Khaled bin Sultan Living Oceans Foundation

Habitat Mapping
and
Coral Reef Assessments

Hogsty Reef, Little Inagua
and Great Inagua, Bahamas

August, 2011

Andrew W. Bruckner

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Front cover: Researchers at work conducting benthic and fish assessments. Photos by Ken Marks, Phil Renaud and Amanda Williams.

Khaled bin Sultan Living Oceans Foundation
8181 Professional Place
Landover, MD, 20785 USA
Philip G. Renaud, Executive Director

http://www.livingoceansfoundation.org

All research was performed under a permit obtained from the Bahamas National Environment and Planning Agency (NEPA) (ref #18/27, 8 December, 2011). No animals were killed or injured during the execution of the project, and no injured or dead marine mammals or turtles were observed. No oil spills occurred from the M/Y Golden Shadow or any of the support vessels, and oil slicks were not observed.

The information in this Report summarizes the outcomes of the research conducted during the August, 2011 research mission to Hogsty Reef, Great Inagua and Little Inagua. Information presented in the report includes general methods, the activities conducted during the mission, general trends and observations, analyzed data and recommendations. A single habitat map and bathymetric map developed by NCRI and prepared by Amanda Williams are included for each of the three areas. The full resolution satellite imagery, habitat maps, bathymetric maps and additional data layers are available in a separate GIS database and a hard copy atlas (under production at the date of this report). The Living Oceans Foundation cannot accept any legal responsibility or liability for any errors.

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The Khaled bin Sultan Living Oceans Foundation (KSLOF) was incorporated in California as a 501(c)(3), public benefit, Private Operating Foundation in September 2000. KSLOF headquarters are in Washington DC. The Living Oceans Foundation is dedicated to the conservation and restoration of oceans of the world, and champions their preservation through research, education, and a commitment to *Science Without Borders®*.

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Habitat Mapping and Coral Reef Assessments:
Hogsty Reef, Great Inagua, and Little Inagua, Bahamas.

August 2011

FINAL REPORT

Andrew Bruckner

Support for the research conducted during August, 2011,
as part of the Global Reef Expedition,
provided by His Royal Highness Prince Khaled bin Sultan

Philip G. Renaud, Executive Director
Andrew W. Bruckner, Chief Scientist

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Contents

SUMMARY

The Khaled bin Sultan Living Oceans Foundation (KSLOF) completed three research missions in the Bahamas during 2011: Cay Sal Bank (4/26/11-5/18/11), Great Inagua, Little Inagua and Hogsty Reef (8/1/11-8/24/11) and Andros Island (10/1/11-10/6/11). Research was undertaken by scientists from KSLOF, the National Coral Reef Institute (NCRI), University of Queensland, University of Miami (RSMAS), Atlantic and Gulf Rapid Reef Assessment Program (AGRRA), Florida Aquarium, University of Michigan, the Bahamas Department of Marine Resources (Fisheries), the Bahamas National Trust, the Nature Conservancy, Bahamas, and College of the Bahamas. The research included two components: habitat mapping and characterization of coral reef community structure and health. Habitat mapping involves acquisition of Worldview-2 (WV2) high resolution Satellite Imagery, aerial reconnaissance and photography, and field work to collect "groundtruth" and geophysical data (continuous bathymetry measurements, drop camera videos, sediment sampling, and low frequency sonar profiles of the seafloor's sub-bottom). Coral reef assessments focused on characterization of: 1) the benthos, including substrate type and cover of benthic organisms; 2) coral community structure, population dynamics and health; 3) fish community structure; and 4) resilience indicators, with emphasis on herbivory and algal growth studies, coral recruitment, coral diseases, and patterns of coral reef recovery.

A total of 23,407 sq. km of satellite imagery was acquired for the 5 areas. Continuous bathymetry was recorded over a 572km track and 1157 drop camera videos were taken. All groundtruth data were linked to a geographic positioning system (dGPS). The researchers completed 1003 dives, for a total of 842 hours and 52 minutes of bottom time, with surveys conducted to a maximum of 30m depth within 81 sites. In these sites, 665 benthic transects, 291 coral belt transects and 764 fish transect surveys were completed. In addition to the recorded underwater data, hundreds of photographic transects, video and still images of habitats and species were taken. In Great Inagua, Little Inagua and Hogsty Reef, 393 dives were completed within 32 sites, and one Legacy Site was established. A total of 3150 sq. km of imagery was used for habitat mapping. Groundtruthing data included 227km of continuous bathymetry readings and 489 drop camera deployments. Key products include 1) a GIS database containing satellite imagery, high resolution (6m) habitat maps depicting 12-15 marine habitats, bathymetric maps for shallow (0-25m) water, and coral reef data, and 2) a hard copy atlas of shallow marine environments (under production at the date of this report).

Coral reefs in Great Inagua, Little Inagua and Hogsty Reef contained a total of 170 species of fish and 48 species of scleractinian corals. Most sites had a high diversity, density and biomass of herbivorous parrotfishes and surgeonfishes, exceeding that seen on Cay Sal and Andros. A relatively high population abundance of groupers was also documented, with the largest populations of Nassau groupers around Great Inagua and fewer in other areas. Coral cover was relatively low everywhere (but higher than Cay Sal), with extensive old mortality attributed to past ecological disturbances. Partial colony mortality was much higher than observed in Andros and Cay Sal. The dominant corals observed throughout the region were lettuce coral (*Agaricia agaricites*), mustard coral (*Porites astreoides*), finger coral (*Porites porites*), starlet coral (*Siderastrea siderea*) and pencil coral (*Madracis* spp.) respectively. These showed high levels of recruitment and high numbers of juvenile colonies. Populations of these species are on an upward trajectory and it is likely that they will dominate these reefs in the future. For the dominant frame-builders (*Montastraea annularis* complex and *Acropora palmata*), most reefs contained dead standing skeletons intermixed with some larger live colonies in excellent condition, many smaller living colonies, and numerous larger corals that had mostly died but still had

small live tissue remnants. *Acropora cervicornis*, another endangered species, was in much better shape on Great Inagua than in all other locations examined. Nevertheless, there was an absence of recruitment of both species of *Acropora* and *Montastraea annularis* (complex). Reef substrates and dead corals in the three locations were colonized by high amounts of fleshy seaweeds (macroalgae), except on the exposed windward reefs. Human impacts were observed to be very low, including low levels of fishing pressure.

On Great Inagua, live coral cover averaged 10.6% for the 19 survey sites with overall highest coral cover (14.3%) and lowest cover of macroalgae (25%) recorded in Man O' War Bay. In Man O' War Bay the dominant genera (by cover) included *Montastraea* (6%), *Agaricia* (3.3%), and *Porites* (2.5%). The southeast "tongue" of Great Inagua had the lowest coral cover (6.6%), even though the area had a well-developed spur-and-groove reef structure. The northwest edge of Great Inagua averaged 9.6% live coral cover, 42% cover of macroalgae, and 12% cover of crustose coralline algae (CCA). This area also had extensive *Acropora palmata* reefs, but live coral cover was low (0.3%). Colonies in these areas were predominantly dead, standing in growth position with the skeletons colonized by either turf algae or CCA. In total, 32 species of corals were observed on Great Inagua with an average of 20 species per site. Coral recruits occurred at a low abundance with the dominant species being *P. astreoides* and *A. agaricites*, followed by *S. siderea;* 79% of 760 quadrats lacked coral recruits, indicating a low potential for near-term coral reef regeneration. Great Inagua had an average of 49 reef fish species per site with the highest diversity (679 species) at site GI-12 (Man O' War Bay) and roughly equal numbers in the southeast "tongue" and the northwest corner (48-50 species). The lowest diversity of reef fish (20 species) was recorded at GI-18.

Surveys on Little Inagua were conducted predominantly along the top of reef walls because habitats located closer to shore consisted of either sand or macroalgae. In reef habitats, coral cover was low (average 9%), and substrates were predominantly colonized by macroalgae (51% cover) with patches of CCA (12% cover). The dominant corals were the *Montastraea annularis* complex (2.7% cover), followed by *Porites, Madracis*, and *Siderastrea* (each about 1% coral cover). Little Inagua contained 22 species of scleractinian corals, with an average of 17 species per site. Most recruits consisted of *P. astreoides*, with lower numbers of *Agaricia, Siderastrea* and *Favia*. Similar to Great Inagua, a large proportion of the quadrats (85%) lacked coral recruits. Little Inagua had a higher diversity of reef fish than Great Inagua and Hogsty Reef, with up to 77 fish species recorded in one survey site and an average of 66 species per site.

Hogsty Reef had the lowest coral cover of the three locations (average 5%), with an average macroalgae cover of 50% and an average CCA cover of 18%. The most common corals were the *Montastraea annularis* complex, *Agaricia, Porites*, and *Siderastrea,* each comprising about 1% live coral cover. Hogsty Reef contained 31 species of corals, averaging 19 species per site. An unusually high abundance of *Dendrogyra cylindrus* was noted and *Acropora cervicornis* was present in most locations, albeit in low densities. A number of large, completely dead colonies of *Colpophyllia natans* and *Montastraea faveolata* were identified, while multiple large, completely live *M. annularis* and *M. faveolata* were still present. High prevalence of dark spots disease was noted on *Agaricia* and *Madracis* colonies. As in the other survey locations, the dominant recruits were *P. astreoides, A. agaricites*, and *S. siderea*, respectively, with 82% of the quadrats lacking coral recruits. Unlike other locations, macroalgae was low on exposed fore reef sites. The East and NE sites also exhibited signs of physical impact, possibly due to high wave exposure and frequent storm damage. Lagoon sites had a high biomass of macroalgae, along with large, mostly live colonies of *Porites porites,* many over 10 m wide and 8-10 m tall. Hogsty Reef had a maximum of 67 species of reef fish in a single site, and an average of 46.

Regional Perspective

A. Reef fish communities

Reef fish communities consisted of 159 species, with an average of 52 species per site. The most common Caribbean species were represented, although grunts (porkfish, smallmouth, Spanish and tomtate) and lane snapper were completely absent. Certain species of fishes were encountered in extremely low numbers, occurring only at a few sites, including all species of eels and filefish, groupers (black, rock hind, yellowfin), hogfish, and snapper (except schoolmaster snapper). These fishes may be rare or absent due to the rarity of mangrove nursery habitats. The paucity of these fishes may also have contributed to the lower overall abundance and biomass of reef fish, as compared to Cay Sal and Andros, as some (grunt and snapper) tend to form large resting schools. In contrast, herbivore density was much higher than at either Cay Sal or Andros. Reef fish density and biomass was not related to the cover of macroalgae, turf algae, live coral, density of coral recruits, or rugosity (vertical relief). This was true when examining all species (pooled) or for pooled species of herbivores. There was, however, a significant positive correlation between parrotfish, macroalgae and coral cover. Densities of parrotfish increased as coral cover increased and macroalgae cover decreased. Surgeonfish densities exhibited the opposite trend, decreasing with macroalgae decline. The density and biomass of all species of herbivores (pooled) was also unrelated to primary productivity. Nevertheless, there was a significant positive relationship between primary production and the density of parrotfishes ($R^2=0.83$, $p<0.001$). One exposed site (with relatively high productivity and low density of parrotfishes) was deemed an outlier and excluded from the analysis.

B. Population status of reef building corals

The majority of the reef environments surveyed exhibited low cover of living coral (5-10%), with numerous dead colonies and moderate amounts of partial mortality on surviving coral colonies. Sites were dominated by *Montastraea annularis* (complex), but live cover of this taxon was generally less than 5%. While many of the long-lived massive species were observed to be in decline, the coral community is becoming dominated by smaller, short-lived corals, especially brooding species. The observed recruitment pattern, combined with the size-class frequencies and the fragmentation index allows us to draw important conclusions about population status and likely trajectories of the dominant taxa as follows:

The *Montastraea annularis* complex, which in recent geological history has been the dominant frame-building corals in the western Atlantic, show little recruitment, high fragmentation, and production of small size classes primarily by shrinkage from bigger size-classes as a result of partial mortality. This is indicative of declining reproductive potential and a downward trajectory. In general, *M. cavernosa* is faring better, with less partial mortality and higher recruitment.

Acropora species were rare and lacked sexual recruitment. *A. palmata* reef framework was observed in many shallow locations but the colonies were predominantly dead, mostly standing in growth position. Small patches of live *A. palmata* were found on Hogsty Reef, the northwest end of Great Inagua, and the southwest end of Little Inagua. A thriving *A. cervicornis* population was observed in a single site (*Great Inagua Legacy Site*). With exception of the healthy patches discovered, the population of both *Acropora* species is on a downward trajectory.

The genus *Porites* varied in survival and abundance. *P. astreoides* was the most common recruiter and the first or second most abundant coral in the small to medium size classes. Populations of *P. astreoides* are on an upward trajectory and likely to dominate these reefs in near future. Note, however, that *P. astreoides* is not considered to be a reef framework building coral. *P. porites* was an uncommon recruiter, and monospecific stands exhibited a high fragmentation index. With exception of lagoonal sites on Hogsty Reef, local populations are possibly on a downward trajectory.

Agaricia agaricites exhibited the second highest levels of recruitment and is the first or second most abundant coral in the small to medium size classes. A high number of colonies exhibited dark spots disease, although mortality from this condition was low. Populations are on an upward trajectory and this taxon is likely to dominate reefs in the near future.

Dendrogyra cylindrus was generally rare but unusually abundant on Hogsty Reef. While a low number of recruits were observed, this species may be spreading through fragmentation associated with storms. Many small, medium and large-sized colonies (completely unaffected by disease) were encountered. Although this is a relatively rare species, our observations suggest an upward trajectory of the population.

Dichocoenia stokesi exhibited fairly rigorous recruitment. Populations had a bimodal size-distribution, suggesting a stable or slightly upward trajectory.

Diploria labyrinthiformis and *D. strigosa* were both relatively common in the sampled depth-range. Sexual recruitment was observed but not very commonly. High mortality due to diseases may suggest an overall declining trajectory.

Eusmilia fastigiata: A common recruiter with an upward population trajectory.

C. Resilience

Two biological health index scores were calculated for each site following a similar protocol used for the Meso-American reef system. The first **biological health index** relies on seven parameters grouped into two categories. The first category is a *Coral Index*, comprised of coral cover, coral disease prevalence and coral recruitment. The second category is a *Reef Biota Index*, comprised of macroalgal index, herbivorous fish abundance (parrotfish and surgeonfish only), commercial fish abundance (grouper and snapper only), and *Diadema* abundance. The second, **simplified health index** was also calculated using only four parameters (coral cover, macroalgae, herbivores and commercial fishes). The values for each of these parameter were ranked from critical (1) to very good (5) using values identified by a scientific review committee based on their experience, perspectives and data. These values represent "*a compromise position between grading for the ideal "pristine" reef conditions and what we can realistically hope to achieve in modern times and conditions*."

Using the first health index, most of the reefs we surveyed were ranked either fair (37%) or poor (34%), with 25% of the sites ranked as good and one site ranked as critical. No survey sites were ranked as very good. The ranks for five of the variables were fairly similar among the three regions (Great Inagua, Little Inagua, and Hogsty Reef). Coral cover and macroalgae were identified as critical or poor in the majority of the sites in all three regions, with significantly lower ranks for both variables at Hogsty Reef. One cause of this may be due to the unusually low numbers of *Diadem*a present. Urchins were rare or absent from most sites, indicating that recovery from the 1982-1983 epizootic has not yet occurred. A moderate number of recruits and low prevalence of disease were positive attributes of these reefs, illustrating the potential for improvement in coral cover in future years. The highest overall scores of "good" were mainly attributed to abundant herbivorous fish populations which may help reduce macroalgal abundances, thereby enhancing substrate quality and the potential for additional recruitment and increases in coral cover. Most reefs on Great Inagua and Little Inagua also had fair to good populations of commercially valuable groupers and snappers, while these species were less common on Hogsty Reef, suggesting that over-fishing may be occurring.

RECOMMENDATIONS

1. Include Hogsty Reef in the Bahamas Network of Marine Protected Areas

- Hogsty Reef is geologically unique
  - It is one of the few atoll-like structures in the Atlantic. Hogsty Reef fits the geomorphic definition of an atoll – having steep sides, a central lagoon with patch reefs and peripheral reef structure. Yet, it is unique in having extensive accumulation of lagoonal sediments (700-800 m thickness) that are largely non-skeletal in origin, consisting predominantly of inorganically precipitated lumps, aggregates, pelletoids and oolites.
  - Coral reefs have developed relatively recently. There are no well-developed spur and groove structures like that found on most Pacific atolls and many Caribbean reefs. Although there are flourishing patch reefs within the lagoon, most Hogsty Reef coral communities form a thin veneer atop a fossilized Aeolian dune.
- Hogsty Reef is remotely located and free of coastal influences and land-based stressors. This suggests the shallow marine environments have a very high resilience.
- The lagoon contains extensive grassbeds. These provide a critical nursery habitat for reef fishes, lobsters and other invertebrates, juvenile habitat, and feeding grounds for commercially important species such as queen conch. This habitat type covers more than half of the shallows at Hogsty Reef. Similar habitats are rare or absent on adjacent Great Inagua and Little Inagua.
- Reef environments include extensive critical habitat for endangered *Acropora palmata*. Lagoonal areas also have extensive stands of *Porites porites* and fore reef locations support many corals which: 1) are uncommon in other Bahamian locations (i.e. *Dendrogyra cylindrus* or pillar coral); or 2) have been decimated by recent bleaching events and coral disease outbreaks such as *Montastraea annularis* (complex).
- Hogsty Reef may serve as a "stepping stone" for the emigration of larvae between the Turks and Caicos, Hispaniola, the Acklins and/or the Great Bahama Bank.
  - Currents generally flow westward, but sharp tidal reversals result in a net eastward flow, possibly enhancing self-seeding of Hogsty Reefs.
- Hogsty Reef represents one of the only banks in the southeast Bahamas that has been able to keep pace with the regional subsidence and, in recent times, has provided critical habitat for development of coral reefs. Numerous surrounding deep banks (e.g. Brown Bank) and guyots exist in the region; several of which are now several hundred meters below the sea surface and do not provide habitat for corals because of their depth.
- Possibly, the greatest human threat to Hogsty Reef is fishing, including illegal foreign fishing. Given the slow pace of recovery of the keystone herbivore, *Diadema antillarum*, the reef habitats are vulnerable to degradation due to potential overfishing of parrotfishes and other herbivores. It is critical that herbivorous fishes are protected to help maintain high quality substrates that can support the recruitment and survival of reef building corals.

Additional Recommendations

2. Establish fishery reserves in key coral areas to prevent exploitation of certain top predators and reduce illegal fishing.

Additional marine protected areas should be established on Little Inagua and Great Inagua to enhance connectivity among sites. In particular, GI-13 received the highest resilience score in the region. This site was located on the southeastern end of the island. This was a unique area with extensive, high relief spur and groove fore reef habitat that extended off the island.

3. Protect herbivorous parrotfishes and surgeonfishes from fisheries harvest.

All of the reefs in the Inaguas region had very high cover of macroalgae. This can inhibit settlement of corals and overgrow existing colonies. Further increases in the biomass of herbivorous fish populations could assist in the reduction of macroalgal biomass.

4. Conduct research on Diadema with a focus on strategies to reintroduce urchins to key sites in the Inaguas, with the goal of establishing local breeding populations.

Diadema antillarum is a keystone herbivore that was nearly extirpated throughout much the Caribbean. It has begun to rebound in some locations, but it remained absent or at very low abundances in the Inaguas. This may be due to high levels of predation pressure on larvae in combination with low abundances of larvae due to an absence of a breeding population within the region, or on upstream reefs. It is imperative that efforts are undertaken to reintroduce these animals, due to their keystone role in controlling macroalgae.

5.Conduct research on nuisance species such as certain sponges and cnidarians to determine factors responsible for their proliferation and options to reduce their prevalence.

Certain species of sponges are increasing in abundance, monopolizing the substrate, and outcompeting and overgrowing corals. There is little information on factors responsible for their proliferation, or options to control these organisms. Research should be directed towards an improvement of our understanding of the life history of these sponges, and possible options to control their spread.

6. Implement a coral reef monitoring program in the Inaguas.

The surveys conducted by KSLOF represent a baseline for the region. We have characterized many of the reef systems and established a single long-term monitoring site (KSLOF Legacy Site) on Great Inagua. It is important to continue to monitor patterns of recovery on these reefs, especially in concert with the implementation of new management measures. This will allow a determination of the effectiveness of the management and identification of additional steps necessary to restore these reefs to their historic condition.

Introduction

Inagua is the southernmost district of the Bahamas, comprised of Great Inagua, Little Inagua and Hogsty Reef.

Great Inagua, the third largest island in the Bahamas (1544 km²), lies about 520 km from Nassau and 90 km from the eastern tip of Cuba. The island is about 90 x 30 km in extent, with a maximum elevation of only 33 m on East Hill. There is one small town (Mathew Town), with a population of approximately 1,200. The island has the second largest solar-powered saline plant in North America; about 450,000 kg of salt are produced each year from the Salinas of Inagua by the Morton Salt Company. The island is also home to the world's largest breeding colony of West Indian flamingoes; these birds primarily inhabit the Great Inagua National Park, within an area covering about half of the island. Great Inagua is known for large bank-barrier reefs that developed in two stages over the last interglacial period. Their growth was interrupted by one major cycle of sea level transgression and regression, resulting in a wave cut platform visible at Devil's Point, off the west coast (Curran and Wilson 1997). This region is also known to have undergone tectonic uplift and tilting during the last 100,000 years; the island is less than 100 km away from the oblique convergence zone between the North American and the Caribbean plates (Kindler et al. 2007).

The neighboring island of Little Inagua is located 8 km to the northeast of Great Inagua. It is a low elevation island that is uninhabited and occupied by a large Land and Sea Park, 78 km^2 in area. The island is fringed by coral reefs, with extensive spur and groove structures located on the windward margins.

Hogsty Reef is a small (9 × 5 km) atoll located nearly equidistant from the Acklins Island, Great Inagua and Little Inagua. Hogsty reef contains two small sand islands, a distinct peripheral reef, a shallow (6 to 8 m depth) lagoon, and a pronounced leeward pass (Milliman 1967a). The bottom depths surrounding the atoll range from 1800-2600 m. While Hogsty Reef can be considered a classic Atlantic atoll (as defined by its geomorphology; steep upper slopes, reef flat, lagoonal patch reefs, and a lagoonal pass connecting it to deep water), it is unlike most Pacific atolls in that it is not formed through the subsidence of a volcano and build-up of coral reefs. Furthermore, present day reef communities form a thin veneer atop a pre-existing structure - the reef flat is believed to be non-coralline in origin, but rather a lithified Pleistocene aeolian dune. Corals and other organisms appear to have only recently colonized the margin, forming a thin veneer on a pre-existing platform. In addition, the lagoon has extensive accumulations of sediments that are up to 800 m in thickness (Milliman 1967b). Lagoonal sediments are very unusual for an atoll, consisting of reef material (mollusk shells, coral, coralline algae) as well as non-skeletal fragments that were inorganically precipitated (Milliman 1967a). Hogsty Reef is separated from Great and Little Inagua by extremely deep (1800 m) water.

Habitat mapping

Satellite imagery

Worldview-2 (WV2) satellite imagery provided an aerial overview of the study areas and the images were used for mission planning and navigation during data collection. DigitalGlobe Inc. delivered the WV2 scenes with geometric corrections, 11-bit digital numbers (DN), and a nearest-neighbor resample kernel. The satellite images had a spatial resolution of 2-m by 2-m (i.e., each pixel covers a 4-m^2 area), and they contained eight broad spectral bands compared to the 4 spectral bands on Quickbird, IKONOS, and Landsat. Due to rapid light attenuation by water, the passive multispectral sensor aboard the WV2 satellite has an inherent depth limitation.. In clearest waters, observations up to depths of 45 m are possible. However, satellite observations were generally limited to a depth of 25 m during this field campaign due to turbidity. The fine spatial resolution of the images allows identification of seafloor features such as reef structures, seagrass meadows, and sand flats prior to surveying of an area. The ground-truth team used the scenes in conjunction with a differential GPS device (dGPS) to efficiently navigate to landscape features of interest. The team gathered depth soundings and benthic video at these points (the methods for both are described below). The satellite imagery was used in conjunction with image processing and feature extraction software to create the bathymetric and benthic habitat maps.

Benthic Video

An underwater video camera attached to a cable ("drop-cam"; Fig. 1) gathered video on the benthic composition at each survey site. At these points the drop-cam was held from the survey boat (Fig. 2) enabling it to ‘fly’ along the sea floor as it recorded video for 15 to 60 seconds. The video was recorded to hard-disk on a laptop aboard the survey vessel in real-time and the geographic position, time, date, boat heading, and boat speed were also recorded and burned into the video. The geopositional data were acquired by a Garmin handheld GPS device with a horizontal accuracy of approximately ±5 m. Drop-cam deployment was limited to depths above 40 m due to the tether cable length (50 m). The acquired videos were used to improve accuracy of the benthic habitat maps by providing knowledge to develop the habitat classification scheme and to train the classification models.

Acoustic depth soundings

Depth soundings were acquired along transects between survey sites using *Hydrobox*, a single-beam acoustic transducer developed by Syqwest (Fig. 3). The instrument emits 3 pings per second. Depths are estimated based on the time the return-pulse reaches the sounder head. Depth estimates were recorded by the *Hydrobox* software on a field laptop aboard the survey vessel. Geopositional data were simultaneously acquired by a dGPS unit and recorded in the bathymetric file. The soundings were used to train a water-depth derivation model based on the spectral attenuation of light in the water column, which is then applied to the WV2 satellite imagery. The final topographic map has the same spatial resolution as the WV2 satellite imagery.

