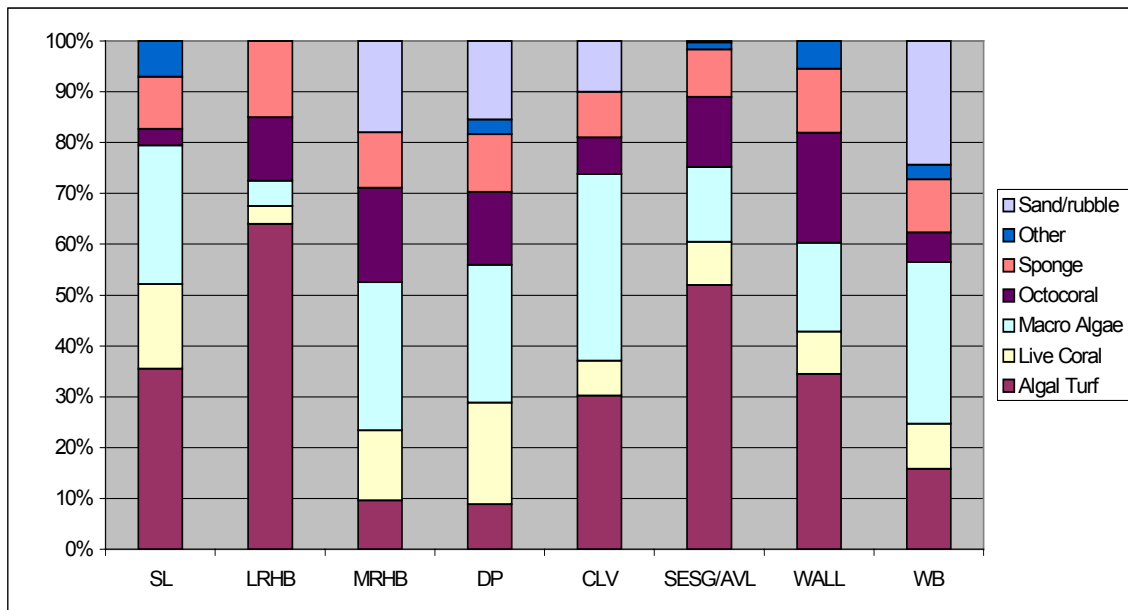
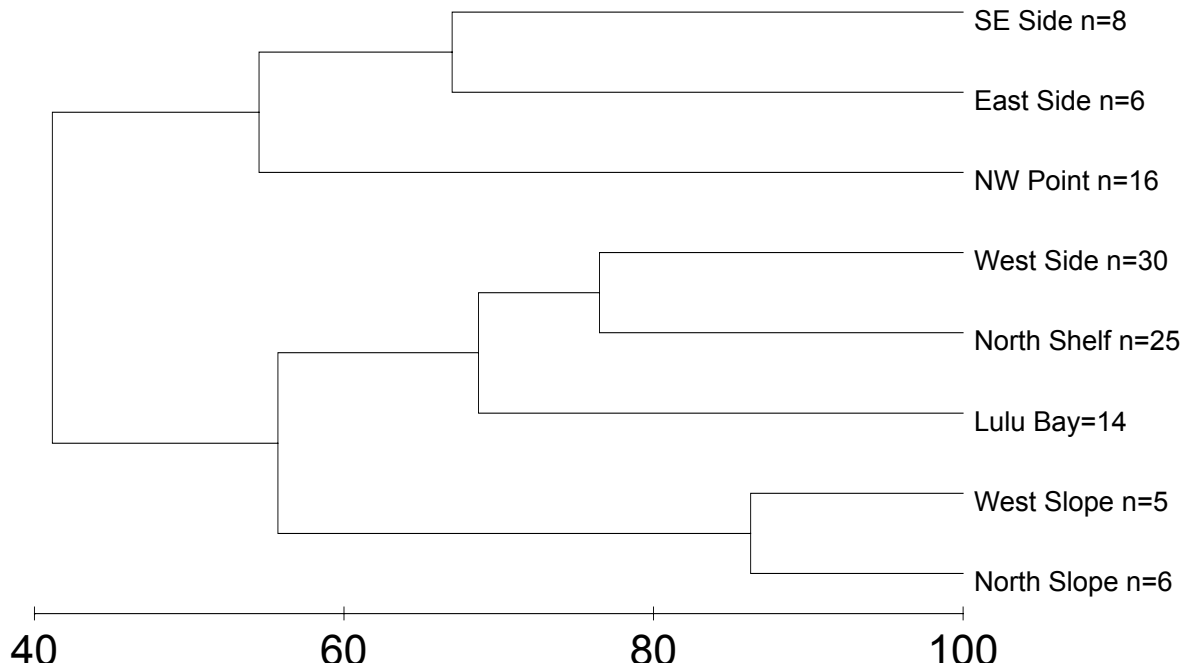


Figure 4. Percent cover of bottom type component by habitat type (see Chapter 3, Table 1) for RVC samples at Navassa Island, from October 30 through November 11, 2002.

a)



b)

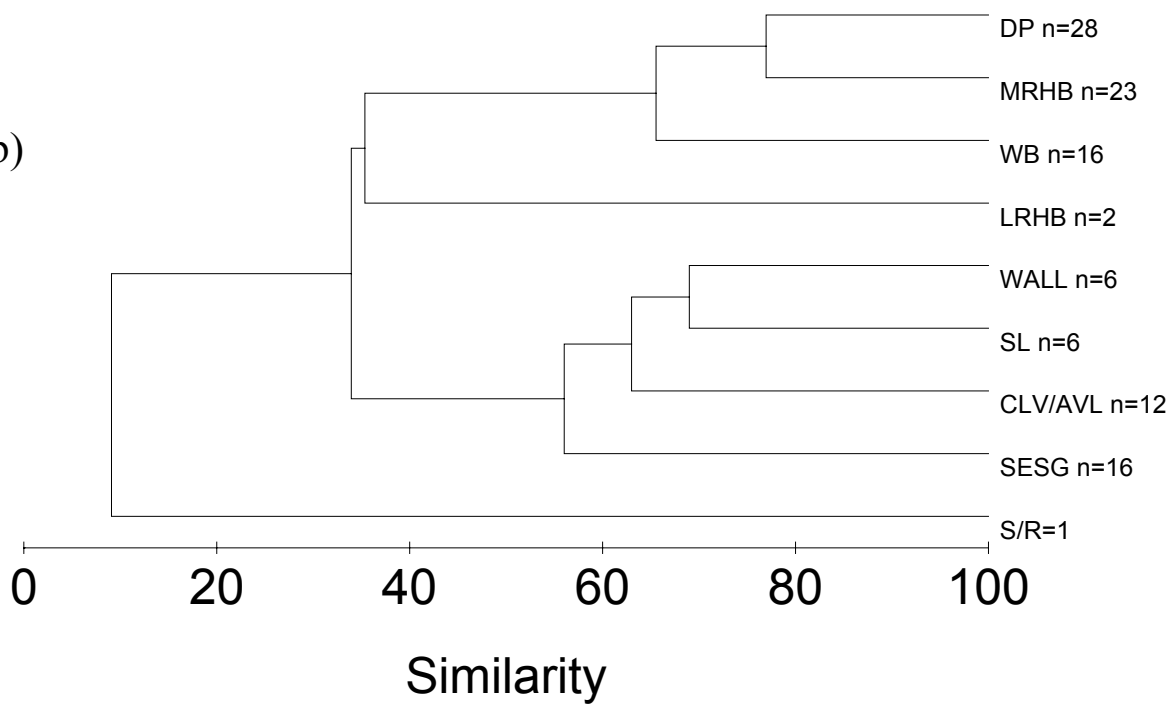


Figure 5. Bray-Curtis similarity matrix dendrograms of RVC samples for Navassa Island, October 30 through November 11, 2002. Data analyzed were pooled mean species abundance for all sites (a) and habitats (b). Habitat codes given in Chapter 3, Table 1.

Average of Mean			
Family	Mean	+STD	-STD
Barracudas	87.29	115.77	58.81
Groupers	17.78	25.52	10.04
Grunts	18.74	30.39	7.09
Jacks	26.35	31.33	21.38
Parrotfishes	17.84	24.67	11.01
Snappers	34.28	44.23	24.33

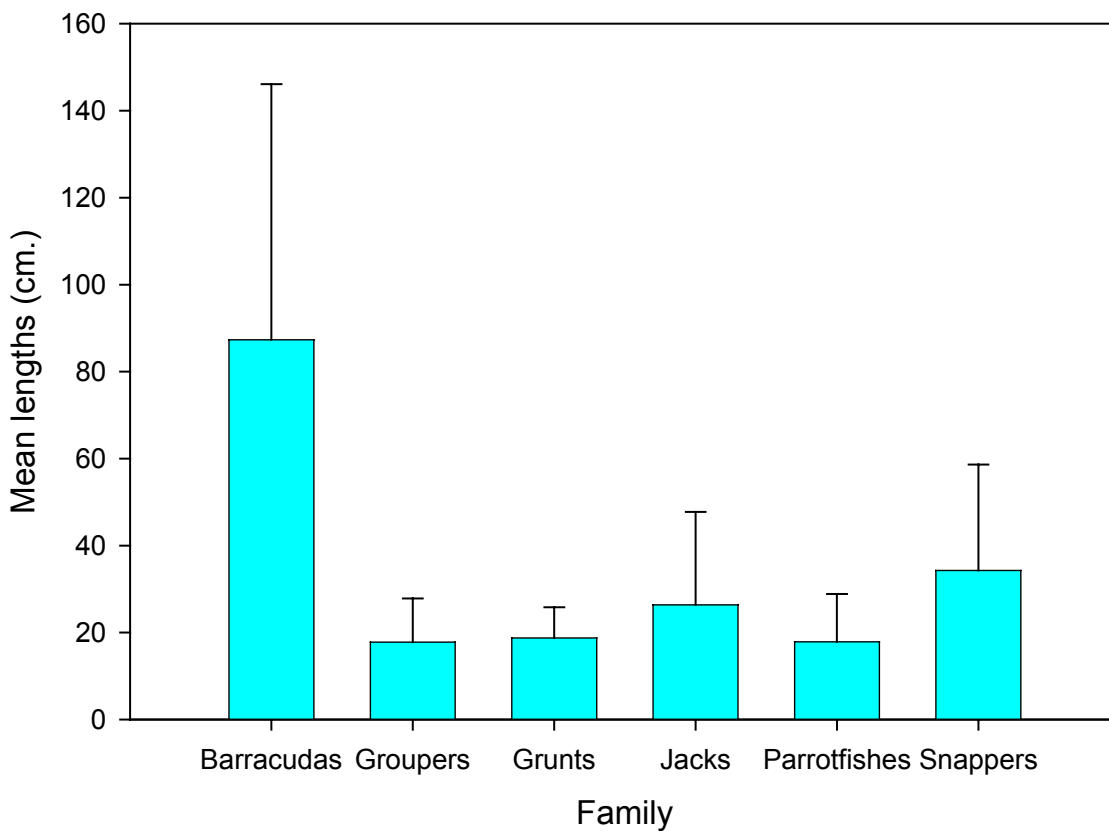


Figure 6. Mean lengths of selected species observed in RVC samples from Navassa Island, from October 30 through November 11, 2002. Family groups do not include smaller individuals <12 cm, such as hamlets and small parrotfishes too small to capture with the fishing gear observed in use (hook and line, traps, nets)

Table 1. Summary analysis of all fishes sampled during visual sampling of reef fishes at Navassa Island, 30 October through 11 November, 2002. See Appendix 3 for reef fish codes.

Species	SAMPLE FREQUENCY				SAMP. FREQ. RANGE		FISH LENGTH (cm)			BIOMASS Total(gms)	
	Total Indiv. (N=110)	%	Mean Abund.	Stand. Dev.	High	Low	Mean	Min.	Max.		
1 ABU SAXA	9	5	4.5%	0.08	0.41	3	0	9.8	8	12	284.5
2 ACA BAH1	136	52	47.3%	1.24	1.95	11	0	11.1	4	22	4,802.3
3 ACA CHIR	18	9	8.2%	0.16	0.74	6	0	17.7	12	33	2,585.8
4 ACA COER	477	97	88.2%	4.34	6.36	50	0	10.7	3	20	18,630.7
5 ALU SCRI	1	1	0.9%	0.01	0.10	1	0	30.0	30	30	393.0
6 AMB PINO	6	6	5.5%	0.05	0.23	1	0	5.5	4	7	6.0
7 APO BINO	6	1	0.9%	0.05	0.57	6	0	4.0	2	4	5.7
8 AUL MACU	11	10	9.1%	0.10	0.33	2	0	30.9	15	40	912.0
9 BAL VETU	13	13	11.8%	0.12	0.32	1	0	37.4	30	50	18,845.3
10 BOD RUFU	39	27	24.5%	0.35	0.71	3	0	16.9	4	30	4,883.2
11 CAN MACR	13	9	8.2%	0.12	0.42	2	0	26.4	13	32	4,949.6
12 CAN ROST	33	26	23.6%	0.30	0.61	3	0	3.9	2	7	39.1
13 CAN SUFF	34	13	11.8%	0.31	1.02	6	0	43.6	30	60	63,205.3
14 CAR BART	10	5	4.5%	0.09	0.46	3	0	29.2	21	34	4,947.3
15 CAR LUGU	11	6	5.5%	0.10	0.47	3	0	37.8	20	60	16,853.6
16 CAR RUBE	110	49	44.5%	1.00	1.53	9	0	27.8	3	50	50,785.6
17 CEN ARG1	1	1	0.9%	0.01	0.10	1	0	4.0	4	4	1.8
18 CEP CRUE	213	88	80.0%	1.94	1.55	7	0	16.7	5	30	21,062.2
19 CEP FULV	194	50	45.5%	1.76	3.09	16	0	17.1	6	30	19,789.6
20 CHA CAPI	24	15	13.6%	0.22	0.60	3	0	6.3	5	10	236.6
21 CHR CYAN	4,912	83	75.5%	44.65	56.69	250	0	4.6	1	8	11,508.4
22 CHR MULT	761	55	50.0%	6.92	11.41	50	0	5.1	1	10	2,578.5
23 CLE PARR	3,050	58	52.7%	27.73	53.54	250	0	8.4	1	27	57,604.8
24 COR GLAU	216	35	31.8%	1.96	4.38	25	0	2.3	1	4	41.4
25 COR LIPE	8	3	2.7%	0.07	0.52	5	0	1.8	1	2	0.6
26 COR PERS	290	11	10.0%	2.64	9.67	60	0	1.2	1	3	10.1
27 DEC MACA	205	3	2.7%	1.86	14.73	150	0	9.9	8	10	2,240.8
28 DIO HYST	2	2	1.8%	0.02	0.13	1	0	32.5	27	38	3,066.7
29 ECH NAUC	2	2	1.8%	0.02	0.13	1	0	13.5	12	15	62.9
30 EPI GUTT	2	2	1.8%	0.02	0.13	1	0	25.0	15	35	758.9
31 EQU PUNC	5	5	4.5%	0.05	0.21	1	0	24.2	20	30	1,263.4
32 EUP LEUC	4	4	3.6%	0.04	0.19	1	0	4.8	3	6	13.1
33 GNA THOM	3	3	2.7%	0.03	0.16	1	0	3.0	3	3	0.7
34 GOB EVEL	23	10	9.1%	0.21	1.04	10	0	2.2	1	3	2.6
35 GOB OCEA	1	1	0.9%	0.01	0.10	1	0	3.0	3	3	0.3
36 GRA LORE	393	49	44.5%	3.57	7.48	40	0	4.1	1	5	264.8
37 GYM FUNE	2	2	1.8%	0.02	0.13	1	0	85.0	80	90	2,672.9
38 GYM MILI	1	1	0.9%	0.01	0.10	1	0	30.0	30	30	46.3
39 HAE CARB	2	2	1.8%	0.02	0.13	1	0	22.5	15	30	538.7
40 HAE FLAV	19	13	11.8%	0.17	0.66	6	0	13.7	12	16	999.8
41 HAE SCIU	2	2	1.8%	0.02	0.13	1	0	15.5	15	16	144.9
42 HAL BIV1	14	2	1.8%	0.13	1.16	12	0	6.7	5	12	60.1
43 HAL GARN	403	67	60.9%	3.66	5.08	30	0	7.2	2	15	2,500.2
44 HAL MACU	49	23	20.9%	0.45	1.39	12	0	5.1	2	8	70.3
45 HAL RADI	5	4	3.6%	0.05	0.25	2	0	9.6	5	20	137.2
46 HET HALI	25	1	0.9%	0.23	2.38	25	0	10.0	10	10	36.1
47 HOL ADSC	75	41	37.3%	0.68	1.16	7	0	18.7	12	28	12,641.4
48 HOL CILI	2	2	1.8%	0.02	0.13	1	0	32.5	30	35	1,661.1
49 HOL RUFU	57	35	31.8%	0.52	1.09	8	0	13.5	9	20	2,828.5
50 HOL TRIC	100	57	51.8%	0.91	1.23	7	0	10.8	3	25	5,340.2
51 HYP ABER	2	2	1.8%	0.02	0.13	1	0	6.0	4	8	1.6
52 HYP CHLO	3	2	1.8%	0.03	0.21	2	0	6.0	6	6	1.8
53 HYP GEMM	1	1	0.9%	0.01	0.10	1	0	7.0	7	7	5.4
54 HYP GUMM	2	2	1.8%	0.02	0.13	1	0	5.5	5	6	5.1
55 HYP GUTT	8	8	7.3%	0.07	0.26	1	0	6.1	4	10	37.0
56 HYP HYBR	1	1	0.9%	0.01	0.10	1	0	7.0	7	7	5.4
57 HYP INDI	2	2	1.8%	0.02	0.13	1	0	9.5	9	10	28.6
58 HYP NIGR	2	2	1.8%	0.02	0.13	1	0	6.5	6	7	8.6
59 HYP PUEL	30	25	22.7%	0.27	0.54	2	0	7.1	5	10	195.4
60 HYP TANN	1	1	0.9%	0.01	0.10	1	0	5.0	5	5	1.8

61 HYP UNIC	3	2	1.8%	0.03	0.21	2	0	5.3	4	6	7.5
62 KYP SECT	116	19	17.3%	1.05	4.57	35	0	30.3	8	50	87,515.8
63 LAC BICA	1	1	0.9%	0.01	0.10	1	0	15.0	15	15	131.4
64 LAC POLY	8	7	6.4%	0.07	0.29	2	0	20.8	6	35	1,878.2
65 LAC QUAD	3	3	2.7%	0.03	0.16	1	0	19.7	15	24	467.0
66 LAC TRIQ	13	13	11.8%	0.12	0.32	1	0	16.0	8	29	2,365.9
67 LUT APOD	80	31	28.2%	0.73	1.94	16	0	33.4	18	50	63,044.4
68 LUT JOCU	7	7	6.4%	0.06	0.25	1	0	56.4	50	60	22,039.3
69 MAL PLUM	24	15	13.6%	0.22	0.68	5	0	19.3	8	34	2,138.7
70 MAL TRIA	7	4	3.6%	0.06	0.37	3	0	4.1	3	5	5.5
71 MEL NIGE	926	89	80.9%	8.42	12.73	55	0	16.1	8	30	88,155.2
72 MIC CARR	12	1	0.9%	0.11	1.14	12	0	1.0	1	1	0.1
73 MIC CHRY	335	53	48.2%	3.05	5.91	40	0	9.3	1	15	9,504.6
74 MON TUCK	1	1	0.9%	0.01	0.10	1	0	4.0	4	4	1.9
75 MUL MART	85	25	22.7%	0.77	3.02	25	0	20.6	12	37	14,800.3
76 MYC INTE	3	2	1.8%	0.03	0.21	2	0	22.3	12	35	758.7
77 MYC TIGR	5	4	3.6%	0.05	0.25	2	0	48.6	38	70	11,366.6
78 MYC VENE	2	2	1.8%	0.02	0.13	1	0	72.5	70	75	11,321.5
79 MYR BREV	1	1	0.9%	0.01	0.10	1	0	50.0	50	50	232.5
80 MYR JACO	259	40	36.4%	2.35	5.95	45	0	13.3	6	20	18,080.3
81 NEO MARI	116	42	38.2%	1.05	2.70	25	0	10.4	6	13	4,190.0
82 OCY CHRY	22	12	10.9%	0.20	0.76	5	0	30.4	20	45	11,097.8
83 OPH ATLA	45	16	14.5%	0.41	1.44	10	0	5.7	4	7	95.8
84 OPI AURI	43	7	6.4%	0.39	1.93	15	0	5.2	4	6	56.0
85 PAR FURC	17	7	6.4%	0.15	0.72	6	0	18.9	15	25	1,923.6
86 PLA ARGA	5	1	0.9%	0.05	0.48	5	0	35.0	30	40	2,296.3
87 POM ARCU	3	3	2.7%	0.03	0.16	1	0	35.0	35	35	3,950.9
88 PRO ACUL	35	26	23.6%	0.32	0.65	3	0	5.1	4	7	157.2
89 PSE MACU	19	16	14.5%	0.17	0.47	3	0	16.1	10	25	1,679.6
90 RYP SAPO	1	1	0.9%	0.01	0.10	1	0	25.0	25	25	255.3
91 SCA COEL	1	1	0.9%	0.01	0.10	1	0	60.0	60	60	4,262.5
92 SCA CROI	1	1	0.9%	0.01	0.10	1	0	8.0	8	8	8.4
93 SCA TAEN	544	95	86.4%	4.95	4.18	20	0	13.7	2	35	32,528.4
94 SCA VETU	11	7	6.4%	0.10	0.41	2	0	25.0	20	38	3,576.9
95 SER TABA	7	3	2.7%	0.06	0.49	5	0	4.6	1	8	20.4
96 SER TIGR	42	27	24.5%	0.38	0.78	3	0	6.0	4	10	163.6
97 SER TORT	2	1	0.9%	0.02	0.19	2	0	2.0	2	2	0.2
98 SPA ATOM	38	20	18.2%	0.35	0.87	4	0	4.5	3	7	51.4
99 SPA AURO	440	95	86.4%	4.00	3.96	24	0	12.1	2	30	18,407.2
100 SPA RUBR	4	4	3.6%	0.04	0.19	1	0	30.3	25	35	2,255.4
101 SPA VIRI	125	65	59.1%	1.14	1.93	17	0	23.7	4	45	44,671.7
102 SPH BARR	54	26	23.6%	0.49	1.28	8	0	83.2	38	150	306,870.9
103 STE DIEN	92	20	18.2%	0.84	3.03	24	0	3.3	1	7	148.9
104 STE FUSC	617	52	47.3%	5.61	11.63	80	0	5.8	1	11	3,972.6
105 STE PART	1,449	91	82.7%	13.17	12.49	70	0	3.7	1	6	2,096.7
106 STE PLAN	220	24	21.8%	2.00	5.55	30	0	5.6	2	7	1,182.3
107 STE VARI	3	3	2.7%	0.03	0.16	1	0	4.7	4	5	7.9
108 THA BIFA	2,950	95	86.4%	26.82	46.56	400	0	3.5	1	7	1,393.8
109 UNK SPE	40	1	0.9%	0.36	3.81	40	0	1.0	1	1	0.4
110 URO JAMA	9	9	8.2%	0.08	0.28	1	0	20.6	17	25	763.0
111 XAN RING	11	5	4.5%	0.10	0.51	4	0	12.2	8	15	460.0

NO. SAMPLES = 110
NO. SPECIES = 111
TOT. INDIVIDUALS = 20,901
BIOMASS (g) = 1,124,966.4

Table 1 (cont.)

Table 2. Summary of sampling effort, mean number of species, and mean fish abundance, per sample, by habitat and site at Navassa Island, 30 October through 11 November, 2002.