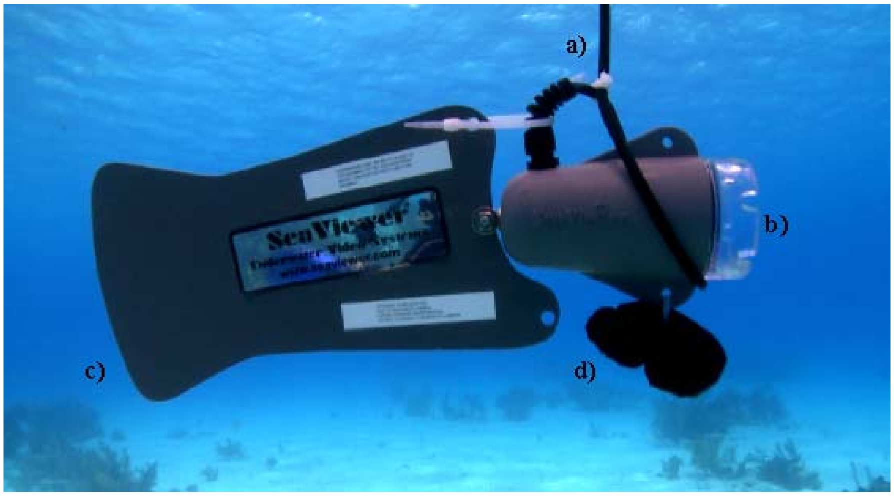


Fig. 1. Profile of the drop-cam. The device is attached to the research vessel by a tethered cable (a) through which video is transmitted to a laptop as it is viewed through the lens (b). A tail-fin (c) stabilizes the camera while it travels through the water and the attached weight (d) reduces sway during deployment.

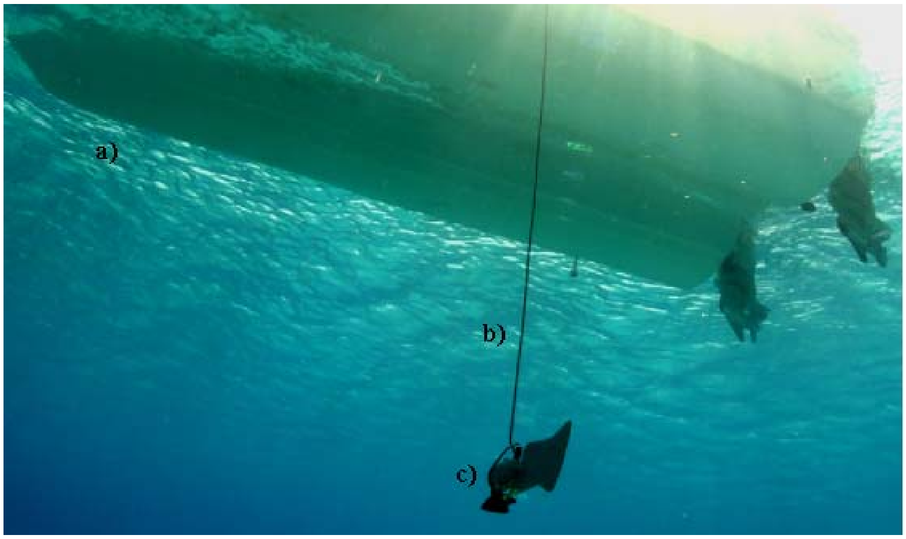


Fig. 2. Example of drop-cam deployment from the survey vessel (a). A researcher adjusts the tether length (b) to raise and lower the videocamera (c).

Acoustic sub-bottom

Profiles of the seafloor's sub-bottom were gathered along transects using the *Stratabox* acoustic sounder, also developed by Syqwest (Fig. 3). Similar to the bathymetric soundings, the sub-bottom profiler emits an acoustic ping which reflects off the seafloor. The acoustic sounder has a low frequency (3.5 Khz) enabling it to penetrate the seafloor. The instrument provides observations on stratal geometry beneath the seafloor along the transect lines allowing estimates of Holocene reef-growth and sediment accumulation to be made. Geopositional data for each ping was simultaneously acquired by dGPS unit and recorded in a data file. Profiles were run shore-perpendicular to capture the geometry of the bank flanks and span a depth range of 300 m to 5 m. Total transect length varies with the variation in slope; steeper slopes resulted in shorter transect lines. Depth is recorded in meters. Projection: WGS 84, UTM zone 18N. Data are extracted to provide sub-bottom profiles of flanks and the lagoon of Hogsty Reef, the Bahamas. The profiles provide reference to assist in interpreting the geologic processes shaping the bank and may be used to inform, guide, or augment survey and assessment of Hogsty Reef.

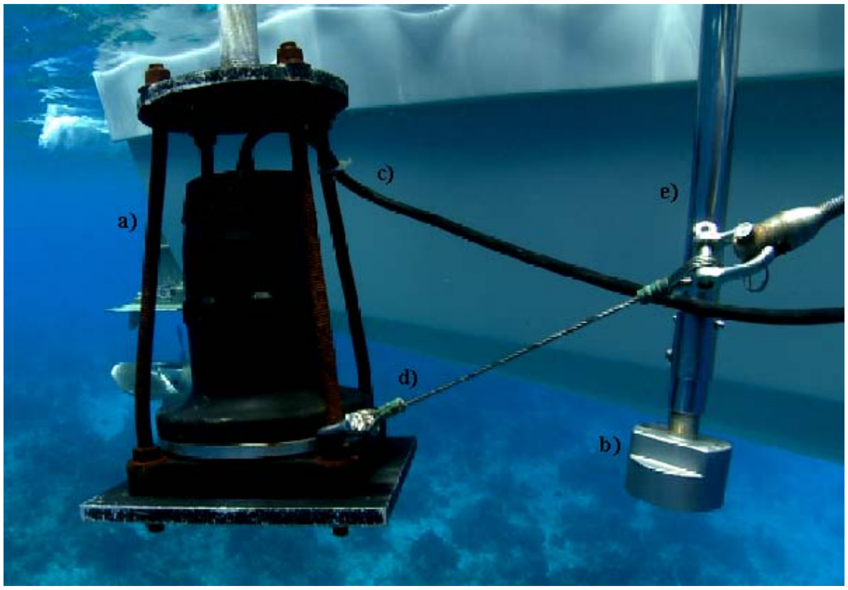


Fig. 3. Acoustic sub-bottom profiler (a) and acoustic depth sounder (b) deployed from survey vessel's side. For the sub-bottom profile, a cable (c) transmits data to a laptop aboard the boat while a second cable (d) stabilizes the transducer during travel along the transect line. The cable for the acoustic depth sounder is housed within the metal pipe (e) attached to the boat.

Hogsty Reef

Benthic videos (*n* = 137), acoustic depth soundings (*n* = 436,893) and a single sub-bottom profile were collected at Hogsty Reef. Figure 4 illustrates the locations of drop-cam surveys around the reef. Benthic habitats observed in the drop-cam videos included: reef crest, scoured hard-grounds, gorgonian-dominated fore-reef, fore-reef build-ups, wall reefs, sparse sea grass, dense sea grass, sand flats, sand with coral bommies, and patch reefs. Sampled depths ranged from 0.48 m to 44.47 m. Figure 5 shows the survey tracks for depth estimates. The sub-bottom profile was collected at the mouth of the lagoon along the western flank.

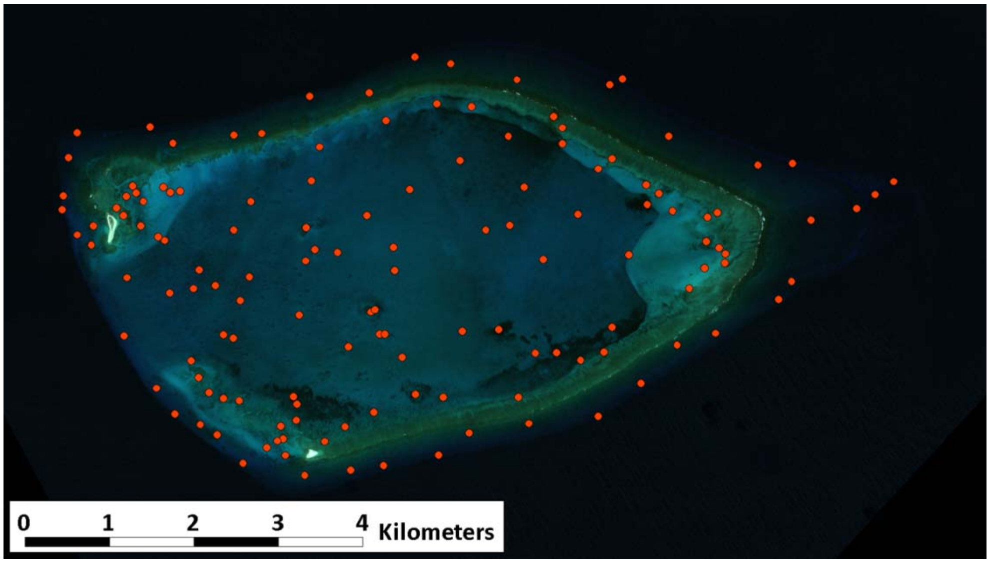


Fig. 4. Locations where drop-cam videos were acquired at Hogsty Reef.

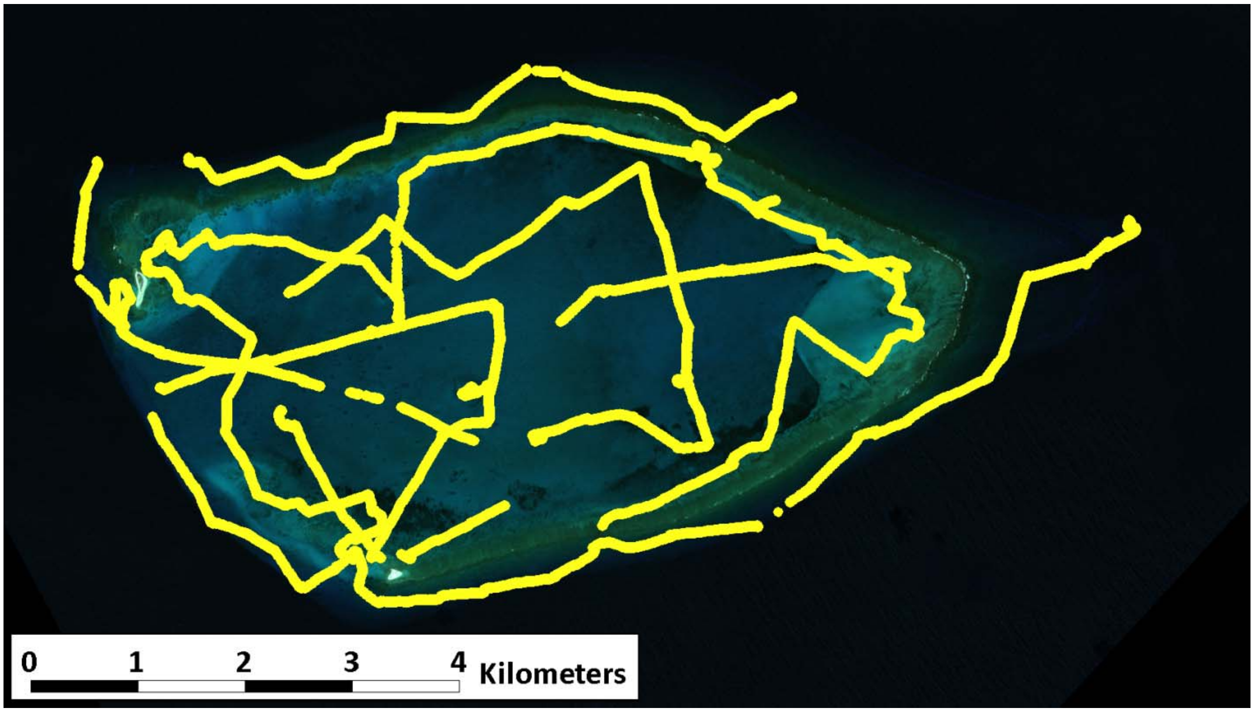


Fig. 5. Tracks along which acoustic depth soundings were acquired at Hogsty Reef.

Great Inagua

Benthic videos ($n = 288$), acoustic depth soundings ($n = 735,140$) and sub-bottom profiles ($n = 11$) were collected around Great Inagua. Sand flats, sparse seagrass, dense seagrass, sand with coral bommies, patch reefs, *A. palmata* reefs, *M. annularis* reefs, scoured hardground, shelf-edge and mid-shelf build-ups, and reef crest. Figure 6 illustrates the locations of drop-cam surveys around the island. Sampled depths ranged from 0.54 m to 70.37 m, and the bathymetric survey tracks are displayed in Fig. 7. Six sub-bottom profiles were collected along the northern ($n = 2$), western ($n = 3$), and southeastern coasts ($n = 1$), and two were collected along portions of the island's tongue on the southeastern portion of the island (Fig. 8). The final two profiles cross the blue hole on the western coast along its north-south and east-west axes. Fig. 9 shows the sub-bottom profiles for Transects 8 and 9 as examples of the resulting sub-bottom profile.

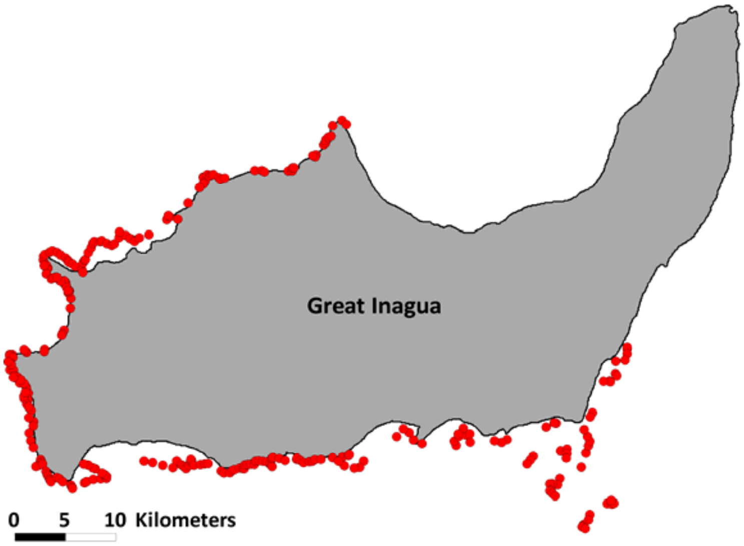


Fig. 6. Locations around Great Inagua where drop-cam videos were acquired.

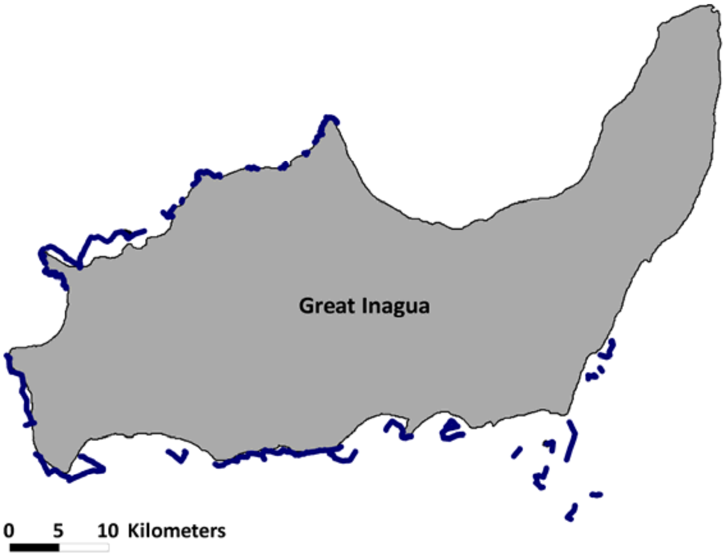


Fig. 7. Tracks around Great Inagua where acoustic depth soundings were acquired.

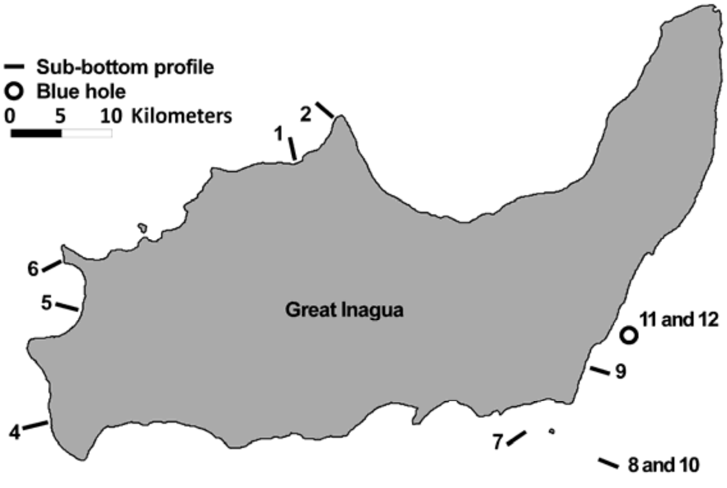


Fig. 8. Locations of the acoustic sub-bottom profiles gathered along Great Inagua.

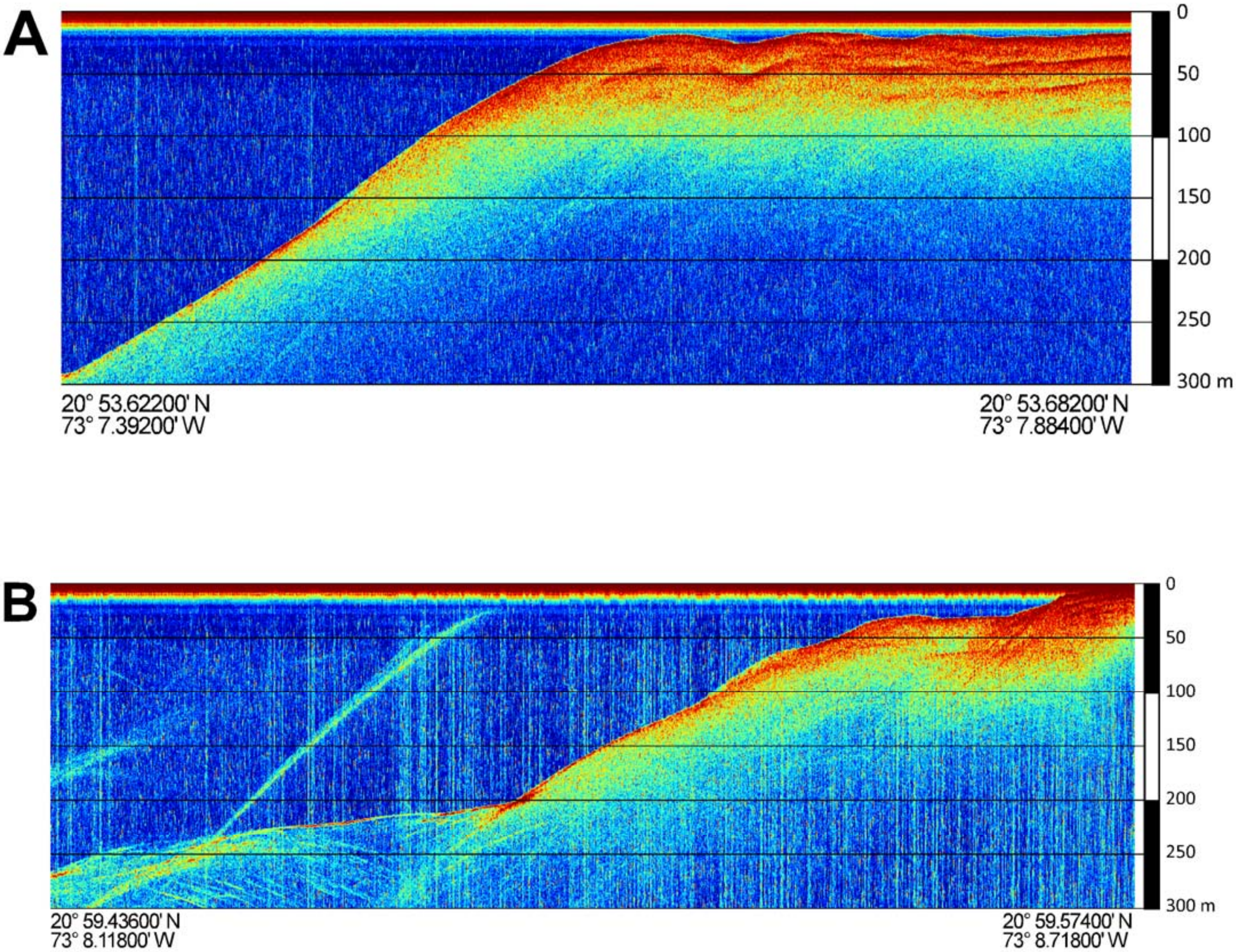


Fig. 9. Sub-bottom profiles for Transects 8 (A) and 9 (B). Transect 8 is along the island's tongue on the southeastern point, and Transect 9 is in the same area but along the coastline (see Fig. 8).

Little Inagua

Benthic videos (*n* =64), acoustic depth soundings (*n* = 262,986) and sub-bottom profiles (*n* = 3) were collected around Little Inagua. Observed benthic habitat classes included sand flats, sparse seagrass, dense seagrass, sand with coral bommies, patch reefs, *A. palmata* reefs, patch reefs, scoured hard-grounds, shelf-edge and mid-shelf build-ups, and reef crest. The location of drop-cam points around the island can be seen in Fig. 10. Sampled depths ranged from 0.35 m to 58.33 m; Figure 11 shows the survey tracks along which depth soundings were collected. A total of three sub-bottom profiles were collected, each along a different coast: the eastern, western, and southern coasts.

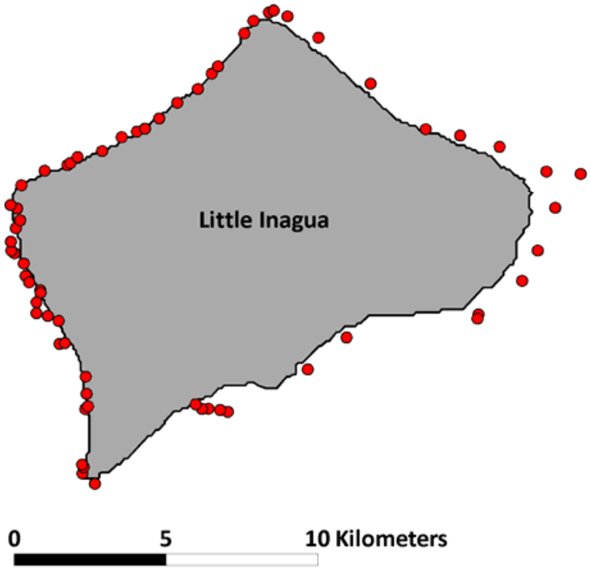


Fig. 10. Locations around Little Inagua where drop-cam videos were acquired.

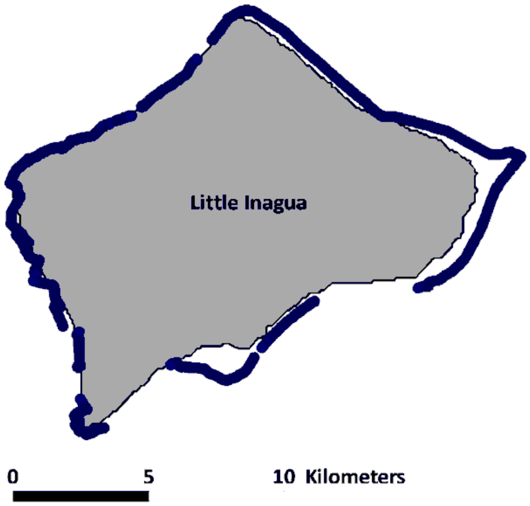


Fig. 11. Tracks around Little Inagua where acoustic depth soundings were acquired.

Habitat classes

Fourteen distinct habitat classes were used to create the benthic habitat maps of Hogsty Reef, Great Inagua and Little Inagua. Maps were generated from Worldview 2 multispectral satellite imagery with a Projection of WGS 84 and UTM Zone 18N. Data are suitable for resource assessment, spatial analyses and the development of geographic information systems (GIS) for planning and environmental management type applications. These habitat maps are not suitable for precise navigation use.

Image data

WorldView-2 (WV2) satellite imagery collected by DigitalGlobe, Inc, in 2010 and 2011 is the basis for the layer. The images have a per pixel spatial resolution of 2-m by 2-m, thus covering a 4 m^2 area, and eight spectral bands covering the wavelength range of 400 - 1050 nm. Six of the eight bands are in the visible (VIS) spectrum (400 – 750 nm), and the remaining two bands are in the near infra-red (NIR) spectrum (750 - 1050 nm). Each WV2 image was evaluated for quality prior to purchase. Scenes with excessive sea-surface-glint, cloud cover, or other factors that obscured bottom features, were avoided. Imagery was delivered as a georectified product. The images were converted from 16-bit digital numbers (DN) to remote sensing reflectance (%) just above the water's surface. Only light between 400 nm and 700 nm penetrates the water column sufficiently to provide usable information on the benthos' composition, thus only the five spectral bands within this region are used for benthic habitat mapping. Land and cloud were masked out of the imagery and a correction for sea-surface glint was applied prior to habitat classification.

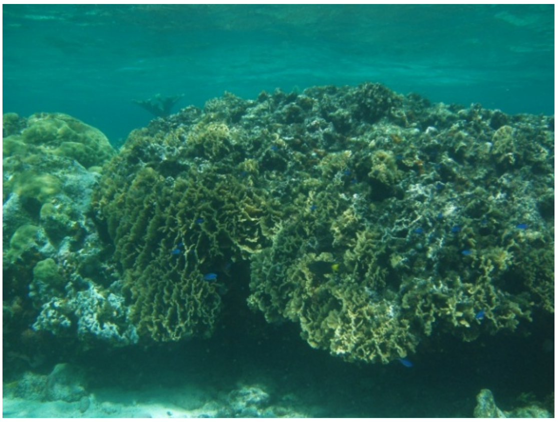
Classification

The product was created through object-oriented mapping using Definiens eCognition software allowing spectral, textural, edge-detection and landscape properties of the seafloor features to be applied in classification workflow. Spectral information draws on the separation of benthic habitats based on differences in reflectance characteristics. Texture based classification considers the systematic variation of brightness within a group of pixels and is a function of the seafloor feature. Edge-detection is a process whereby boundaries are identified within an image corresponding to where brightness changes sharply across a narrow spatial threshold. Edge-detection was used principally to streamline processing through identifying objects with clearly defined (i.e. crisp) boundaries. Landscape contextual editing draws on the fact that geomorphological and ecological zonation across a depositional system follows generic and logical rules (e.g. near-shore sediments are not encountered on the reef-edge).