Habitat	# of Samples	Mean # of Species	Mean Abundance
Ledge (SL)	6	15.2	122.7
Low Relief Hard-bottom (LRHB)	2	18.0	101.5
Medium Relief Reef (MRHB)	23	23.2	246.8
Patch Reef (DP)	28	21.2	186.4
Calves (CLV)	12	20.2	143.3
Sand/Rubble (S/R)	1	7.0	95.0
Sharp-edge Spur and Groove (SESG)/Avalanche (AVL)	16	17.1	189.9
Wall (WALL)	6	15.3	97.2
Wall Base (WB)	16	20.9	97.2
Site			
East Side	6	17.2	103.0
LuLu Bay	14	19.4	137.1
North Shelf	25	20.4	194.1
North Slope	6	22.5	279.3
NW Point	16	18.9	225.3
SE Side	8	20.6	156.8
West Side	30	20.0	186.1
West Slope	5	23.4	278.6
All sites and habitats	110	20.0	190.0

Chapter 5: Reef fish trophic analysis from Navassa Island: Exploring biotic and anthropogenic factors

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Introduction

Coral reef fish communities offer humans a broad range of services. Direct exploitation of the fisheries provides low-income tropical coastal peoples with a critical source of dietary protein (Russ 1991). Money derived from coral reef tourism is quickly becoming a principal component of many tropical island economies (Wilkinson 2002). The bioengineering services of reef fish would be difficult to replace, including the role of herbivorous fish in facilitating coral recruitment (Hughes 1994, Connell 1997, Lirman 2001) and the spectacular role of scarids in eroding coral skeletons into the white sand valued throughout the tropics (Bruggemann et al. 1996).

The indirect contributions of reef fisheries are equally impressive. Reef fish typically have a pelagic larval period preceding settlement to the benthic community during which time the fish suffer high predation rates. This predation creates a direct energetic link between reef productivity and economically-important pelagic fisheries (Randall 1967). Additionally, larval fish that avoid predation can provide a spatial link among benthic sites, driving source-sink population dynamics among reef sites (Crowder et al. 2000). Understanding the fundamental community dynamics of a location is essential to the efficient management of the services provided by the local fishery.

During this expedition to Navassa Island, we sought to identify the status of the local benthic community both in terms of human exploitation and in terms of biological conservation. In this chapter and Chapter 4, we explore the demographic characteristic of the fish community to gain insights into both the health and the biological value of Navassa's fishery. Chapter 4 provides insights into the status of the fish community using temporally and spatially replicated sampling protocols. These analyses provide invaluable views into the condition of the fish community relative to previous Navassa expeditions (Grace et al. 2000, Collette et al. 2003) as well as to other Caribbean sites (Bohnsack et al. 1999, Ault et al. 2001). The current chapter expands on the trophic dynamics of the fish community. Here I view the impacts of processes

working from the bottom up (i.e. the role of planktonic food resources and of geography) and from the top down (i.e. impacts of human fishing practices). I use information of fish densities as well as size distributions (with associated biomass) to draw possible conclusions regarding the factors determining local fish community characteristics.

Using both counts and biomass descriptors

The primary determinant of individual fish reproductive output is body mass. Gamete production typically scales linearly or faster than linearly with fish mass (Sadovy 1996). As a result, censuses of fish communities that account for only the number of individuals without body sizes do not allow the accurate estimation of reproductive yield. Pelagic fisheries science has consistently relied upon fish biomass to predict reproductive yield, often with high accuracy (Beverton and Holt 1957, Gabriel et al. 1989).

Fish are unusual amongst vertebrates in the capacity for plastic and indeterminate growth (Helfman et al. 1997). Numerous experimental (Jones 1986, Forrester 1990, Anderson and Sabado 1995) and observational (Thresher 1983, Clifton 1995) studies in tropical and temperate waters demonstrate that the growth of individual fish is tightly coupled to the amount of food consumed. Fish grow faster when provided with more food. Also, abundant evidence suggests that coastal fish communities remove most of the planktonic (Hamner et al. 1988, Clarke 1992) and digestible algal (Robertson et al. 1976, Thresher 1976) resources in their environment. The combination of food-limited plastic growth and extreme resource limitation leads inevitably to the conclusions that: (1) the reproductive output of a coastal, benthic fish community is in large part determined by the rate at which food is supplied to the system, and (2) competition for food regulates fecundity.

As a complement to the repeated fish census techniques employed on this Navassa expedition (Chapter 4), this survey allows alternate views into the local reef fish community. This alternate census technique was designed to accurately estimate the size distributions and standing crop biomass of the fish community, therefore providing a proxy of the reproductive and harvest potential from the location. We are thus capable of comparing results from two independent fish census techniques, strengthening the conclusions regarding the structure of the Navassa fish community. Additionally, a preliminary survey of the planktonic community

around the island was conducted, offering a first view into the pelagic contribution to the food resources on the island.

Methods

Fish censuses

Thirty-seven 5m x 2m quadrats were sampled between 10-30m depth across the island of Navassa. During a 12 min sampling interval, one diver recorded the species and length of all site-attached fish present in a quadrat. Length was estimated to the nearest centimeter by sight and corroboration with direct measurement of nearby landmarks.

Mobile species were counted three times throughout the sampling interval, with counts taken each 6min. The diver left the quadrat for one minute prior to the count, then a scan sample of all fish in the column of water above the quadrat was recorded. Fast-moving fish were counted individually, noting species identity and length estimate.

Lengths of fish were converted into biomass estimates based on published length-mass relations (available online at <http://www.fishbase.org>). The simple allometric function $M = \alpha L^\beta$ was used, where M is the mass of the fish, L represents fish standard length, and α and β are species-specific constants. Although this functional form is not ideal for estimating all size classes of a fish species, it provides an efficient size-specific mass scaling for this analysis. For species lacking specific allometric constants, parameters from a closely related, similarly shaped species were used (Table 1). Final quadrat biomass estimates were calculated as the sum of all site-attached fish plus one third of the biomass of each fish counted in each of the three transient fish counts. The transient fish mass estimates thus were averaged across the three replicate scan samples. Fish densities and size-frequency distributions were equivalently computed as this weighted sum of resident and transient fish. This technique minimizes the overrepresentation of mobile species in long duration counts, yet still allows a reasonably efficient means to account for all types of fish on the reef.

Plankton sampling

Plankton density was sampled in the waters above the benthic community on the reefs of Navassa. Large zooplankters were sampled with a 30cm diameter simple plankton net with 153 μ m mesh. One or two divers pulled the net following a 100m transect, either along a 5m or

20m isobath. To compensate for biases due to long-shore currents, a transect was followed in both directions, resulting in a total 200m transect. The resultant volume sampled was 14.1m³.

Twenty plankton samples were collected in total. To control for island-wide fluctuations of plankton, locations were selected across the island. The sum of plankton samples for the island is therefore a representation of the integrated plankton abundances available to fish on a reef throughout our cruise duration.

Plankton samples were stored in a buffered formalin solution (1% formaldehyde). To identify the contents of the sample, a 0.5ml sub-sample was taken from each preserved 30ml sample, after fully shaking the sample to homogenize and reduce clumping. Three repeated identification counts were performed on each sample at low magnification, classifying items to the lowest relevant taxonomic level. Each sub-sample was returned to the sample bottle for mass analysis. (Although duplicate plankton samples would be preferred, one for visual identification and one for mass analysis, the logistic constraint of the cruise prohibited repeated plankton tows.) Standard preparation protocols were followed to generate sample mass estimates (ash free dry weight; Dumont 1992).

Results

Fish community composition

A total of 37 10m² quadrats were censused at various sites around Navassa (see map), counting 2683 fish. The majority of these fish were ‘resident’ fish (1820), and the remaining 863 individuals were ‘transient’, passing through the quadrats during one of the three scan samples. The following summary statistics count ‘resident’ fish as 1 individual, and ‘transients’ as 1/3 of an individual. As previously described, this scan sampling and associated normalization reduces overrepresentation of fast-swimming fish during prolonged fish counts. The estimated density of the diurnal fish was 5.6 ± 0.4 fish m⁻², and the community biomass was 49.3 ± 4.6 g m⁻² (mean \pm SEM, n=37).

Trophic guilds were not evenly represented across the reefs. Within the censused quadrats, most fish were planktivores (70.8%), followed distantly by herbivores (17.8%). The remaining trophic groups each accounted for less than 5% of the community density (Figure 1a). In units of biomass, planktivores were the dominant contributors to reef community (36.3%). Piscivores and herbivores were the next most massive guilds (28.9 and 24.7%, respectively).

Browsers composed 7.8% of community mass, and the two groups of invertebrate feeders each composed less than 2% of the total biomass (Figure 1b).

Guild-specific length-frequency distributions help to reconcile the disparity between guild contributions to density and to biomass (Figure 1). Across all sampled fish, the average total length was 4.6cm. Microinvertivores, planktivores, and macroinvertivores each were smaller than the community mean, averaging 3.5, 4.1, and 4.1cm TL, respectively (Figure 2). Herbivores, browsers, and piscivores each were larger than the overall mean length (5.1, 8.6, and 17.7cm TL respectively; Figure 2). Despite low density of piscivores (Figure 1a), the high per capita mass of fish in the guild greatly increased their contribution to the total community biomass (Figures 1b & 2b).

Plankton sampling

The average plankton mass from the twenty samples was 2.56 ± 0.17 mg m⁻³ (AFDW, mean \pm SEM), ranging from 1.37 – 4.51 mg m⁻³ (Figure 3). There appears to be some spatial consistency of these samples, with the windward sites recording a higher mass of plankton than more leeward sites (Figure 4). However, these results should be viewed with caution, as the sample sizes from each site across the island were small and therefore lack statistical power.

The diversity of the holoplankton was low (Figure 5) with approximately 2/3 of the individuals in each sample being copepods. Qualitative analyses revealed that these copepods were not all the same size, showing appreciable amounts of within and across sample variability of plankter lengths. Therefore, the relative contribution of copepods to the mass of each sample is not directly quantifiable from these data. Eggs were the second most common contributors to the samples.

Discussion

Navassa is a small uplifted fossil coral island in the central Caribbean (18° 25' N, 75° 02' W), one fourth of the way from Haiti to Jamaica. The relative remoteness of this island to the scientific community has caused us to have only a rudimentary, though growing, view of the coral reef community surrounding the island (Grace et al. 2000, Collette et al. 2003). In this expedition to Navassa, we sought to rapidly and efficiently characterize the reef resources to

assist the U.S. Fish and Wildlife Service in the development of a management strategy for the island.

In this chapter and Chapter 4, we find that many characteristics of Navassa's fish community can be explained by the island's geography and history of human use. The reefs of Navassa have a limited diversity of diurnal fish (Appendix 3). Remote videography of reef sites did not add any new species to this list. Principally, Navassa is a remote, small island, which likely isolates the reefs from distant sources of fish recruits. This limited diversity would be predicted from the island biogeography theory (MacArthur and Wilson 1967). Additionally, there was a specific rarity of grunts and snappers (Haemulidae and Lutjanidae) around the island. Navassa's reefs lack nearby the mangroves and seagrass beds that are important nursery habitats for these families. The combination of isolation by distance from source populations of recruits and a local absence of nursery habitats are the most likely agents causing low fish diversity on the Navassa reefs.

Both the density and the biomass of the fish community on Navassa were low relative to other Caribbean locations and relative to past surveys at the same location (Chapter 4, Miller & Gerstner 2002). Recruitment limitation is a possible agent leading to low density of fish, however the low biomass is more likely due to exploitation by local fishers and local food limitation. The average fish community biomass for sampled sites on Navassa was $49.3 \pm 4.6 \text{ g m}^{-2}$ (mean \pm SEM). Comparable sampling in the Netherlands Antilles has given estimates between $114 - 185 \text{ g m}^{-2}$, suggesting that the fish community on Navassa is well below 50% of other developed reef sites in the Caribbean (S.A. Sandin *unpublished data*).

Human exploitation is the most likely cause of the notably small size structure and low biomass of the piscivore and herbivore guilds on Navassa. Although fish in both guilds were larger than average for the entire community (Figure 2), the average fish were only 17.7 and 5.1 cm SL (piscivore and herbivore, respectively). On unexploited reefs, both piscivores and herbivores are typically massive contributors to the fish community biomass, greatly exceeding the contributions recorded on Navassa (Roberts 1995, Russ and Alcala 1996). In interviews with local fishers, we noted that piscivores and herbivores are among the most favored catch around the island (see Chapter 10). It is therefore not surprising that both guilds appear underrepresented in the fish community. The current piscivore biomass on Navassa is comparable to that of Curaçao, Netherlands Antilles, a reef system suffering heavy fishing

exploitation. In contrast, both Navassa and Curaçao have piscivore biomass much below that of Bonaire, where an effective marine park significantly reduces fishing pressure (Navassa, 14.2 g m⁻²; Curaçao, 11.7 g m⁻²; Bonaire, 41.7 g m⁻²; S.A. Sandin, unpublished data).

The low biomass of the planktivore guild, however, may be a response to a depauperate pelagic planktonic contribution to the island of Navassa. Local fishers did not indicate an interest in capturing planktivorous species (Chapter 10), leaving food limitation as a likely force regulating the biomass of this guild. The plankton density data collected during this expedition will provide preliminary insights into the trophic dynamics working around Navassa, though few similar studies currently exist to which to compare these data (Figure 3). Therefore, quantitative interpretations of these values will rely on future sampling at a number of alternate sites across the Caribbean and through time on Navassa. A number of observations support the hypothesis that planktivores on Navassa are limited by food. First, the water around the island was quite clear relative to other Caribbean sites, suggesting low levels of suspended particles in the water column. Additionally, the fish community did not include a large group of large midwater planktivores, typically composed of brown chromis (*Chromis multilineata*) and creole wrasse (*Clepticus parrae*). Instead, most planktivores were smaller individuals hovering within 1-2m of the reef surface. The sit-and-wait strategy of planktivory typical of benthic planktivores is superior for capture of smaller plankters (Hamner et al. 1988, Hobson 1991), suggesting that the holoplanktonic delivery lacks a dominant contribution of larger food particles.

Plankton consumption is a fundamental process in the reef community, in that it introduces appreciable amounts of allochthonous energy and nutrients to the reef. Energy inputs to the whole community of reef fish include both the growth of the planktivore guild's biomass and the copious defecation that allows for secondary holoplankton consumption through coprophagy (Robertson 1982, Hobson 1991). Quantification of planktonic resources is therefore an important contribution to this survey of the Navassa reef community. The simple geography of Navassa lends itself well to potential further studies of trophic interactions within the fish community. Pelagic contribution of plankton can be easily estimated at an island scale, while the fish community is spatially limited. Therefore, paired surveys quantifying plankton on both the upcurrent and downcurrent shores of the island could be used to directly quantify the amount of planktonic food resources extracted by the local fish community. A dedicated research project to this end on Navassa would offer significant insights into reef fish trophodynamics.

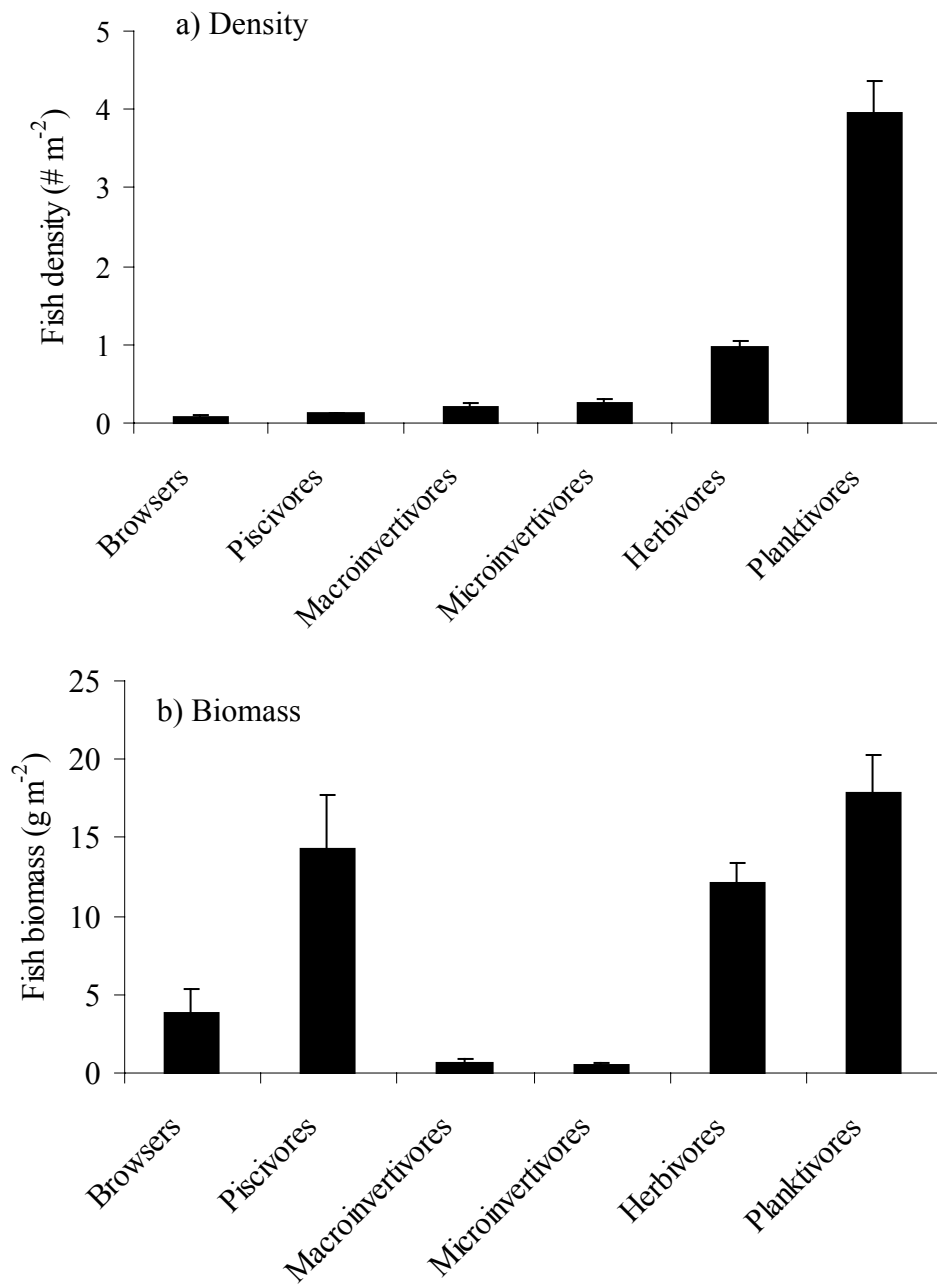


Figure 1: Diurnal fish density (a) and biomass (b) across trophic guilds. Averages (and SEM bars) are taken across 37 10m² quadrats. Fish were partitioned into trophic guilds based on the dominant food items consumed by adults of constituent species (see Table 1).

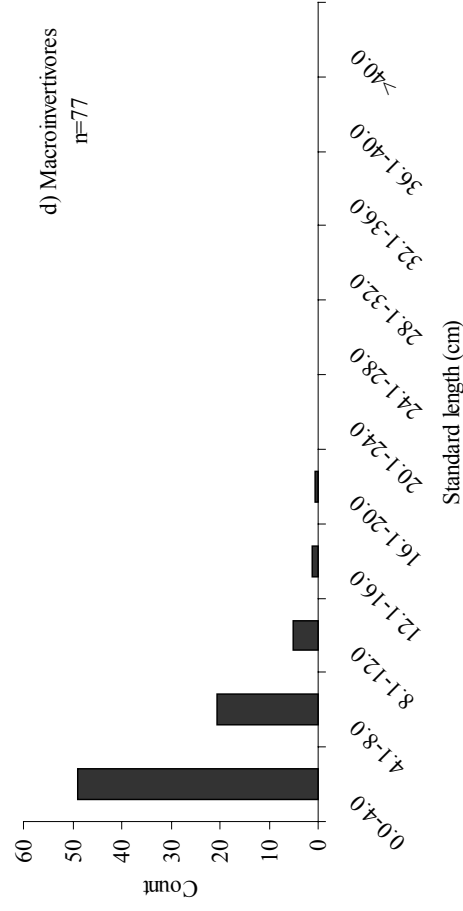
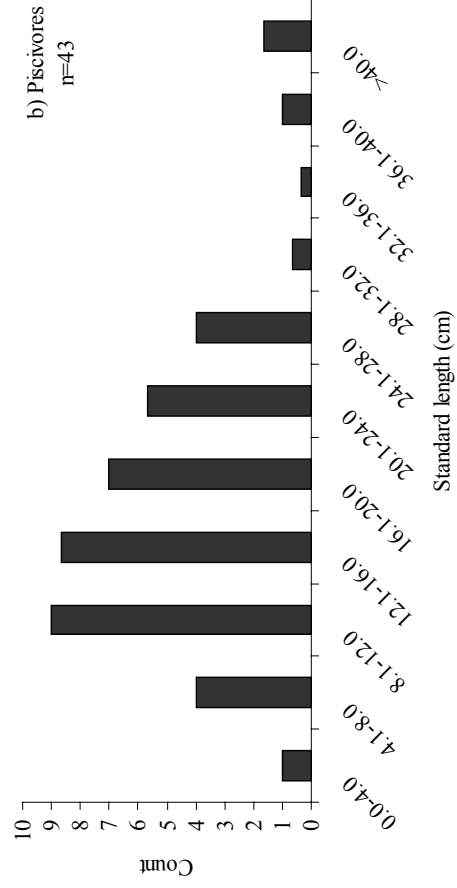
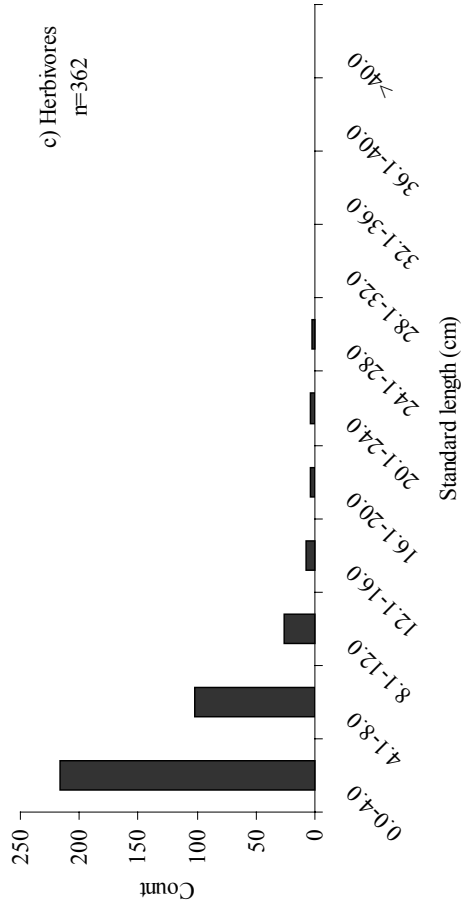
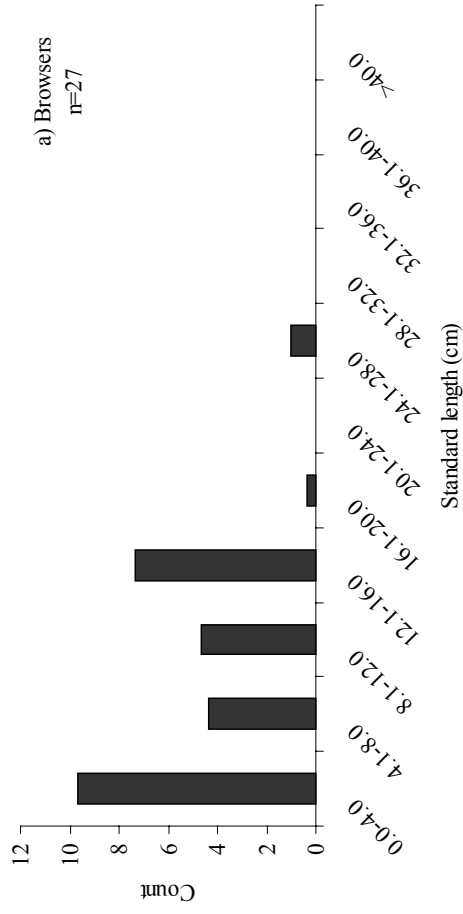


Figure 2 (see caption below)