The eCognition software employs a multi-resolution segmentation algorithm to group neighboring pixels based on their spectral properties to form polygons representing observed seafloor features. The resulting polygons are assigned classes representing different benthic habitats, as determined from drop-cam videos with known geographic positioning, either automatically through spectral and textural thresholding or manually by producer assignment. The polygons are exported from eCognition as ESRI shapefiles (*.shp) to create the final polygons of the benthic habitat map. The final map maintains the native resolution of the WV2 imagery (2-m by 2-m).

[1] *Acropora palmata* framework – A patch reef formed primarily by skeletons of *Acropora palmata*. Living colonies were present, but with low cover (<10%). This class was observed leeward of the reef crest, only in the eastern portion of the lagoon (lower left).

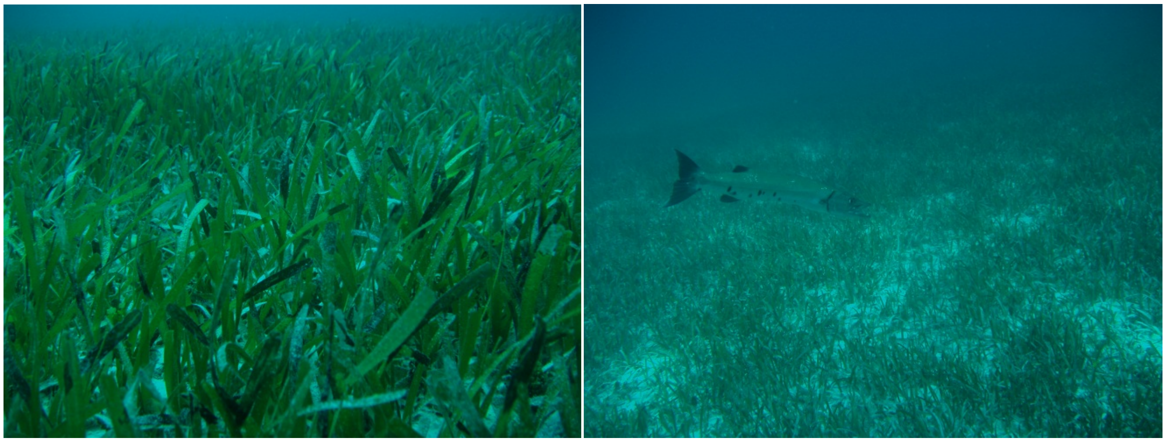
[2] Shallow coral framework – Areas of coral growth (e.g., *Acropora palmata*, *Montastraea* spp., *Agaricia tenuifolia*) shallower than 5 m, located in close proximity to the reef crest and on the reef flat. Live coral cover is less than 15% (lower right).



[3] Shelf-edge coral framework – Areas of coral growth (e.g., *Montastraea* spp., *Dendrogyra cylindrus*) located deeper than 10 m, near the platform edge, seaward of the reef crest, with live coral cover less than 20%.

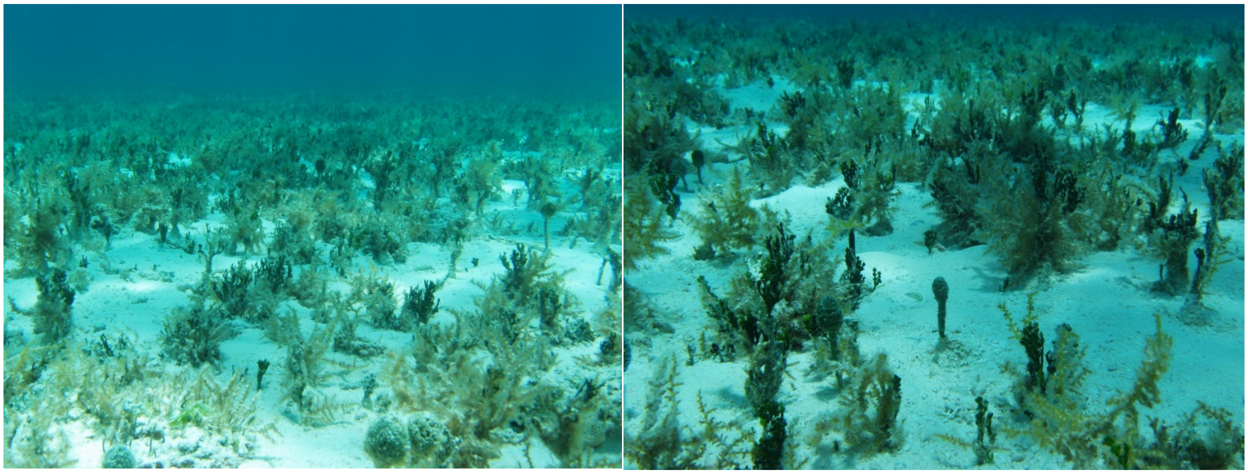
[4] Patch reef – Hardground areas within the lagoon, or in the case of a poorly developed reef rim, leeward of the platform margin. Assemblage comprised of scleractinian corals, hydrozoan corals, and gorgonians. Diameters of the patches vary from a few meters to several tens of meters. These structures typically occur in depths above 10 m, and the tops may reach up to a depth of 1 m. Live coral cover is less than 15%.

[5] Dense seagrass – Luxuriant meadows of seagrass (>60% cover) dominated by *Thalassia testudinum*. Other seagrasses (*Syringodium filiforme*) and macroalgae are typically present, but at a low density. The meadows are found within lagoons and in the sheltered platform interior, between depths of 3 m and 15 m.

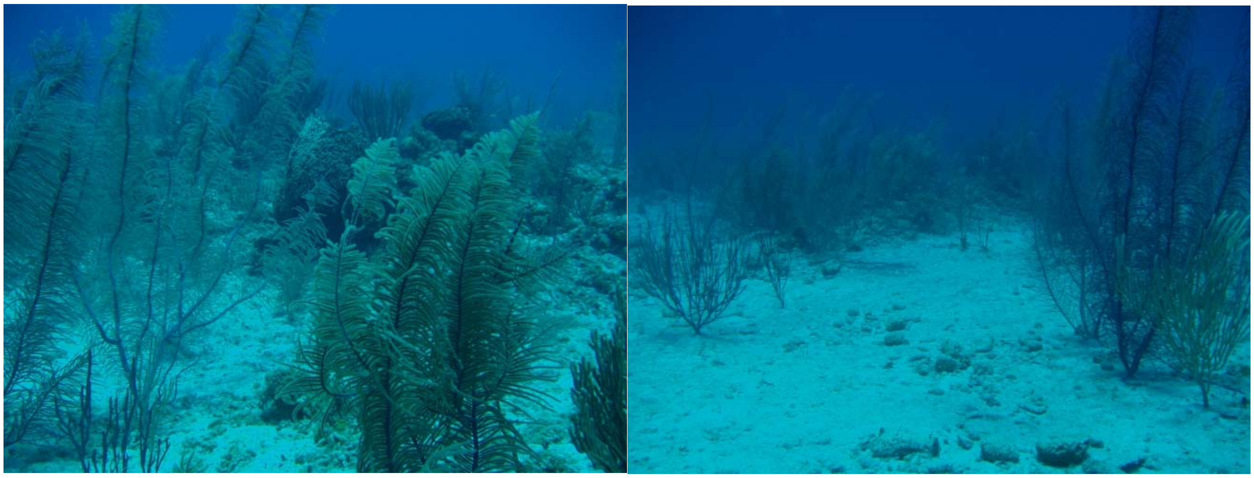


[6] Sparse to medium density seagrass – Sand with <60% seagrass cover. Dominant species are *Thalassia testudinum* and *Syringodium filiforme*. This class occurs most often in the lagoon and sheltered platform interior between depths of 3 m and 15 m.

[7] Medium to dense macroalgae in sand – Areas of unconsolidated sand with <5% seagrass cover and relatively high macroalgae cover (>60%). Located adjacent to the platform margin and leeward of the reef crest in depths above 5 m. Macroalgae are typically calcareous green algae.



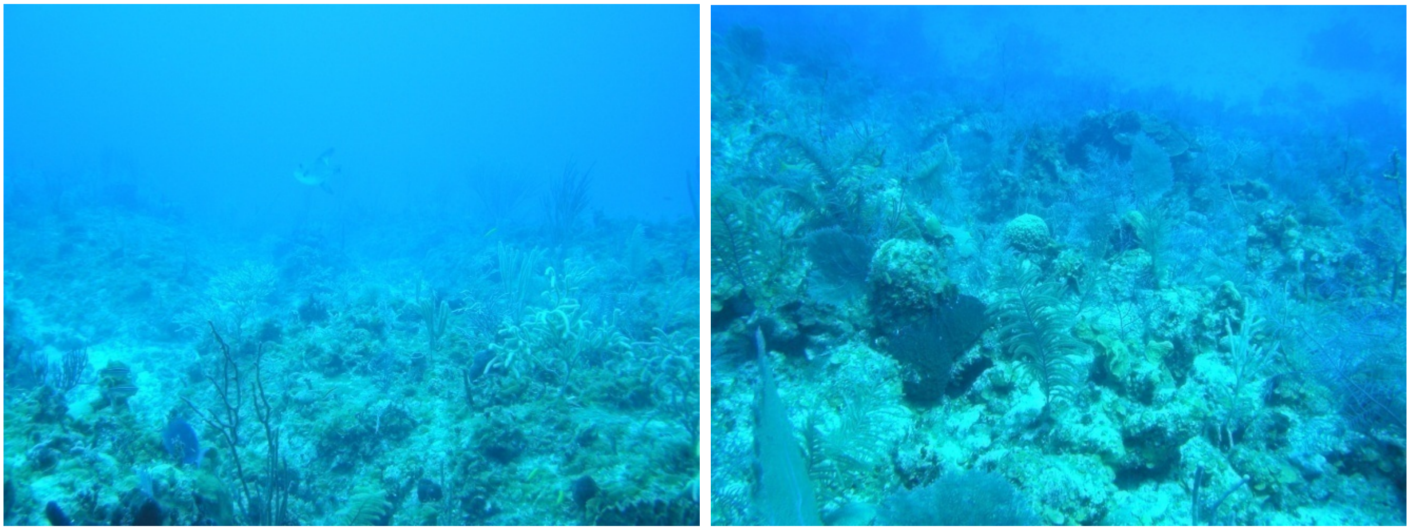
[8] Gorgonian-dominated hardground – Low rugosity sandy hardground hosting a high gorgonian density (> 10 m^{-2}), located leeward of the platform margin, in depths above 5 m.



[9] Macroalgae-dominated hardground – Low rugosity, rubbly hardground dominated by macro- and turf-algae with invertebrate cover (e.g., scleractinian corals, gorgonians, sponges) less than 5%. Encountered in proximity to the platform margin, leeward of the reef crest and atop the reef flat, in depths above 4 m.

[10] Scoured hardground – Bare flat hardground typically covered by a veneer of turf algae with sparse invertebrate cover (e.g., scleractinian corals, gorgonians, sponges) less than 5%. The class is encountered seaward of the reef crest occupying the reef slope between depths of 5 m and 15 m.

[11] Pleistocene-surface with coral colonies – Areas where the Pleistocene surface is exposed allowing growth of scleractinians (e.g., *Montastraea* spp., *Diploria* spp., *Dendrogyra cylindrus*), gorgonians, poriferans, and macroalgae. In aerial view, the features appear to be spur and groove structures, but *in situ* diver inspection finds they do not consist of coral framework. Instead, they are Pleistocene spurs interspersed with sand filled channels. This class is primarily located deeper than 10 m, and is found near the platform's flanks. Live coral cover is less than 20%.



[12] Sand – Unconsolidated, mobile, rippled sand sheets with little to no growth of invertebrates, seagrasses, or macroalgae. The category occurs over all depths and in all geomorphological zones.

[13] Land – Emergent sand cays formed by sediment accumulation.

[14] Deep water – Water depth exceeds 25 m and the seabed is too deep to map via satellite imagery.

Bathymetry

Bathymetric digital elevation model

A digital elevation model (DEM) representing seafloor topography was derived from the visible bands of the WV2 satellite imagery using field data and a statistical model. Geolocated water depth estimates were gathered using an acoustic depth sounder attached to a small research vessel. These data points were paired with WV2 image pixels using a nearest neighbour kernal. The statistical model was an expansion of the band ratio of Stumpf et al (2003) from linear regression to multiple linear regression (MLR). The MLR model contained six band ratios. The model's coefficients were estimated by comparing the water depth soundings with the paired band ratio values. The estimated coefficients were used to predict water depth for all pixels within the satellite image.

Map products

Satellite imagery, habitat maps and bathymetric maps are shown from each of the three locations (Fig. 12-14). Shallow marine habitats (<25 m) formed a narrow band around each island (Great Inagua and Little Inagua) and Hogsty Reef, before dropping abruptly into deep water a few hundred meters from shore. A well-developed shallow lagoonal environment was found inside the atoll-like shallow coral framework of Hogsty Reef. Small lagoonal habitats also occurred at the south/southwestern end of Great Inagua and Little Inagua. Hogsty Reef and Great Inagua had a shelf-edge coral framework at the edge of the drop-off consisting of a build-up of high relief *Montastraea* colonies on a Pleistocene substrate. This build-up was absent from Little Inagua. Instead, scattered coral colonies occurred on the Pleistocene substrate. A similar Pleistocene substrate with scattered coral colonies was also identified on Great Inagua. A framework composed of *Acropora* skeletons was identified in shallow water on Hogsty reef. Considerable *Acropora* habitat occurs in shallow (< 5 m depth) areas on both Great Inagua and Little Inagua. These areas, however, did not contain significant framework composed of these corals. Much of the habitat was hardground areas with some dead skeletons, living *Acropora palmata* colonies, and scattered gorgonians. Because of this, these habitat types are included as shallow coral framework.

In total, shallow marine habitats (areas less than 25 m depth) on Hogsty Reef covered a total of just over 39 sq. km, with 14% coral habitat, 21% hardground and 56% seagrass (Table 1). In Great Inagua, shallow marine habitats covered 354 sq. km. This included 27% coral habitat, 33% hardground, 20% seagrass, 33% hardground areas, and 18% sand (Table 2). In Little Inagua, shallow marine habitats amounted to 36 sq. km, with 43% coral habitat, 24% hardground, 12% seagrass and 21% sand (Table 3).

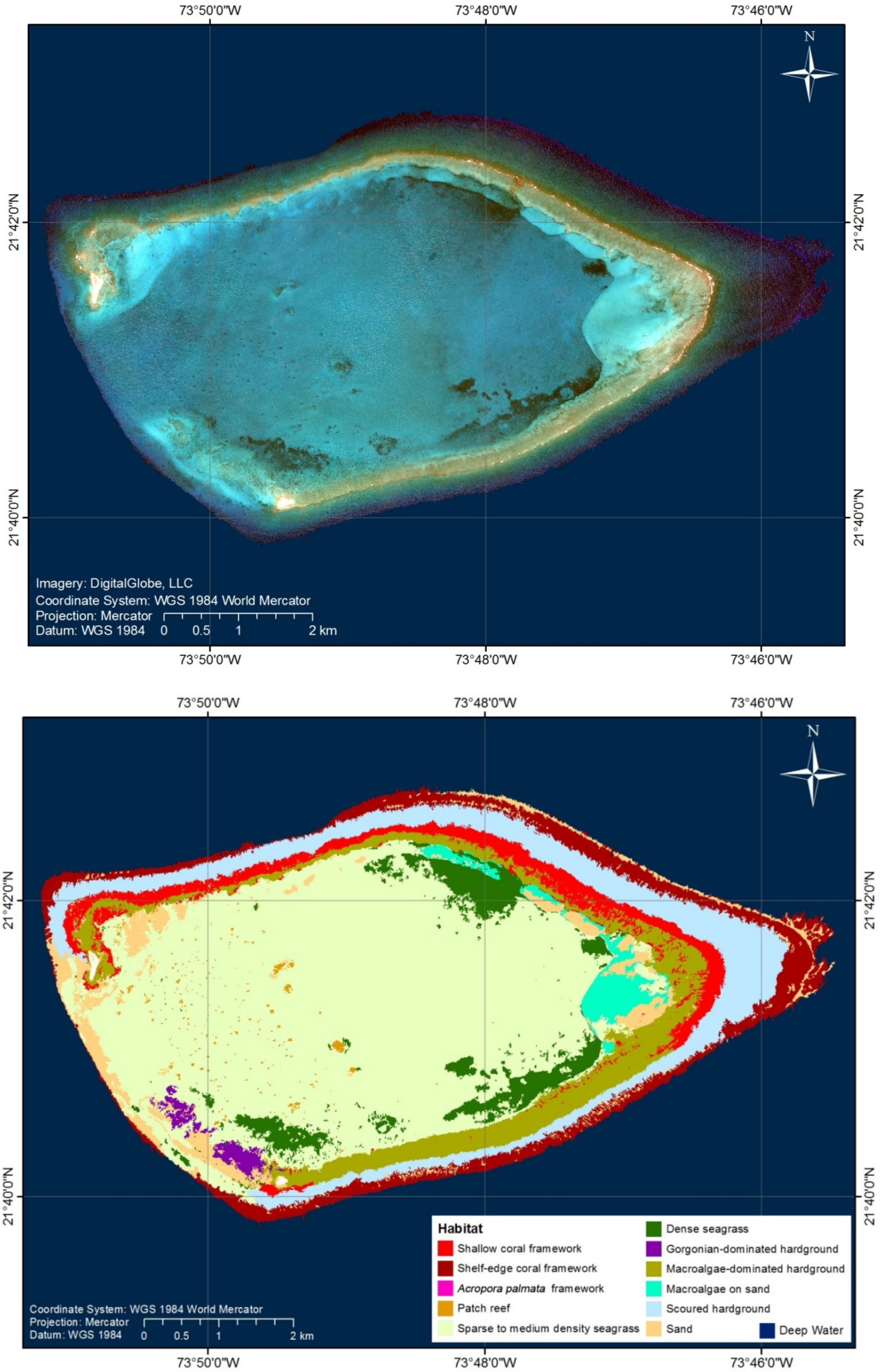


Fig. 12a. WorldView-02 satellite imagery (top) and resulting habitat map (bottom), Hogsty Reef, Bahamas.

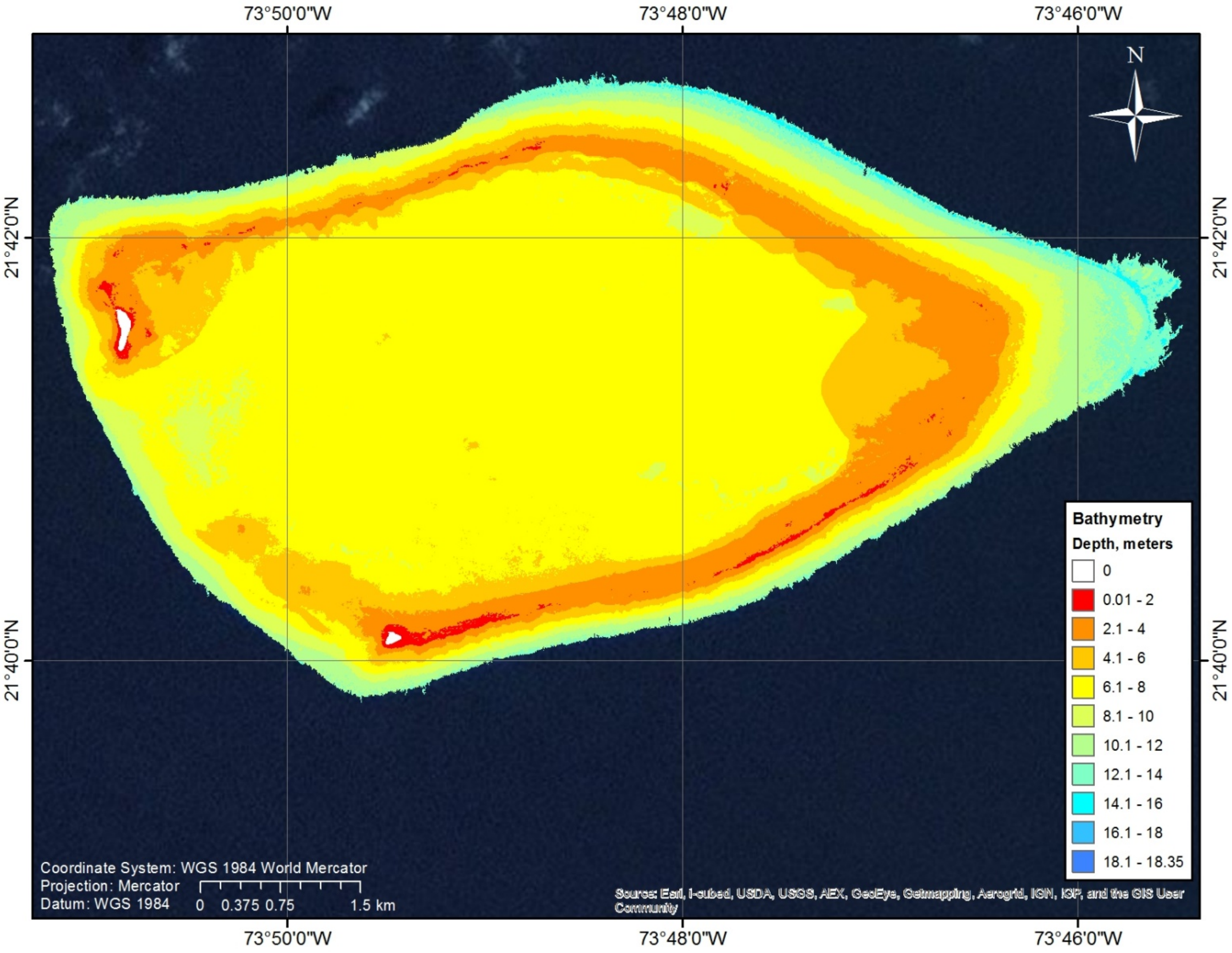


Fig. 12b. Underwater DEM of the seafloor for Hogsty Reef, the Bahamas. Depth values are in meters. Maximum estimated depth is 25 m.

Table 1. Total area of each habitat type identified on Hogsty Reef.

Hogsty Reef	**sq. km**
Shallow coral framework	2.19
Shelf-edge coral framework	3.27
Acropora palmata framework	0.00056
Patch reef	0.18
Sparse to medium density seagrass	20.02
Dense seagrass	2.03
Gorgonian-dominated hardground	0.33
Macroalgae-dominated hardground	3.39
Medium to dense macroalgae on sand	0.78
Scoured hardground	4.66
Sand	2.27
Land	0.04
Total	**39.16**

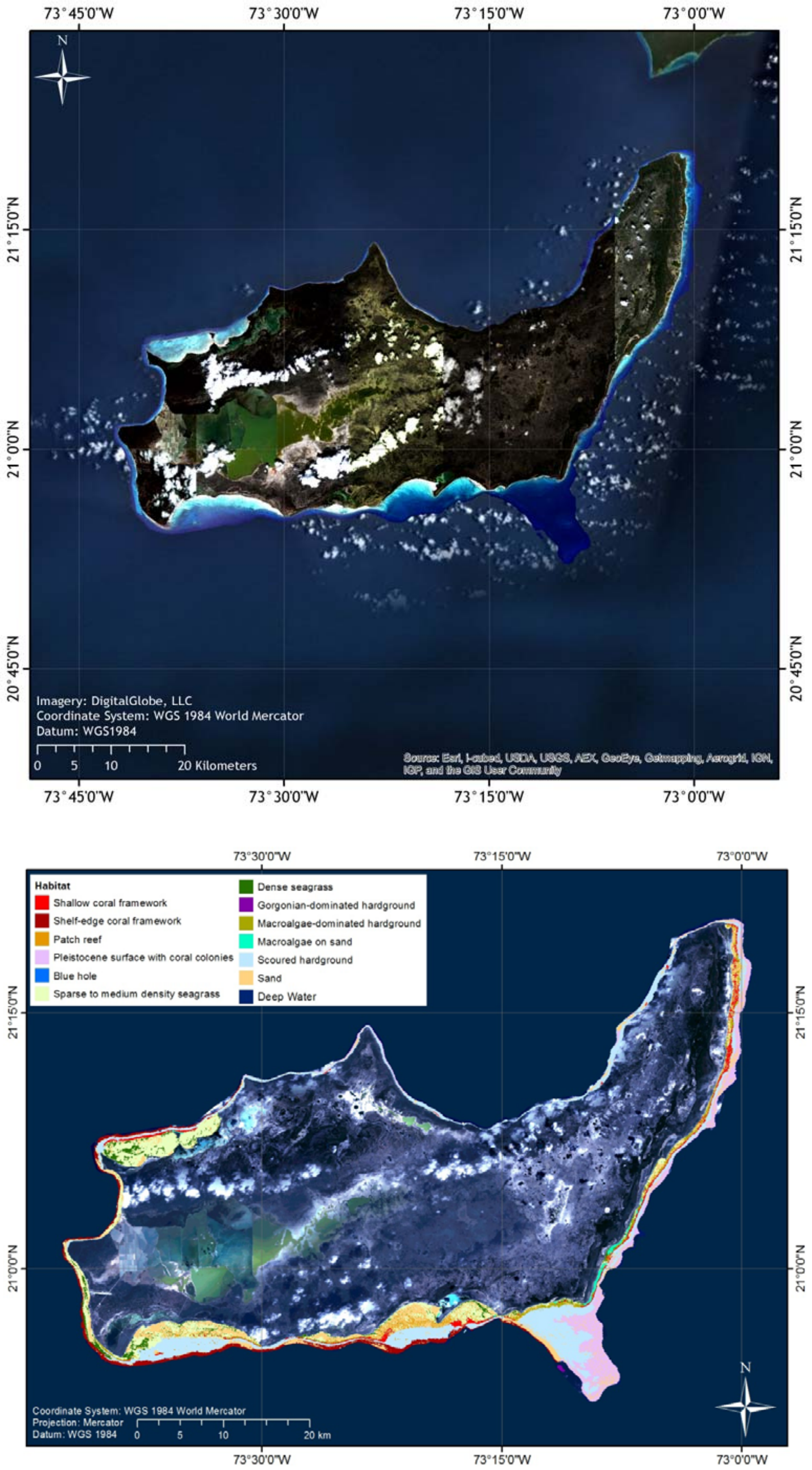


Fig. 13a. WorldView-02 satellite imagery (top) and resulting habitat map (bottom), Great Inagua, Bahamas.