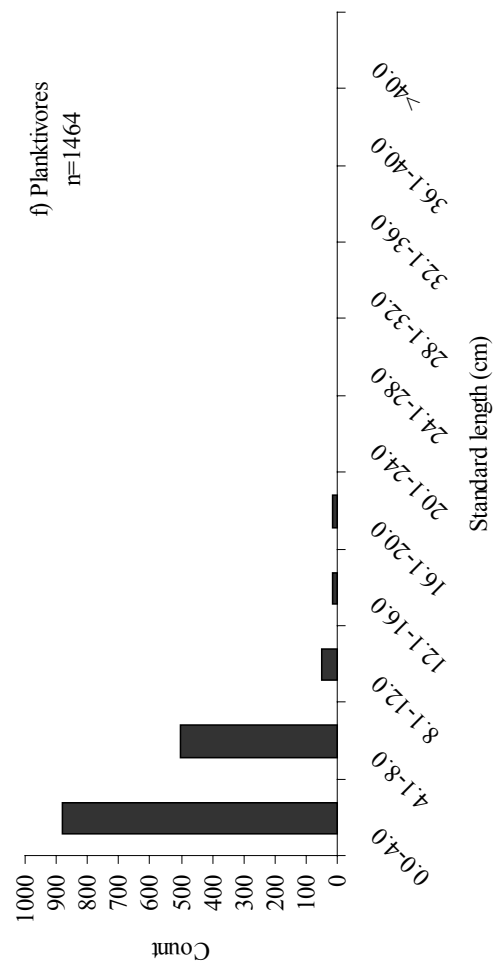
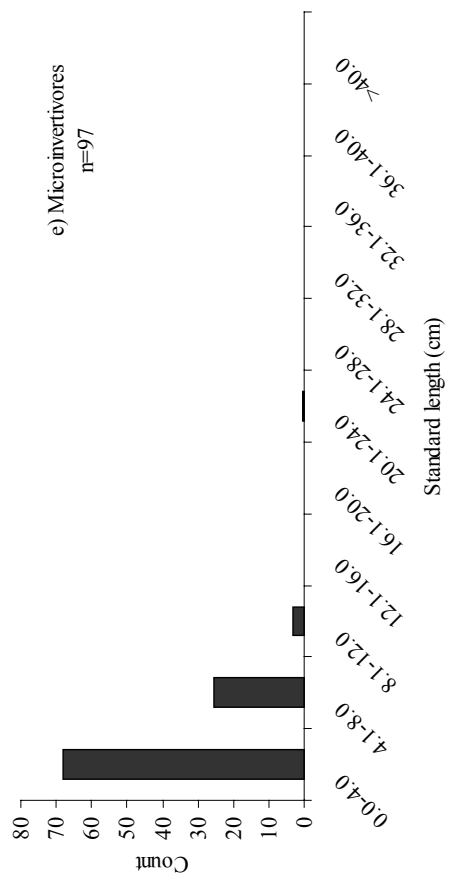
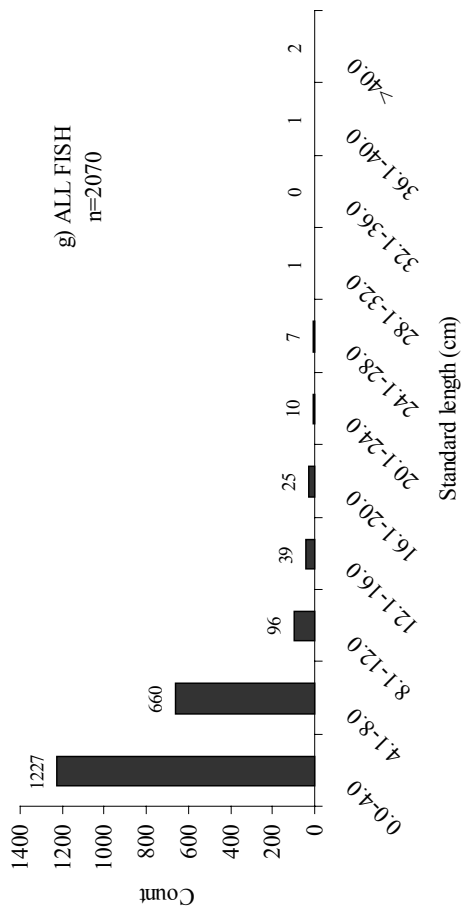


Figure 2: Fish community size frequency distributions. Functional guilds are presented separately (a-f), and combined (g). Counts are summations across 37 10m² quadrats and account for sampling design, with ‘resident’ fish counting as 1 and transient fish counting as 1/3. See text for details.

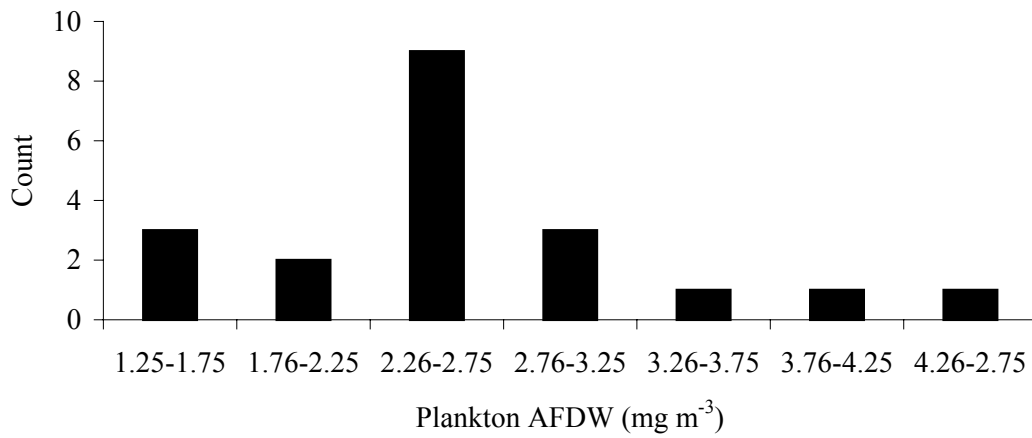


Figure 3: Distribution of plankton mass estimates (n=20). All masses are ash-free dry weight estimated per unit volume of sampled water.

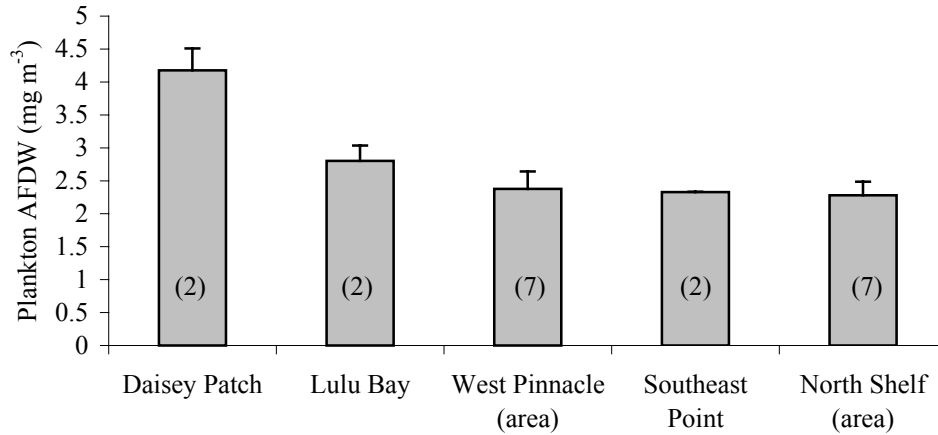


Figure 4: Spatial variability of plankton mass estimates. Bar represent plankton sample ash-free dry weight, and the bars are the SEM. Sample size is in parentheses. Note: none of these averages are statistically different due to the extremely low sample size for plankton samples. This spatial representation of the data is for preliminary, illustrative purposes *only*.

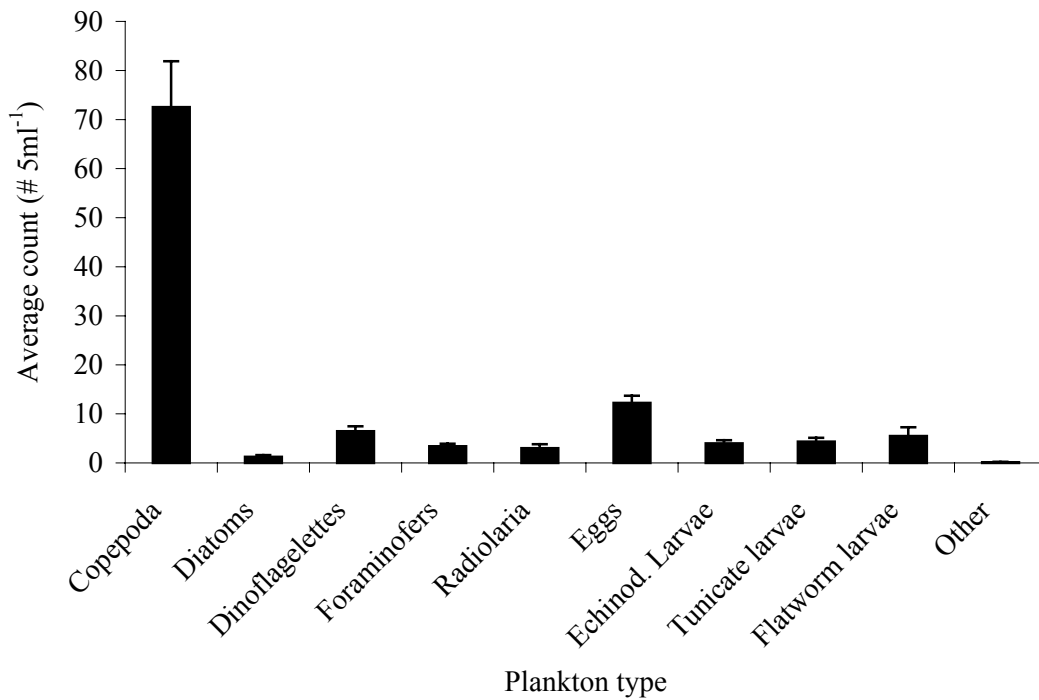


Figure 5: Prevalence of dominant plankters in samples from Navassa samples. Presented here are mean counts per 5ml sample (+SEM bars above). These data include only counts of items, not accounting for the sizes of the individuals, both within and among plankton types.

Table 1 – Species list for small plot fish surveys. Allometric scaling factors fit the mass (M) to length (L) relationship, $M = \alpha L^\beta$. Trophic categories correspond to the primary food resource used by species adults, and are taken from Bohnsack et al. (2000) with the exception of those in bold print (B, browser; H, herbivore; F, piscivore; Mi, microinvertebrate; Ma, macroinvertebrate; P, planktivore). Counts represent the number of individuals surveyed in the 111 3.3min sampling intervals (i.e. ‘resident’ fish from the 10min sampling interval count for 3, ‘transients’ count for 1; see text for details). Species-specific mean standard length and biomass are presented. Note: standard errors were only computable for species observed more than one time.

Species	Common name	Family	α	β	Trophic category	Count	Length (cm) mean [SEM]	Biomass (g) mean [SEM]
<i>Acanthurus bahianus</i>	ocean surgeonfish	Acanthuridae	0.0236	2.975	H	3	10.3 [1.3]	27.1 [10.8]
<i>Acanthurus coeruleus</i>	blue tang	Acanthuridae	0.0305	3.000	H	30	6.9 [0.7]	19.7 [4.1]
<i>Aulostomus maculatus</i>	trumpetfish	Aulostomidae	0.0040	2.866	F	4	37.0 [3.0]	131.4 [28.5]
<i>Melichthys niger</i>	black durgon	Balistidae	0.0058	3.554	P	8	19.3 [0.5]	217.4 [19.8]
<i>Xanthichthys ringens</i>	sargassum triggerfish	Balistidae	0.0058	3.554	Mi	1	12.0	39.7
<i>Ophioblennius atlanticus</i>	redlip blenny	Blenniidae	0.0333	2.391	H	9	5.3 [0.2]	1.8 [0.1]
<i>Carangoides ruber</i>	bar jack	Carangidae	0.0083	3.191	F	2	36.5 [6.5]	891.3 [462.2]
<i>Prognathodes aculeatus</i>	longsnout butterflyfish	Chaetodontidae	0.0222	3.140	B	6	7.0 [0.3]	10.2 [1.2]
<i>Chaetodon capistratus</i>	four-eye butterflyfish	Chaetodontidae	0.0470	2.860	B	2	8.5 [0.5]	21.6 [3.6]
<i>Amblycirrhitus pinos</i>	redspotted hawkfish	Cirrhitidae	0.0026	3.427	Mi	45	4.8 [0.2]	0.8 [0.1]
<i>Malacoctenus sp</i>	unknown blenny	Clinidae	0.0089	3.000	Mi	3	3.0 [0.0]	0.2 [0.0]
<i>Coryphopterus glaucofraenum</i>	bridled goby	Gobiidae	0.0345	2.680	H	193	2.3 [0.1]	0.5 [0.1]
<i>Coryphopterus hyalinus</i>	glass goby	Gobiidae	0.0345	2.680	P	195	1.5 [0.0]	0.1 [0.0]
<i>Coryphopterus lipernes</i>	peppermint goby	Gobiidae	0.0345	2.680	Mi	51	2.2 [0.1]	0.3 [0.0]
<i>Gobiosoma spp</i>	neon-like gobies	Gobiidae	0.0080	3.137	Mi	90	2.6 [0.1]	0.3 [0.0]
<i>Gramma loreto</i>	fairy basslet	Grammatidae	0.0145	3.048	P	45	3.9 [0.2]	1.2 [0.2]
<i>Bodianus rufus</i>	spanish hogfish	Labridae	0.0145	3.053	Ma	1	9.0	11.9
<i>Clepticus parrae</i>	creole wrasse	Labridae	0.0177	3.000	P	320	9.9 [0.3]	29.4 [1.8]
<i>Halichoeres garnoti</i>	yellowhead wrasse	Labridae	0.0052	3.375	Ma	228	4.1 [0.2]	3.1 [0.7]
<i>Halichoeres maculipinna</i>	clown wrasse	Labridae	0.0028	3.693	Mi	74	3.1 [0.2]	0.7 [0.1]
<i>Thalassoma bifasciatum</i>	bluehead	Labridae	0.0107	2.916	P	1508	2.9 [0.0]	0.5 [0.0]
<i>Pseudopeneus maculatus</i>	spotted goatfish	Mullidae	0.0159	3.026	Mi	1	22.0	183.5
<i>Gymnothorax funebris</i>	green moray	Muraenidae	0.0041	2.856	F	3	40.0 [0.0]	154.3 [0.0]
<i>Gymnothorax miliaris</i>	goldentail moray	Muraenidae	0.0011	2.574	F	9	16.7 [2.8]	2.3 [0.9]
<i>Myrichthys breviceps</i>	sharptail eel	Ophichthidae	0.0010	3.158	F	1	50.0	231.9
<i>Lactophrys polygona</i>	honeycomb cowfish	Ostraciidae	0.0179	3.000	B	1	18.0	104.4
<i>Lactophrys sp</i>	unk juvenile trunkfish	Ostraciidae	0.0309	3.000	B	6	1.0 [0.0]	0.0 [0.0]
<i>Holacanthus tricolor</i>	rock beauty	Pomacanthidae	0.0337	2.900	B	15	6.3 [1.0]	15.2 [5.4]
<i>Chromis cyanea</i>	blue chromis	Pomacentridae	0.0185	3.238	P	1488	4.3 [0.1]	3.8 [0.1]

<i>Chromis multilineata</i>	brown chromis	Pomacentridae	0.0185	3.238	P	243	5.0 [0.1]	4.4 [0.2]
<i>Microspathodon chrysurus</i>	yellowtail damselfish	Pomacentridae	0.0239	3.082	B	52	10.2 [0.9]	73.2 [17.4]
<i>Stegastes diencaeus</i>	longfin damselfish	Pomacentridae	0.0353	2.896	H	202	3.4 [0.1]	2.2 [0.3]
<i>Eupomacentrus fuscus</i>	dusky damselfish	Pomacentridae	0.0353	2.896	H	36	8.3 [0.5]	21.2 [2.8]
<i>Eupomacentrus leucostictus</i>	beaugregory	Pomacentridae	0.0303	2.887	H	3	8.0 [0.0]	12.3 [0.0]
<i>Stegastes partitus</i>	bicolor damselfish	Pomacentridae	0.0182	3.152	P	586	3.9 [0.1]	2.0 [0.1]
<i>Stegastes planifrons</i>	threespot damselfish	Pomacentridae	0.0379	2.857	H	200	7.8 [0.1]	15.1 [0.7]
<i>Scarus croicensis</i>	striped parrotfish	Scaridae	0.0166	3.020	H	2	16.0 [1.0]	72.7 [13.6]
<i>Scarus taeniopterus</i>	princess parrotfish	Scaridae	0.0177	3.000	H	67	8.6 [0.9]	42.8 [10.1]
<i>Sparisoma aurofrenatum</i>	redband parrotfish	Scaridae	0.0206	3.000	H	226	5.1 [0.3]	17.1 [4.0]
<i>Sparisoma rubripinne</i>	redfin parrotfish	Scaridae	0.0156	3.064	H	4	23.5 [3.0]	285.0 [95.8]
<i>Sparisoma viride</i>	stoplight parrotfish	Scaridae	0.0370	2.905	H	29	3.6 [0.6]	6.9 [5.6]
<i>Cephalolepis cruentatus</i>	graysby	Serranidae	0.0121	3.082	F	106	15.5 [0.6]	86.5 [8.9]
<i>Cephalolepis fulvus</i>	coney	Serranidae	0.0223	2.933	F	3	17.7 [3.8]	126.9 [54.3]
<i>Hypoplectrus puella</i>	barred hamlet	Serranidae	0.0090	3.040	Mi	9	10.3 [0.4]	11.2 [1.1]
<i>Hypoplectrus unicolor</i>	butter hamlet	Serranidae	0.0110	3.182	Mi	3	4.0 [0.0]	0.9 [0.0]
<i>Liopropoma carmabi</i>	candy basslet	Serranidae	0.0145	3.048	Mi	3	7.0 [0.0]	5.5 [0.0]
<i>Serranus tigrinus</i>	harlequin bass	Serranidae	0.0145	3.048	Mi	10	5.9 [0.3]	3.4 [0.5]
<i>Sphyaena barracuda</i>	great barracuda	Sphyaenidae	0.0267	2.920	F	1	55.0	3223.8
<i>Canthigaster rostrata</i>	sharpnose puffer	Tetraodontidae	0.0729	2.500	H	81	3.7 [0.1]	2.4 [0.2]
<i>Urolophus jamaicensis</i>	yellow stingray	Urolophidae	0.0072	3.083	Ma	1	17.0	44.8

Table 1.cont'd

Chapter 6: Crustose coralline algae and juvenile scleractinian corals of Navassa

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Introduction

In recent decades wide-spread disturbances have killed corals throughout the Caribbean. Overfishing, mass mortality of *Diadema antillarum*, hurricanes, diseases and bleaching events have all contributed to the important degradation of coral reefs (Hughes 1994). Even more disturbing is the relative lack of recovery of Caribbean reefs compared to Indo-Pacific reefs (Connell 1997). The resilience of coral reefs depends on high rates of recruitment (Kojis & Quinn 2001), and recent studies have shown a sharp decline in coral recruits coincident with the decline in Caribbean reefs (Hughes & Tanner 2000). It is possible that the reduction in the number of adult colonies has reduced the fertilization success, thereby limiting larval supply (Hughes et al. 2000). Another possibility is that recruitment limitation occurs at a later stage, and that suitable substrate for settling coral (nursery microhabitat) has become rare and limits larval settlement and subsequent survival of coral spat.

Crustose coralline algae (CCA) may be an important substrate for settling coral larvae. CCA have been shown to induce metamorphosis in larvae of hermatypic scleractinians in the laboratory (Morse et al. 1988), and approximately 90% of juvenile agariciids in Panama and Bonaire had originally settled on CCA. Moreover, a circumtropical coralline alga, *Titanoderma prototypum*, was found recently to be a biological nursery habitat for approximately 60% of scleractinian corals on the Great Barrier Reef (Steneck et al., in prep). *T. prototypum* is found throughout the Caribbean but no study to date has evaluated its role as a catalyst for coral settlement in the Caribbean. Further, few studies have investigated the interactions between CCA and settling corals in the field in the Caribbean.

The phase-shift to macroalgae documented on several Caribbean reefs (Hughes 1994) may have reduced the abundance and diversity of CCA. If coralline algae are a necessary nursery habitat to Caribbean corals as they appear to be in the Indo-Pacific, then their potential reduction in abundance may have important effects on the recovery of corals in the Caribbean.

A study encompassing several sites in the Caribbean (Bahamas, Belize, Bonaire, Mexico, US Virgin Islands) was initiated in June 2002 to identify the role of crustose coralline algae in

coral settlement. The 2002 expedition to Navassa allowed the inclusion of another site to this large-scale study and was an opportunity to characterize the coralline flora and quantify coral juveniles of this oceanic island.

Methods

Benthic surveys

Major components of the benthos were quantified using 10m transects at six locations varying in depth between 7 and 25m (same transects reported in Chapter 3, this report; two to four replicate transects at each location). Organisms were classified in 7 categories: scleractinian corals, gorgonians/sponges, macroalgae, turf algae, articulated coralline algae, crustose coralline algae and non-coralline crustose algae. For each category, the number of cm occupied by the organisms along the 10m transect was counted. For macroalgae, turf algae and articulated coralline algae, the canopy height was also measured to provide an estimate of biomass. We used a survey technique by which the transect tape was stretched over the reef (and did not follow small-scale topography of the reef) and the diver looked directly down from the transect tape to score each cm as one of the 7 categories.

On each transect, approximately 10 specimens of crustose coralline algae were collected for microscope identification to provide an estimate of abundance of individual species. Moreover, another 10 specimens were collected haphazardly on a separate occasion on the reef slope of the west deep reef, at depths of 30-40m.

Coral juveniles were identified to the lowest taxon possible and counted within a belt of 1m on each side of the transect (total area 20 m²). Coral juveniles were defined as colonies smaller than 40 mm in maximum diameter, that did not show fractured edges characteristic of asexual fragmentation recruits (Rogers et al. 1984, Edmunds 2000). Urchins *Diadema antillarum* were also counted within a one meter area on each side of the transects.

Coral settlement plates

Twenty five coral settlement plates were deployed at each of two sites: on the north shelf and on the NW point (see Appendix 1 for location). Settlement plates on the north shelf were placed at a depth of 7-8 m and those on the NW point were at 10m. The type of plate and protocol were the same as used in a parallel study in other locations in the Caribbean so that

results can directly be compared. Plates were terracotta tiles 10 cm x 10 cm x 1 cm with a 0.8 cm hole in the center, similar to those described in Mundy (2000). They were attached to the substrate directly by drilling holes in dead coral heads (mostly *Montrastraea faveolata*). Plastic wall anchors were inserted in the holes and plates were fastened using a 6.25 cm lag bolt. PVC spacers were also placed between the substrate and the settlement plate to create a one cm gap, because the underside of the settlement plates are known to be the area with the highest density of coral recruits (Maida et al. 1994).

The terracotta plates are expected to be colonized by crustose coralline algae within a few months (same experiment in Mexico shows coralline coverage comparable to the surrounding habitat within six months) and the subsequent recruitment of coral on the corallines or on bare substrate will help resolve the interactions between crustose coralline algae and the early life phases of corals.

Data analysis

Since three of the survey locations were on shallow reefs (7 to 13 m) and the other three on deeper “calves” habitats at the base of walls (17 to 25 m), the data were analyzed to compare results between these depths. Differences in the species composition for juvenile corals between sites and between depths were analyzed using non-metric multi-dimensional scaling (NMDS) followed by ANOSIM (Clarke 1993).

Results

Benthic surveys

A. BENTHIC COVER

Results of benthic surveys are very similar to those obtained with the point intercept method (Chapter 3) and will not be discussed in detail. Cover of live scleractinian coral for all six sampled locations ranged between 4 % and 37.5%, and averaged 16.1 ± 8.7 %. Coral cover was much higher at the shallow reefs (7 to 13m deep: coral cover $20.8 \pm 3.3\%$) compared to mid-depth reefs at the base of walls (17 to 25m deep: coral cover $10.5 \pm 5.4\%$). Similar differences between shallow and mid-depth reef communities were seen for several functional groups, in particular macroalgae (more abundant at mid-depth sites: $47.1 \pm 17.5\%$) and crustose coralline algae (more abundant at shallow sites). Cover of crustose coralline algae varied between 1.5 and

43%, and averaged $25.3 \pm 9.5\%$ and $14.9 \pm 12.3\%$ (shallow and mid-depth sites, respectively). Results of surveys are summarized in Table 1.