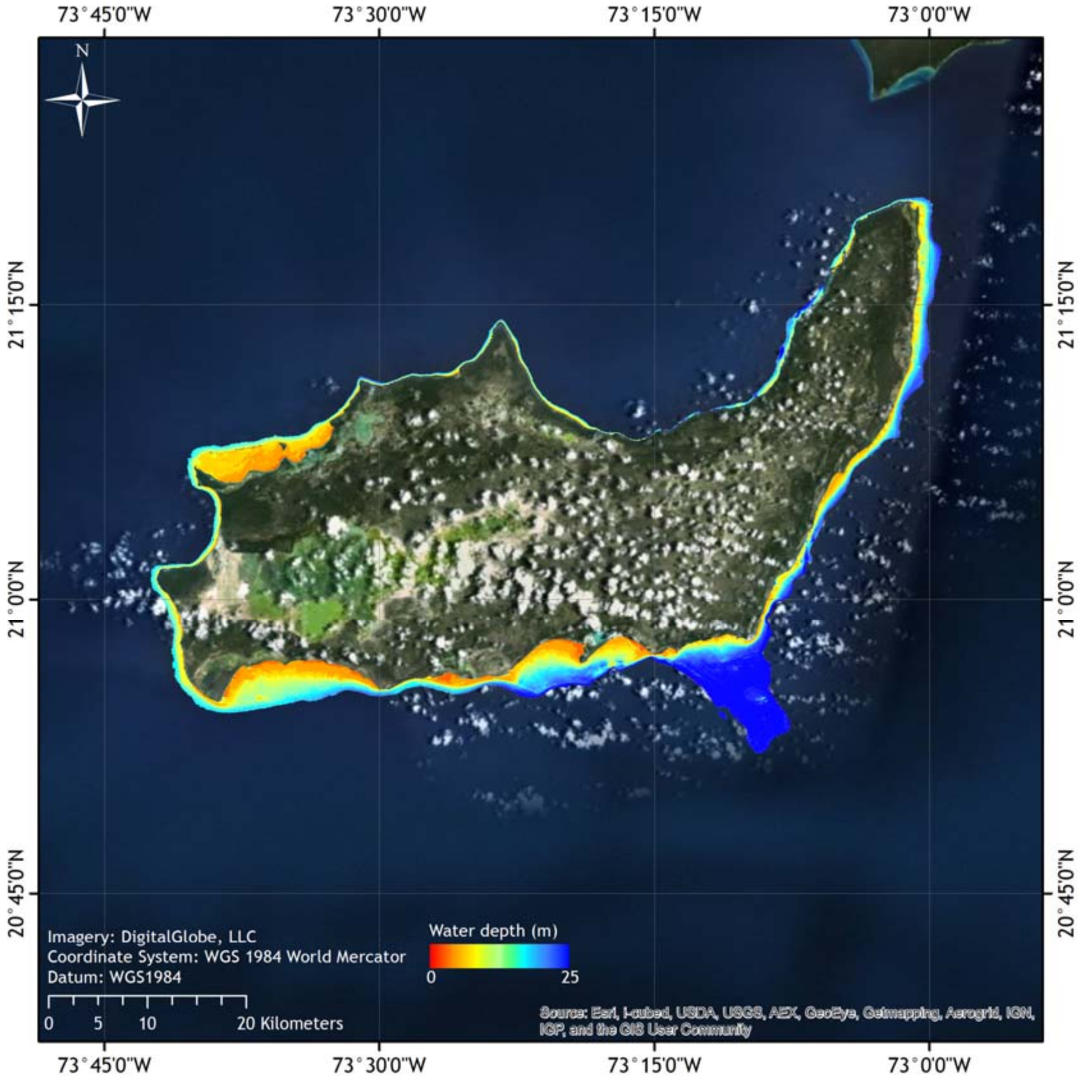
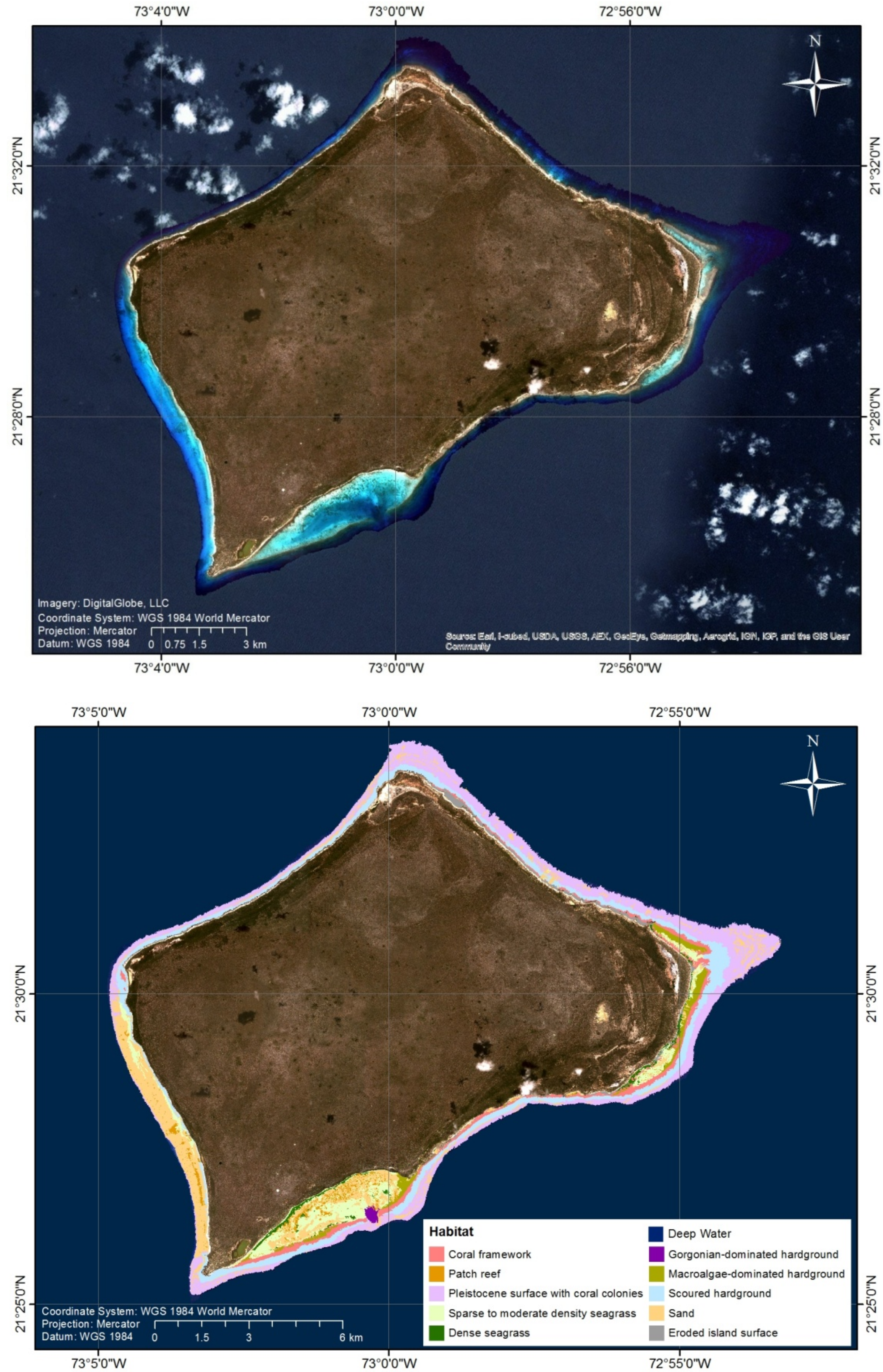


Table 2. Total area of each habitat type identified on Great Inagua.

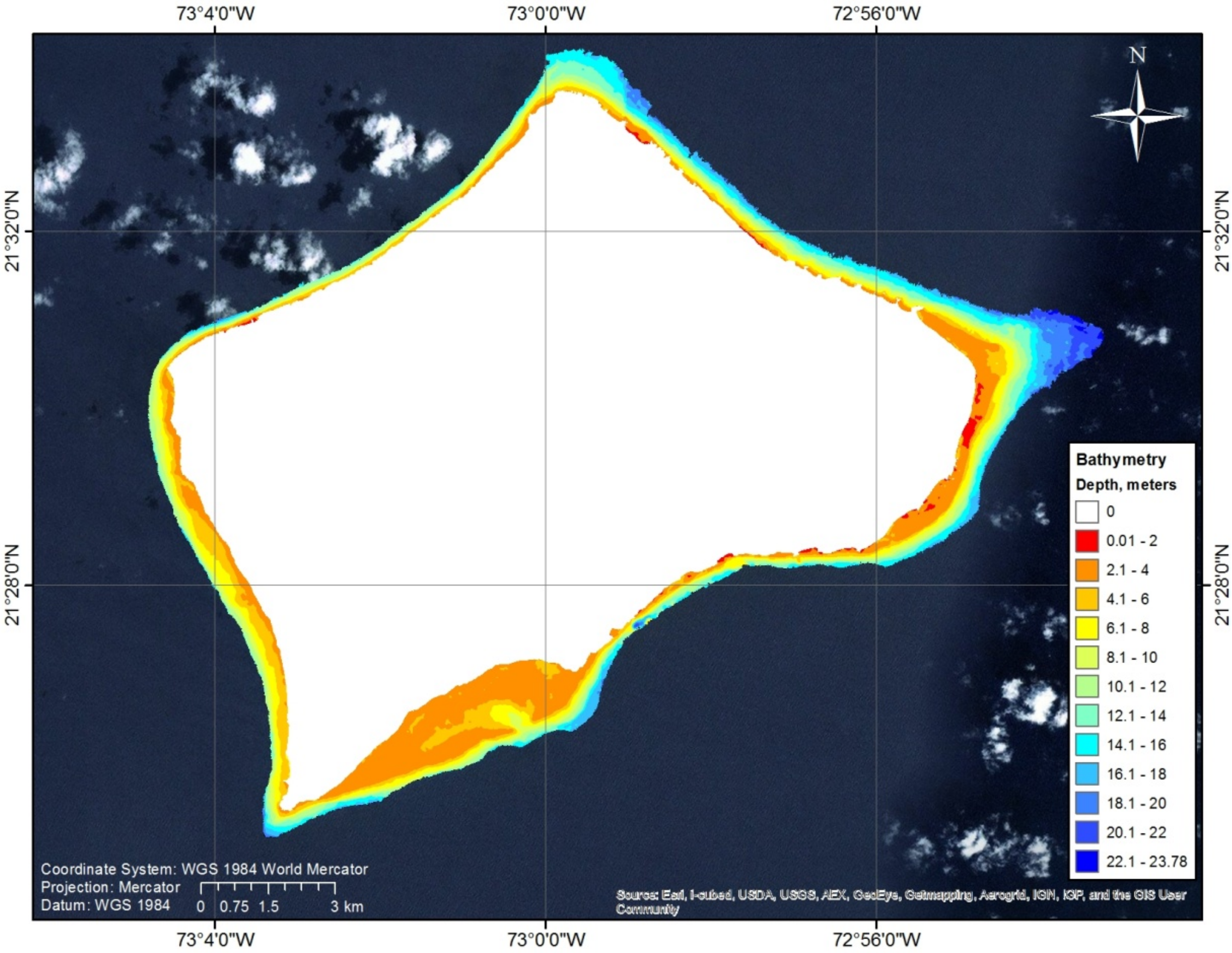
Great Inagua	**sq. km**
Shallow coral framework	14.87
Shelf-edge coral framework	26.10
Patch reef	7.88
Pleistocene surface with coral colonies	46.43
Sparse to medium density seagrass	57.68
Dense seagrass	14.50
Blue hole	0.002
Gorgonian-dominated hardground	0.42
Macroalgae-dominated hardground	9.06
Macroalgae on sand	3.09
Scoured hardground	65.29
Sand	108.86
Land	1765.92
Total	**2120.11**



Imagery: DigitalGlobe, LLC

Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Fig. 14a. WorldView-2 satellite imagery (top) and resulting habitat map (bottom), Little Inagua, Bahamas.



Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Fig. 14b. Resulting bathymetric map for Little Inagua, Bahamas.

Table 3. Total area of each habitat type identified on Little Inagua.

Little Inagua	**sq. km**
Coral framework	2.79
Patch reef	0.98
Pleistocene surface with coral colonies	11.89
Sparse to medium density seagrass	3.63
Dense seagrass	0.65
Gorgonian-dominated hardground	0.17
Macroalgae-dominated hardground	1.35
Scoured hardground	7.23
Sand	7.66
Eroded island surface	0.76
Land	151.10
Total	**188.21**

Coral reef assessments

General overview

Coral reef data presented here were collected predominantly on fore reef locations from 0-30 m depth, with one lagoonal site on Hogsty Reef (HR-08) and one reef crest site on Great Inagua (GI-03). A total of 18 sites were assessed on Great Inagua, 5 on Little Inagua and 8 on Hogsty Reef (Fig. 15). The coordinates and mean depths of each site are presented in Table 4.

The population dynamics of 3179 reef building corals were assessed within 59 belt transects on Great Inagua (52% of the corals), 27 on Hogsty Reef (36% of the corals), and 12 on Little Inagua (12% of the corals). Benthic assessments consisted of a total of 255 point intercept transects within Great Inagua (n=149), Hogsty Reef (n=67) and Little Inagua (n=39). A total of 288 fish surveys were conducted on Great Inagua (n=174), Hogsty Reef (n=66), and Little Inagua (n=48).

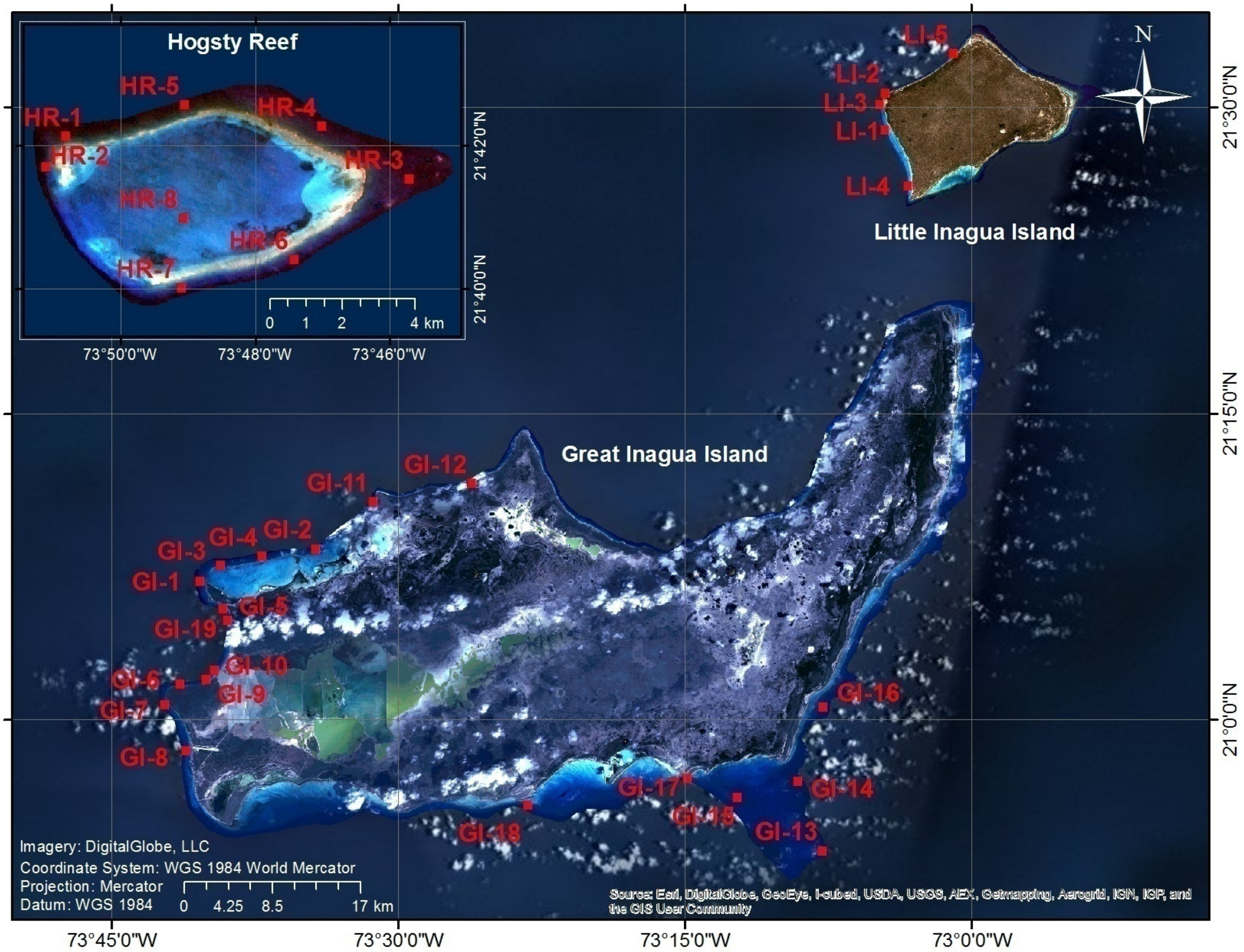


Fig. 15. Location of dive sites assessed on Great Inagua, Little Inagua and Hogsty Reef.

Table 4. Location and depth of dive sites assessed on Great Inagua (GI), Little Inagua (LI) and Hogsty Reef (HR).

Site	Island	Date	Latitude °N	Longitude °W	Depth (m)
GI-1	Great Inagua	8/6/2011	21.112410	-73.672710	18.0
GI-2	Great Inagua	8/7/2011	21.138840	-73.571520	11.6
GI-3	Great Inagua	8/7/2011	21.125590	-73.654720	3.0
GI-4	Great Inagua	8/8/2011	21.132903	-73.618659	16.0
GI-5	Great Inagua	8/8/2011	21.089570	-73.652510	9.0
GI-6	Great Inagua	8/12/2011	21.028540	-73.690210	12.0
GI-7	Great Inagua	8/12/2011	21.011520	-73.703640	11.0
GI-8	Great Inagua	8/12/2011	20.973790	-73.684740	9.0
GI-9	Great Inagua	8/13/2011	21.031890	-73.667540	15.0
GI-10	Great Inagua	8/13/2011	21.039340	-73.659720	13.0
GI-11	Great Inagua	8/14/2011	21.177470	-73.521470	9.0
GI-12	Great Inagua	8/14/2011	21.192410	-73.435320	10.0
GI-13	Great Inagua	8/15/2011	20.891640	-73.129650	17.0
GI-14	Great Inagua	8/15/2011	20.948550	-73.151500	14.0
GI-15	Great Inagua	8/15/2011	20.935350	-73.204070	13.0
GI-16	Great Inagua	8/16/2011	21.009120	-73.128970	14.0
GI-17	Great Inagua	8/16/2011	20.950750	-73.247720	8.5
GI-18	Great Inagua	8/16/2011	20.929300	-73.386670	11.0
GI-19	Great Inagua	8/17/2011	21.080230	-73.648860	15.0
LI-1	Little Inagua	8/18/2011	21.480960	-73.075150	10.0
LI-3	Little Inagua	8/19/2011	21.501690	-73.080150	17.0
LI-2	Little Inagua	8/19/2011	21.511390	-73.075390	16.0
LI-4	Little Inagua	8/20/2011	21.435660	-73.054910	18.0
LI-5	Little Inagua	8/20/2011	21.543700	-73.015750	19.5
HR-1	Hogsty Reef	8/9/2011	21.702000	-73.847000	11.0
HR-2	Hogsty Reef	8/9/2011	21.695000	-73.852000	12.0
HR-3	Hogsty Reef	8/10/2011	21.692100	-73.762020	18.0
HR-4	Hogsty Reef	8/10/2011	21.704480	-73.783610	17.0
HR-5	Hogsty Reef	8/10/2011	21.709420	-73.817710	11.0
HR-6	Hogsty Reef	8/11/2011	21.673580	-73.790470	13.0
HR-7	Hogsty Reef	8/11/2011	21.666860	-73.818470	12.0
HR-8	Hogsty Reef	8/11/2011	21.683170	-73.817770	5.0

Methods

A combination of quantitative methods including belt transects, radial plots and quadrats were used to assess corals, fish and other benthic organisms. Five measures were recorded for corals: 1) benthic cover; 2) coral diversity and abundance (by species); 3) coral size class distributions (by species); 4) recruitment; and 5) coral condition. Additional information was collected on causes of recent mortality, including signs of coral disease and predation. For fish, data on abundance and size structure were collected along 2 m X 30 m belt transects for about 70 species of fishes, targeting species that have a major functional role on reefs or are major fisheries targets. Other indicators recorded along belt transects included large motile invertebrates (urchins, octopus, lobster, large crabs, sea cucumbers); cover and biomass of algae (fleshy macroalgae, turf algae and crustose coralline algae); and prevalence of nuisance species.

Sampling for corals smaller than 4 cm was done using a minimum of five 0.25 m^2 quadrats per transect, with each quadrat located at fixed, predetermined intervals (2, 4, 6, 8, 10 m), alternating between right and left side of the transect line. Recruits were identified in both point intercept surveys and belt transects. Recruits were divided into two categories: corals up to 2 cm diameter and larger corals, 2-3.9 cm diameter.

Visual estimates of tissue loss were recorded for each colony over 4 cm in diameter using a 1 m bar marked in 1 cm increments for scale. If the coral exhibited tissue loss, estimates of the amount of remaining tissue, percent that recently died and percent that died long ago were made based on the entire colony surface. Tissue loss was categorized as recent mortality (occurring within the last 1-5 days), transitional mortality (filamentous green algae and diatom colonization, 6-30 days) and old mortality (>30 days). For each coral with partial or whole colony mortality, the cause of mortality was identified if possible. The diagnosis included an assessment of the type of disease, extent of bleaching, predation, competition, overgrowth or other cause of mortality. Each coral was first carefully examined to identify cryptic predators. Lesions were initially diagnosed into four categories: recent tissue loss, skeletal damage, color change, and unusual growth patterns; an individual colony could have multiple characteristics (e.g. color change and recent tissue loss). The location (apical, basal, medial) and pattern of tissue loss (linear, annular, focal, multifocal, and coalescing) were recorded, and when possible a field name was assigned.

Cover of benthic organisms (plants and animals) was estimated using a point intercept method. At each site, a minimum of six 10 meter long transects were deployed. The organism and substrate type were recorded every 10 cm for a total of 100 points per transect. Substrates included hardground, rubble, sand/silt, and dead coral. All corals were identified to species and recorded as live, bleached, recently dead or long dead. Invertebrates were identified to the lowest taxonomic level possible. Sponges, if present, were differentiated into crustose, rope, massive, tube and barrel sponges, unless identification was possible. Algae were divided into five functional groups (fleshy macroalgae, erect coralline algae, crustose coralline algae, turf algae, cyanobacteria). Additional measurements of algal height were recorded for macroalgae.

On each reef two divers completed a minimum of six 30 X 2 m belt transects to assess the community structure of the dominant reef fish assemblages. All species were identified and their size was estimated to the nearest 5 cm using a T-bar marked in 5 cm increments for scale. The assessment focused on species that are ecologically relevant to the health of reefs and also important for commercial or recreational fisheries. The emphasis was on herbivores, invertebrate feeders and larger piscivores. Additional roving surveys were undertaken to characterize species diversity.

Benthic cover

Substrate type

A total of 255 point intercept transects were used to determine the cover of benthic organisms and substrate types within Great Inagua (n=149), Hogsty Reef (n=67) and Little Inagua (n=39). Reef substrates were predominantly hardground with <5% consisting of rubble, sand, dead coral, and up to 21% live coral (Fig. 16). Hardground was mostly colonized by macroalgae (Fig. 16), and very little bare substrate was present. While dead coral was a minor component of the substrate, several sites had a moderate cover of dead coral, including transects on GI-17 (8.2%), LI-01 (10.8%), LI-03 (9.3%), LI-04 (6.5%), HR-06 (6.3%) and HR-07 (10.3%).