B. CRUSTOSE CORALLINE ALGAE

Due to time constraints only a subset of the CCA specimens has been identified to date. To provide an estimate of coralline diversity and changes in species abundance with depth, we chose to identify a subset of specimens from each depth sampled.

The three taxa that dominated shallow zones $\leq 10\text{m}$ were *Neogoniolithon mamillare* (Harvey) Setchell et Mason, *Paragoniolithon accretum* (Foslie et Howe), and *Porolithon pachydermum* (Foslie) Foslie. *Paragoniolithon solubile* (Foslie et Howe) dominated mid-depths from 17 to 25 meters. The deepest corallines with maximum abundances 30 m or greater were *Neogoniolithon munitum* (Foslie et Howe), *Neogoniolithon dispalatum* (Foslie et Howe) Adey, and *Mesophyllum syntrophicum* (Foslie) Adey. Two taxa (*Hydrolithon boergesenii* (Foslie) Foslie and *Titanoderma prototypum* (Foslie) Adey) had disjunct distributions, which probably resulted from undersampling (Figure 1).

C. CORAL JUVENILES

At least 18 species of scleractinian coral were present as juveniles (Table 2). The real number of species is likely to be higher because several species may have been present in genera that were not identified to species (*Agaricia* sp., *Madracis* sp., *Scolymia* sp. and *Isophyllastrea* sp.). Density of coral juveniles averaged 1.2 ± 0.6 colonies/m². Most abundant taxa included *Agaricia* sp. (0.5/m²), *Siderastrea radians* (0.2/m²), *Favia fragum* (0.15/m²), *Siderastrea siderea* (0.11/m²) and *Porites astreoides* (0.1/m²). Those five taxa accounted for 86% of all juveniles.

Total density of juveniles varied little between depths but species composition did. NMDS and ANOSIM showed significant differences in assemblage of juvenile corals between depths. Taxa showing most important differences include *Favia fragum* (more abundant in shallow water), *Siderastrea siderea* and *Leptoseris cucullata* (more abundant at depth). Variation between sites within a depth range was much less important.

D. ABUNDANCE OF *DIADEMA ANTILLARUM*

The number of urchins (*Diadema antillarum*) per transect (20 m²) varied between 0 and 16. *D. antillarum* was much more abundant at the mid-depth locations, with densities of $0.16 \pm 0.24 /\text{m}^2$, compared to $0.02 \pm 0.02/\text{m}^2$ at shallower depths.

Settlement plates

The coral settlement plates that were deployed on this cruise will be left in the water until the next opportunity to retrieve them, but will be in place at least through the settlement period following the 2003 summer/fall mass spawning events.

Discussion

Cover of live scleractinians on Navassa reefs was relatively high. Macroalgal abundance was low on shallow reefs but increased markedly with depth (to mid-depth reefs; deep (> 25m) reefs were not surveyed for macroalgae). Abundance of *Diadema antillarum* was relatively low, but similar to that reported from a previous expedition to Navassa (Miller & Gerstner 2002). CCA cover was high, especially on shallow reefs.

The coralline zonation conforms with patterns described for reefs throughout the Caribbean (i.e., Macintyre et al. 2001). The three shallow taxa are representative of corallines that grow under conditions of high light and high levels of herbivory. They are typically thick with somewhat protected conceptacles (Steneck 1986, 1997). The three deep taxa are representative of corallines that grow under conditions of low light and low levels of herbivory and are usually found in cryptic habitats in shallow zones or in deep water (Macintyre et al. 2001).

CCA community at intermediate depth (17-25m) was dominated by *Paragoniolithon sobubile* but also included several species (*Paragoniolithon accretum*, *Porolithon pachydermum* and *Neogoniolithon mammilare*) typically found in much shallower waters (shallow forereef environments). The presence of these species in much deeper water may reflect the exceptionally clear water around Navassa; following the same pattern, a small colony of elkhorn coral *Acropora palmata* was found at an exceptional depth of 24m (Appendix 2).

Titanoderma prototypum, a CCA that has been identified in the Pacific to have an inordinate positive impact on coral recruitment (Steneck et al., in prep), was found at several depths at Navassa. *T. prototypum* is likely to have been undersampled in this sampling since it

grows mostly in cryptic environments. The monitoring of the settlement plates in future years will allow sampling and better quantification of cryptic species of CCA (which are likely to grow on the undersides of plates) and identify their role in coral recruitment.

Density of juvenile coral was relatively high ($1.2/m^2$, all sites combined). It is comparable to that reported recently from Jamaica (Hughes & Tanner 2000), Florida (Chiappone & Sullivan 1996, Hughes & Tanner 2000) and St. Croix, USVI (Steneck and Bégin, unpublished data), and slightly lower than that recorded in St. John, USVI (Steneck and Bégin, unpublished data). As documented elsewhere in the Caribbean (Chiappone & Sullivan 1996, Edmunds 2000, Steneck and Bégin unpublished data), a high proportion of juvenile coral at Navassa are of brooding species. Indeed, *Agaricia* sp., *Porites astreoides*, *Favia fragum* and *Siderastrea radians* are all brooders (Richmond 1997). Only one species commonly found as juveniles (*Siderastrea siderea*) is a broadcast spawner.

Conclusion

The relatively high density of adult colonies and of coral juveniles at Navassa, along with the presence of a high abundance and diversity of CCA (including species previously identified as promoters of coral settlement), all suggest that reefs around Navassa have a high coral recruitment potential. Further monitoring of the settlement plates will allow better understanding of processes affecting early life history of scleractinian corals and provide insight into the resilience of corals of Navassa and other Caribbean locations.

Table 1. Mean percent cover and standard deviation of benthic organisms based on 10 m transects. Units are percentage except for canopy height, measured in mm.

	All sites		Shallow sites		Mid-depth sites	
	Mean	SD	Mean	SD	Mean	SD
Scleractinian coral	16.1	8.7	20.8	8.3	10.5	5.4
Gorgonians/sponges	17.6	12.2	19.2	14.9	15.8	8.2
Crustose coralline algae	20.6	11.9	25.3	9.5	14.9	12.3
Turf	16.8	12.1	21.0	13.2	11.9	8.8
Turf canopy height (mm)	0.1	0.1	0.2	0.1	0.1	0.05
Macroalgae	28.2	22.0	12.5	8.8	47.1	17.5
Macroalgae canopy height (mm)	3.4	1.2	3.0	0.8	4.0	1.5
Non-crustose coralline algae	2.5	2.9	4.0	3.1	0.9	1.2
Articulated coralline algae	0.3	0.6	0.3	0.5	0.4	0.8
Art. coralline canopy height (mm)	0.5	1.0	0.5	0.9	0.6	1.2

Table 2. Mean density and standard deviation (SD) of the urchin *Diadema antillarum* and of juvenile scleractinian corals for all sites combined, and for shallow stations (7-10m, n=12) and mid-depth stations (17-25m, n=10).

	All sites		Shallow sites		Mid-depth sites	
	Mean	SD	Mean	SD	Mean	SD
<i>Diadema antillarum</i>	0.08	0.17	0.02	0.02	0.16	0.24
<i>Acropora palmata</i>	0.002	0.01	0.004	0.01		
<i>Agaricia</i> spp	0.50	0.37	0.56	0.35	0.43	0.40
<i>Dichocoenia stoksi</i>	0.01	0.02			0.02	0.03
<i>Eusmilia fastigiata</i>	0.01	0.02			0.02	0.03
<i>Favia fragum</i>	0.15	0.23	0.27	0.26	0.01	0.02
<i>Leptoseris cucullata</i>	0.04	0.05	0.01	0.02	0.07	0.05
<i>Madracis</i> sp	0.01	0.03			0.03	0.04
<i>Millepora alcicornis</i>	0.01	0.03	0.02	0.04		
<i>Montastraea cavernosa</i>	0.01	0.02			0.02	0.03
<i>Montastraea faveolata</i>	0.00	0.01	0.01	0.02		
<i>Porites astreoides</i>	0.10	0.09	0.11	0.09	0.10	0.09
<i>Porites porites</i>	0.04	0.06	0.03	0.06	0.05	0.06
<i>Scolymia</i> sp.	0.01	0.03			0.03	0.04
<i>Siderastrea radians</i>	0.20	0.32	0.21	0.42	0.20	0.16
<i>Siderastrea siderea</i>	0.11	0.15	0.04	0.06	0.21	0.17
<i>Stephanocenia michelinii</i>	0.01	0.02	0.004	0.01	0.02	0.02
<i>Isophyllastrea</i> sp	0.01	0.02	0.004	0.01	0.01	0.03
<i>Oculina</i> sp	0.01	0.04	0.02	0.05		
Total juvenile colonies	1.24	0.60	1.30	0.66	1.18	0.55

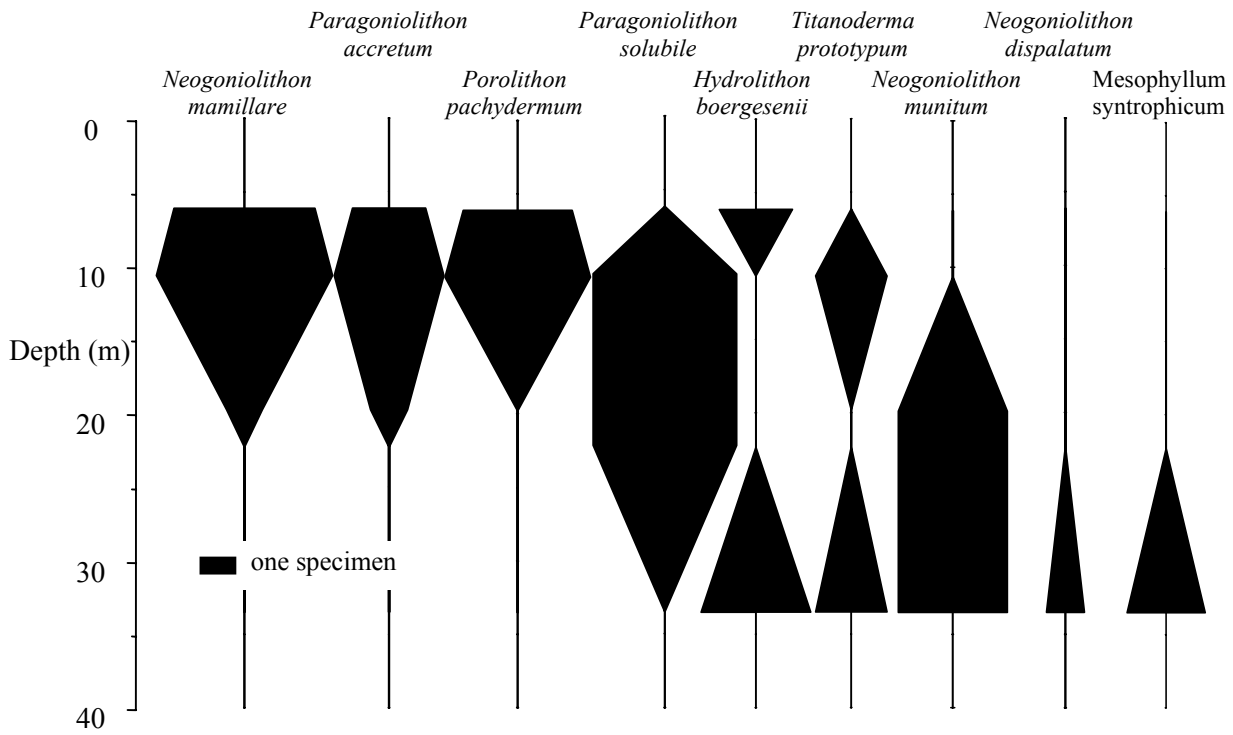


Figure 1 Nongeniculate coralline algae as a function of depth. Widths represent the number of specimens identified per taxa for a given depth.

Chapter 7: Coral population structure of Navassa Island

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Summary

The island of Navassa is a remote reef system and due to its offshore location potentially unaffected by anthropogenic factors that cause reef degradation elsewhere in the Caribbean. In November 2002, the local community structure of scleractinian corals was studied to provide insight in the current status of Navassa's reefs. The densities of individuals and population structure (i.e. size frequency distribution of the eleven most common corals) was quantified. Size frequency distributions of corals reflect the processes shaping them and therefore carry relevant information on the local conditions that corals have to contend with (Bak and Meesters 1998, Meesters et al. 2001, Vermeij and Bak 2003). Navassa reefs show evidence of being unaffected as well as being degraded. Coral colonies are small, and brooding species dominate the local coral fauna. Furthermore braincorals (*Diploria* spp. and *Colpophyllia natans*) in some deep habitats are heavily affected by diseases, resulting in high (partial) mortality rates especially for smaller individuals. Populations of branching corals (mainly *Porites porites* and *Madracis mirabilis*) showed high numbers of juveniles due to fragmentation, possibly resulting from recent hurricanes .

Methodology

Coral size frequencies were obtained by measuring all colonies in 7x 0.5m belt transects that were haphazardly placed around the island at various depths between 15 and 25m. All colonies were measured to the nearest cm^2 while colonies below 5cm^2 were measured to the closest mm^2 . A colony is defined as the summed surface of living tissue that is connected through a shared skeleton and assumed to have originated from one zygote. We measured the living tissue area by overlaying the colony with a flexible transparent sheets with 4, 2, 1, 0.25 and 0.0625 cm^2 grids. Coral sizes were log transformed following Vermeij and Bak (2003) and analyzed using standard statistics. Coral community structure was determined using the point-intercept method. Every 10cm along a 10 to 15m long transect the animal, plant or structure was

denoted. Per site a minimum of 5 of these transects was used to determine the local community structure. For the classes used see Table 1.

Results

Coral diversity

All major Caribbean coral species are represented in Navassa (Table 2) except for *Solenastrea* and some *Oculina* species. Spawning corals (*Montastraea* spp., *Siderastrea siderea* and *Colpophillia* spp.) are more abundant at the deeper reefs, but the dominance of brooders in the shallow (<15m) water is most striking. Densities of all species are relatively low indicating low recruitment (Table 3). On November 9, 2002, the coral *Madracis senaria* was observed releasing planulae at a depth of 38m at 08:00 in the morning. The observation of planulae release at daytime is rare and has not been reported previously for any coral species in the Caribbean.

Size frequency distributions

Since many characteristics (i.e. fecundity, mortality) of clonal organisms, such as corals, depend on size, size frequency distributions indicate important information. Log transformation of size data enhances the resolution in the smallest size classes (Vermeij and Bak 2003), that are believed to react sooner, and thus better reflect, changes in environmental conditions (Meesters et al. 2001). Size data were haphazardly collected around Navassa and. The size frequency distributions of the eleven most common species at Navassa are given in Figure 1. The size frequency distributions of most corals are similar to those elsewhere in the Caribbean (Curaçao, Saba, Florida; Vermeij unpubl. data). Species-specific characteristics account for nearly twice as much variation in the structure of size frequency distributions as environmental factors. That is, species differ not only in colony size, but also in their size frequency distributions and when two populations differ from one another to a certain degree, 67% of this difference is dependent on species influences (unless you consider the same species) and 33% is due to the environment (Meesters et al. 2001, Vermeij and Bak, in press). This indicates that although the conditions at Navassa seem initially marginal for coral population development, populations of most species are able to develop in a natural way. This could be interpreted as acclimatization of the local populations to the local suite of environmental factors or no susceptibility to environmental

structuring in the first place. Populations of spawning species display lower size variation as indicated by their lower coefficient of variation (CV; 0.21-0.41) compared to brooders (0.52-1.21; Table 4). All populations are characterized by a low proportion of juveniles (low values for skewness). Braincorals (*Diploria* spp. and *Colpophyllia natans*) show negative values indicating that large colonies are relatively abundant. The under-representation of small colonies in the populations of these species is unnatural and caused by disease. An estimated 40% of colonies at the deeper reefs was affected by what appears to be White Plague Type II and many totally dead colonies were observed. This observation confirms recent suggestions that WP II is currently responsible for a large decrease in braincorals in the Northern Caribbean that mainly occurred during the summer of 2001.

Branching corals at Navassa show relatively high skewness values compared to conspecific populations elsewhere in the Caribbean. High skewness (g_1) values indicate an overrepresentation of small individuals compared to a normal size distribution. Many fragments (i.e. asexual recruits) are an additional source of juveniles in coral populations and were often observed on Navassa reefs for all branching species. The frequent passage of hurricanes at Navassa is likely the cause for this high number of asexual recruits.

In short, although coral population structure of coral species at Navassa is largely similar to other locations in the Caribbean, the infection of braincorals by disease and increased fragmentation due to hurricanes, are characteristic for its coral community.

Community structure

The spatial complexity studied at a 10cm scale is low within a site (i.e. approx. 200m sector of reef parallel to the island). Reefs are either dominated by horizontal or vertical surfaces, whereas the first represents the offshore reefs, whereas the latter represents the vertical walls surrounding the island. Habitat complexity affects the evolution and ecology of coral reef organisms. The near bimodal distinction in horizontally and vertically dominated habitats that are relatively well separated on a small spatial scale (i.e. within the island) is rare for the Caribbean.

Discussion

The coral fauna close to Navassa and to a lesser extent at the more remote deep reefs is less speciose compared to similar reefs in the Caribbean. However, this in itself should not be a reason for pessimism since the causal factors underlying the depauperate state of the local reefs are presently unknown. The effect of hurricanes should not be underestimated at this island: likely continuous substrate rearrangement, dislodgment of colonies present and scouring by the large amount of sand present around Navassa don't provide the conditions for optimal reef development at ecological time scales. The fact that brooding species dominate the local coral fauna is another indication of suboptimal ecological conditions on a decadal scale as brooding is believed to have developed to escape the limitations of a life history that can deal with temporal variability on an ecological scale (Vermeij and Ginsburg, in prep). The turnover of bottom elements as well as sand scouring increases juvenile mortality and limits near-indeterminate growth. The absence of small colonies, low coral colony density, the absence of so called "giant corals", confirms this hypothesis. Furthermore the presence of an extended deep forereef can easily be the result of colony transport from the shallower reef to the surrounding sand flats during severe storm events.

Coral dynamics at Navassa: open vs closed populations

Brooding corals (mainly *Agaricia* and *Porites* species) dominate the scleractinian fauna of Navassa. This phenomenon provides some interesting perspectives on retention mechanisms for coral offspring. Local hydrodynamic conditions (i.e. strong currents and a relative small island to watermass ratio) prevent retention of gametes to the island favoring species with short larval dispersal distances (i.e. brooding coral species). Two main characteristics of brooding corals, short dispersal distances as well as high competence make them the ideal inhabitants of Navassa reefs. The suggestion that Navassa harbors a local fauna, largely unaffected by input of juveniles upstream, is also supported by the observations of the fish community around the island. Fish biomass is low indicating low recruitment and species that favor habitats not present at Navassa (e.g. mangroves or seagrass beds) are absent. Based on these data it seems warranted to conclude that Navassa harbors isolated populations of various taxa that are independent of recruitment from elsewhere. Whether the island is a source itself remains uncertain but this is

unlikely as the same barriers to export exist as for recruits coming from elsewhere. The isolated or closed nature of the island suggests that major changes to its biota are relatively irreversible.

Conclusion

Navassa is an isolated island near Haiti. Its isolation is reflected in its surrounding biota, where low biomass, reduced coral richness and minimal reef accretion characterize the underwater landscape. It needs to be stressed that these characteristics, although not very attractive from an esthetical perspective, do not necessarily represent marginal conditions where species struggle to survive. On the contrary, brooding corals dominate the local reefs and are perfectly adapted to such conditions and although macroalgal cover is high, its direct effect on the coral community is not directly visible. To study these processes in a controlled environment is not easy in general since reefs are connected through transport of juveniles by watermasses. Navassa seems to provide us with an opportunity to study biogeographical patterns on an island scale due its closed population structure. This is where a major value of Navassa lies, namely as a natural laboratory.

In addition, it seems unlikely that Navassa is an important source of juveniles or useful potential refuge site in the region. The low presence of corals will provide only a small number of propagules. The lack of obvious success in importing juveniles from elsewhere makes successful export equally unlikely.

One needs to consider that all these conditions could change relatively fast during an episodic event where many coral species settle successfully on Navassa's reefs. A similar event has occurred on Bermuda where a single settlement event by braincorals several decades ago still echoes in its present day community structure. This stresses the importance of temporal variation in possible peaks in import of various organisms to Navassa that could change the situation for many years afterwards.

Table 1: Coral species diversity at Navassa

Faviina	Meandrinidae	<i>Dendrogyra cylindrus</i> <i>Dichocoenia stokesi</i> <i>Favia fragum</i> <i>Meandrina meandrites</i>	Astrocoeniina	Acroporidae	<i>Acropora cervicornis</i> <i>Acropora palmata</i>
	Faviidae	<i>Montastraea annularis</i> <i>Montastraea faveolata</i> <i>Montastraea franksi</i> <i>Montastraea cavernosa</i> <i>Diploria strigosa</i> <i>Diploria clivosa</i> <i>Diploria labyrinthiformis</i> <i>Manicina areolata</i> <i>Colpophyllia natans</i>		Pocilloporidae	<i>Madracis mirabilis</i> <i>Madracis decactis</i> <i>Madracis pharensis</i> <i>Madracis senaria</i> <i>Madracis formosa</i> <i>Madracis carmabi</i>
	Mussidae	<i>Mycetophyllia lamarckiana</i> <i>Mycetophyllia aliciae</i> <i>Mycetophyllia ferox</i> <i>Mycetophyllia danae</i> <i>Mycetophyllia reesi</i> <i>Isophyllia sinuosa</i> <i>Isophyllastrea rigida</i> <i>Scolymia cubensis</i> <i>Scolymia wellsi</i> <i>Scolymia lacera</i> <i>Mussa angulosa</i>		Astrocoeniidae	<i>Stephanocoenia michelinii</i>
			Fungiina	Poritidae	<i>Porites porites</i> <i>Porites furcata</i> <i>Porites divaricata</i> <i>Porites branneri</i> <i>Porites asteroides</i> <i>Porites colonensis</i>
				Agariciidae	<i>Leptoseris cucullata</i> <i>Agaricia fragilis</i> <i>Agaricia lamarcki</i> <i>Agaricia grahamae</i> <i>Agaricia agaricites</i> <i>Agaricia humilis</i> <i>Agaricia tenuifolia</i>
Caryophylliidae	Caryophylliidae	<i>Eusmilia fastigiata</i>		Siderastreidae	<i>Siderastrea siderea</i> <i>Siderastrea radians</i>
Dendrophylliina	Dendrophyllidae	<i>Tubastrea coccinea</i>			

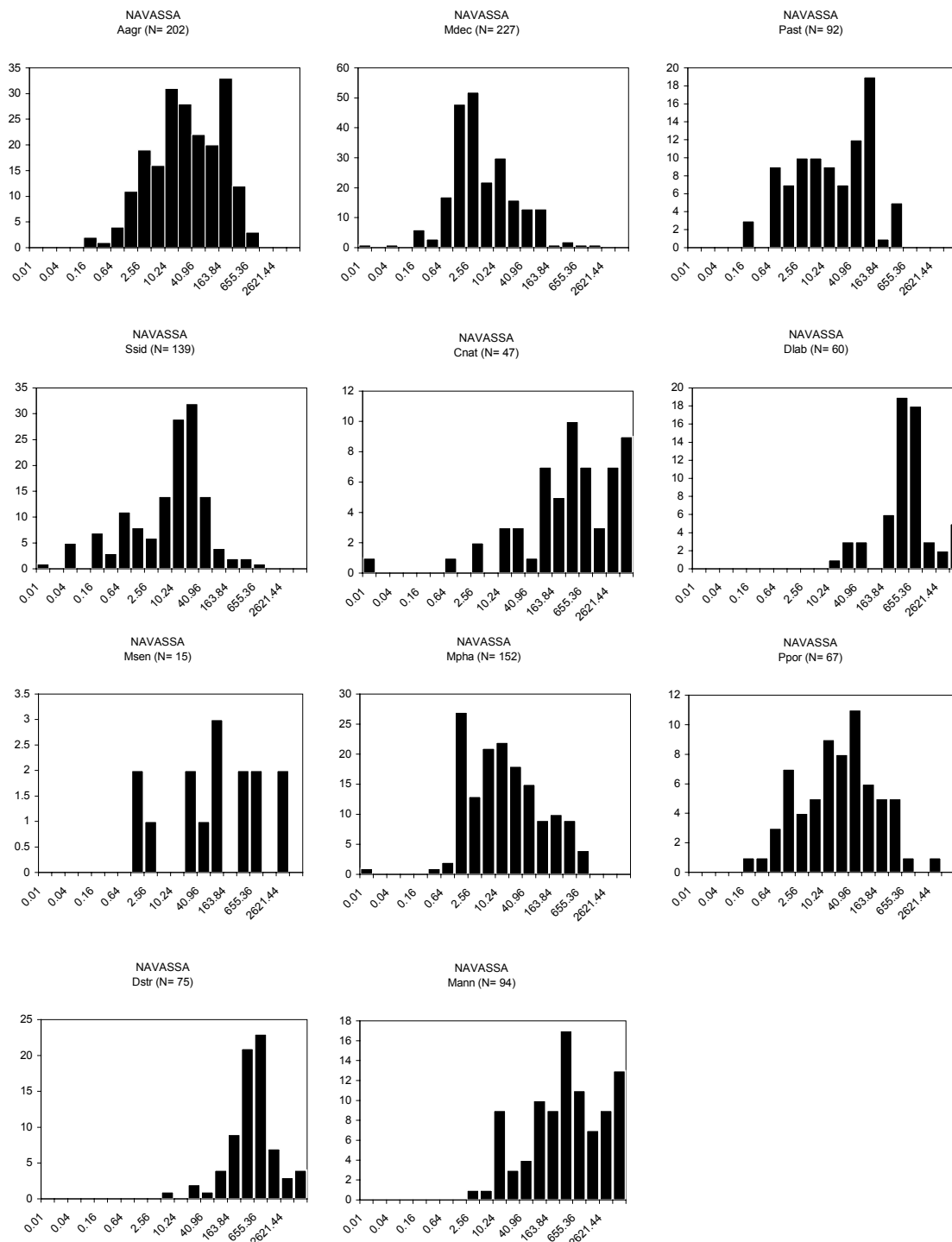
Table 2: Densities of most common coral species at Navassa. Data from all transects is pooled to indicate island-wide average.

	mean (n /3.5m ²)	SD
<i>A. agaricites</i>	25.3	14.1
<i>S. siderea</i>	17.4	11.4
<i>P. porites</i>	9.3	8.7
<i>M. decactis</i>	8.9	6.1
<i>P. astreoides</i>	8.3	2.9
<i>M. annularis</i> s.l.	4.9	6.1
<i>P. divaricata</i>	3.9	6.6
<i>L. cucullata</i>	3.1	2.4
<i>E. fastigiata</i>	2.9	2.2
<i>A. fragilis</i>	2.3	2.4
<i>M. pharensis</i>	1.9	2.0
<i>F. fragum</i>	1.6	4.2
<i>M. cavernosa</i>	1.4	2.5
<i>Scolymia</i> sps.	1.3	1.8
<i>S. michelinii</i>	1.1	2.0
<i>M. danae</i>	0.8	2.1
<i>P. branneri</i>	0.8	1.8
<i>D. stokesi</i>	0.6	0.5
<i>A. humilis</i>	0.6	1.1
<i>A. lamarcki</i>	0.4	0.7
<i>I. rigida</i>	0.4	0.7
<i>M. meandritis</i>	0.4	0.5
<i>S. radians</i>	0.1	0.4

Table 3: Overview of transformed (log) and untransformed size distribution statistics for 11 coral species at Navassa

	<i>untransformed</i>													
	species	aagr	mdec	mpha	past	ppor	ssid	cnat	dlab	dstr	srad	mmir	mcar	mann
Mean	50.93	16.61	43.63	30.84	64.03	18.09	1300.51	692.53	613.27	6.09	44.73	176.69	3733.32	320.80
Standard Error	5.28	4.65	7.45	5.01	23.46	4.49	347.84	147.04	117.77	0.77	21.07	76.59	1342.56	144.71
Standard Deviation	75.03	70.07	91.88	48.02	192.01	52.90	2671.80	1138.94	1019.96	9.16	238.41	603.05	13016.63	560.47
CV	1.47	4.22	2.11	1.56	3.00	2.92	2.05	1.64	1.66	1.50	5.33	3.41	3.49	1.75
Kurtosis	6.51	117.25	12.74	7.83	50.62	65.36	10.98	9.16	16.65	19.00	79.04	33.83	44.49	3.80
Skewness	2.38	10.04	3.35	2.66	6.76	7.48	3.30	3.01	3.82	3.52	8.49	5.46	6.16	2.17
Minimum	0.16	0.01	0.00	0.09	0.09	0.01	0.00	7.50	3.24	0.01	0.25	0.40	1.50	1.00
Maximum	432.00	900.00	600.00	252.00	1512.00	527.00	12348.00	5880.00	6468.00	72.00	2400.00	4200.00	107136.00	1800.00
Count	202.00	227.00	152.00	92.00	67.00	139.00	59.00	60.00	75.00	143.00	128.00	62.00	94.00	15.00
Conf Level (95.0%)	10.41	9.16	14.72	9.94	46.83	8.87	696.27	294.22	234.67	1.51	41.70	153.15	2666.06	310.38
<i>transformed</i>														
Mean	4.25	2.31	3.54	3.51	3.96	2.86	7.85	8.23	8.26	2.06	1.94	3.45	8.13	5.89
Standard Error	0.15	0.12	0.18	0.23	0.29	0.16	0.42	0.25	0.20	0.12	0.21	0.40	0.34	0.83
Standard Deviation	2.19	1.78	2.26	2.21	2.37	1.83	3.21	1.95	1.75	1.42	2.35	3.14	3.32	3.22
CV	0.52	0.77	0.64	0.63	0.60	0.64	0.41	0.24	0.21	0.69	1.21	0.91	0.41	0.55
Kurtosis	-1.05	1.84	-0.52	-1.23	-0.41	0.30	-0.14	0.90	2.48	-0.58	2.85	0.12	-0.18	-0.96
Skewness	0.07	1.38	0.64	0.15	0.35	0.38	-0.43	-0.35	-0.54	0.55	1.79	1.11	0.32	-0.12
Minimum	0.21	0.01	0.00	0.12	0.12	0.01	0.00	3.09	2.08	0.01	0.32	0.49	1.32	1.00
Maximum	8.76	9.82	9.23	7.98	10.56	9.04	13.59	12.52	12.66	6.19	11.23	12.04	16.71	10.81
Count	202.00	227.00	152.00	92.00	67.00	139.00	59.00	60.00	75.00	143.00	128.00	62.00	94.00	15.00
Conf Level (95.0%)	0.30	0.23	0.36	0.46	0.58	0.31	0.84	0.50	0.40	0.24	0.41	0.80	0.68	1.78

Figure 1: Size frequency distributions of the most common scleractinian corals at Navassa (depth >15m).



Chapter 8: Population demographics of the corallivorous snail *Coralliophila abbreviata* from Navassa Island

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Introduction

Coralliophila abbreviata (short coral snail) is a corallivorous snail found on shallow reefs throughout the Caribbean where it feeds on the live tissue of a variety of scleractinian corals (Wells & Lalli, Miller 1981, Hayes 1990, Bruckner et al. 1997). It is considered a capable predator, particularly on Acroporid corals (Brawley & Adey 1982, Hayes 1990, Bruckner et al. 1997, Baums et al. 2003) where it leaves significant feeding scars. Its abundance, distribution patterns and population structure are of interest in understanding its effect on coral populations.

Populations of this snail in the Florida Keys have been monitored for several years (Miller et al. 2002, Baums et al. 2003) for characteristics such as size-distribution, sex ratios, abundance and infestation rates on different coral hosts (i.e. coral species). Additionally, other regions of the Caribbean have been sampled in 2002 (Baums et al. in prep) for comparison to Florida Keys populations. *Coralliophila abbreviata* population(s) from Navassa Island were sampled for inclusion in this comparison. What follows is a snapshot of some fundamental population demographics, comparison with other sampled locations in the Caribbean, and a brief interpretation of their meaning.

Sampling Methods

Transect Survey

Living coral colonies along two randomly placed 10m x 1m transects (see Chapter 3 for detailed methods) were identified and searched for *Coralliophila abbreviata* at six sites around the island. When present, *C. abbreviata* (snails) on the host colony were counted. *Coralliophila abbreviata* infestation (% colonies with ≥ 1 snail) among each coral host taxa (*Agaricia* spp., *Montastraea annularis*, and *Diploria* spp.) from each site was calculated for each transect. Also, the number of snails found on each infested colony (group size) was averaged for each host.

Haphazard Predator Sampling

Coralliophila abbreviata (snails) were collected haphazardly from colonies of several coral hosts (independent from colonies encountered on transect surveys) at several sites around Navassa Island. Host corals included *Diploria strigosa*, *Diploria clivosa*, *Diploria labyrinthiformes*, *Agaricia* spp., *Montastraea annularis*, *Acropora palmata* and *A. cervicornis*. Host species were selected haphazardly and searched for *C. abbreviata*. When snails were found, all individuals found on that colony were collected. Where possible, all snails found on a single colony were kept together for analysis as a 'group'. These data were analyzed separately from the group size data collected from transect surveys due to the different sampling methods and due to the inclusion of snails found on *Acropora palmata* (not encountered on transect surveys). The shell length of each snail was measured and sex was determined. Individuals were identified as male when a penis was found and/or female when lacking a penis and egg cases were found. Some individuals could not be clearly identified because neither a penis nor egg

cases could be found, but these were typically smaller individuals with unusually translucent tissue, these individuals were identified as NP (no penis).

Statistical Analyses & Results

Transect Survey

Of the greater than 30 coral species (*Agaricia* grouped at genus level) encountered in transect surveys, *Coralliophila abbreviata* were found on only six: *Agaricia* spp., *Montastraea annularis* (complex), *Diploria clivosa*, *D. labyrinthiformes*, *D. strigosa*, and *Leptoseris culculata* (excluded from further analysis-only found on one colony). Host colony infestation (% of host colonies with ≥ 1 *C. abbreviata*) and the average number of *C. abbreviata* found on an infested colony ('group size') are shown in Table 1. Both variables were compared between hosts and sites using a Kruskal Wallis non-parametric ANOVA using the sampling transect as the replicate.

Table 1. Survey of *Coralliophila abbreviata* (snail) and its host corals *Agaricia* spp., *Montastraea annularis* (species complex) and *Diploria* spp. from six sites around Navassa Island. The percent infested colonies shown here is not the same parameter as used in the statistical tests reported (i.e. the average % infestation for the two replicate transects).

	Site	Total # host colonies (A)	Total # infested colonies (B)	Overall infestation (=B/A)	Average Group size
<i>Agaricia</i> spp.	North Shelf	98	4	4%	1.3
	NW Pt.	89	0	0%	
	East Side	27	2	7%	5.7
	SE Pt.	78	5	6%	1.8
	W. Pinnacles	90	5	6%	1.8
	Lulu Bay	65	2	3%	1.0
	All Sites	447	18	4%	2.2
<i>Montastraea annularis</i>	North Shelf	5	1	20%	7.0
	NW Pt.	4	1	25%	4.0
	East Side	1	0	0%	
	SE Pt.	13	0	0%	
	W. Pinnacles	4	1	25%	5.0
	Lulu Bay	9	3	33%	2.3
	All Sites	36	6	17%	3.8
<i>Diploria</i> spp.	North Shelf	8	0	0%	
	NW Pt.	3	0	0%	
	East Side	1	1	100%	1.0
	SE Pt.	2	0	0%	
	W. Pinnacles	0	0		
	Lulu Bay	27	5	19%	2.0
	All Sites	41	6	15%	2.0

Based on these surveys, the prevalence of *Coralliophila abbreviata* was not statistically different between sites ($p=0.56$, $n=12$) or hosts ($p=0.71$, $n=33$) due to the small sample size ($n=2$ transects at each site). Also, both *Montastraea annularis* and *Diploria* spp. were rare along

transects (compared to *Agaricia* spp. – Table 1) resulting in variability that likely confounded comparisons between hosts (Figure 1). Regardless, the relatively high infestation of the rarer host taxa (i.e. *Diploria* spp. and *Montastraea* spp.) while the numerically dominant *Agaricia* spp. showed a substantially lower infestation (Table 1) suggests that some level of host preference is being expressed by these predators.

Similarly, the number of snails per infested colony (group size) was not statistically different among hosts ($p=0.061$, $n=30$) (Figure 2), though the variability and small sample size (30 colonies) may obscure differences. For example, the ‘East Side’ site had one *Agaricia* spp. colony with 15 snails compared to 1 to 2 snails typically found on this host. This may simply represent an outlier. The ‘East Side’ site was, however, characterized by low coral density (Table 1) and the average number of snails on an infested colony was greater. This pattern suggests that these predators may aggregate in response to low host density.

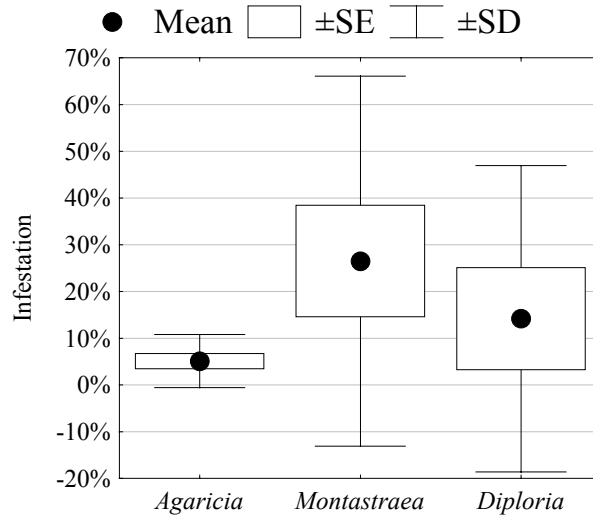


Figure 1. Infestation (% host colonies infested) among *Agaricia* spp., *Montastraea annularis* and *Diploria* spp. colonies (sites pooled).

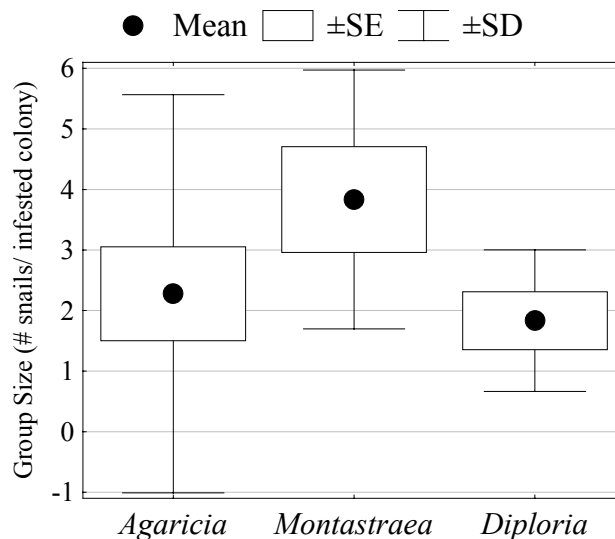


Figure 2. Number of snails per infested host coral colony encountered during transect surveys. (all sites pooled).

Haphazard Predator Sampling

Mean snail size (length) compared between all identified host species of a given genus was not significantly different among species of *Montastraea* (annularis complex) (Kolomogorov-Smirnov, $p > 0.1$, $n = 49$) or *Diploria* (Kruskal-Wallis, $p = 0.82$, $n = 39$) but was significantly different among species of *Acropora* (Kolomogorov-smirnov, $p < 0.05$, $n = 103$). Thus snail size was compared between *Montastraea*, *Diploria*, *Agaricia*, *A. cervicornis* and *A. palmata* and found to be significantly different (Kruskal-Wallis, $p \leq 0.0001$, $n = 261$) (Figure 3). Pair-wise comparisons (Conover 1980) revealed that the mean size is significantly different between all host pairs except *Diploria* and *Montastraea*. Snails found on *Agaricia* spp. were the smallest while those found on *A. palmata* were the largest. Snails found on *A. cervicornis* were significantly smaller than those found on *A. palmata* but still larger than those found on the other hosts.

Sex ratios (Table 2) and the size frequency distributions (Figure 4a-e) for each sex were also calculated for each host (grouped at the generic level as in first analysis). The percentage of the population composed of females ranged between 22-34%, however these results are complicated by the NP designation, particularly in *Agaricia*.

Table 2. Sex ratios of snails collected from each host.

	Female	Male	NP	Total N
<i>Agaricia</i>	1.0	1.4	0.5	68
<i>Montastraea</i>	1.0	1.9	0.1	48
<i>Diploria</i>	1.0	2.7		37
<i>A. cervicornis</i>	1.0	3.5		18
<i>A. palmata</i>	1.0	2.5		85

Size differences between male and female snails were compared non-parametrically using a Kruskal-Wallis ANOVA for *Agaricia* and a Kolomogorov-Smirnov test for other hosts. Male snails are significantly ($p < 0.05$) smaller than females from all hosts except *A. cervicornis* from which males were smaller but not significantly ($p > 0.1$). Additionally, 'NP' snails from *Agaricia* were significantly smaller than males (Figure 5).

The number of snails per colony (group size) was also compared between hosts (Figure 6) using a Kruskal-Wallis ANOVA, which found significant differences in group size ($P < 0.0001$). Pair-wise comparisons revealed significant differences in all pairs except *Montastraea* versus *Diploria*, and *Acropora palmata* had significantly higher numbers per colony than all others. Snails collected from *A. cervicornis* were not included in this analysis because they were collected from a small thicket where colonies could not be distinguished, however these snails were typically observed alone or in pairs during collection. Additionally, for various group sizes the sex frequencies and median sizes were calculated (Table 3). However, it should be noted that the pattern of sex frequency with group size depicted in Table 3 is confounded by host taxa in that large groups were only found on *A. palmata*.

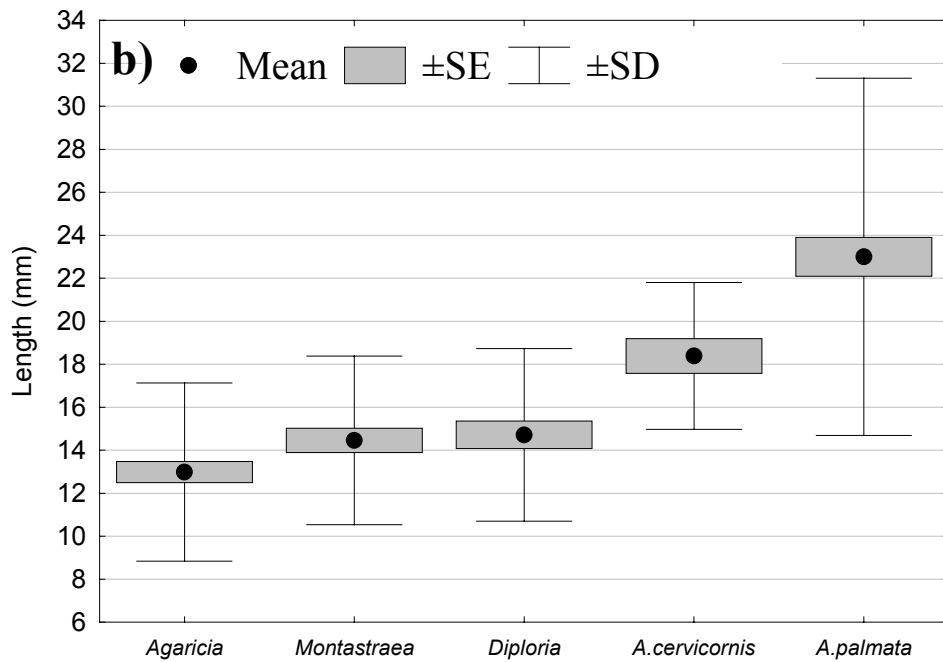
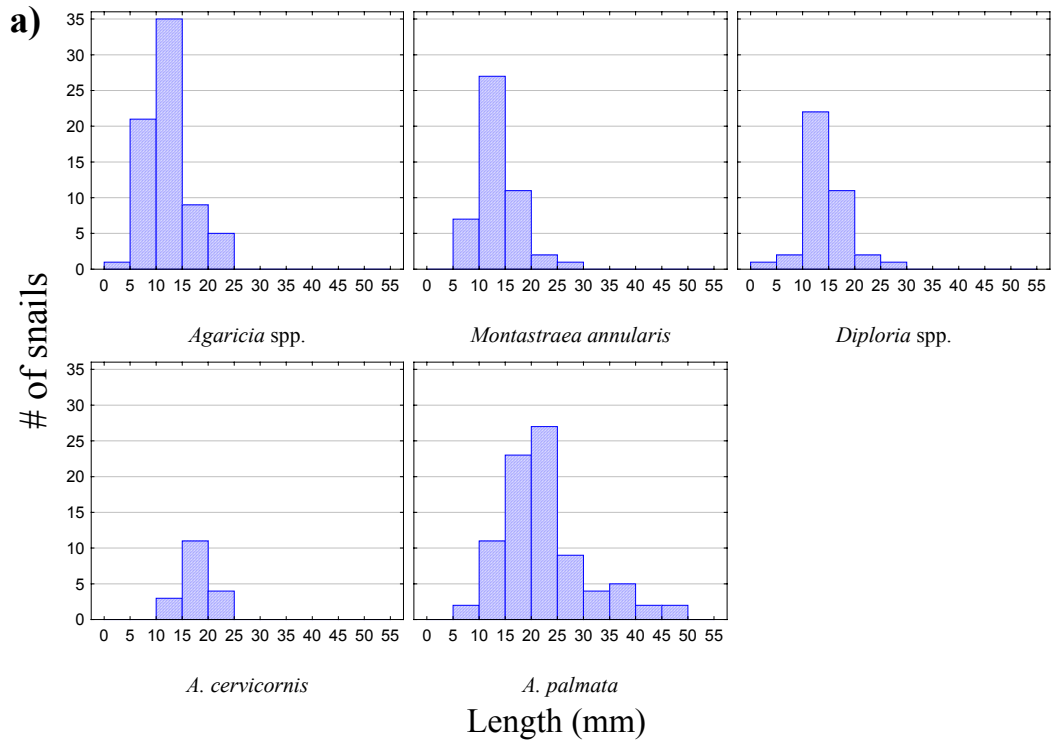


Figure 3. (a) Size-frequency distributions of snails found on various hosts; (b) box-whisker plot showing the mean, SE and SD for snails collected from various coral hosts.