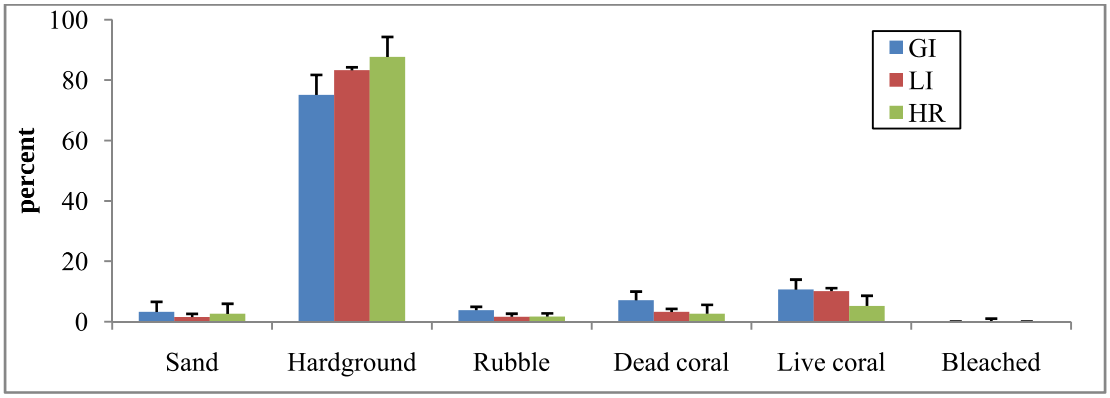


Fig. 16. Type of substrate on reefs examined on Great Inagua (blue), Little Inagua (red) and Hogsty Reef (green).

Algal cover

Cover of algal functional groups (Fig. 17a) varied considerably among sites. Fleshy macroalgae ranged from <6-63%, with higher cover overall at Hogsty Reef (mean=49%) and lowest at Great Inagua (mean=26%). Erect coralline algae was uncommon at Hogsty Reef (mean cover = 1.4%) and moderately abundant at Little Inagua (mean cover= 10.4%). Three sites on Great Inagua (GI-03, 4, and 15) had unusually high cover of fleshy macroalgae, while all sites on Hogsty Reef and two sites on Little Inagua (LI-02, 5) had high cover of fleshy macroalgae. Crustose coralline algae ranged from 4-26%, with the highest mean cover at Hogsty Reef (18.6%). Cover of turf algae was similar at Great and Little Inagua, and roughly equal to the cover of crustose coralline algae (CCA), while CCA was fairly high (18.6%) and turf algae was very low (1.4%) at Little Inagua. Cyanobacteria was rare, except on Great Inagua at GI-10 (3.3%), GI-18 (4.5%) and GI-19 (4.3%) (Fig. 17b).

Fig. 17a. Typical algal community on a reef wall off Great Inagua. A small coral colony (*Madracis* spp.) in the top center is surrounded by erect coralline algae (*Halimeda*), with a small patch of crustose coralline algae (CCA) below the coral and filamentous red cyanobacteria intermixed with the *Halimeda*.

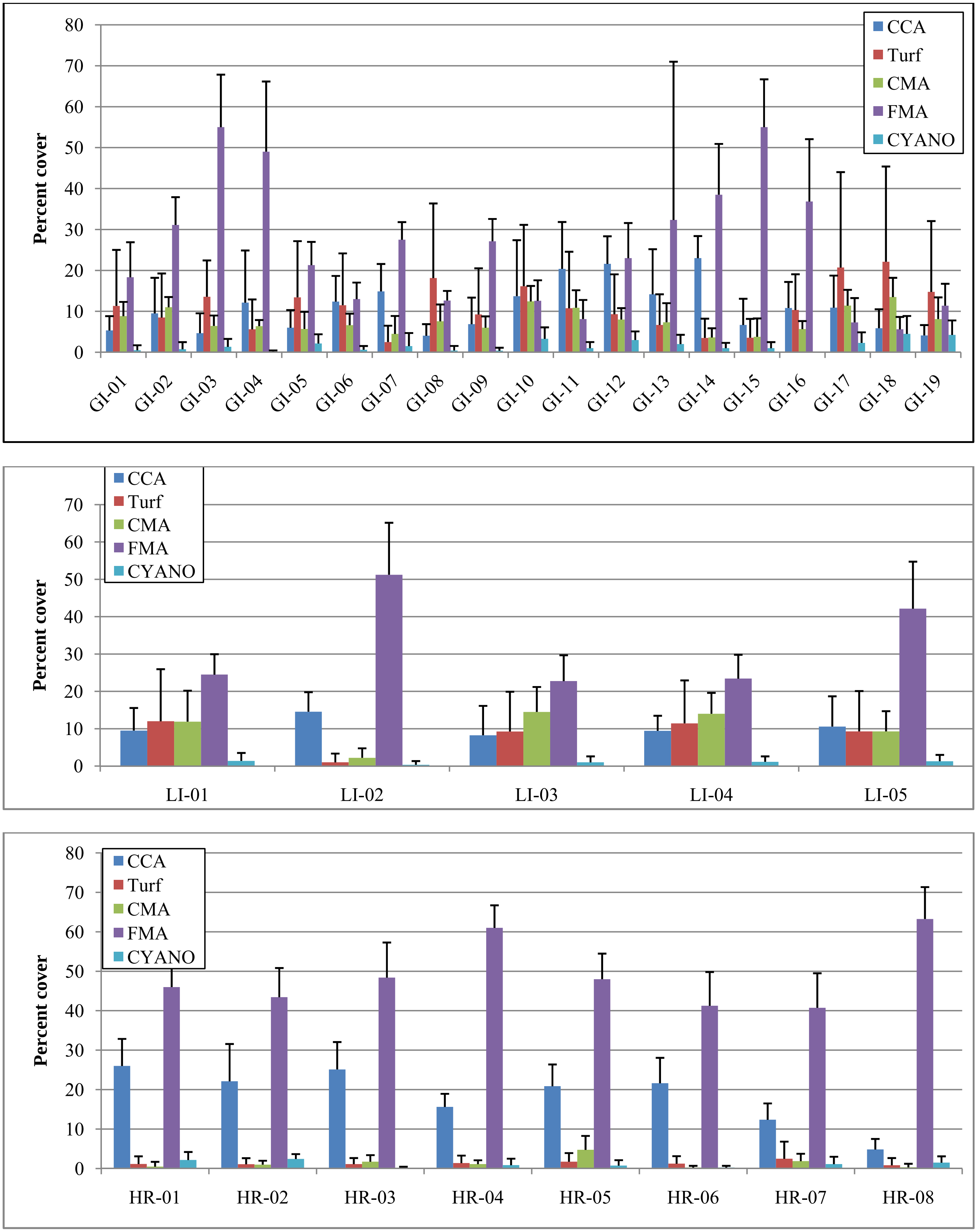


Fig. 17. Cover of major algal functional groups at Great Inagua (top), Little Inagua (middle) and Hogsty Reef (bottom) each survey location. CCA= crustose coralline algae; TURF=turf algae; CMA=erect coralline algae; FMA=fleshy macroalgae; CYANO=cyanobacteria.

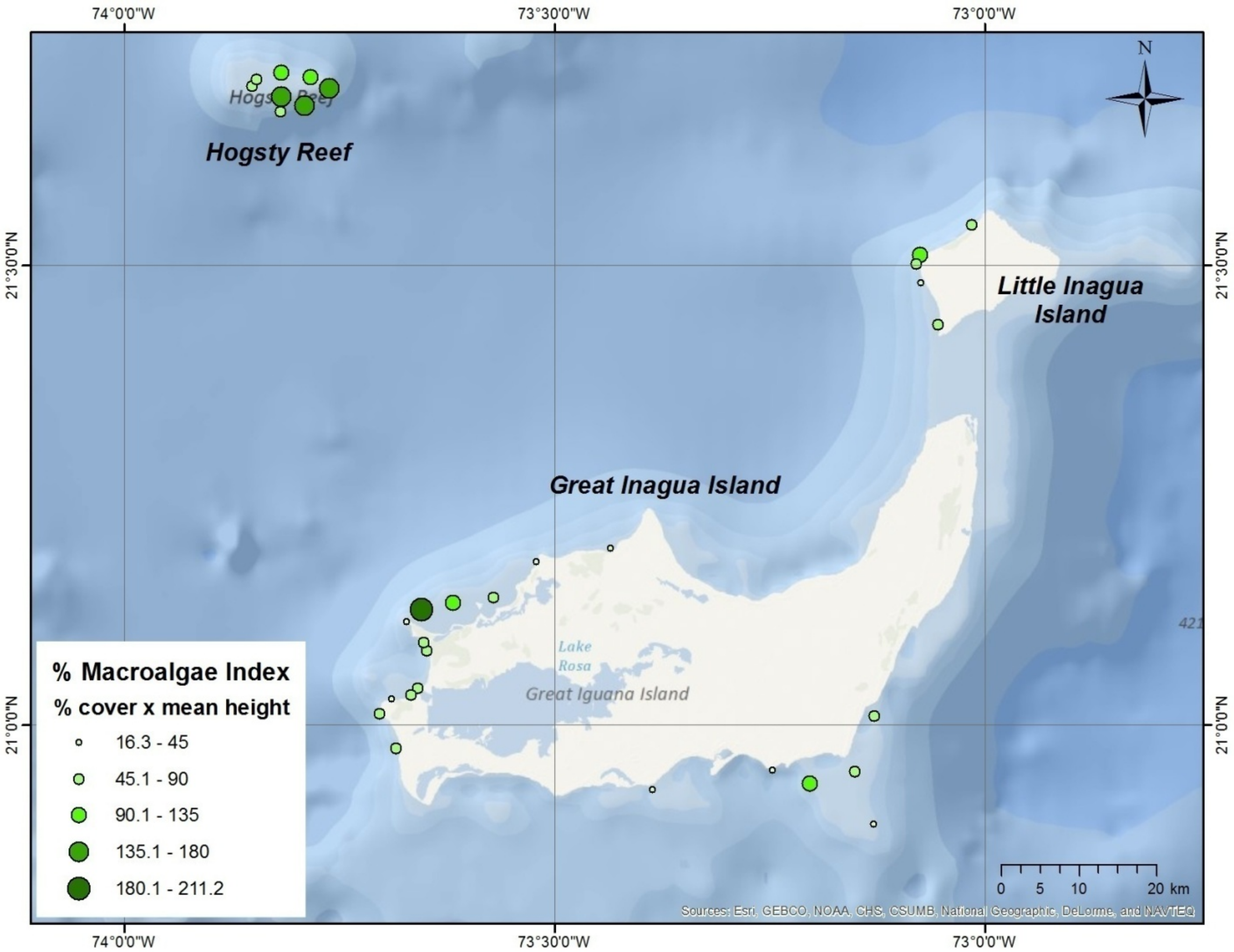


Fig. 18. Map of the macroalgal index at study locations in Great Inagua, Little Inagua and Hogsty Reef. The larger green circles indicate sites with higher biomass of fleshy macroalgae.

Macroalgal index

To get a better sense of the amount of macroalgae at each site, percent cover and canopy height of macroalgae was assessed as a proxy for macroalgal biomass. Reefs in decline often have a high fleshy macroalgal biomass. Macroalgal cover and algal height varied threefold among sites. Lowest cover overall was observed at Great Inagua (five sites had 18-19% cover) and highest at Hogsty Reef (cover exceeded 40% at every site examined), while algal height varied from a low of 0.8 cm (LI-01) to 3.2 cm (GI-03). In general, the macroalgal index was lowest at Great Inagua, with exception of one site (GI-03). The mean value (all reefs pooled) was nearly twice as high at Hogsty Reef compared to Great Inagua and Little Inagua (Fig. 18).

Coral cover

Coral cover (corrected for sand), estimated for each site from 6-10 transects, ranged from a low of 1% (GI-15, GI-16) to a maximum of 21.4% (GI-05). Coral cover was highest on Great Inagua (mean=10.9%), followed by Little Inagua (10.2%) and Hogsty Reef (5.4%) (Fig.19).

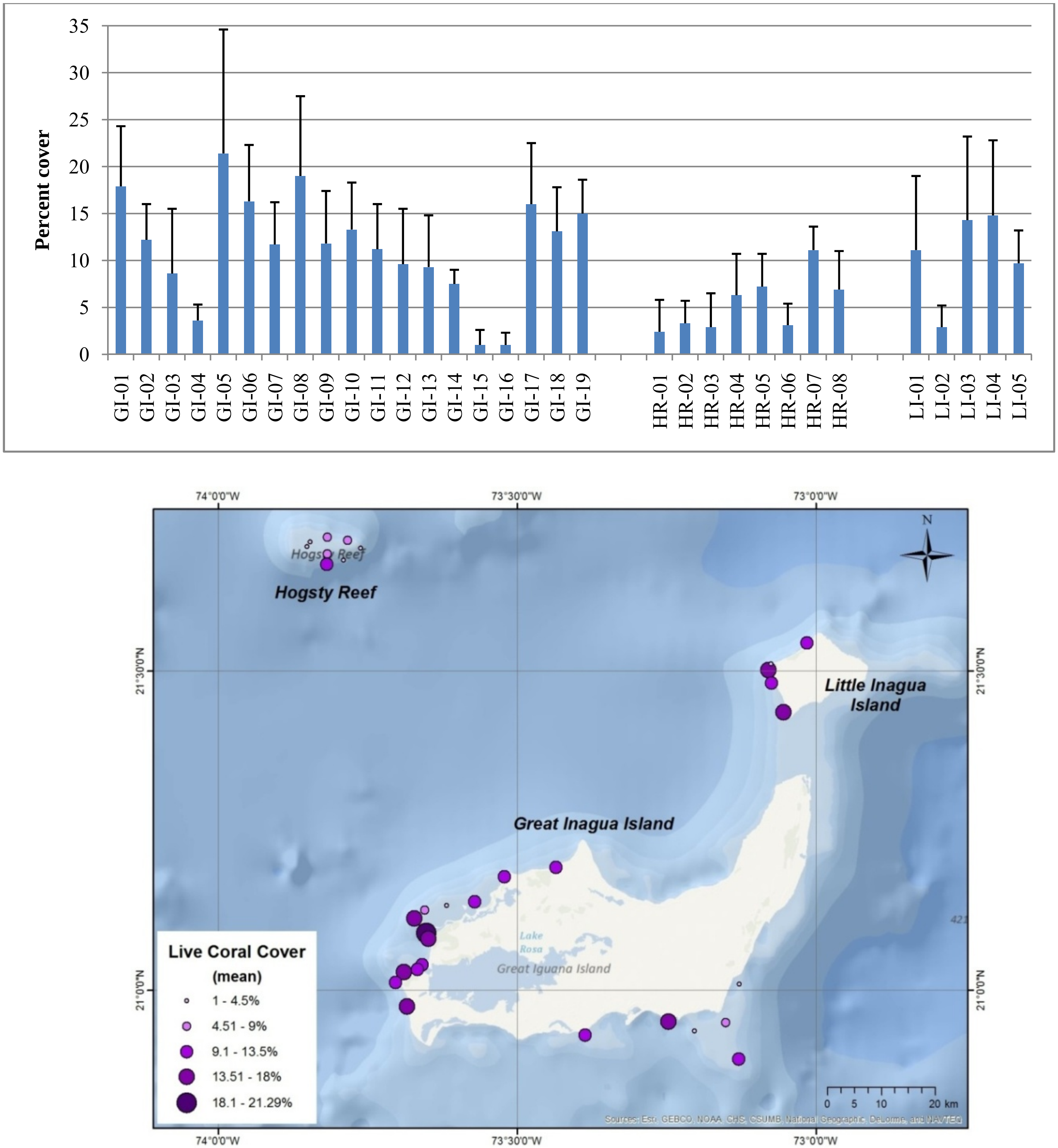
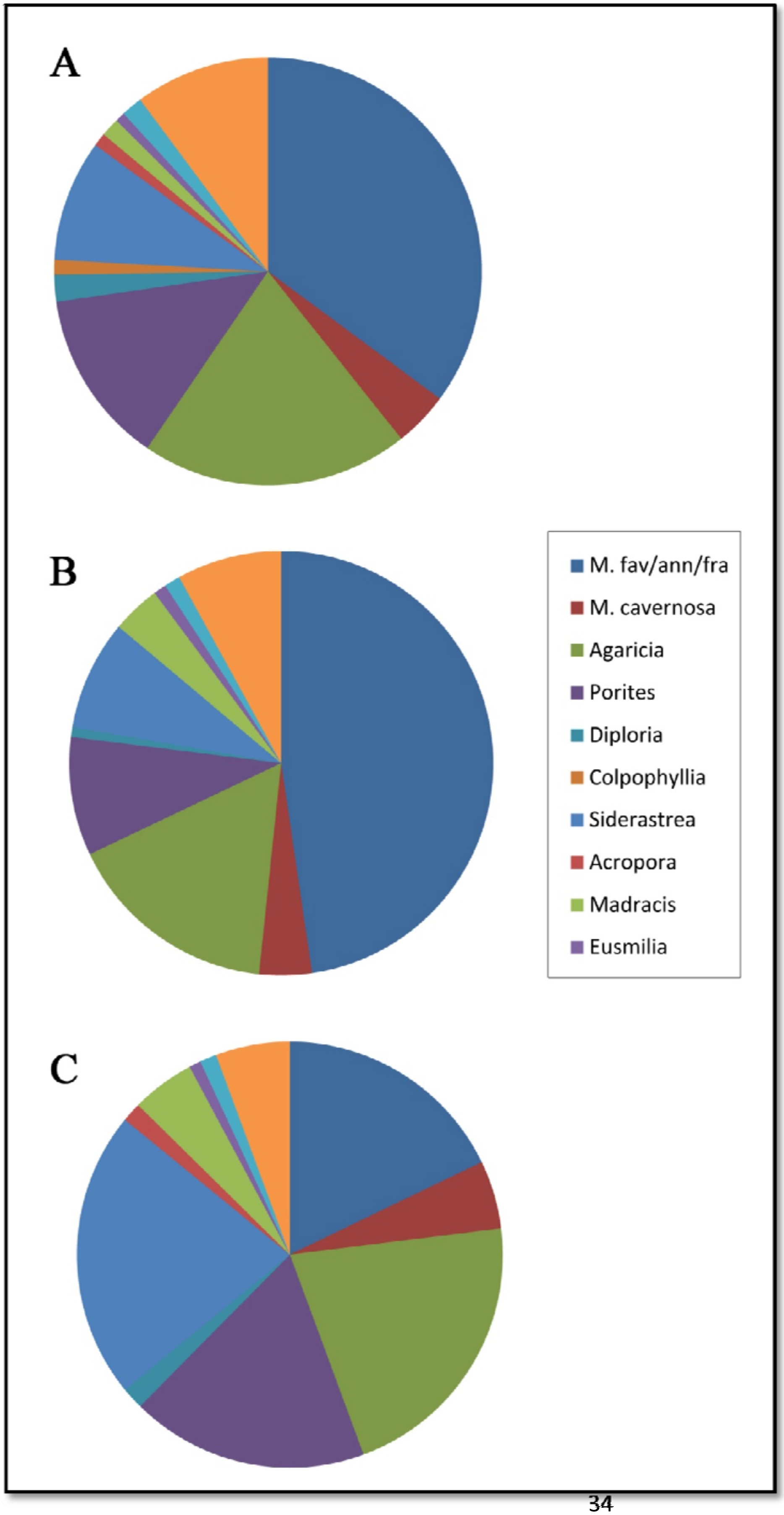


Fig. 19. Mean percent live coral cover at sites examined in Great Inagua, Little Inagua and Hogsty Reef. The top figure shows the mean and standard error for each site examined while the lower figure provides a map-based bubble plot illustrating differences in cover.



Coral population structure

Live cover by species

Living coral cover was dominated by 10 species, with the remainder of the corals composing less than 1.1% cover (all species pooled) (Fig. 20). The three species of *Montastraea annularis* made up most of the live cover in the three locations (pooled for all sites in each location), although this amounted to only 0.9% (Hogsty) – 4.8% (Little Inagua) living cover. At two sites *M. annularis* (complex) cover exceeded 10% (LI 03, LI 05); cover of this complex was greater than 5% at seven other sites (GI-05, 06, 09, 17, LI-01, 03, 04). Other genera with cover exceeding 3% included *Agaricia* (GI-01, 05, 06, 11, 19; LI 04), *Porites* (GI-05, 13, 19), and *Siderastrea* (HR-08). Living coral cover for all other corals was lower.

Fig. 20. Relative cover illustrated as the proportion of each taxon for the dominant corals at Great Inagua (A), Little Inagua (B) and Hogsty Reef (C). All species in each genus are pooled except *Montastraea* which is separated into the *M. annularis* complex (dark blue; M.fav/ann/fra) and *M. cavernosa* (dark red).

Coral diversity

A total of 39 species of corals were identified in transects, with two other species observed outside of transects (*A. cervicornis* and *Dendrogyra cylindrus*). Corals occurred at a density of 2.8 (GI), 4.2 (HR), and 3.3 (LI) colonies per square meter. In the three locations, *Agaricia agaricites* was the most abundant coral (23%), followed by *Siderastrea siderea* (18.2%), *Porites astreoides* (15.4%), *Montastraea annularis* (10%), *M. cavernosa* (5.4%), *M. faveolata* (4.6%) and *P. porites* (4.3%). Hogsty Reef had a significantly higher proportion of *A. agaricites* and *S. siderea* colonies and fewer *M. annularis* colonies than the other two locations, while *P. astreoides* was more abundant at Little Inagua (Fig. 21).

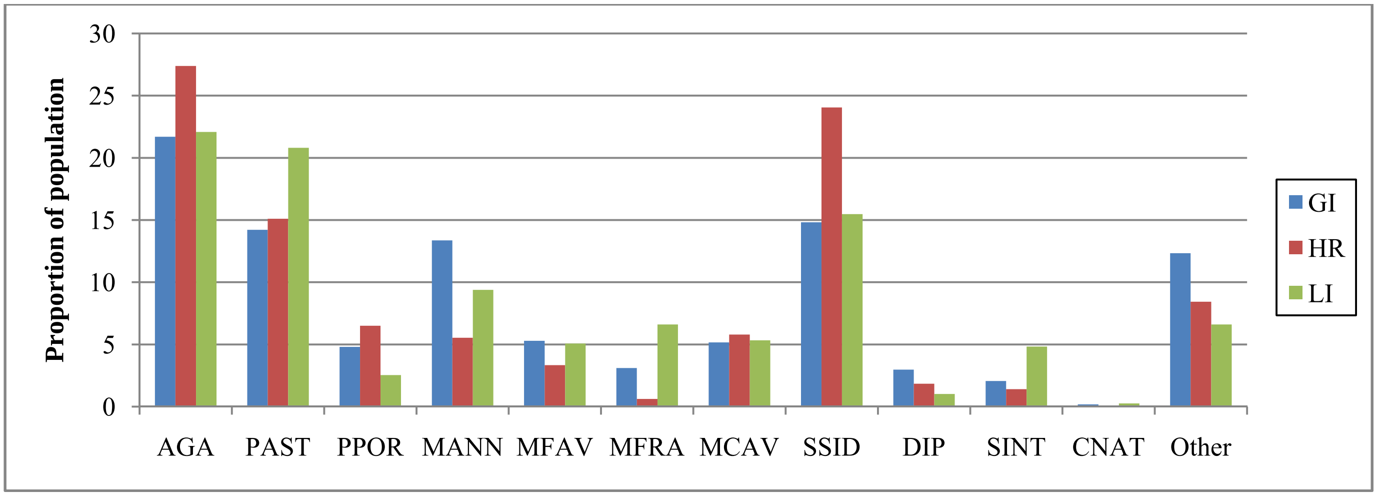


Fig. 21. Relative abundance (percent of the total population of corals) of the dominant coral taxon for Great Inagua (blue bars) Hogsty Reef (red bars) and Little Inagua (green bars). AGA is predominantly *Agaricia agaricites* with a low number of five other species of *Agaricia*. DIP includes *Diploria strigosa*, *D. labyrinthiformis* and *D. clivosa*. Other includes 22 species.

Coral size-frequency distributions

Coral sizes (diameter and height) were measured for all corals 4 cm diameter or larger within belt transects. Reef communities (all sites pooled) were dominated by small to medium-sized corals (11-160 square cm), with a total of 20% of the population consisting of colonies larger than 320 sq. cm (Fig. 22).

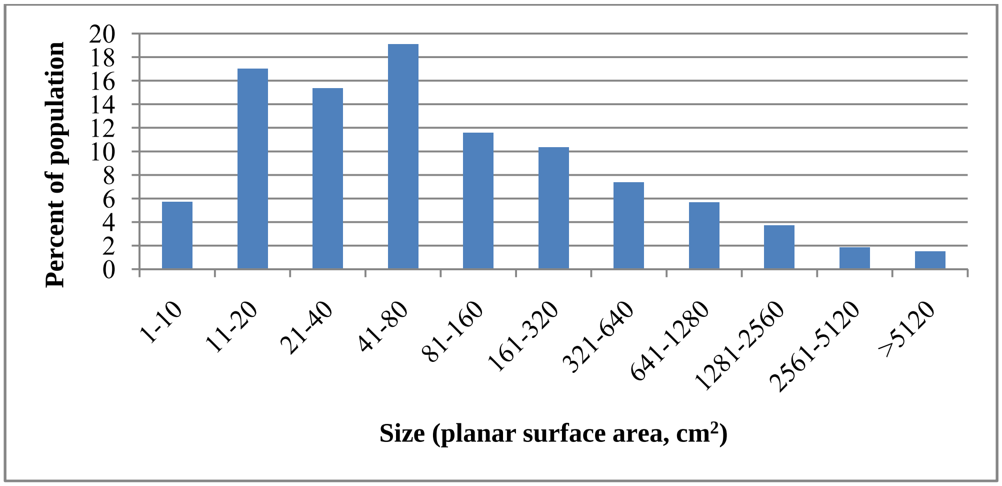


Fig. 22. Mean size of corals on Great Inagua, Hogsty Reef and Little Inagua. All sites and species are pooled. Size is the planar surface area calculated for an ellipse (3.14 X 1/2 diameter X 1/2 width).

Distinct differences in size were observed among species with *M. annularis* colonies being larger than all other corals, overall (Fig. 23-25). The only exceptions were a small number of *A. palmata*, isolated *Dendrogyra cylindrus* and *Colpophyllia natans*. In general, brooding species (*Agaricia* and *Porites*) were dominated by small colonies (< 80 sq. cm; Fig 23), while *M. annularis* complex populations consisted predominantly of large colonies (Fig. 24) and massive broadcast spawners (*M. cavernosa*, *S. siderea*, *S. intersepta*) had both small and medium-sized colonies (Fig. 25).