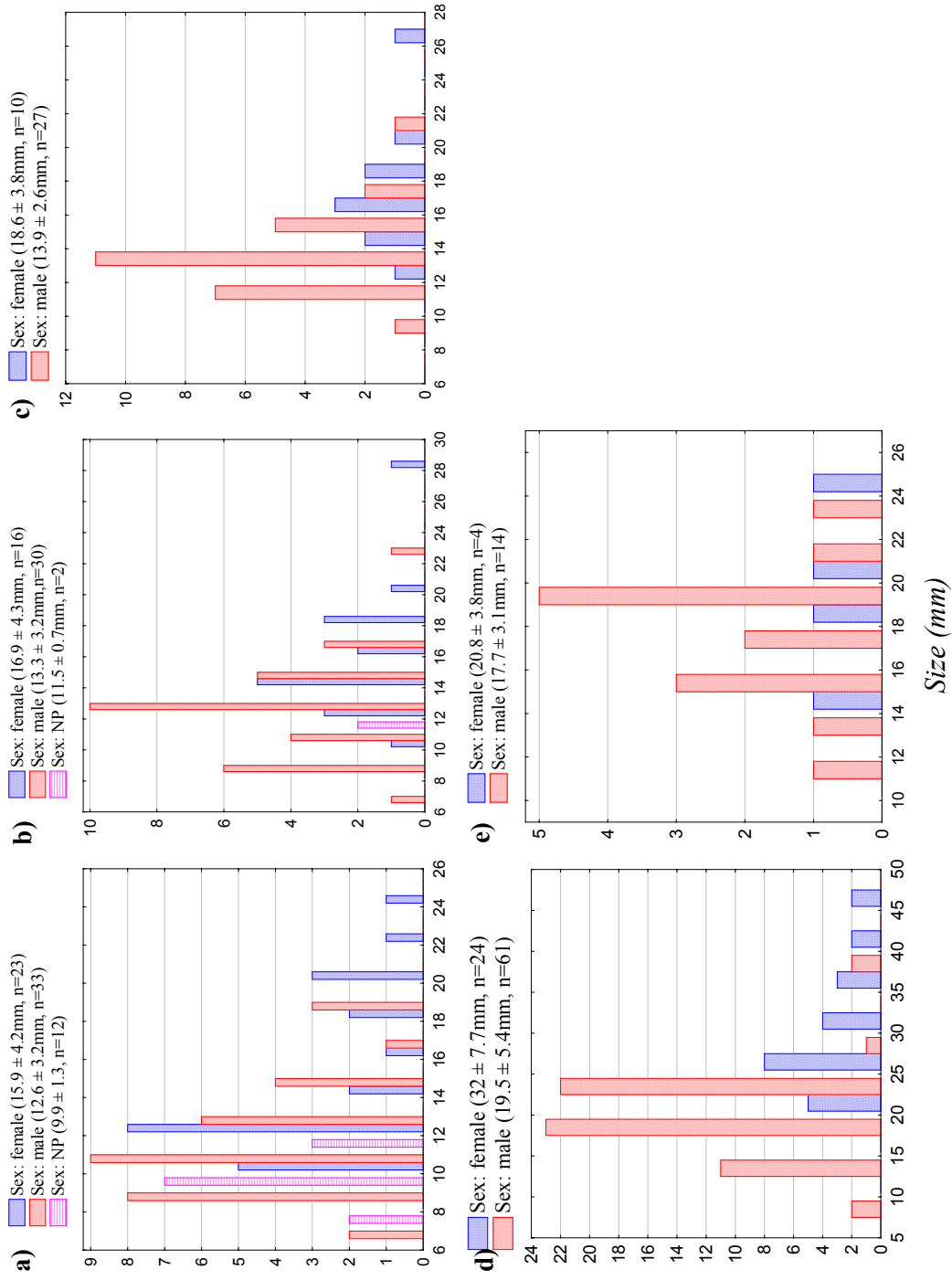


Figure 4. Size-frequency distributions of male, female and 'NP' snails collected from a) *Agaricia* spp., b) *Montastraea annularis* (complex), c) *Diploria* spp., d) *Acropora palmata* and e) *Acropora cervicornis*. Mean \pm standard deviation and number in sample included in legend.

Table 3. Group (collected from same colony) sizes of snails along with sex-frequency and median shell length for each group size. N depicts the number of snails found in the given group size.

Group size	Female	Male	NP	Median length	N
1	39%	44%	11%	13.5	18
2	21%	50%	21%	13	24
3	25%	75%	0%	13.5	12
4	42%	50%	8%	15.5	12
5	40%	60%	0%	15.5	10
6-10	39%	59%	2%	14	41
11-20	26%	72%	0%	19	43
>21	23%	77%	0%	22	35

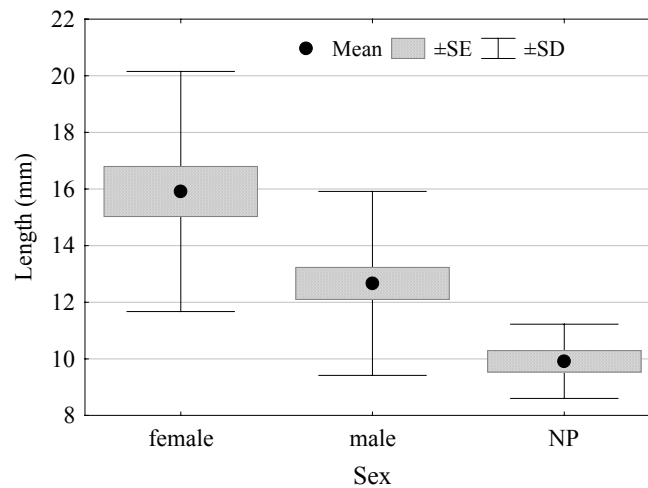


Figure 5. Mean size of snails grouped by sex collected from haphazardly sampled *Agaricia* spp. hosts.

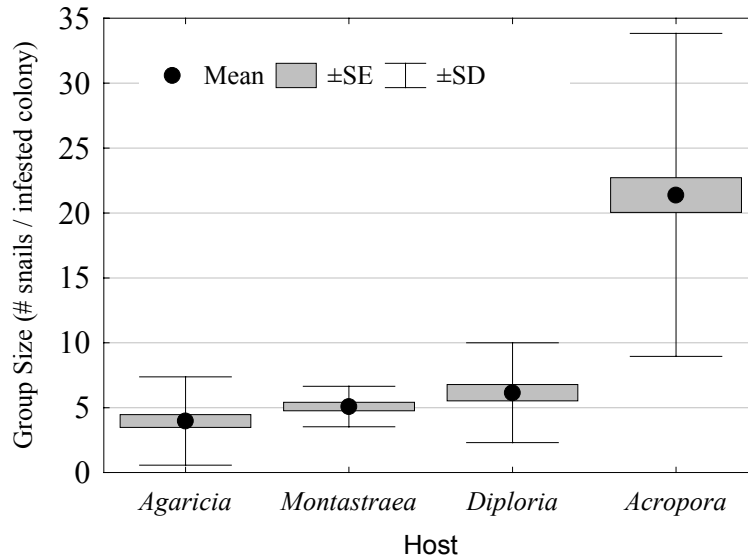


Figure 6. Group (found on same colony) size of snails found on each haphazardly sampled coral host.

Discussion

Coralliophila abbreviata population structure sampled from Navassa Island mimics trends documented elsewhere (Table 4): snails found feeding on *Acropora* spp. were larger than those feeding on massive or sheeting corals (Brawley & Adey 1982, Hayes 1990, Bruckner et al. 1997, Miller et al. 2001, Baums et al. 2003); snails found feeding on *A. cervicornis* were smaller than those on *A. palmata* (authors unpubl. observation), and males were smaller than females (Wells & Lalli, 1977, Bruckner et al. 1997).

Coralliophila abbreviata displays a clear sexual size dimorphism that is shown here (Figure 4) and consistently in other similar surveys (Wells & Lalli 1977, Hayes 1990, Bruckner 1997, Baums et al. 2003): males are significantly smaller than females. This trend is consistent with the hypothesis that *C. abbreviata* is a protandrous hermaphrodite (Hayes 1989 and Baums et al. in press). This trait has not been clearly demonstrated for *C. abbreviata* but is documented in *C. violacea* (Chen et al. 1998), which has a very similar population structure (Soong & Chen 1991). If *C. abbreviata* are protandrous hermaphrodites, there is clearly a great deal of plasticity in the onset of sex change as the smaller size distribution of snails on a given host does not coincide with a higher male proportion on that host and the size distributions of males and females differ substantially among host taxa (Table 4, Figure 4). For example, mean female size on *Montastraea* hosts are usually smaller than mean male size on *A. palmata* hosts (Table 4).

The female to male ratio reported from other surveys has varied, even within a given coral host, from 1:1 to 1:3 (Wells & Lalli, 1977, Hayes 1990, Bruckner et al. 1997, Baums et al. in press) though this survey found it to be between 2 to 3.5 males per female (Table 2) except for *Agaricia* which had 1.4 males per female due to the prevalence ‘NP’ snails.

Snails designated ‘NP’ (no penis) were small and could represent males with a penis that was simply difficult to locate due to the small body size and damage done when opening the shell. However these individuals were largely found on *Agaricia* hosts (85%) and, given that *Agaricia* seems to be selected against as a host taxa (Table 1, Rylaarsdam 1983), it is plausible that *Agaricia* is nutritionally poorer and results in delayed maturation. These NP individuals may be simply immature; in addition to their small size their tissue was more translucent than

others in their size range. Snail occurrence on *Agaricia* around Navassa could simply reflect the sheer abundance of *Agaricia* relative to other prey corals [Table 1].

Table 4. Summary of mean snail lengths in mm (std. dev.) from Navassa and other locations sampled in 2002 (Baums et. al. in prep).

Region	Whole population		<i>A. palmata</i>		<i>M. annularis</i>	
	<i>A. palmata</i>	<i>M. annularis</i>	Female	Male	Female	Male
Florida Keys	24.9 (7.4)	16.6 (4.5)	-----	-----	-----	-----
Bahamas- LSI	20.5 (5.6)	13.9 (3.6)	24.8 (4.8)	17.6 (4.2)	16.6 (2.8)	12.5 (2.9)
Bahamas- ELSP	19.7 (5.2)	15.3 (3.4)	24.5 (4.6)	17.9 (4.2)	17.3 (2.4)	14.92 (3.0)
Navassa	23.0 (8.3)	14.5 (3.9)	32.0 (7.7)	19.5 (5.4)	16.9 (4.3)	13.3 (3.2)
Curacao**	21.5 (5.4)	15.7 (3.2)	30.0 (5.4)*	20.3 (3.6)	18.0 (2.9)	13.8 (1.6)
Bonaire**	22.2 (4.2)	18.3 (2.3)	23.9 (5.3)*	22.2 (4.7)	19.2 (2.5)*	17.1 (1.7)*

* very small sample (n ≤ 6), ** Data from Baums et al. (2003)

Coralliophila abbreviata can often be found in pairs or aggregations (Hayes 1990, auth. unpubl. obs.), presumably for mating purposes, as they are believed to mate nearly year-round (Wells & Lalli 1977). Their tendency to aggregate on a single colony was greater in *A. palmata* than on other hosts, which, coupled with the faster tissue consumption on *Acropora palmata*, may produce larger lesions. When standardized for area, larger lesions are slower and less likely to heal than smaller more numerous lesions (Lirman 2000). *Acropora palmata*'s relatively fast growth may counteract this damage in most cases, however a group of 35 snails is likely to do irreparable damage (Figure 7).



Figure 7. Feeding scar (lesion) left by a group of 35 *Coralliophila abbreviata*. Photo taken after snails were collected from the thin white margin of the lesion (one snail is visible at arrow).

The sex frequency for each group size was calculated specifically to determine if ‘single’ snails were more likely to be male compared to snails in larger groups. This might be expected if sex change from male to female were triggered by social factors such as the sex of a neighbor as it is in *C. violacea* (Chen et al. 1998). This pattern was not detected here as 39% of singles were female. However, it is unclear how far members of an aggregation might ‘wander’ or in other words, how far the “neighborhood” of a given snail might reach. In the current study all snails on a coral head were considered a group and this may not be appropriate. Furthermore, females that are alone may simply not be receptive to mating.

Chapter 9: Symbiont-bearing Foraminifera of Navassa Island

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Introduction

Benthic (or ‘larger’) foraminifera are protists with a calcite test (internal shell) that harbor algal symbionts. They contribute to reef sediments and have many of the same requirements as corals and can therefore indicate a habitat’s suitability for corals (Hallock 2000). Reef dwelling taxa are represented by two major suborders Miliolina and Rotaliina. Miliolid foraminifera have thicker porcelaneous tests and require more light than the Rotaliid foraminifera, which have highly transparent hyaline tests and require minimal light (Sen Gupta 1999). In fact, laboratory experiments have revealed that *Amphistegina* spp., a rotaliid foraminifer with diatom endosymbionts can tolerate only very low light levels, exhibiting bleaching stress in excess light (Hallock 1981 Hallock et al. 1986, Williams 2002).

Since 1991 *Amphistegina* spp. worldwide have displayed bleaching symptoms (Hallock 2000), which are believed to be associated with exposure to stressful intensities of solar radiation (Hallock et al. 1994, 1995, Williams 2002). Bleaching was first observed in the Florida Keys among populations of *Amphistegina gibbosa*, the western Atlantic species; these populations were monitored from 1992 through 1999. In addition to bleaching, these stressed populations of *A. gibbosa* also experienced compromised reproduction (Williams 2002) and increased breakage (Toler 2002).

Reproduction in *A. gibbosa* typically consists of a bi-phasic, semelparous life cycle with the asexual reproduction phase taking place in late spring or early summer. The parent’s cytoplasm (including symbionts) divides (mitosis) to produce 300-600 (0.05mm) recruits. These individuals grow to 1.0 - 1.5 mm by late fall when they undergo the gametogenesis phase, broadcast their gametes and die. Recruitment from sexual reproduction is much lower than from asexual reproduction (Harney et al. 1998). Stressed populations have been found to skip the sexual phase and undergo repeated asexual reproduction (Harney et al. 1998), presumably in an attempt to increase recruitment. However, the stressed population in the Florida Keys showed signs of reduced recruitment from asexual reproduction (Williams 2002).

Prior to the 1991 onset of bleaching, test breakage was found to affect 5% of the population. Following the onset of bleaching in 1991, 20% of the population was broken. Toler (2002) suggested that breakage increased because stressed individuals were behaviorally and/or physically more susceptible to predation.

Symbiont-bearing foraminifera from Navassa Island were sampled and assessed following the protocol used the Florida Keys monitoring project so that comparisons to the Florida Keys populations could be made. Particular attention was paid to *Amphistegina gibbosa* (Figure 1).

Methods

Fist-sized pieces (5 to 10) of reef rubble were collected from reef habitat at 8m, 15m and 38m depth. The rubble was scrubbed with a small brush to remove sediment, algae and associated foraminifera. This sediment was then examined under the microscope to identify the taxa that were present along with approximate population abundance of selected species.

All *Amphistegina gibbosa* were picked out of the sediment, and counted. A subsample of approximately 200 were measured and assessed for their degree of visible symbiont loss (normal, mottled or bleached) and shell breakage (Figure 2). Population density was calculated using the total number of individuals standardized to rubble area, which was estimated by tracing the rubble and calculating the area.

Results & Discussion

All taxa surveyed as part of the Florida Keys Monitoring Project were also found in samples from Navassa Island (Table 1). Additionally, several not formally surveyed but still present in the Florida Keys were also found including: *Triloculina* spp., *Quinqueloculina* spp., *Pyrgo* sp., *Discorbis* sp., and *Elphidium* sp.

Table 1. Abundance of forams from Navassa Island. List of taxa surveyed was the same as that examined in the Florida Keys Monitoring Project. Note the figure numbers for photos of selected specimens.

Taxa	8m	15m	38m
<i>Amphistegina gibbosa</i> (Figure 1, 2)	171	1089	1719
<i>Asterigerina carinata</i>	16	5	8
<i>Heterostegina antillarum</i> (Figure 3)	3	0	22
<i>Archias angulatus</i> (Figure 4)	1	18	0
<i>Cyclorbiculina compressus</i> (Figure 4)	0	24	86
<i>Broekina orbitolitoides</i> (Figure 4)	0	3	57
<i>Laevipeneroplis bradyi</i>	1	0	0
<i>Laevipeneroplis proteus</i>	0	0	20
<i>Sorites marginalis</i> (Figure 5)	31	57	23
<i>Peneroplis pertusus</i>	0	0	11
<i>Borelis pulchra</i>	3	8	4
<i>Gypsina</i> sp.	0	0	1
Rubble Area Sampled (cm ²)	294	240	416

Amphistegina gibbosa population densities from 15 and 38m were similar to those expected in healthy populations while the low density population found at 8m appears to be a stressed population at the shallow extent of its depth range. Furthermore, many individuals from 38m had recently undergone gametogenesis (also a sign of a healthy population), which may have significantly reduced the density in this sample. Recent reproduction does not however explain the low density in the 8m population since empty tests were absent from this sample. Further, the size frequency distribution (Figure 6) from the 8m sample is consistent with a population that is undergoing successive asexual reproductive phases; very small juveniles (<0.5mm) were relatively more abundant in the sample and there were few larger (≥ 1.1 mm) individuals (Table 2). These very small juveniles are lacking in the 15m and 38m samples which both appear to have produced a cohort in mid to late summer. The lack of larger individuals at 38m and the abundance of empty tests indicate recent gametogenesis while the lack of empty tests and abundance of larger individuals at 15m suggests imminent reproduction. The samples

were not formally monitored for reproduction; however, one month after the initial counts the larger individuals from 15m had apparently undergone gametogenesis supporting this interpretation.

Bleaching was found in all three populations sampled and was comparable to bleaching seen during winter in Florida Keys populations (Table 2, Williams 1997, Williams 2002). However, winter sampling in the Florida Keys likely occurred after the fall reproductive event when bleaching would have been at its lowest while these samples appear to have been collected in the midst of a reproductive event and before bleaching has dropped to its lowest (many individuals that bleached in the summer have not yet reproduced and are therefore still in the population).

Breakage (Table 2, Figure 2) among these populations also appears to be comparable to the Florida Keys populations. Without replicate samples it is impossible to evaluate the significance of this highly variable symptom, though conservatively it can be stated that breakage is elevated in this population compared to the numerous populations of *Amphistegina* spp. studied prior to 1991 (Hallock et al. 1995, Toler et al. 1998, Toler 2002).

Table 2. Key population parameters for *Amphistegina gibbosa* collected from Navassa Island.

Parameter	8m	15m	38m
Density (#/cm ²)	0.6	4.5	4.1
% Bleached	33	25	24
% 'Recovering'	2	9	12
% Broken	25	11	20
% Juvenile (<0.5mm)	21	6	17
Average diameter	0.72	0.88	0.67
% ≥ 1.1mm	15	28	9

Notable observations of the *Amphistegina gibbosa* populations include:

1. Samples from 15 and 38m yielded high abundances (>4/cm²) indicating a generally healthy (reproductively successful) population.
2. Bleaching symptoms affected between 23 and 33% of the population which is comparable to winter bleaching among Florida Keys populations (20-25%).

In summary, the assemblage present at Navassa Island is fairly typical of Caribbean reef foraminifera with evidence of extended depth ranges: *Cyclorbiculina compressus* living in moderate abundance at 38m, deeper than its typical range (abundances decline dramatically beyond 15m in Florida Keys populations). Populations are relatively abundant and healthy except for sub-lethal bleaching in *Amphistegina gibbosa*, which is also typical throughout the Caribbean.

Acknowledgements

I would like to thank Dr. Hallock Muller of the College of Marine Science, University of South Florida for access to much needed laboratory equipment, microscope and camera.



Figure 1. Healthy *Amphistegina gibbosa* (bar =0.5mm).

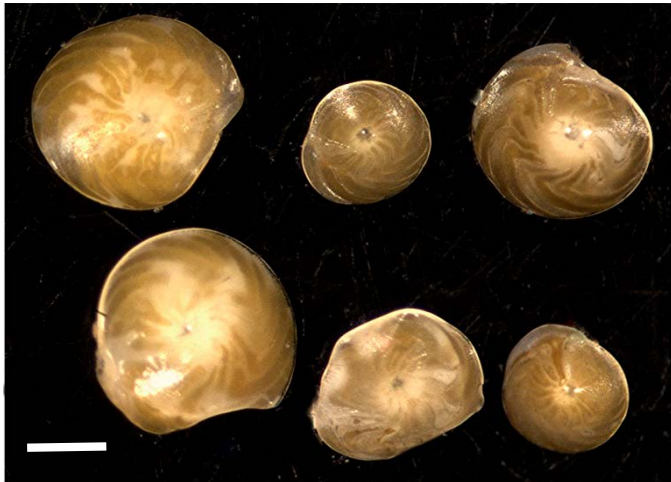


Figure 2. *Amphistegina gibbosa* collected from 38m; healthy, mottled and broken individuals shown (bar=0.5mm).



Figure 3. *Heterostegina depressa* collected from 38m (bar = 0.05mm).

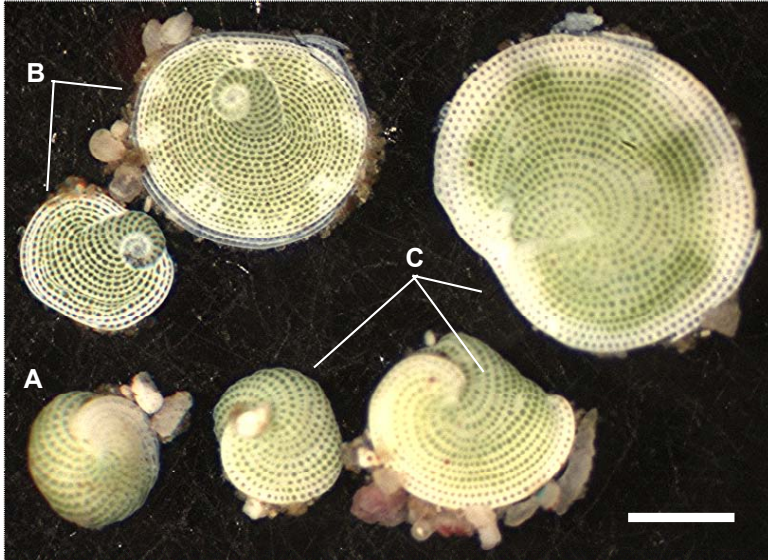


Figure 4. Some Miliolid foraminifera with Chlorophyte endosymbionts from 15m and 38m (bar=0.5mm); A) *Archaias angulatus*, B) *Broekina orbitolitoides*, C) *Cyclorbiculina compressus*.



Figure 5. *Sorites marginalis* from 38m (bar=0.5mm).

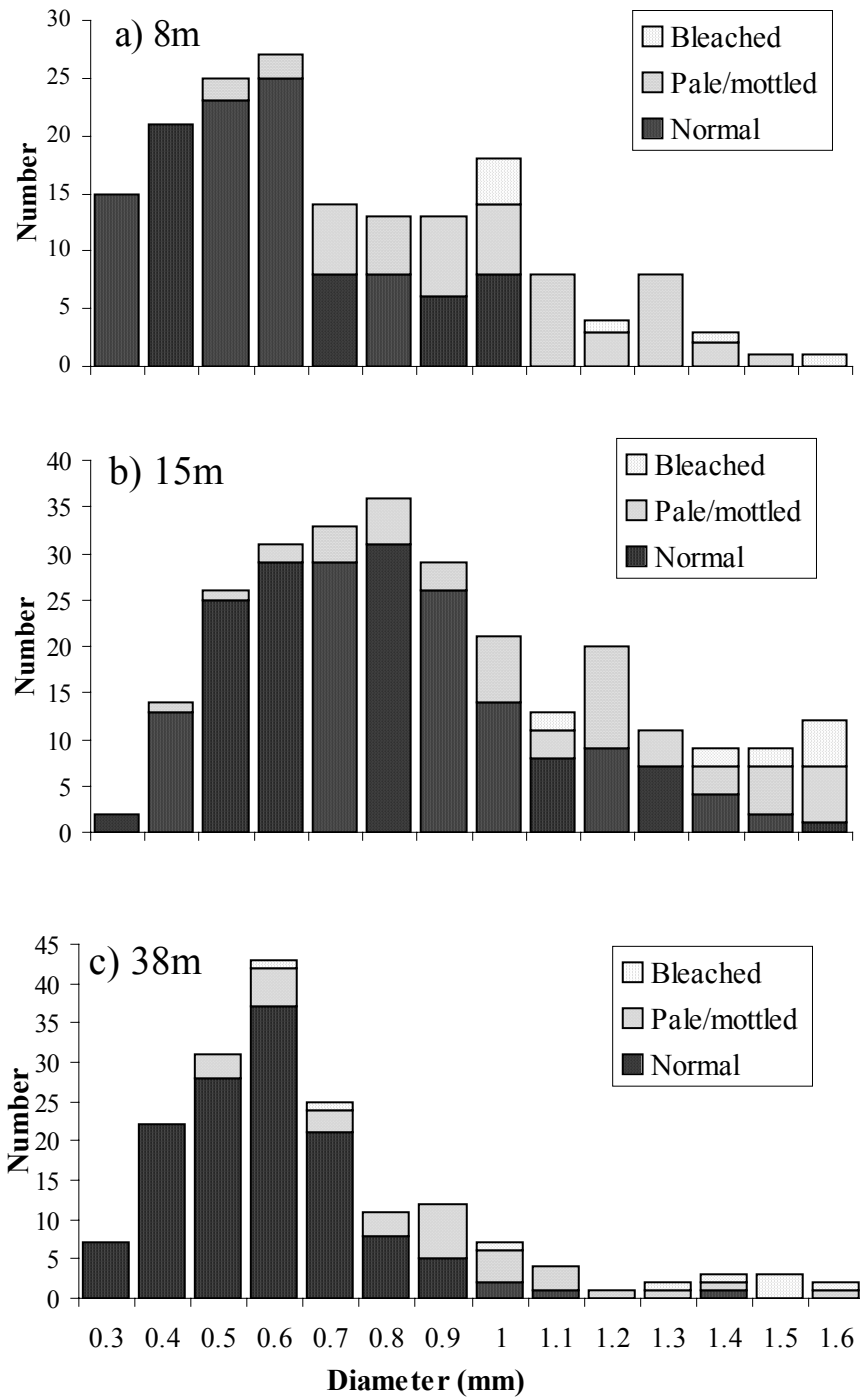


Figure 6. Size-frequency distributions from a) 8m, b) 15m and c) 38m partitioned by degree of bleaching.

Chapter 10: Observations on fisheries activity at Navassa Island, Caribbean Islands National Wildlife Refuge, November 2002

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Abstract

Unmanaged and unquantified artisanal fishing is ongoing at Navassa Island, a small oceanic island ~40 miles west of Haiti. Concern has been expressed regarding the possible impact of these fishing activities on reef resources and no quantitative catch or effort data is available. However, informal qualitative observations made during a cruise in November 2002 suggest that escalation in fishing activity (and impact) has occurred since previous observations made in Apr 2000. Namely, size structure of fish was markedly reduced and the adoption of net fishing has allowed the novel exploitation of conch (*Strombas gigas*) and hawksbill turtles (*Eretmochelys imbricata*).

Introduction

Despite extremely high rates of primary production, net yield is relatively low in coral reef fisheries. The ecological complexity, richness, and specialized life histories of coral reef organisms and communities make them particularly susceptible to overexploitation (summarized by Birkeland 1997). Results of such overexploitation in Caribbean islands are seen in drastic documented declines in catch-per-unit-effort, size structure, and/or species shifts in the fisheries of Jamaica, Grenada, the USVI, and others (Koslow et al. 1988, Jeffery 2000, Rogers and Beets 2001). Indeed, subsistence fishing to support a single family has been described as impacting target populations on the scale of a whole bay in the US Virgin Islands (Coblentz 1997).

Navassa is a small island and, although claimed by the US as part of the Caribbean Islands National Wildlife Refuge, sovereignty is disputed by Haiti. Due to its isolation, uninhabited status (except for squatters), and some preliminary quantitative visual fish census work Navassa has been described as displaying a *relatively* pristine reef community (Anonymous 2000, Grace et al. 2000, Miller and Gerstner 2002). However, this interpretation has also been questioned due to the observation of ongoing fishing activity by migrant Haitians, the complete

lack of quantitative information regarding the intensity of this fishing activity, and the potential for its rapid escalation (Collette et al. 2003, Grace et al. 2000, Miller and Gerstner 2002)

Navassa is ~ 5km² in area and is comprised of a raised plateau surrounded by cliffs which reach down to a submarine terrace at 23-30m depth. The primary fishery habitats are reef walls formed by the cliffs and large boulders (or “calves” as analogous to the chunks that fall off of icebergs) that have been dislodged from the cliffs, scattered patch reefs and hardbottom areas on the 25-30m terrace and deeper reef slopes at shelves (>30m) farther offshore that have not been well described. Navassa’s oceanic position in the Windward Passage exposes it to substantial physical energy. The east coast, particularly, bears the brunt of persistent swells and, seemingly, regular storms and hurricanes. Inshore and backreef habitats, which are important in the life history of several reef fish groups, are largely absent at Navassa.

Despite its status as a National Wildlife Refuge, regulations are not enforced and fisheries at Navassa are unmanaged. Fishing activities are, however, undertaken by migrant Haitian subsistence fishers and these activities appear to have been ongoing since at least the 1970's. Anecdotal observations from a previous NMFS expedition¹ report 5 Haitians fishing out of a 14 foot sailboat along the north/northwest coast and “catching only small grunts and one small barracuda”. Other anecdotal accounts suggest that some technological escalation in this fishery had occurred between scientific expeditions which had occurred in 1997 and 2000 in that no motors were observed in 1997, while all the vessels observed during a 2000 expedition had 10-15 hp motors (Anonymous 2000, pers obs).

Quantification of catch or effort has not been undertaken for the fisheries at Navassa, though 1-4 small boats per day were observed trap and handline fishing during the 2000 expedition (Miller and Gerstner 2002). Because of this complete lack of quantitative fisheries information, and inadequate quantification of reef fish status (particularly in the recent past) the impact of these ongoing subsistence fisheries is difficult to assess. Underwater visual transect census conducted in the western nearshore reef habitats in 2000 reported moderate to high density of large reef fishes (including snappers, groupers and parrotfishes), suggesting minimal fishery impact in these nearshore habitats (Miller and Gerstner 2002) though other reports suggest that large fishes had already been greatly reduced at least in the northwest (Collette et al.

¹ Miller GC (1977, Unpubl.). Cruise results for Oregon II 77-08 (80), Navassa Island resource assesment survey. 12 p. NMFS, SEFSC, Miami, FL.

2003). Miller and Gerstner (2002) also suggested that strong socioeconomic “push” factors in Haiti made it likely that fishing intensity and impact at Navassa would increase, possibly rapidly and it is well known that reef communities can be overfished very rapidly (e.g. Coblenz 1997).

There are many definitions of overfishing, most of which are not evaluable in the absence of quantitative fisheries statistics (e.g. growth overfishing, Malthusian overfishing). However, qualitative fisheries information can be suggestive of patterns indicating, for example, serial overfishing, (i.e., a progression where the largest most vulnerable species are removed first, followed by a series of shifts to smaller, less-desirable targets as each is depleted). For Navassa Island, such qualitative observations are all that are available, and the following descriptions are offered as indicative of such a pattern.

Methods

Observations were made at Navassa Island from 29 October - 8 November 2002 based aboard the R/V Coral Reef II. The primary objective of the expedition was in-water assessment of reef condition (both benthic and fish assemblages). Fishery observations were opportunistic. Each day, note was made of how many fishing boats were present at Navassa. In addition, direct interviews and observations were made with three different boats on different occasions. A small boat from the R/V Coral Reef II was used to approach a Haitian fishing boat and engage its occupants in conversation. The interviews were conducted in French and designed to obtain information directly from the fishers on their fishing practices. Also, the interviews afforded opportunity to observe directly the catch (species and approximate amounts and sizes) that was visible in each boat, though thorough unpacking or exact measurements were not undertaken.

Results/Observations

Boat presence and characteristics:

Upon arrival on 29 October, one expansion of fishing activity impact (since the observations in April 2000) was immediately apparent: the presence of an extensive temporary mooring system in the relative shelter of Lulu Bay with four fishing boats moored here. Moorings consisted of bottle floats tied to a large rock anchor (Figure A) on the bottom to hold the sterns while the bows of the boats were secured with lines to the island cliff. These four boats were present for the next two days, but apparently all left on the morning of 1 November.

A new group of boats began arriving on 5 November and four boats were again present at the end of our observations.

The open boats are wooden, approximately 20 - 30 ft in length. One of the boats we observed was powered only by sail and paddles (Figure B), but the rest had 10-15 hp outboard motors (Figure C). The motors are used only intermittently to conserve fuel and several fishers told us that they had run out of fuel (and would be sailing home). One of the interviewed boats had an ice box for keeping catch, but the rest did not. Fishers were observed smoking and salting fish both in their boats and on the island. Fishing boats had between 3 and 6 persons aboard with 4 being the mode.

Fishing practices

Three boat crews were interviewed and gave consistent information regarding their fishing practices. They travel from Haiti for 8-10 day trips (~ 1 day crossing each way), navigating by the sky (sun/stars). They indicated that they did not fish in any other areas, either in Haiti or in transit. One crew indicated that there were 10 boats from a single Haitian village that fish Navassa in groups of four boats at a time (consistent with our direct observation). One crew also indicated that they ceased trips for some seasonal periods (“after November”) but this is not clear.

Fishing activities were concentrated on the more protected southwest coast terrace and involved hand lines, traps, and nets. No in-water fishing activities were observed, nor any tendency for the fishers to swim, with the exception of a direct transit from one boat to another. The traps used are standard Antillean Z- traps constructed of bamboo with 3-4 cm mesh size (Figure D). The bamboo is most likely transported to Navassa and construction of the traps takes place on site as the finished traps were larger than the beam of the boats. Hand lines were monofilament rigged with 2-4 small hooks and a small rock tied to the bottom for weight. Bait was anything not consumed; sand tilefish was most commonly observed being cut up for bait. Nets were some sort of entangling net such as a trammel, trawl, or purse, but we did not directly observe the practice of net use.

Observations on catch

A diverse array of taxa appeared in the fishers’ catch, as observed in their boats and in

underwater refuse piles at the mooring site at Lulu Bay (Table 1, Figure E-G). The dominant species observed in the catch were conch, ocean triggerfish, schoolmaster snapper, and bar jacks. Other common taxa included juvenile hawksbill turtles, spiny lobster, yellow stingrays, squirrelfish, surgeonfish, trunkfish, and black durgions. Some snapper and red hind were observed, but most were smaller than 30 cm and many were less than 20 cm. Only one parrotfish was observed.

Discussion

Several qualitative differences in the fisheries activities at Navassa Island were noted between the expeditions in April 2000 and November 2002. First, the use of nets was not observed in 2000. Fisheries studies in Papua New Guinea have found a pattern of adoption and increased reliance on net fishing (compared to spearfishing, hook and line and traps) as larger fishes are depleted (Locke 1986). Thus it is plausible to interpret this observed shift in Navassa fishing activity as an indicator of depletion. A more direct indicator of depletion is the qualitative observation of relative finfish sizes between the two sets of observations. Large red-colored snapper was observed in the catch in 2000 (>40cm) while the vast majority of caught fish observed in 2002 (excluding barracuda) were less than 30 cm. This small size structure of the reef fish assemblage at Navassa is also born out in extensive reef fish visual censuses conducted during the expedition (Chapter 4).

The adoption of net fishing appears to have great impacts on the nature of the catch, allowing the exploitation of novel targets. Fishers reported that both conch and turtles were caught by net, and this report is consistent with direct observation in 2000 (MWMiller, pers obs) when neither net fishing nor conch and turtle harvest were observed. In contrast to the finfish catch, the abundant conch catch observed in 2002 was composed of large, mature animals (25-30cm TL), suggesting that conch exploitation is in the early phases. While hawksbill turtles were not large, it is likely that Navassa serves as a juvenile habitat similar to other offshore islands in the Caribbean such as Buck Island (St. Croix, USVI) or Mona Island (Puerto Rico). We observed ~8 captured hawksbill turtles and a total of <10 live hawksbill turtles in the water (over 300 person dives). Evidence that turtle harvest is ongoing was observed in the underwater trash piles at Lulu Bay where numerous piles of turtle bones/plates were observed, but no carapaces, which are likely returned to Haiti for the curio trade (Figure I).

The actual method by which conch are harvested with nets is not clear and we did not directly observe net fishing activities. Shallow coastal habitats are absent at Navassa and the only conch habitat is on an interspersed sand/patch reef terrace surrounding the island at 25-30m depth (Figure J). It is not clear how these small boats tow nets in a way to snag conch from such a depth. Conch are captured by fish traps off south Florida (Sutherland and Harper 1983). However, the fish traps we observed at Navassa did not appear to have openings that would accommodate the size of conch we observed in the fishing boats. It is hypothesized that the nets are baited and laid horizontally on the substrate for a period of time to attract foraging conch and fishes onto the net before being hauled to the surface (i.e. trammel netting).

Ruddle (1996) notes that the intensity of reef fisheries is often determined by the availability of alternative economic activities or employment outside the fisheries sector. The gloomy economic condition in Haiti may thus imply that fishery exploitation at Navassa is bound to increase. The current paper adds to a mounting information base of qualitative observations regarding fishing activities at Navassa which, though not adequate for clear documentation of the fishing regime, represents the only insight available. Although quantitative analysis is precluded by the lack of historical populations estimates, comparison with recent observations in a protected marine reserve at Little Cayman Island in December 2002 shows much greater snapper and grouper sizes than observed at Navassa (McClellan, pers obs). Smaller grouper such as coney and graysby are now targeted by Haitian fishers. If local stocks are necessary for repopulating these fishes, it is likely that the vast majority of settling juveniles are caught before they reach sexual maturity. It is also highly likely that substantial shifts in species composition have already occurred in the Navassa fishery.

These observed patterns (reduced abundance and size structure of highly desirable target stocks such as snapper and grouper coupled with novel exploitation of new stocks with novel gear such as conch with nets) are consistent with expectations under a scenario of serial overfishing. Hence, any future attempts at fishery management or regulation for Navassa need to take into account the likelihood of an already-shifted baseline.

Concerted effort must be applied to collecting quantitative catch and effort data. Such fishery information is a pre-requisite for beginning to think about a possible fishery management strategy for Navassa or for understanding the relationship between fishing pressure and reef status.

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Table 1: Summary of taxa in the catch that was exposed and visible in Haitian fishing boats observed at Navassa Island, 29 Oct - 9 Nov 2002. Relative abundance is scored as O(ne), F(ew, <10), or M(any, 10-100)

Taxa		Rel Abundance
Spiny Lobster	<i>Panulirus argus</i>	F
Hawksbill Turtle	<i>Eretmochelys imbricata</i>	F
Black Durgeon	<i>Melichthys niger</i>	F
Yellow Stingray	<i>Urobatis jamaicensis</i>	F
Scrawled Filefish	<i>Aluterus scriptus</i>	F
Schoolmaster	<i>Lutjanus apodus</i>	F
Sand Tilefish	<i>Malacanthus plumieri</i>	F
Snapper sp.		F
Great Barracuda	<i>Sphyraena barracuda</i>	F
Squirrelfish	<i>Holocentrus sp.</i>	F
Queen Conch	<i>Strombas gigas</i>	M
Trunkfish	<i>Acanthostracion quadricornis</i>	M
Ocean Trigger	<i>Canthidermis sufflamen</i>	M
Surgeonfish sp.		M
Bar Jack	<i>Carangoides ruber</i>	M
Stoplight Parrot	<i>Sparisoma viride</i>	O
Queen Trigger	<i>Balistes vetula</i>	O
Atlantic Stingray	<i>Dasyatis sabina</i>	O
small sharks		O
Coney	<i>Cephalopholis fulvus</i>	O
Red Hind	<i>Epinephelus guttatus</i>	O

Observed fishing and fishing-related activities at Navassa Island, 29 Oct-12 Nov 2002. A) Rock anchor in Lulu Bay used in temporary mooring system for fishing boats; B) Single sail-powered boat observed; C) Typical Haitian fishing vessel with 10-15 hp motor; D) Typical Antillean Z-trap used at Navassa Island; E) Miscellaneous fin-fish catch from hook and line in only ice chest observed; F) Large gravid lobster; G) Mixed catch including small hawksbill turtle, conch, and fin-fish; H) *In situ* conch



I) Underwater refuse pile observed at Lulu Bay containing turtle bones and ventral plates, fish skin, and bamboo; J) Terrace habitat where live conch (circled in yellow) were observed at 25-30m depth;



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APPENDIX 1: Description of permanent reef monitoring installations

In addition to the reef characterization sampling described in the main part of this report, permanent installation of settlement plates and plot markers to enable future sampling of coral settlement/survival/mortality and change in benthic community structure were also undertaken during the 2002 Navassa expedition. These are the first permanent reef monitoring approaches to be deployed at Navassa and include

- Permanent 1m² plots at North Shelf (14 @ 30ft depth) and West Pinnacles (15 @ 70ft depth)
- Permanent markers for video transects at deep patch reef (90 ft) near West Pinnacles
- Settlement plates to examine coral and crustose coralline algal settlement. 25 at North Shelf and 25 at Northwest Pt. all at ~ 25 ft depth. These plates were installed by and belong to Dr. Robert Stenneck, Univ of Maine as described in Chapter VI. It is hoped that these plates can be collected within 1-2 years for quantification.

This summary provides documentation for location/layout of the permanent installations to facilitate their re-sampling on whatever future trip might occur.

Permanent Plots at North Shelf:

One m² plots were laid out along a 30 m transect running from west to east. The transect was laid out following the reef contour (ie. conformed to the reef spurs/ribs and grooves) so the total distance covered is less than 30 m. A small square buoy was left in the vicinity of the westernmost stake. The plots were placed at haphazard intervals along the transect in areas that were flat enough to accommodate a quadrat frame. At the east end, several plots (#13&14) clumped around the 30m area at the base of a *Dendrogyra* colony with the easternmost plot (#15) encompassing an *A.palmata* on a shallow reef rib to the southwest. The following coordinates were obtained by a snorkeller above each landmark on a hand held Etrex GPS unit.

West Stake (plot #1): 18°24.810N, 75°01.334W

East end of transect: 18°24.809N, 75°01.371W

Plot #15 on shallow spur: 18°24.808N, 75°01.390

Each plot has a copper/steel stake in the northeast corner (EXCEPTIONS: plot #13 stake is in NW corner; Stake #9 is missing (already was dislodged and found displaced)). A numbered cattle-ear tag cable-tied to each stake designates the plot numbers (orange 1-15 for North shelf). At one or more other corners, a blank (un-numbered) tag is attached to the reef itself. A pvc quadrat frame is used to facilitate survey of the plot. Photos, drawings, and map (attached) should accompany future attempts to relocate the plots. Five digital still photos of each plot include 1) the entire 1m² frame and 2-5) close-ups of the four quarters beginning in the upper left corner (stake corner) and going clockwise.

Permanent Plots at West Pinnacles:

Plots were laid along a transect running ~135° heading along the wall base at 63-70 ft depth from the first stake at:

18°24.331N, 75°011.507W

The numbered stake is at the NW corner of each plot and at least one other corner has a blank tag. The cow tags at this site are white. Maps, drawings and annotated photos (as described for NW pt) are in archive copies at both SEFSC (Miami) and CINWR (Puerto Rico).

Permanent video transects at Deep Patch reef:

Four numbered stakes (white # 17-20) were deployed in a 15m square configuration at a deep patch reef adjacent to the W.Pinnacles permanent plots. These markers are at 93 ft depth and provide for 6 fixed video transects. Location at

18o24.277N, 75o01.613W

Marker 17 is closest to the patch reef edge nearest the island. Fifteen haphazard photo quadrats were also taken in this area.

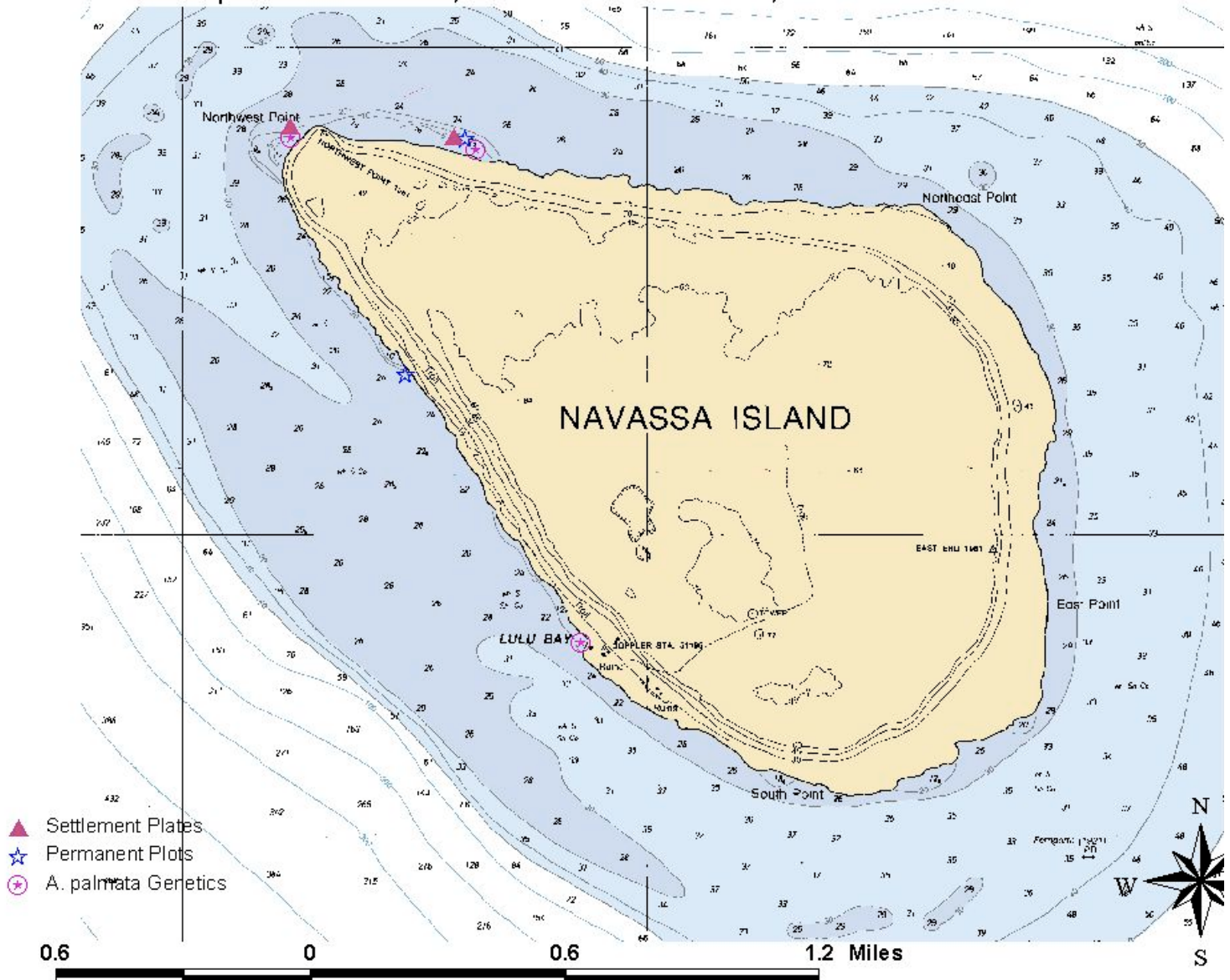
Settlement Plates:

Dr. Steneck's settlement plates (as described in Chapter 6 above) were installed in clumps with bolts drilled into dead coral surfaces in the vicinity of the following coords:

North Shelf: 18°24.813N, 75°01.383W

NW Pt: 18°24.825N, 75°01.786W

Acropora Genetics, Settlement Plates, and Permanent Plots



APPENDIX 2: Notes on *Acropora* spp. status at Navassa and Sampling of Elkhorn coral (*Acropora palmata*) for Caribbean population genetics study

The status of *Acropora palmata* and *A. cervicornis* were of particular interest to the expedition as NMFS is currently considering them for listing under the Endangered Species Act. The only historical notes of *Acropora* spp. status at Navassa Island were made the by the Littlers in their 1998 cruise report noting the presence of “~12 medium sized heads” of *A. palmata* at Lulu Bay. Observations made in the April 2000 cruise confirmed the presence of a decent *A. palmata* stand at Lulu Bay and scattered encrusting colonies at NW Point. The *A. palmata* population at these sites has clearly rebounded substantially since April 2000. In addition to Lulu Bay, large *A. palmata* colonies were also observed at NW Point and North Shelf.



Fig 1: The *A. palmata* stand at Lulu Bay, 29 Oct. 2002. Many colonies have an unusual encrusting morphology, seemingly due to the high physical disturbance regime and form a carpet on much of the wall around Lulu Bay at the top of the left photo. *A. palmata* also occurs unusually deep at Navassa including this colony (right) growing at 72 ft depth.

Acropora cervicornis is still extremely rare around Navassa. We found only two or three colonies along the wall base and patch reefs of the west coast. All were heavily infested with threespot damselfish and partially to mostly dead (Figure 2).