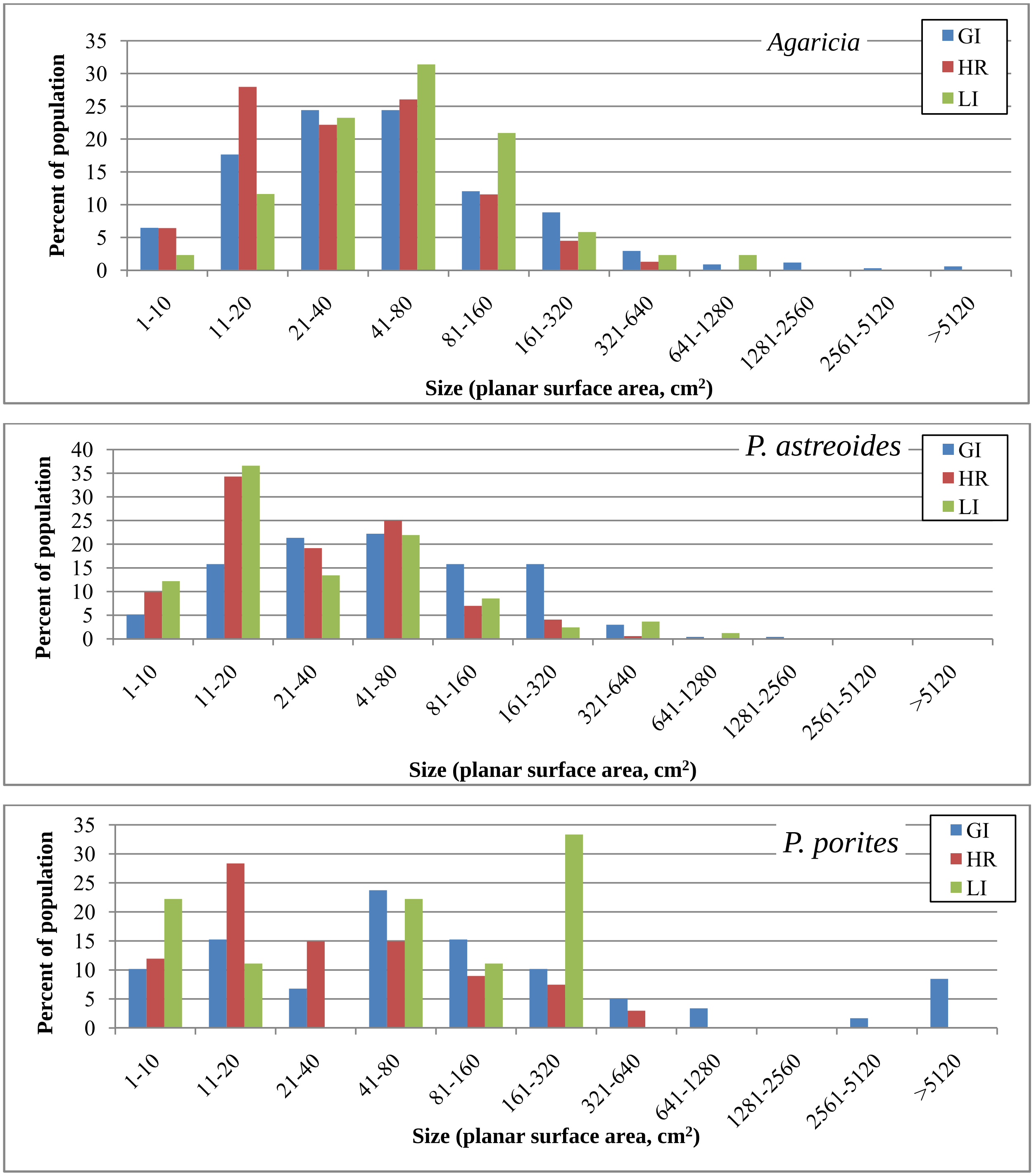
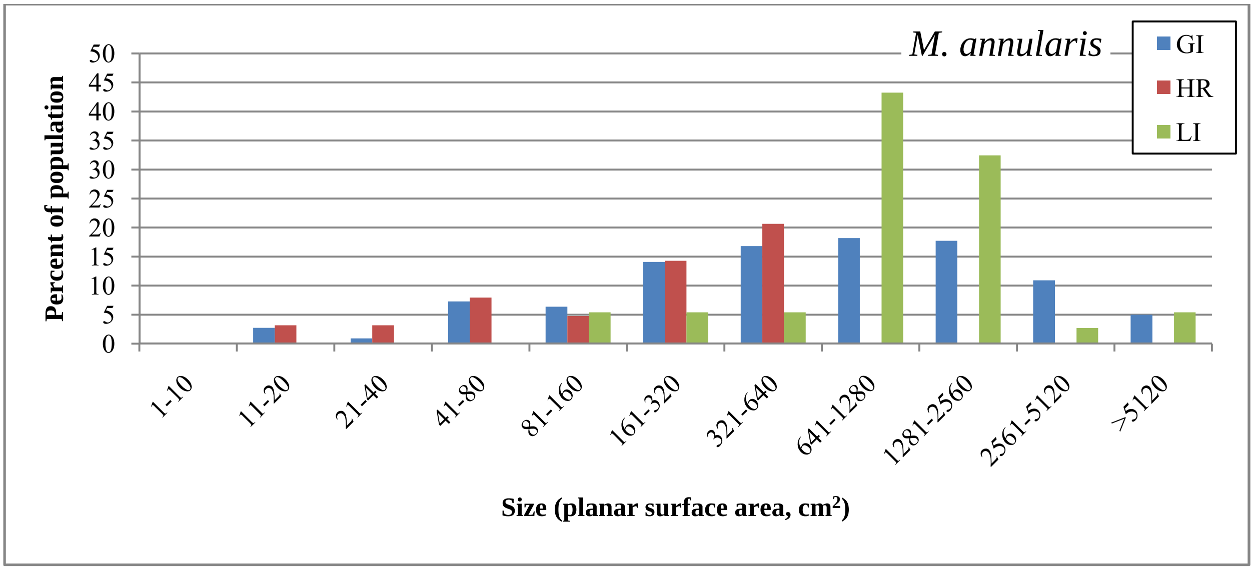
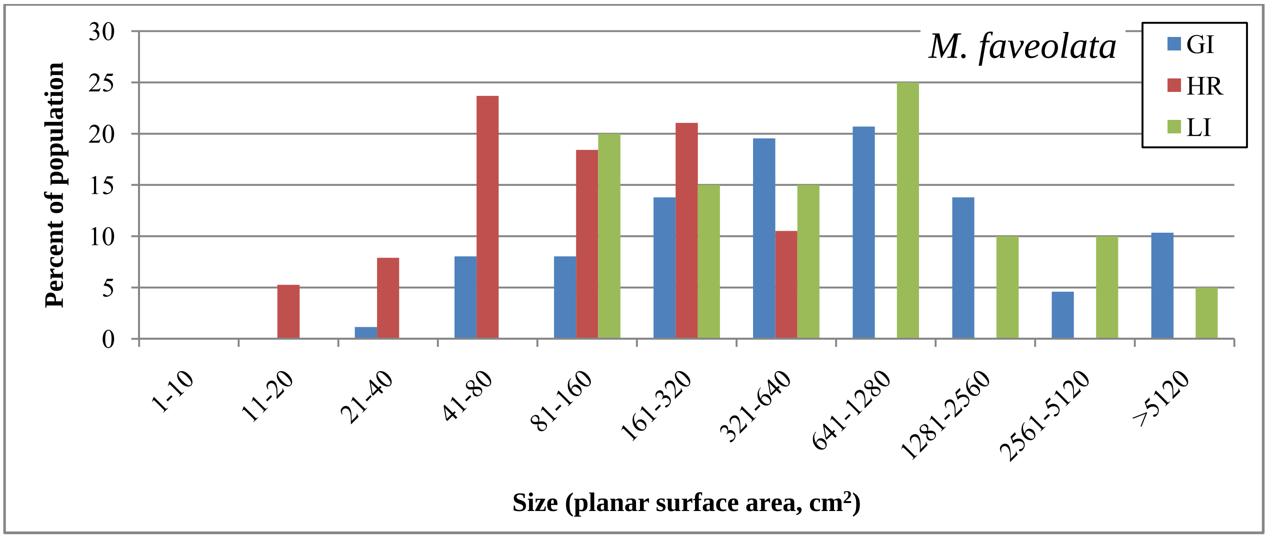


Fig. 23. Size structure of brooding corals in the genus *Agaricia* and *Porites* for Great Inagua (Blue bars), Hogsty Reef (red bars), and Little Inagua (green bars). Size is depicted as planar surface area (pi*1/2 length * 1/2 width).





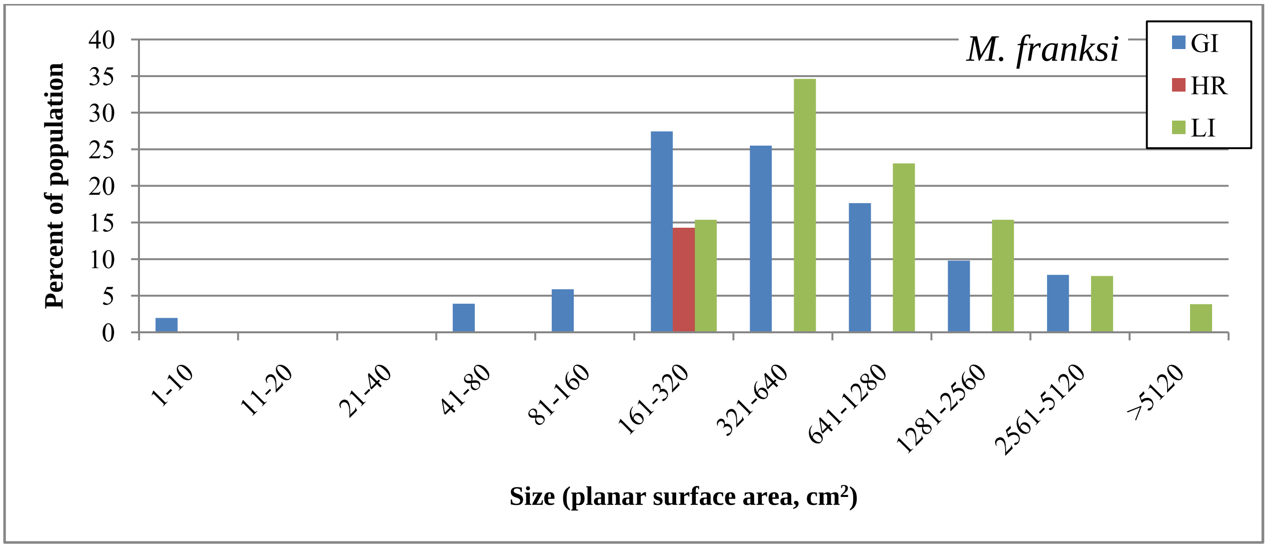
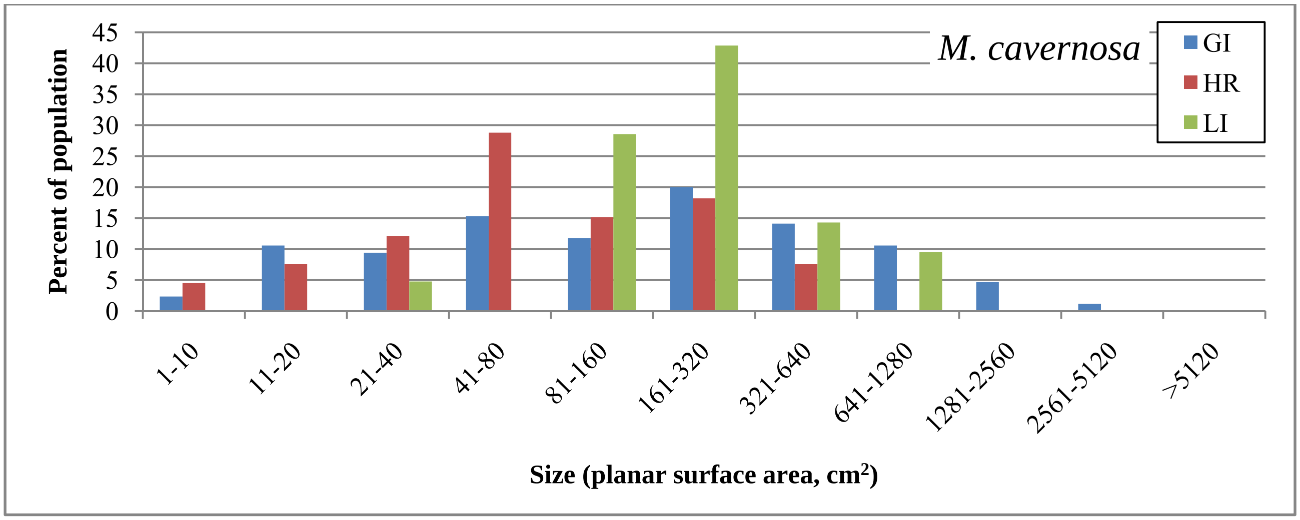
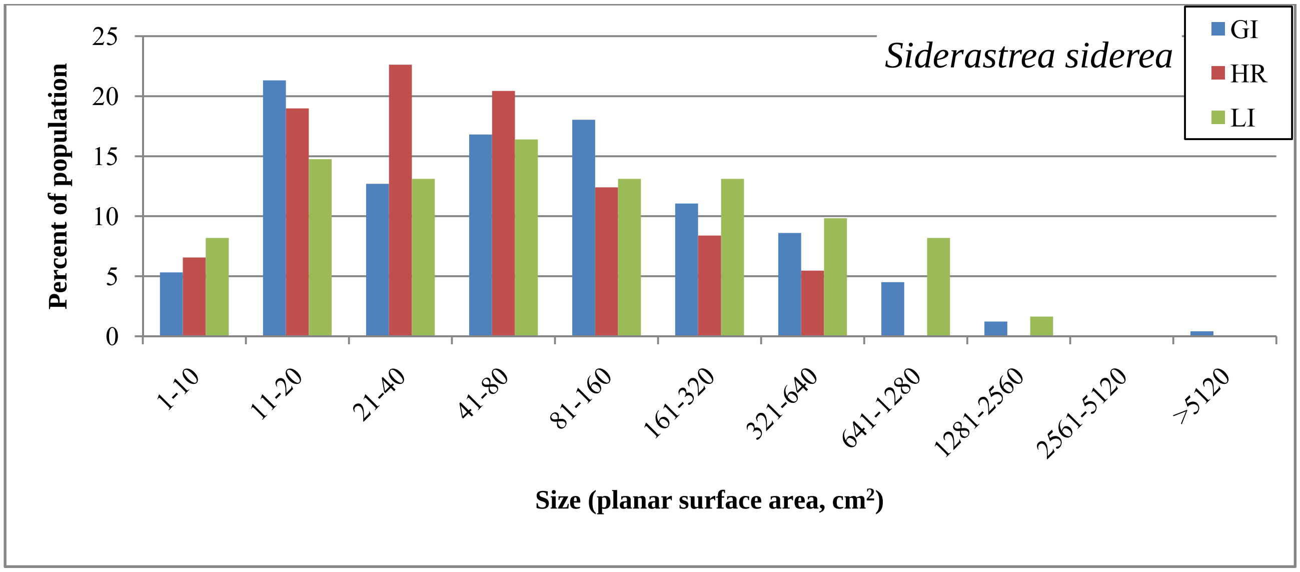


Fig. 24. Size structure of *Montastraea annularis* (complex) for Great Inagua (blue bars), Hogsty Reef (red bars), and Little Inagua (green bars). Size is depicted as planar surface area (pi*1/2 length * 1/2 width).





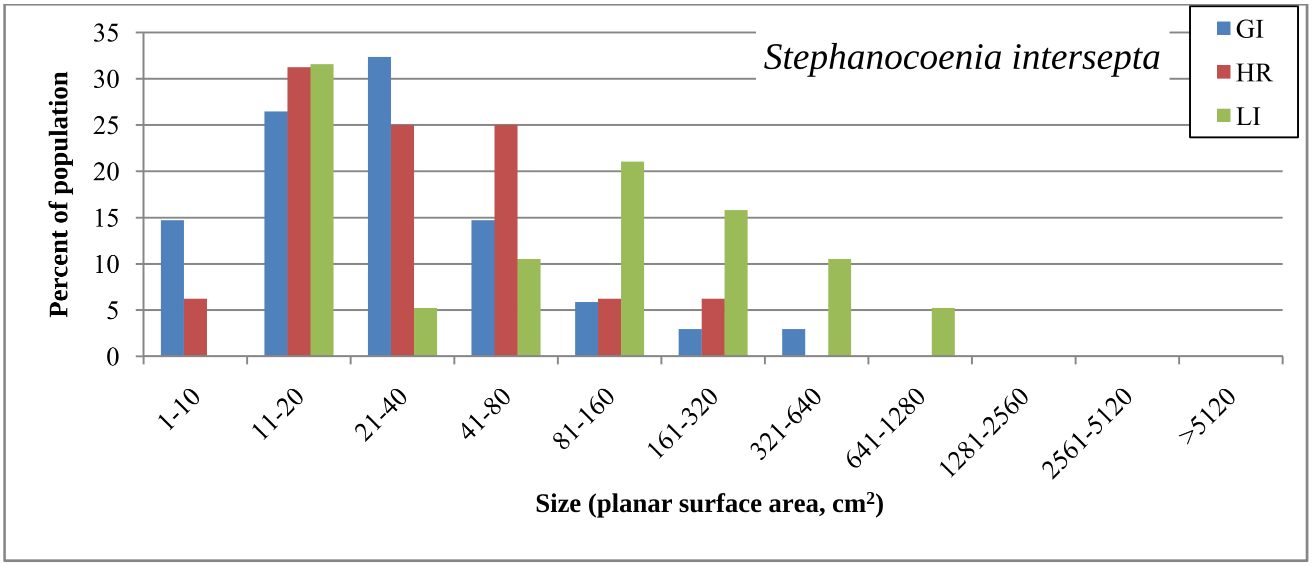


Fig. 25. Size structure of *Montastraea cavernosa, Siderastrea siderea* and *Stephanocoenia intersepta* for Great Inagua (blue bars), Hogsty Reef (red bars), and Little Inagua (green bars). Size is depicted as planar surface area (pi*1/2 length * 1/2 width).

Coral mortality

Colonies were missing an average of 25% of their tissue (pooled for all species and sites; Fig. 26). Over half of all corals exhibited partial mortality, with 40% (Great Inagua and Little Inagua) and 46% (Hogsty Reef) showing no mortality. Very little of the tissue loss was categorized as recent mortality (0.8-1.8%) and few corals showed signs of recent mortality (2.8% on Little Inagua; 5.7% on Great Inagua and 7.2% on Hogsty Reef).

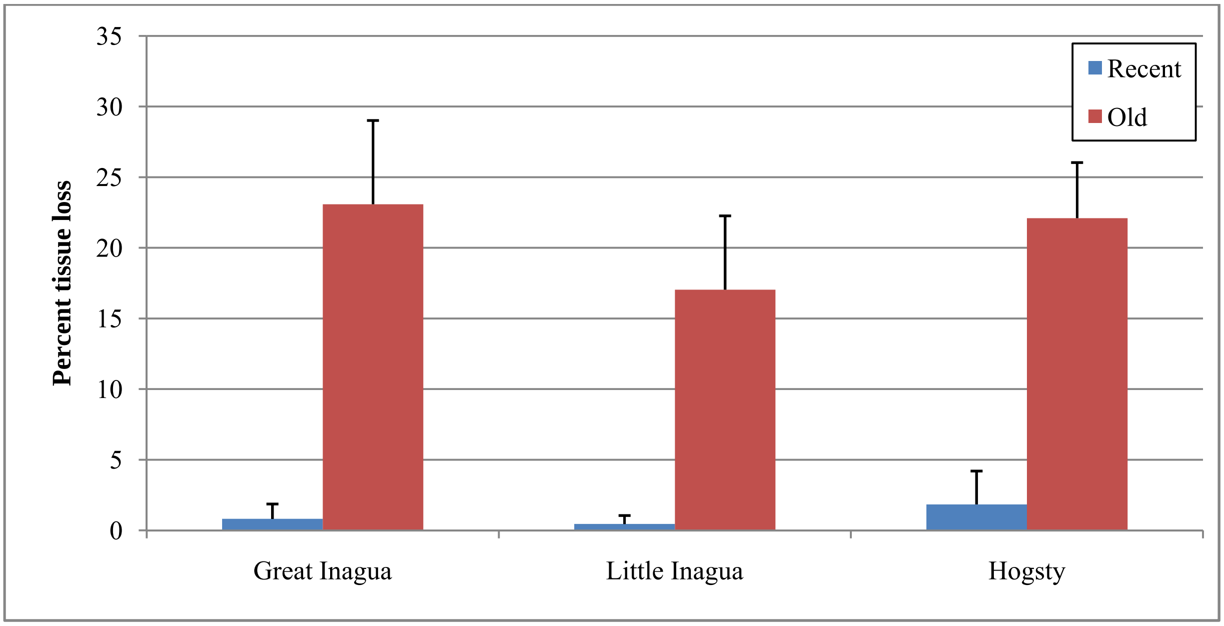


Fig. 26. Amount of partial tissue loss to living corals separated into recent mortality (new and transitional mortality are pooled; blue bars) and old mortality (red bars). All corals are pooled for each location.

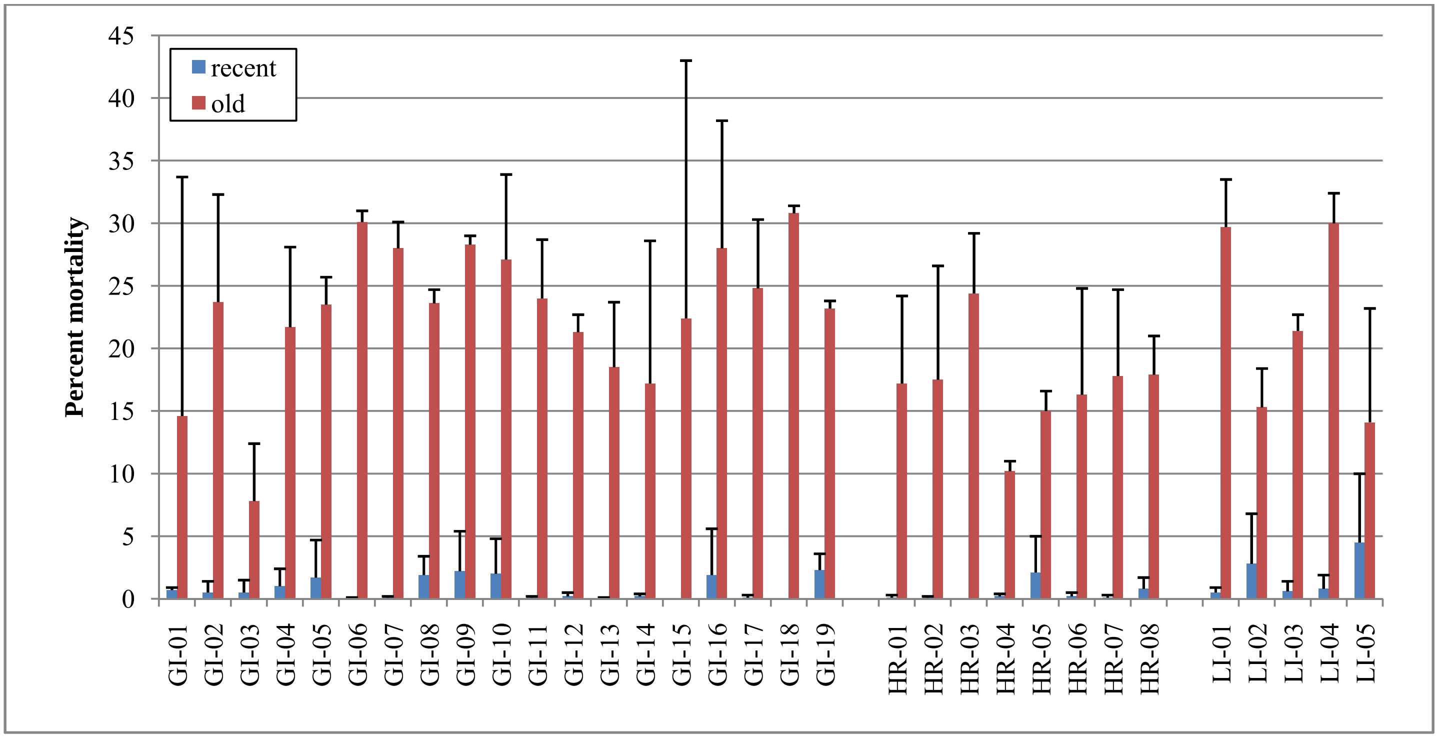


Fig. 27. Amount of partial tissue loss to living corals separated into recent mortality (new and transitional mortality are pooled; blue bars) and old mortality (red bars). All corals are pooled for each site.

Differences in the amount of recent and old partial mortality were noted between sites (pooled species; Fig. 27) and between species (Fig. 28). The mean percent recent partial mortality and old mortality were both positively correlated to the prevalence (percent) of colonies affected by mortality (R^2=0.6, p<0.001). There was no correlation with the prevalence of disease (all diseases pooled) or the prevalence of dark spots disease (R^2=0.08, p=0.12) for all species. Nevertheless, three fairly uncommon corals found on Great Inagua (*Madracis mirabilis*, 19% recent mortality; *Mycetophyllia ferox*, 9% recent mortality), Little Inagua and Hogsty Reef (*Agaricia lamarcki*, 9-12.5% recent mortality) had an unusually high amount of recent tissue loss associated with white syndrome.

Large differences in the amount of partial tissue loss were noted between species and locations. Partial colony mortality was greatest overall on *M. annularis* (57%), followed by *Colpophyllia natans* (48%), *M. franksi* (42%), *M. faveolata* (36%), and *Madracis mirabilis* (38%) (Fig. 28). Colonies of *M. faveolata* had significantly less partial mortality on Hogsty Reef, while partial mortality on *Agaricia agaricites* was highest on Little Inagua. Differences in percent old mortality by region are shown for the ten most abundant corals in Fig. 31.

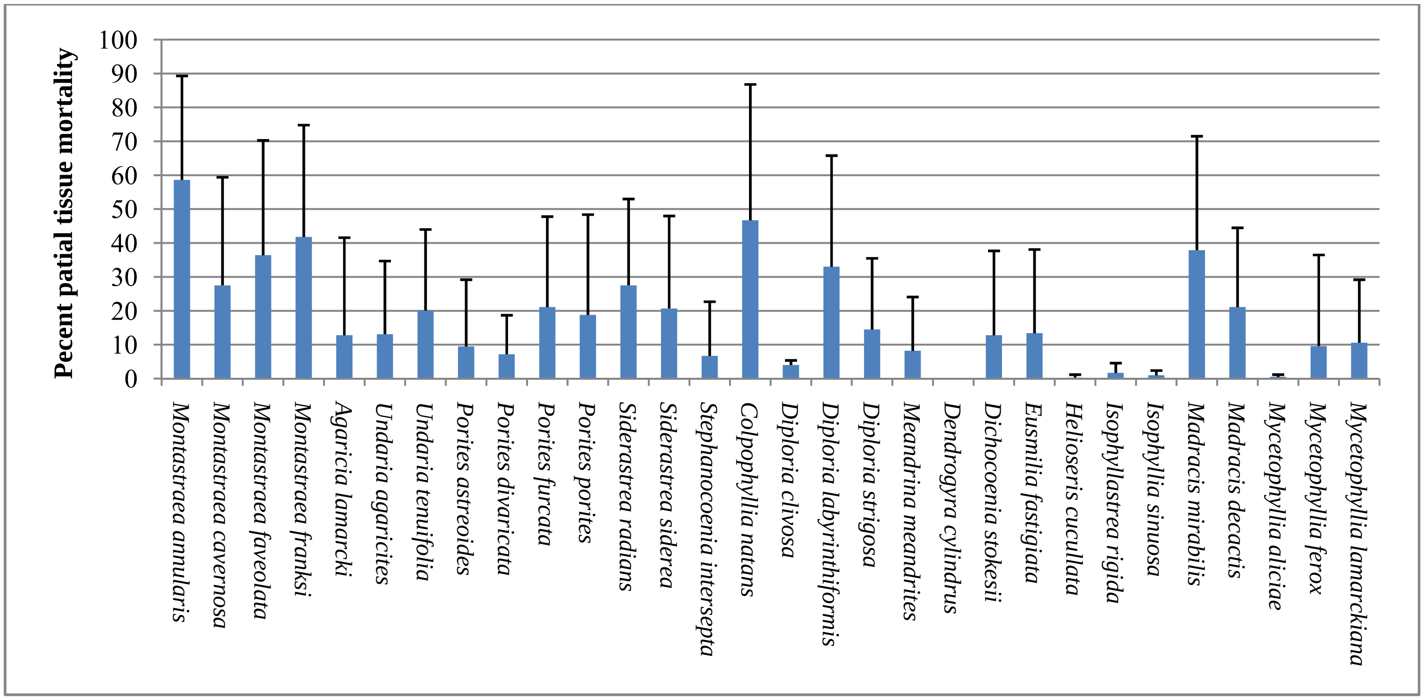


Fig. 28. Percent of tissue loss in surviving scleractinian corals. New, transitional and old mortality are pooled. For each species, corals are pooled from fore reef sites on Great Inagua, Little Inagua and Hogsty Reef.

Coral diseases

The common western Atlantic diseases (BBD, WBD, white plague, white patch disease, yellow band disease, Caribbean ciliate infection, red band disease, growth anomalies and dark spots disease) were observed on these reefs (Fig. 29-30). With exception of dark spots disease, these coral diseases were fairly uncommon, ranging from 2.9% (Great Inagua) to 3.7% (Hogsty Reef) when all sites are pooled. There were some sites, however, that had a higher proportion of affected colonies (6-8%; Fig. 32). A low number of corals were also affected by partial or patchy bleaching (mean= 5.2%), with up to 12% affected at some sites (Fig. 32); very few of these corals were fully bleached (white).

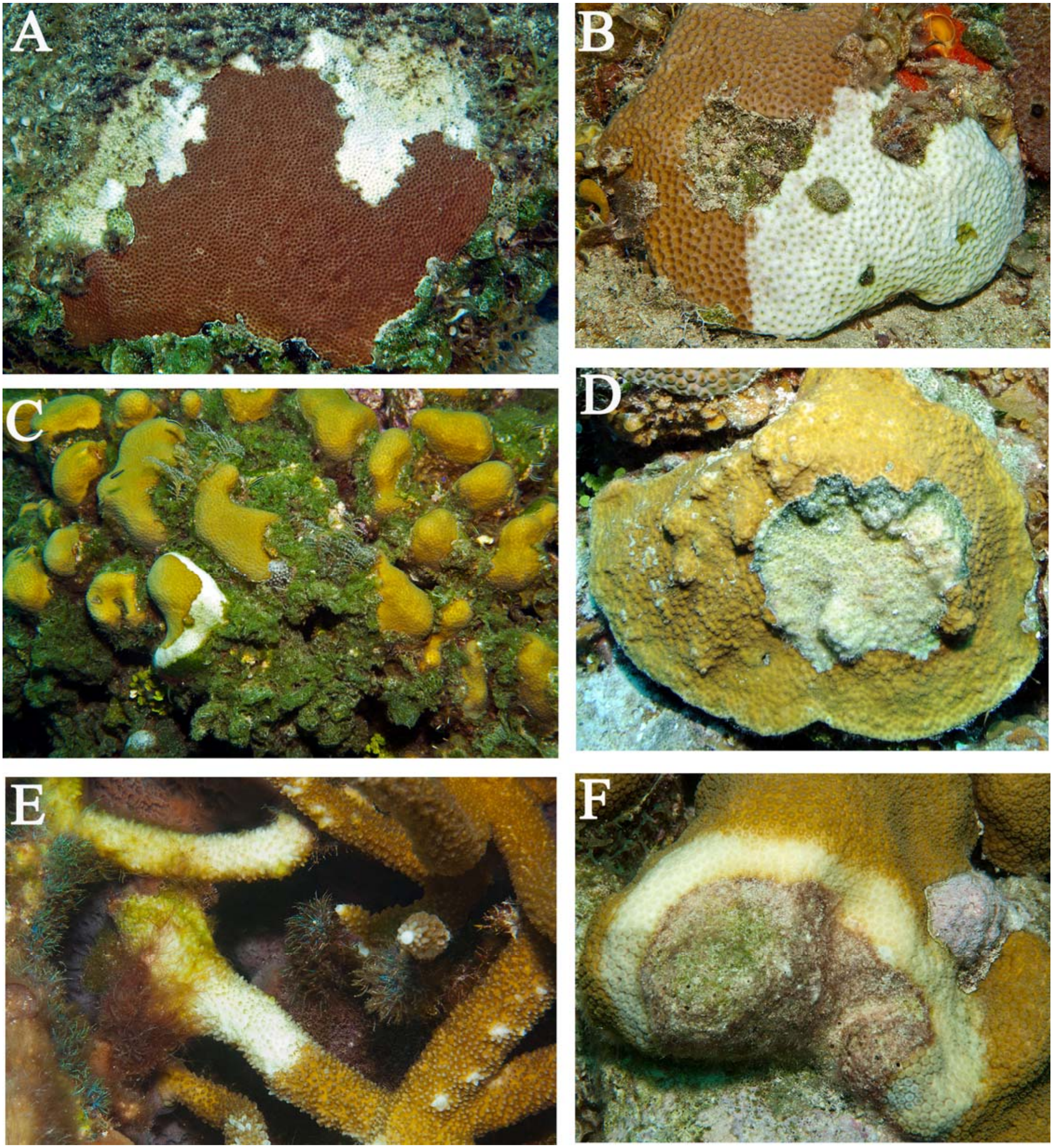


Fig. 29. Diseased corals identified on Great Inagua, Little Inagua and Hogsty Reef. A. White syndrome on *Siderastrea siderea*. B. White plague on *Siderastrea siderea*. C. White plague on a single lobe of *M. annularis*; dense macroalgae (*Microdictyon*) has also colonized the bases of lobes. D. Caribbean ciliate infection on *M. franksi*. E. White band disease on Acropora cervicornis. F. Yellow band disease on *M. annularis*.

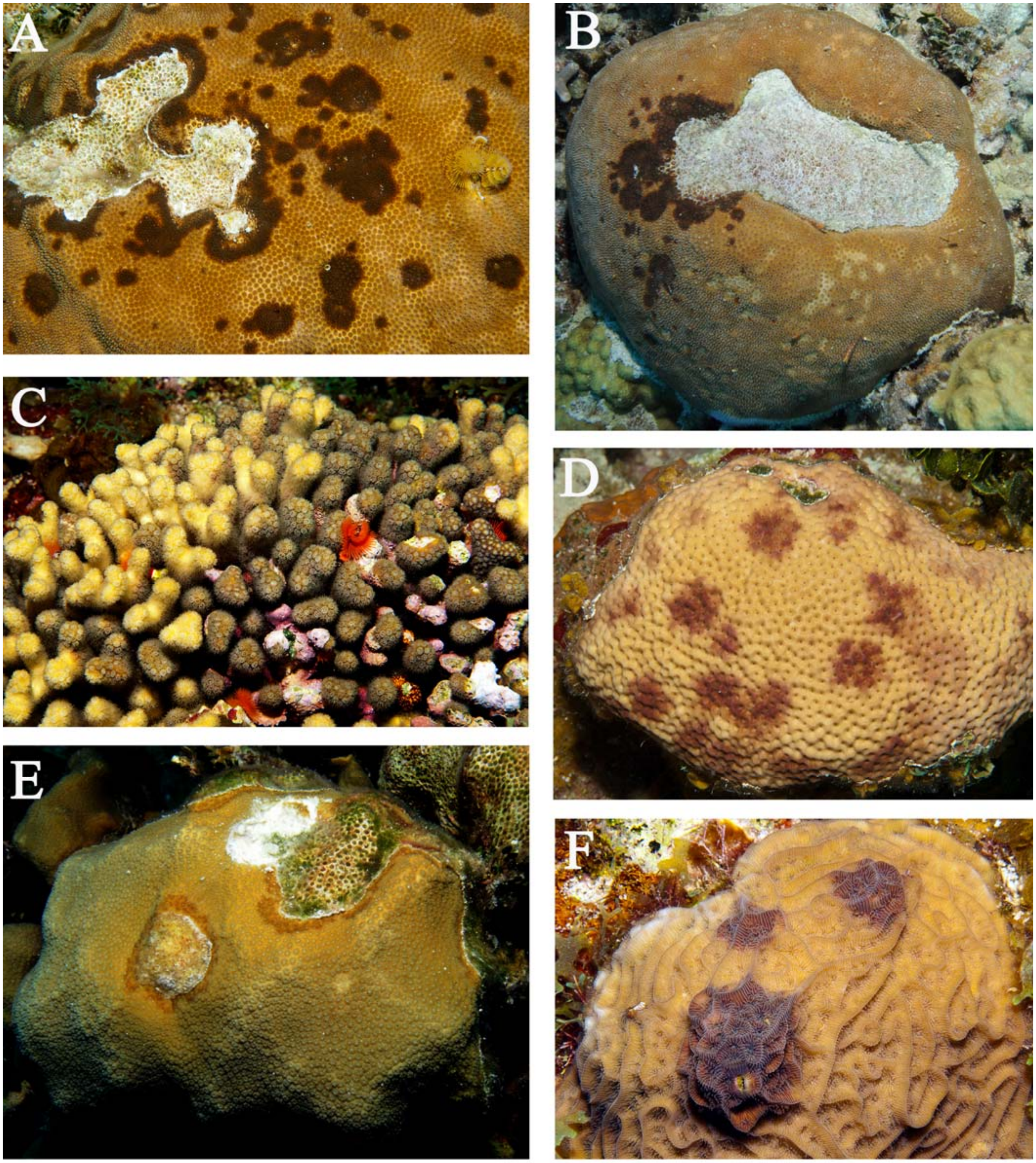


Fig. 30. Examples of dark spots disease (DSD) on stony corals. A. Close-up of *Stephanocoenia intersepta* with dark spots disease. A small area has died and affected tissue surrounds the lesion. B. A colony of *S. intersepta* with DSD. The center of the colony died several months ago; affected tissue is at the perimeter of the old mortality. C. *Madracis mirabilis* with DSD. This coral was not previously reported with this syndrome, but was commonly affected in the Inaguas. Some of the affected branches have died and are colonized by CCA. D. *Siderastrea siderea* with darks spots but no mortality. E. *M. annularis* with a dark band adjacent to an old lesion. F. *Agaricia agaricites* with DSD.

Dark spots disease was the most common affliction, but colonies affected by this disease exhibited very little recent mortality. The disease was observed among the typical susceptible corals (*Siderastrea*, *Stephanocoenia*), although a high prevalence was also noted among *Agaricia* and *Madracis*.

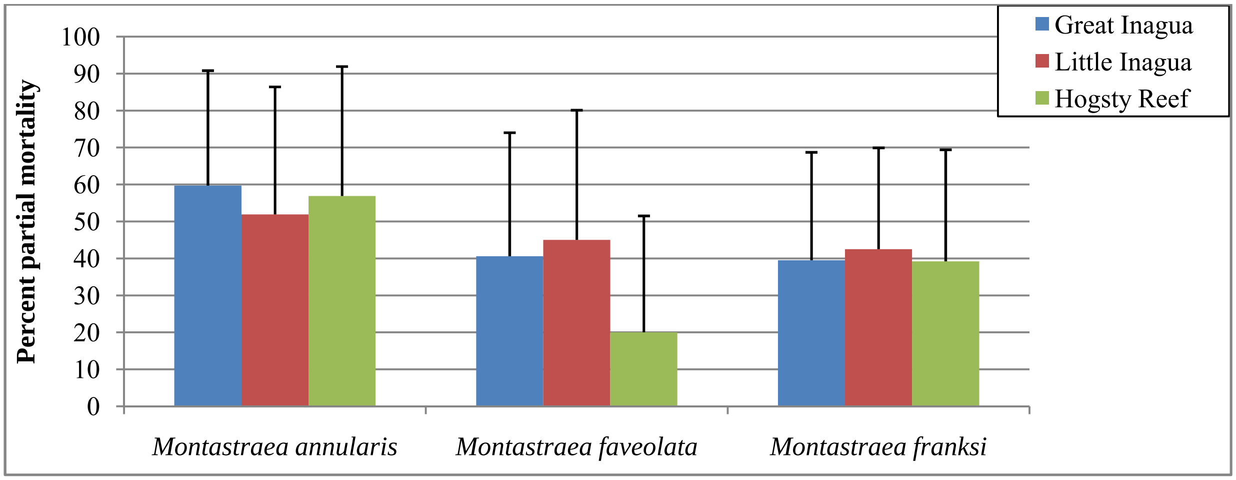


Fig. 31a. Amount of partial mortality for the *M. annularis* complex.

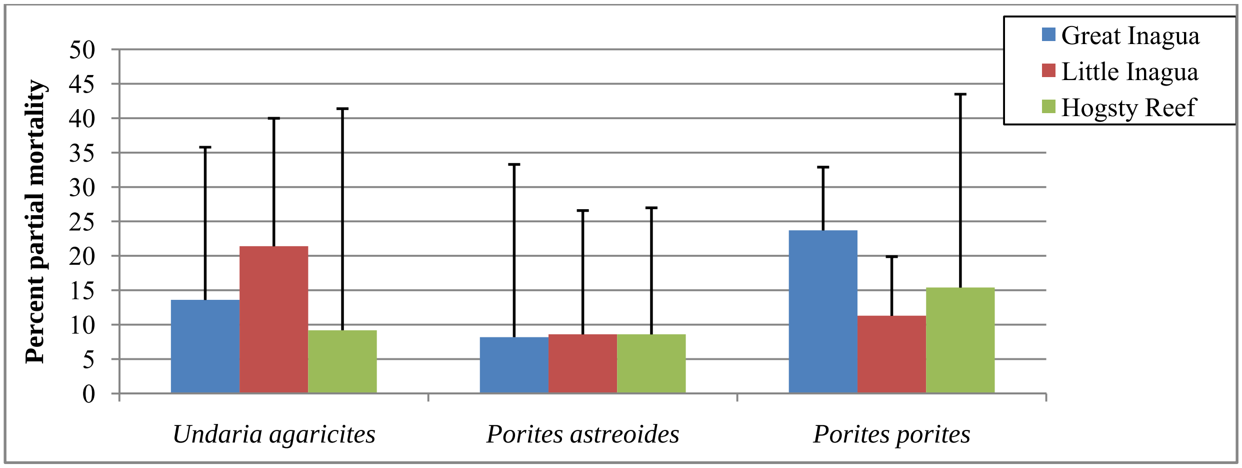


Fig. 31b. Amount of partial mortality for the dominant brooders.

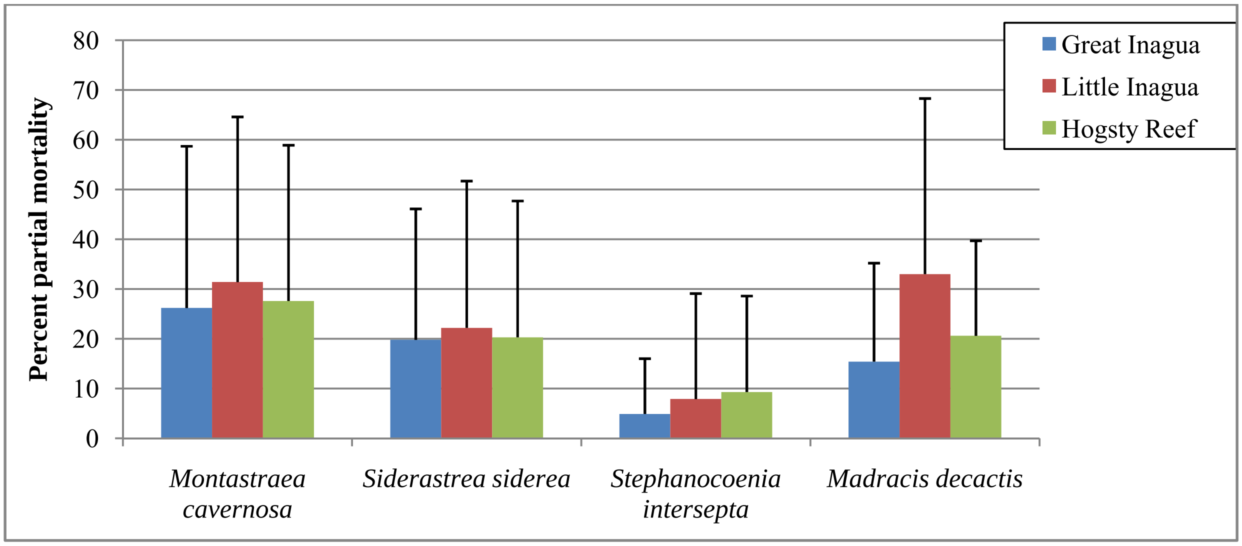


Fig. 31c. Amount of partial mortality for the other dominant corals.

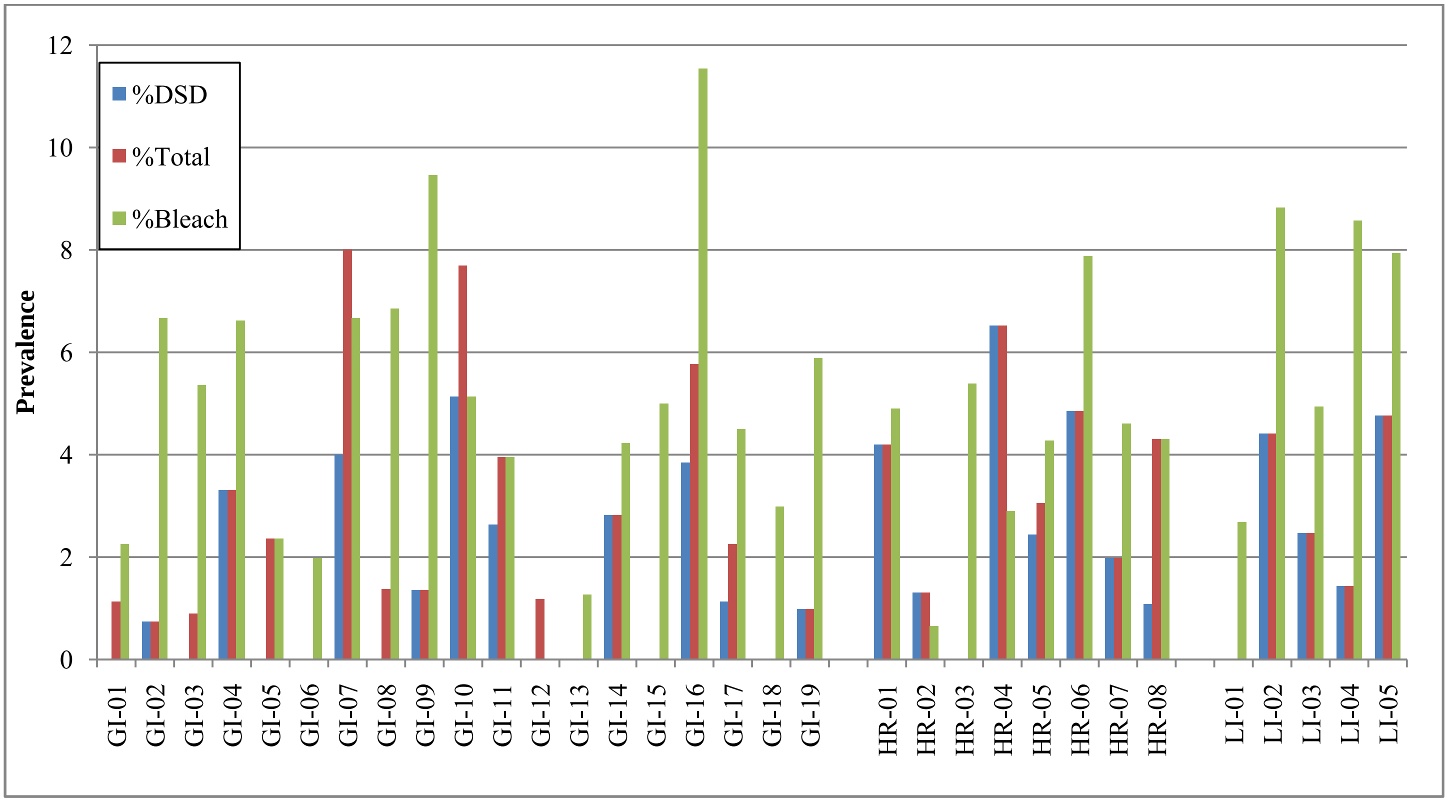


Fig. 32. Prevalence (percent of corals affected) of coral diseases and bleaching. Diseases are pooled (red bars) and are presented for dark spots disease (blue bars). Bleaching categories (pale, partial, full) are combined. Data are presented for all corals pooled by site.

Coral recruitment

A total of 1255 quadrats, each 0.25 m^2 in area, were assessed for coral recruits (0-2 cm diameter). In total, 59% of the quadrats examined were from Great Inagua, 26% on Hogsty Reef and the remainder on Little Inagua. Within these quadrats, a total of 314 recruits (0-2 cm) were identified (Fig. 33). The distribution of recruits over species was skewed, with *Porites astreoides* (42%) and *Agaricia agaricites* (32%), making up over half of all encountered recruits, followed by *Siderastrea siderea* (8%) and lower numbers of 12 other species (18%) (Fig. 34). *Montastraea annularis* (complex) were among the rarer recruits with a higher frequency of *M. cavernosa* recruits (5 recruits, 1.6%), a total of 3 M. *annularis/M. faveolata*, and no observed recruits of *M. franksi*.

The density of recruits varied between sites and locations (Fig. 35). The highest recruitment (all species pooled) overall was noted at GI-05, GI-06, HR-07, and the lowest recruitment at GI-16, GI-14, HR-03. Further, there were significantly lower numbers of *Agaricia* recruits at Little Inagua and slightly higher recruitment of *Porites* and *Siderastrea* at Hogsty Reef. Spatial differences between habitats were also noted. For instance, recruits within the reef crest at Great Inagua were less than the mean number of recruits observed on fore reef sites ($n=1.4/m^2$), while recruits in the lagoonal site examined on Hogsty Reef were higher than the mean number of recruits overall ($n=2.7/m^2$); individual fore reef sites on Hogsty Reef had much higher recruitment than the lagoonal sites ($max = 3.9/m^2$), however. Within these same quadrats an additional 219 juvenile corals (2.1-4 cm) were observed, most of which were also *Agaricia*, *Porites* and *Siderastrea* (Table 5).