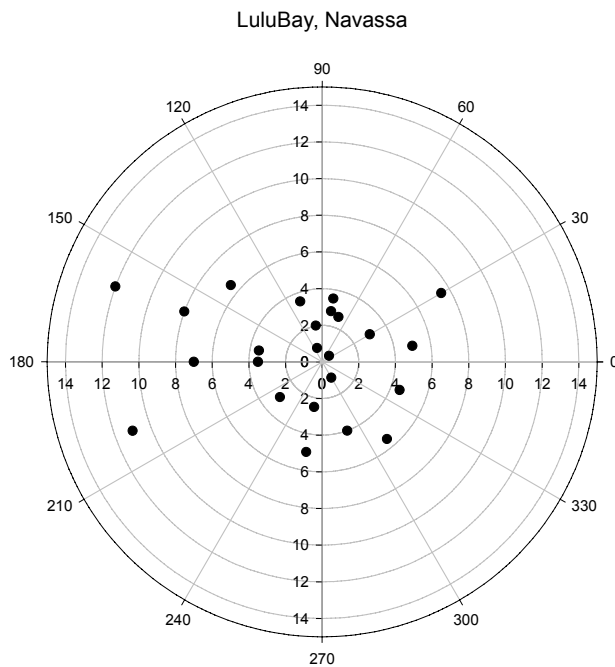
Figure 2. The largest *A.cervicornis* “thicket” observed at Navassa on Oct/Nov 2002 expedition near the West Pinnacles permanent plots. Only branch tips remained alive. Threespot damselfish (one visible in lower left center of photo) and corallivorous snails were both observed causing damage to this thicket and nearby colonies.

Acropora palmata genetics sampling:

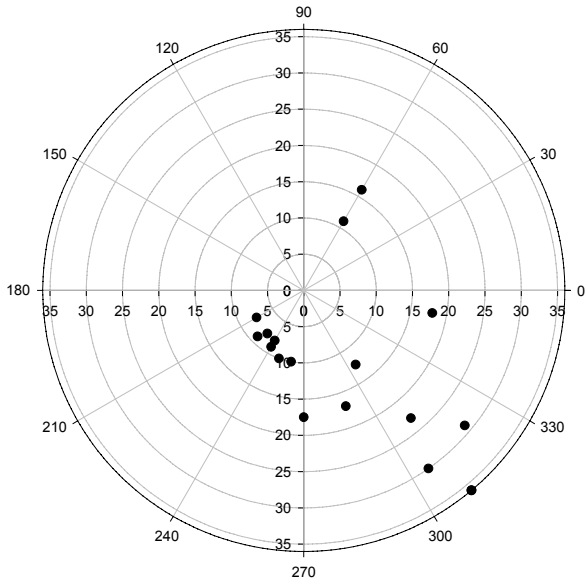
As part of a Caribbean-wide population genetics study led by Iliana Baums (RSMAS/University of Miami), tissue samples of *Acropora palmata* were collected at Lulu Bay (21 colonies), Northwest Point (28 colonies), and North Shelf (18 colonies; see map App. 1). This study is using microsatellite genetic markers to genotype individual colonies sampled and a standardized sampling approach to examine two aspects of *A.palmata* population structure. First, the clonal structure of individual remnant patches of *A.palmata* is being analyzed by random sampling and careful mapping. This is an interesting question since *A.palmata* generally reproduces asexually by branch fragmentation and thus, populations may be highly clonal.

Second, by sampling multiple sites within each region and knowing the genotype of each colony, the degree of genetic connectivity and/or population differentiation will be examined for this species. This is an important issue which will allow better evaluation of the potential for this species to repopulate areas where it has become rare or even suffered local extirpation.

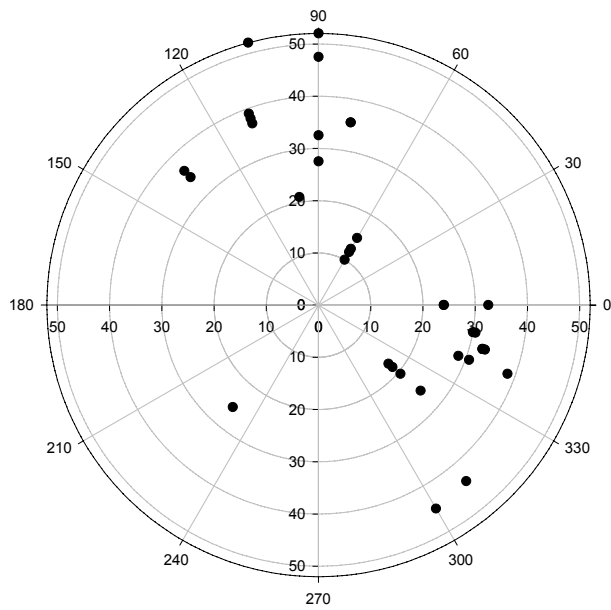
The following figures show maps of the colonies sampled at the three sites which, once the samples have been genotyped, will be used to plot the clonal distribution at these sites. It should be noted that the higher density patch at Lulu Bay was randomly subsampled (using a pre-selected list of random heading/distance coordinates from a haphazardly placed center stake) whereas the areas represented in the sparser patches at NW Point and North Shelf were sampled completely (note larger distance scale).



North Shelf, Navassa



NW Point, Navassa



APPENDIX 3. Phylogenetic listing of families and species observed from Navassa Island in 2002. Names are according to Robins et al. (1991) and W. Richards (pers comm), with the exception that *Hypoplectrus* species (denoted by #) which were all listed as *H. unicolor*. The species codes were derived from the first three and four letters, respectively, of the genus and trivial species name. Trophic level codes: B, browser; F, piscivore; H, herbivore; Ma, macroinvertivore; Mi, microinvertivore; P, planktivore. Predominate adult trophic mode indicated in bold and * denotes species not previously reported from Navassa (Collette et al. 2003).

FAMILY NAME	<i>Scientific name</i>	<u>Family common name</u>	Species common name	Trophic Level	Species Code
RHINCODONTIDAE		<u>Carpet sharks</u>			
	<i>Ginglymostoma cirratum</i>		Nurse shark	Ma,F	GIN CIRR *
DASYATIDAE		<u>Stingrays</u>			
	<i>Dasyatis americana</i>		Southern stingray	Ma	DAS AMER
UROLOPHIDAE		<u>Round stingrays</u>			
	<i>Urolophus jamaicensis</i>		Yellow stingray	Ma,Mi	URO JAMA
MYLIOBATIDAE		<u>Eagle rays</u>			
	<i>Aetobatus narinari</i>		Spotted eagle ray	Ma	AET NARI *
MURAENIDAE		<u>Morays</u>			
	<i>Gymnothorax funebris</i>		Green moray	F,Ma	GYM FUNE
	<i>Gymnothorax miliaris</i>		Goldentail moray	F,Ma	GYM MILI
	<i>Gymnothorax moringa</i>		Spotted moray	F	GYM MORI
OPHICHTHIDAE		<u>Snake eels</u>			
	<i>Myrichthys breviceps</i>		Sharptail eel	F,Ma	MYR BREV *
	<i>Myrichthys ocellatus</i>		Goldspotted eel	F,Ma	MYR OCEL *
CONGRIDAE		<u>Conger eels</u>			
	<i>Heteroconger halis</i>		Brown garden eel	P	HET HALI *
EXOCOETIDAE		<u>Flyingfishes</u>			
	<i>Cheilopogon melanurus</i>		Atlantic flyingfish	P	CHE MELA
BELONIDAE		<u>Needlefishes</u>			
	<i>Platybelone argalus</i>		Keeltail needlefish	F	PLA ARGA
HOLOCENTRIDAE		<u>Squirrelfishes</u>			
	<i>Holocentrus adscensionis</i>		Squirrelfish	Ma,Mi	HOL ADSC
	<i>Holocentrus rufus</i>		Longspine squirrelfish	Ma,Mi	HOL RUFU
	<i>Myripristis jacobus</i>		Blackbar soldierfish	P	MYR JACO
	<i>Neoniphon marianus</i>		Longjaw squirrelfish	Ma,Mi	NEO MARI
AULOSTOMIDAE		<u>Trumpetfishes</u>			
	<i>Aulostomus maculatus</i>		Trumpetfish	F	AUL MACU
SYNATHIDAE		<u>Pipefishes and seahorses</u>			

	<i>Micrognathus ensenadae</i>	Harlequin pipefish	P	MIC ENSE*
SERRANIDAE	<u>Sea basses</u>			
	<i>Cephalopholis cruentatus</i>	Graysby	F, Ma	CEP CRUE
	<i>Cephalopholis fulvus</i>	Coney	F, Ma	CEP FULV
	<i>Epinephelus guttatus</i>	Red hind	Ma, F	EPI GUTT
	<i>Hypoplectrus aberrans</i> #	Yellowbelly hamlet	Mi	HYP ABER *
	<i>Hypoplectrus chlorurus</i> #	Yellowtail hamlet	Mi	HYP CHLO *
	<i>Hypoplectrus gemma</i> #	Blue hamlet	Mi	HYP INDI *
	<i>Hypoplectrus gummigutta</i> #	Golden hamlet	Mi	HYP GUMM *
	<i>Hypoplectrus guttavarius</i> #	Shy hamlet	Mi	HYP GEMM
	<i>Hypoplectrus (hybrid)</i> #	Hybrid hamlet	Mi	HYP HYBR *
	<i>Hypoplectrus indigo</i> #	Indigo hamlet	Mi	HYP GUTT *
	<i>Hypoplectrus nigricans</i> #	Black hamlet	Mi	HYP NIGR *
	<i>Hypoplectrus puella</i> #	Barred hamlet	Mi	HYP PUEL
	<i>Hypoplectrus (tan)</i> #	Tan hamlet	Mi	HYP TANN *
	<i>Hypoplectrus species</i> #	Tan hamlet	Mi	HYP SPE.
	<i>Hypoplectrus unicolor</i> #	Butter hamlet	Mi	HYP UNIC *
	<i>Liopropoma carmabi</i>	Candy basslet	Mi	LIO CARM
	<i>Liopropoma rubre</i>	Peppermint bass	Mi	LIO RUBE
	<i>Mycteroperca interstitialis</i>	Yellowmouth grouper	F, Ma	MYC INTE *
	<i>Mycteroperca tigris</i>	Tiger grouper	F, Ma	MYC TIGR
	<i>Mycteroperca venenosa</i>	Yellowfin grouper	F, Ma	MYC VENE *
	<i>Paranthias furcifer</i>	Creole-fish	P, F	PAR FURC
	<i>Rypticus saponaceus</i>	Greater soapfish	F, Ma	RYP SAPO
	<i>Rypticus subbifrenatus</i>	Spotted soapfish	F	RYP SUBB
	<i>Serranus tabacarius</i>	Tobaccofish	Mi	SER TABA
	<i>Serranus tigrinus</i>	Harlequin bass	Mi	SER TIGR
	<i>Serranus tortugarum</i>	Chalk bass	Mi	SER TORT
GRAMMIDAE	<u>Basslets</u>			
	<i>Gramma loreto</i>	Fairy basslet	Mi	GRA LORE
PRIACANTHIDAE	<u>Bigeyes</u>			
	<i>Priacanthus cruentatus</i>	Glasseye snapper	Ma, P	PRI CRUE
APOGONIDAE	<u>Cardinalfishes</u>			
	<i>Apogon binotatus</i>	Barred cardinalfish	P	APO BINO *
	<i>Apogon maculatus</i>	Flamefish	P	APO MACU
MALACANTHIDAE	<u>Tilefishes</u>			
	<i>Malacanthus plumieri</i>	Sand tilefish	Mi, Ma	MAL PLUM
ECHENEIDAE	<u>Remoras</u>			
	<i>Echeneis naucrates</i>	Sharksucker	F, Ma	ECH NAUC
CARANGIDAE	<u>Jacks</u>			
	<i>Carangoides bartholomaei</i>	Yellow jack	F	CAR BART
	<i>Carangoides ruber</i>	Bar jack	F, Ma	CAR RUBE
	<i>Caranx crysos</i>	Blue runner	F	CAR CRYC *
	<i>Caranx latus</i>	Horse-eye jack	F, Ma	CAR LATU
	<i>Caranax lugubris</i>	Black jack	F	CAR LUGU
	<i>Decapterus macarellus</i>	Mackerel scad	P	DEC MACA
	<i>Elagatis bipinnulata</i>	Rainbow runner	P	ELA BIPI
CORYPHAENIDAE	<u>Dolphinfishes</u>			

	<i>Coryphaena hippurus</i>	Dolphinfish	F	COR HIPP
LUTJANIDAE	<u>Snappers</u>			
	<i>Lutjanus apodus</i>	Schoolmaster	F, Ma	LUT APOD
	<i>Lutjanus buccanella</i>	Blackfin snapper	F, Ma	LUT BUCC *
	<i>Lutjanus griseus</i>	Gray snapper	F, Ma	LUT GRIS *
	<i>Lutjanus jocu</i>	Dog snapper	F, Ma	LUT JOCU
	<i>Ocyurus chrysurus</i>	Yellowtail snapper	F, Ma, Mi, P	OCY CHRY
LOBOTIDAE	<u>Tripletails</u>			
	<i>Lobotes surinamensis</i>	Atlantic tripletail	F	LOB SURI
HAEMULIDAE	<u>Grunts</u>			
	<i>Haemulon album</i>	Margate	Ma	HAE ALBU
	<i>Haemulon carbonarium</i>	Caesar grunt	Ma	HAE CARB *
	<i>Haemulon flavolineatum</i>	French grunt	Ma	HAE FLAV
	<i>Haemulon macrostomum</i>	Spanish grunt	Ma	HAE MACR *
	<i>Haemulon sciurus</i>	Bluestriped grunt	Ma	HAE SCIU
SCIAENIDAE	<u>Drums</u>			
	<i>Equetus punctatus</i>	Spotted drum	Ma	EQU PUNC
MULLIDAE	<u>Goatfishes</u>			
	<i>Mulloidichthys martinicus</i>	Yellow goatfish	Mi	MUL MART
	<i>Pseudupeneus maculatus</i>	Spotted goatfish	Mi	PSE MACU
KYPHOSIDAE	<u>Sea chubs</u>			
	<i>Kyphosus sectatrix</i>	Bermuda chub	H	KYP SECT
CHAETODONTIDAE	<u>Butterflyfishes</u>			
	<i>Chaetodon capistratus</i>	Foureye butterflyfish	B	CHA CAPI
	<i>Chaetodon ocellatus</i>	Spotfin butterflyfish	B	CHA OCEL *
	<i>Chaetodon striatus</i>	Banded butterflyfish	B	CHA STRI
	<i>Prognathodes aculeatus</i>	Longsnout butterflyfish	B	PRO ACUL
POMACANTHIDAE	<u>Angelfishes</u>			
	<i>Centropyge argi</i>	Cherubfish	B	CEN ARGI
	<i>Holacanthus ciliaris</i>	Queen angelfish	B	HOL CILI
	<i>Holacanthus tricolor</i>	Rock beauty	B	HOL TRIC
	<i>Pomacanthus arcuatus</i>	Gray angelfish	B	POM ARCU
POMACENTRIDAE	<u>Damselfishes</u>			
	<i>Abudefduf saxatilis</i>	Sergeant major	P	ABU SAXA
	<i>Chromis cyanea</i>	Blue chromis	P	CHR CYAN
	<i>Chromis insolata</i>	Sunshinefish	P	CHR INSO
	<i>Chromis multilineata</i>	Brown chromis	P	CHR MULT
	<i>Eupomacentrus leucostictus</i>	Beaugregory	H	EUP LEUC *
	<i>Microspathathogon chrysurus</i>	Yellowtail damselfish	P	MIC CHRY
	<i>Stegastes diencaeus</i>	Longfin damselfish	H	STE DIEN
	<i>Stegastes fuscus</i>	Dusky damselfish	H	STE FUSC
	<i>Stegastes partitus</i>	Bicolor damselfish	P	STE PART
	<i>Stegastes planifrons</i>	Three spot damselfish	H	STE PLAN
	<i>Stegastes variabilis</i>	Cocoa damselfish	H	STE VARI *
CIRRHITIDAE	<u>Hawkfishes</u>			
	<i>Amblycirrhitus pinos</i>	Redspotted hawkfish	Mi	AMB PINO

SPHYRAENIDAE	<u>Barracudas</u>			
	<i>Sphyraena barracuda</i>	Great barracuda	F, Ma	SPH BARR
LABRIDAE	<u>Wrasses</u>			
	<i>Bodianus rufus</i>	Spanish hogfish	Ma, Mi	BOD RUFU
	<i>Clepticus parrae</i>	Creole wrasse	P	CLE PARR
	<i>Halichoeres bivittatus</i>	Slippery dick	Ma, Mi	HAL BIVI
	<i>Halichoeres cyanocephalus</i>	Yellowcheek wrasse	Mi, Ma	HAL CYAN *
	<i>Halichoeres garnoti</i>	Yellowhead wrasse	Ma, Mi	HAL GARN
	<i>Halichoeres maculipinna</i>	Clown wrasse	Mi, Ma	HAL MACU
	<i>Halichoeres radiatus</i>	Puddingwife	Mi, Ma	HAL RADU
	<i>Hemipteronotus species</i>	Unidentified rasonfish	Ma, Mi	HEM SPE.
	<i>Thalassoma bifasciatum</i>	Bluehead	P, Mi, Ma	THA BIFA
SCARIDAE	<u>Parrotfishes</u>			
	<i>Scarus coelestinus</i>	Midnight parrotfish	H	SCA COEL
	<i>Scarus croicensis</i>	Striped parrotfish	H	SCA CROI *
	<i>Scarus taeniopterus</i>	Princess parrotfish	H	SCA TAEN
	<i>Scarus vetula</i>	Queen parrotfish	H	SCA VETU
	<i>Sparisoma atomarium</i>	Greenblotch parrotfish	H	SPA ATOM
	<i>Sparisoma aurofrenatum</i>	Redband parrotfish	H	SPA AURO
	<i>Sparisoma chrysopterus</i>	Redtail parrotfish	H	SPA CHRY
	<i>Sparisoma rubripinne</i>	Redfin parrotfish	H	SPA RUBR *
	<i>Sparisoma viride</i>	Stoplight parrotfish	H	SPA VIRI
OPISTOGNATHIDAE	<u>Jawfishes</u>			
	<i>Opistognathus aurifrons</i>	Yellowhead jawfish	P	OPI AURI
CLINIDAE	<u>Clinids</u>			
	<i>Malacoctenus species</i>	Unidentified blenny	Mi, P	MAL SPE.
	<i>Malacoctenus triangulatus</i>	Saddled blenny	Mi, P	MAL TRIA
BLENNIIDAE	<u>Combtooth blennies</u>			
	<i>Ophioblennius atlanticus</i>	Redlip blenny	H	OPH ATLA
GOBIIDAE	<u>Gobies</u>			
	<i>Coryphopterus glaucofraenum</i>	Bridled goby	H	COR GLAU *
	<i>Coryphopterus hyalinus</i>	Glass goby	P	COR HYAL
	<i>Coryphopterus lipernes</i>	Peppermint goby	Mi	COR LIPE *
	<i>Coryphopterus personatus</i>	Masked goby	P	COR PERS
	<i>Gnatholepis thompsoni</i>	Goldspot goby	H	GNA THOM
	<i>Gobiosoma evelynae</i>	Sharknose goby	Mi	GOB EVEL
	<i>Gobiosoma oceanops</i>	Neon goby	Mi	GOB OCEA *
	<i>Gobiosoma species</i>	Goby-like fish	Mi, H	GOB SPE.
	<i>Microgobius carri</i>	Seminole goby	P	MIC CARR *
	<i>Microgobius microlepis</i>	Banner goby	H	MIC MICR *
ACANTHURIDAE	<u>Surgeonfishes</u>			
	<i>Acanthurus bahianus</i>	Ocean surgeon	H	ACA BAHU
	<i>Acanthurus chirurgus</i>	Doctorfish	H	ACA CHIR
	<i>Acanthurus coeruleus</i>	Blue tang	H	ACA COER
BOTHIDAE	<u>Lefteye flounders</u>			
	<i>Bothus lunatus</i>	Peacock flounder	F, Ma	BOT LUNA

BALISTIDAE	<u>Triggerfishes</u>			
	<i>Aluterus scriptus</i>	Scrawled filefish	H,B	ALU SCRI
	<i>Balistes vetula</i>	Queen triggerfish	Ma	BAL VETU
	<i>Canthidermis sufflamen</i>	Ocean triggerfish	Ma,P	CAN SUFF
	<i>Melichthys niger</i>	Black durgon	P	MEL NIGE
	<i>Xanthichthys ringens</i>	Sargassum Triggerfish	P,Mi	XAN RING
MONACANTHIDAE	<u>Filefishes</u>			
	<i>Cantherhines macrocerus</i>	Whitespotted filefish	B,H	CAN MACR
	<i>Cantherhines pullus</i>	Orangespotted filefish	B,H	CAN PULL
	<i>Monacanthus tuckeri</i>	Slender filefish	Mi	MON TUCK
OSTRACIIDAE	<u>Boxfishes</u>			
	<i>Lactophrys bicaudalis</i>	Spotted trunkfish	B	LAC BICA
	<i>Lactophrys polygonia</i>	Honeycomb cowfish	B	LAC POLY
	<i>Lactophrys quadricornis</i>	Scrawled cowfish	B	LAC QUAD
	<i>Lactophrys trigonus</i>	Trunkfish	B	LAC TRIG
	<i>Lactophrys triqueter</i>	Smooth trunkfish	B	LAC TRIQ
TETRAODONTIDAE	<u>Puffers</u>			
	<i>Canthigaster rostrata</i>	Sharpnose puffer	H,B,Mi	CAN ROST
	<i>Diodon holocanthus</i>	Balloonfish	Ma	DIO HOLO
	<i>Diodon hystrix</i>	Porcupinefish	Ma	DIO HYST
UNKNOWN	<u>Unknown</u>			
	<i>Unidentified sp.</i>	Unidentified species		UNK SPE.

APPENDIX 4: Quantification of substrate complexity (MJA Vermeij & SA Sandin)

As part of a study on the evolutionary dynamics in the coral genus *Madracis*, Navassa provided an unique setting to test earlier theories developed during work in the Netherlands Antilles, Florida Keys, St. Croix and Panama. Each of these locations has a characteristic geomorphologic complexity that affects the eco-evolutionary trajectories of two *Madracis* species that prefer vertical and horizontal positions on the reef respectively. Fixation of one of the two morphs occurs under specific habitat conditions affecting the evolutionary trajectory of the species. Navassa allowed us to test our evolutionary models in single habitat reefs (i.e. they are either horizontal or vertical). It suggests that genetic variation in scleractinian coral populations is reduced and the likelihood of speciation increases in response to directional selection related to environmental variation (i.e. habitat complexity in our case). Local habitat heterogeneity was quantified using a REEFER. The REEFER consists of a 2m wide frame containing vertical, free moving 1.5 m long PVC-poles every 10cm over its entire width. To use, one diver lowered the REEFER until all poles touched the benthic surface. Keeping the frame horizontal, a second diver recorded the height that each of the 21 poles extended above the frame. Height differences between consecutive poles were compared to estimate the surface profile in each 10cm section of sampled reef. We defined a 10cm height difference between consecutive poles as the threshold distinguishing horizontal ($<45^\circ$) and vertical ($\geq 45^\circ$) surfaces. Using this method, bottom complexity was defined as the distribution of horizontal and vertical surfaces at a 10cm scale.

For vertical walls, a variation to the original REEFER, the VEEFER (Vertical Environment Efficient Estimator of Relief) was used. The VEEFER works analogous to a REEFER turned 90° to the benthic surface. The vertical poles of the REEFER were too short when used on a vertical wall since successive poles (corresponding to a horizontal movement of 10cm), which results in a near infinite distance along the z-axis on a vertical wall. A weight and floating object were attached to a flexible measurement tape and placed in front of a vertical wall. The distance to the wall was determined by positioning a calibrated measurement pole horizontally between the tape and the wall every 10cm. The measurement pole was kept horizontal by referring to an attached leveling instrument. Differences over 10cm between successive measurements (i.e. $>45^\circ$) now correspond to horizontal surfaces and the same decision angle was used to distinguish between vertical and horizontal surface. Thus, for the

VEEFER a height difference of 10cm, or higher, between two consecutive poles defines a horizontal surface.