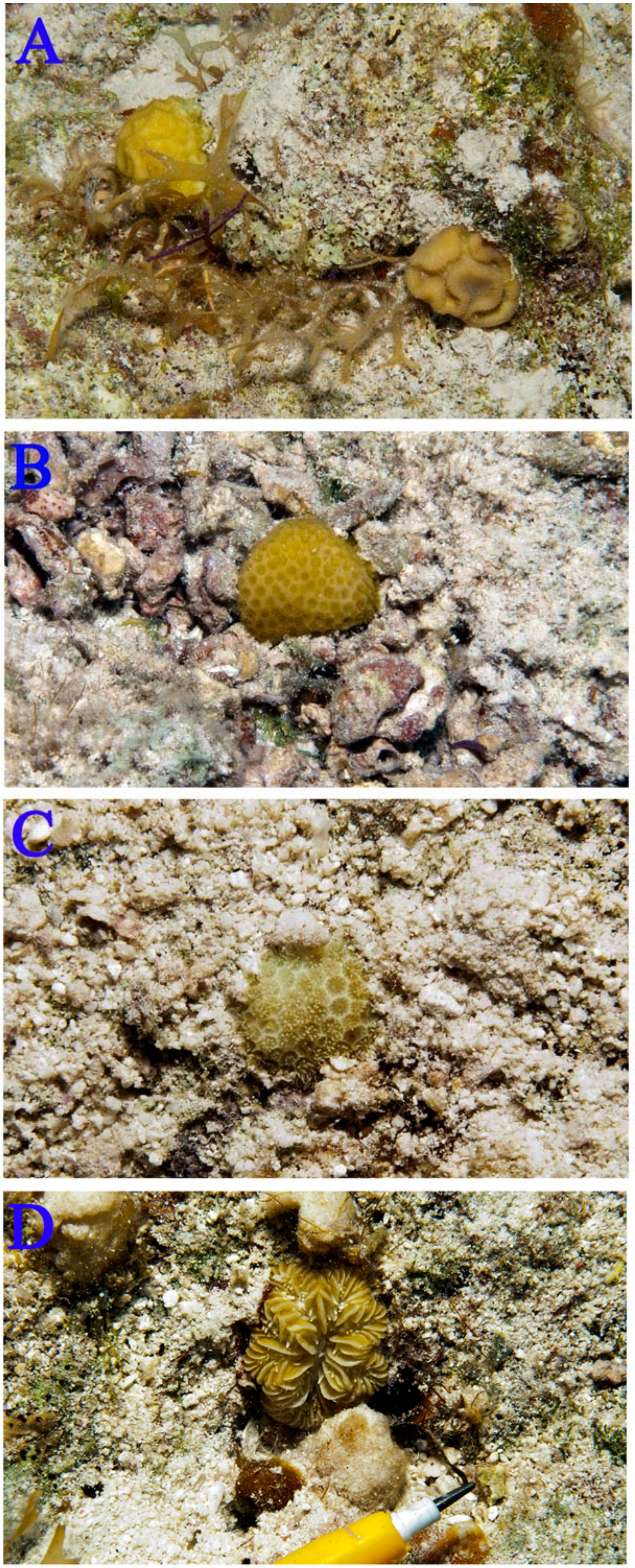


Fig. 33, Examples of recruits identified within quadrats on Great Inagua, Little Inagua and Hogsty Reef. A. *Agaricia agaricites* and *Diploria labyrinthiformis* on hard bottom with *Dictyota* (brown macroalgae) and turf algae. B. *Porites astreoides* on hard bottom/rubble substrate with CCA. C. *Porites porites* on hard bottom substrate covered in a thin layer of sediment. D. *Meandrina meandrites* among turf algae and sediment. Pencil tip provides scale.

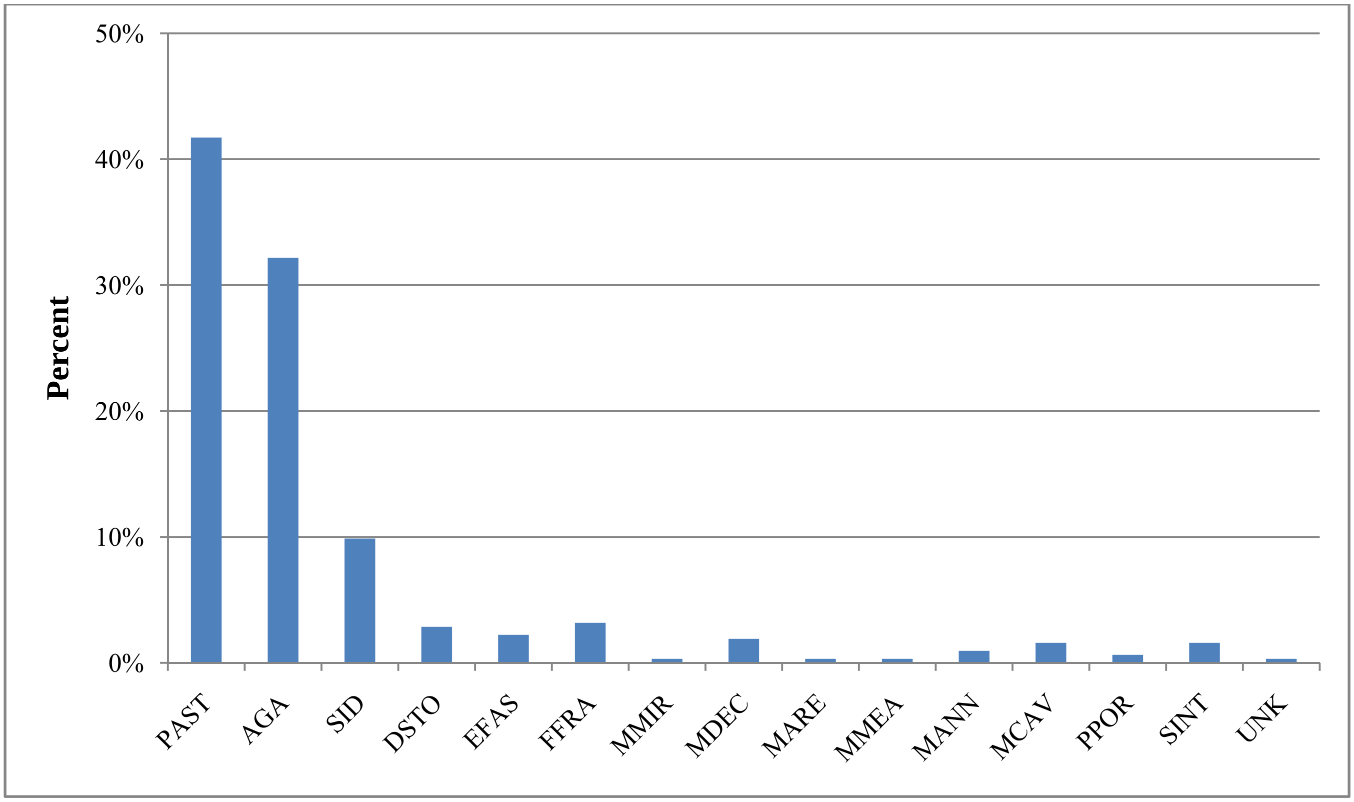


Fig. 34. Proportion of recruits for each coral taxon. Data are pooled for all sites in Great Inagua, Hogsty Reef and Little Inagua. Abbreviations represent individual species except SID (*S. siderea* and *S. radians*) and MANN (*M. annularis* and *M. faveolata*).

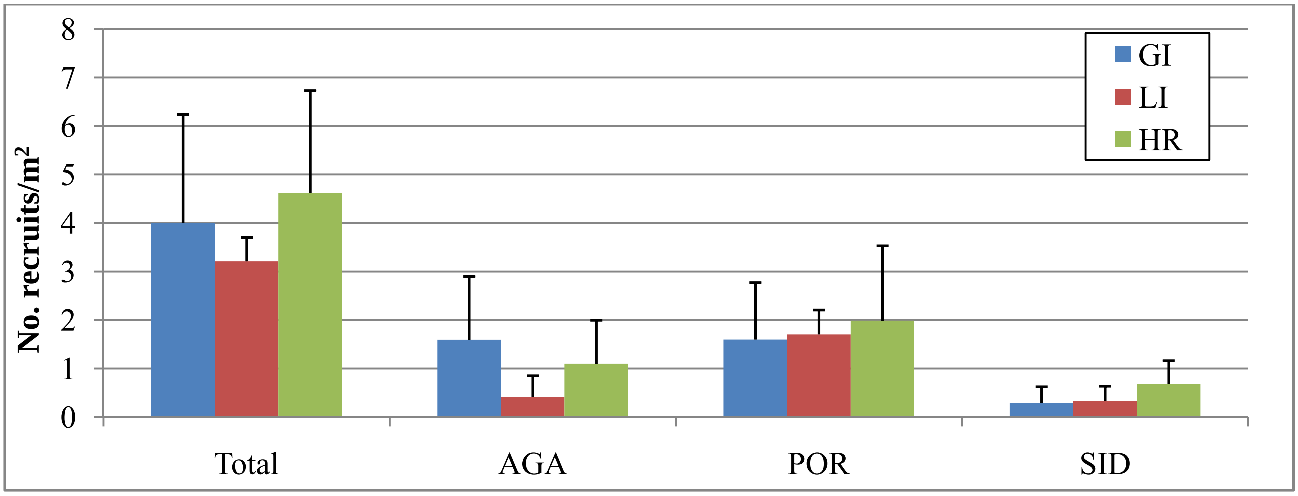


Fig. 35. Density of recruits observed for all species pooled (total), *A. agaricites* (AGA), *P. astreoides* and *P. porites* (POR) and *S. siderea* and *S. radians* (SID) for the three locations. All sites in each location are pooled.

Table 5. Recruits and juvenile corals of the three dominant settlers within quadrats at Gt. Inagua shown by size.

	<1cm	1-2 cm	2.1-3 cm	3.1-4 cm
# Encountered	105	125	124	95
Agaricia agaricites	29%	26%	41%	46%
Porites astreoides	42%	32%	19%	15%
Siderastrea siderea	10%	14%	9%	13%

Primary productivity and herbivory

Targeted research was conducted by a Khaled bin Sultan Living Oceans Foundation Fellow, Dr. Sonia Bejarano, to determine the amount of primary productivity and relationships with herbivory. Research included: 1) quantification of the amount of primary production on shallow reefs located along a gradient of wave exposure; 2) examination of the relationship between the primary production of a reef and the total density and biomass of herbivorous reef fish; and 3) variations in the nature and strength of this relationship across families and species.

Preparing coral tiles

On April 2011, 12 large columnar fragments of dead *Montastraea* colonies were collected from shallow reefs around Rose Island in Nassau (Bahamas). Fragments were cut transversally with an electric masonry saw (Husqvarna Portasaw MS355) to produce 74 square coral tiles of 7 x 7 cm of 1 cm thickness (Fig 36). Each tile was numbered and photographed with a small ruler as a size reference, so that the total flat surface area of each tile could be calculated accounting for all its surface irregularities. Tiles were mounted on 12 rectangular racks of PVC pipe previously cut transversally. The racks were deployed in a shallow reef (9 m) near Gilligan's Island (Nassau) for preconditioning and secured to the reef substratum using cable ties and stainless steel eye screws. The tiles were allowed to develop algal turfs therefore ensuring the presence of algal propagules at the starting point of the productivity experiment. The racks were recovered after three months and cut apart using an electric saw, such that each tile remained screwed onto a 30 cm-length section of PVC pipe.

Tiles were kept in aerated saltwater aquariums on board the Golden Shadow research vessel until the day they needed to be deployed in the experimental reefs. Tiles were carefully scraped the night before deployment, using a small metallic spatula and preserving the scrapped material to account for natural among-tile differences in the amount of algal growth.

Fig. 36. Masonry saw used to cut the coral fragments, (2) transversal sections of the coral fragments, (3) tile photographed with a size reference, (4) tile attached to the PVC rack for preconditioning.

Measurement of primary productivity over a 5 day period

Twelve reefs within the 7-12 m depth contour were selected along the west coast of Great Inagua for this study (Fig. 37). At each of these sites 6 tiles were suspended inside cylindrical cages (PVC coated wire mesh, with hexagon 1 inch mesh weave) 20 cm above the substratum to protect them from the impact of large grazers (> 10 cm TL). Cages were secured to the reef substratum by hammering metallic fence staples across the mesh flaps of the cage. Caged tiles were left in the experimental reefs for 5 full days to allow the development of an algal turf. After retrieval, all tiles were stored at -20° C. The majority of the tiles developed a sparse algal turf visible to the naked eye; however no visual difference was apparent among sites.

Tiles were transported to the National Coral Reef Institute (Fort Lauderdale), thawed at room temperature, and subsequently scraped using a scalpel. The scraped material (sediment and turf algae) was transferred to pre-weighed glass vials and oven dried at 40 °C for 12 hours. Samples were weighed inside the vials in a 4-digit analytical scale to obtain their dry weight. Dry samples were transferred to a muffle furnace and ashed at 400 °C for 6 hours to eliminate their organic fraction (turf algae). Ashed samples were weighed and this final weight was subtracted from their dry weight to obtain the weight of the turf algae that was present in the tiles.

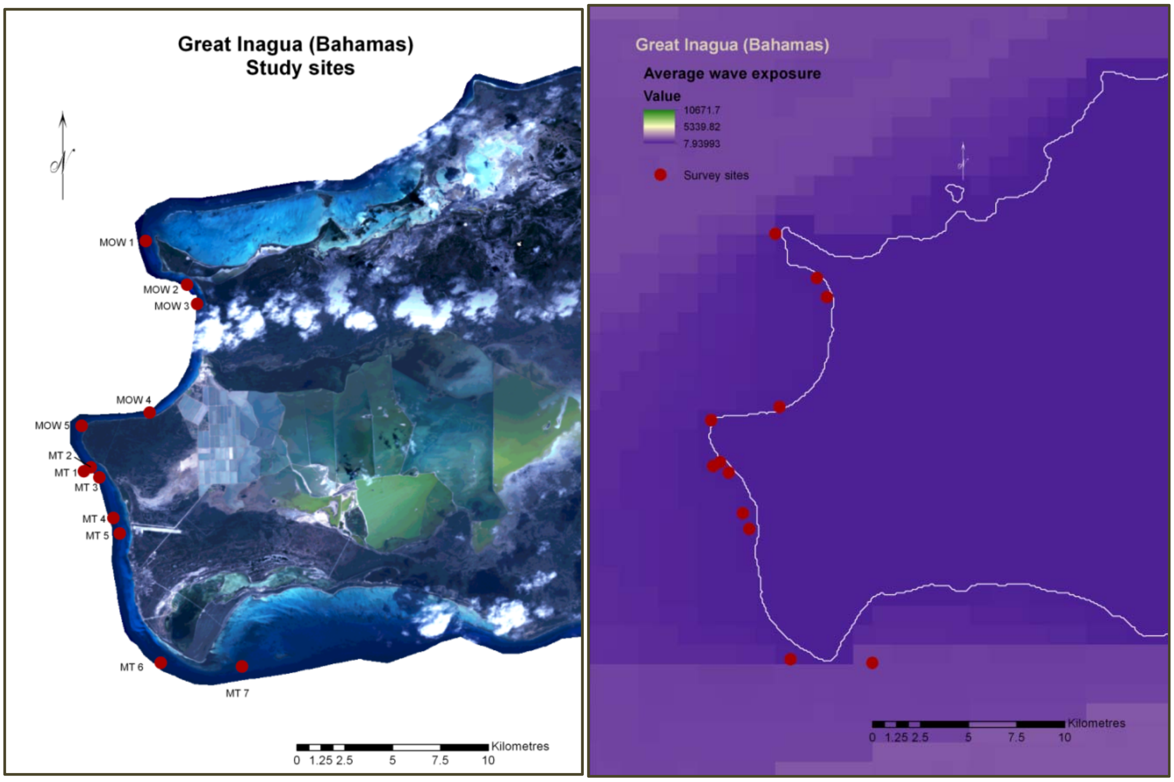


Fig. 37. Location of the 12 study sites where caged tiles were deployed. Map on the right indicates the average wave exposure modelled using an algorithm involving wind speed and direction and fetch.

Physical environment and cage effects

Water flow was measured in each of the survey sites by quantifying the dissolution rate of 3 small gypsum moulds (Fig. 38) attached to the outside of the experimental cages for the duration of the experiment. Light intensity was measured using one light sensor (HOBO Pendant temp/light UA-002-64) per site, attached to a 3 pound lead weight with cable ties. To quantify the effects of the caging, one light sensor was placed inside a cage without a tile at site MOW3, MT3, and MT4, and one gypsum mould was attached to the interior of an empty cage at MOW2, MOW3, and MT5.

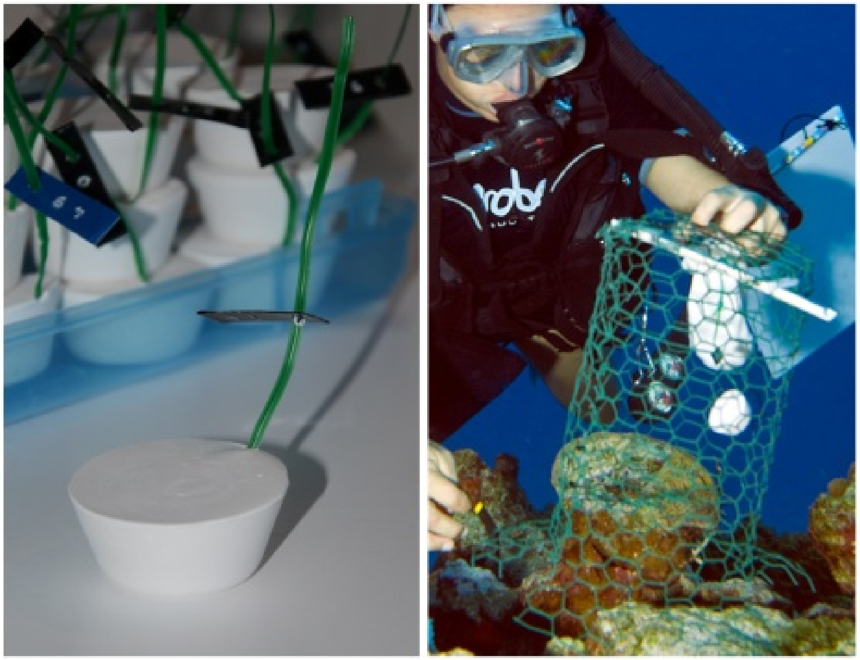


Fig. 38. Moulds prepared with plaster of Paris to measure the water flow in the different reef sites and to measure its attenuation inside the experimental cages.

Primary productivity (in the absence of herbivory)

Primary productivity in the west coast of Great Inagua ranged from 0.18 to 0.66 g turf m^{-2} day^{-1}. The southernmost site near Mathew town (i.e. MT7) had the highest values, whereas MOW4 and MOW5 located on the southern shore of Man of War Bay had the lowest productivity values (Figs 39-40).

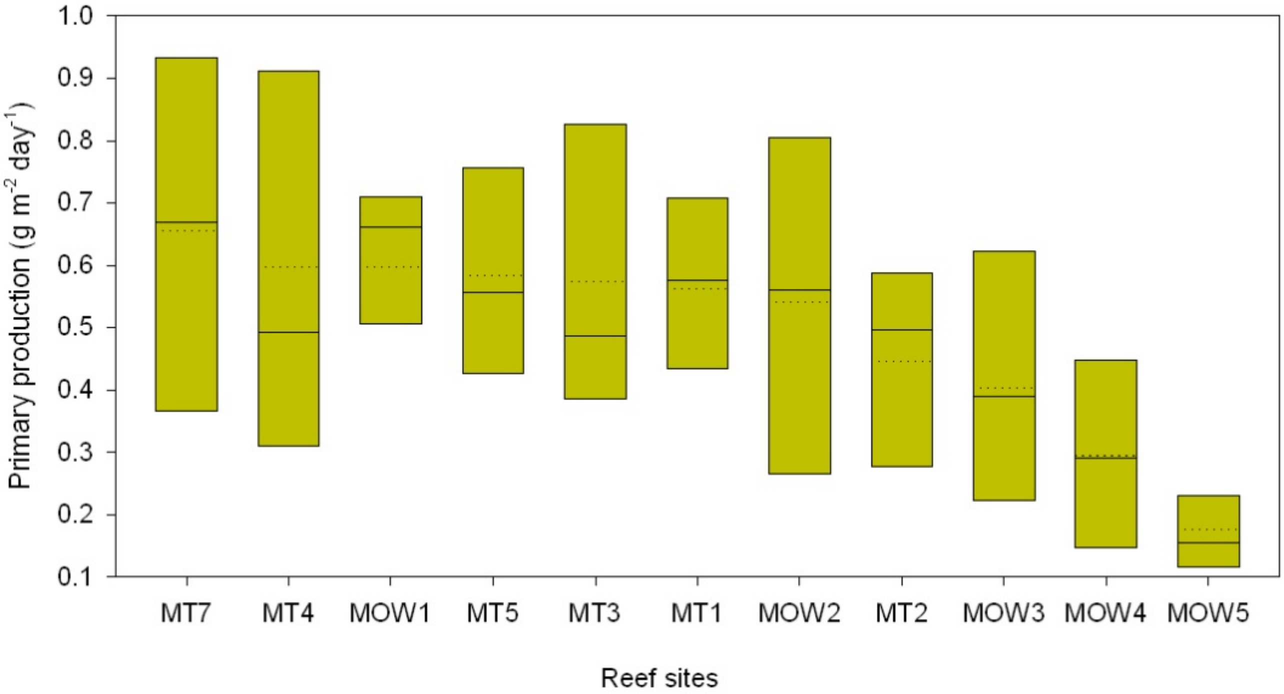


Fig. 39. Box plots indicating the primary productivity (g turf m^{-2} day^{-1}) in the absence of roving herbivorous fish in 11 survey sites along the southwest coast of Great Inagua. Dotted lines inside the boxes indicate mean values of productivity.

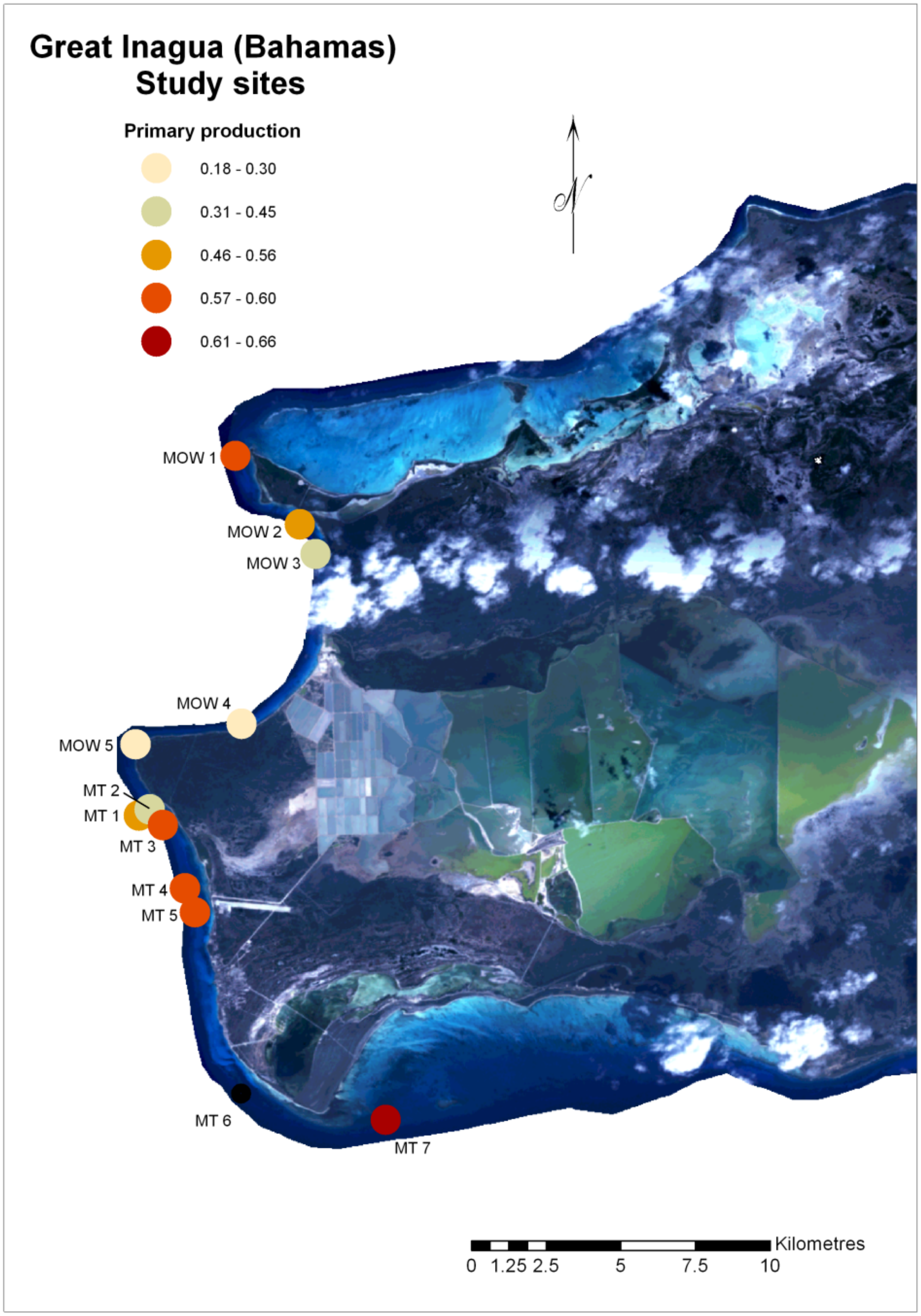


Fig. 40. Map indicating the primary productivity (g turf m^{-2} day^{-1}) of the survey sites along the west coast of Great Inagua. Darker red circles indicate highly productive sites, whereas light colored dots indicate less productive sites. Note that due to adverse weather conditions cages could not be retrieved from site MT6 (black), therefore primary production could not be measured in this site.

Physical environment and cage effects on water flow

Wave exposure for the west coast of Great Inagua was modelled and mapped using an algorithm that involves wind direction and speed and fetch (Chollet-Ordaz et al., *in prep*; Fig 36) and water flow values were calculated from gypsum moulds recovered prior to total dissolution (Fig. 40). The southernmost site near Mathew town (i.e. MT7) was several orders of magnitude more exposed than the rest, whereas all sites located on the western side of the island were similarly sheltered with MOW 1 and MOW 5 being slightly more exposed (Fig 41). Gypsum mould dissolution followed a pattern similar to that of the modeled wave exposure.

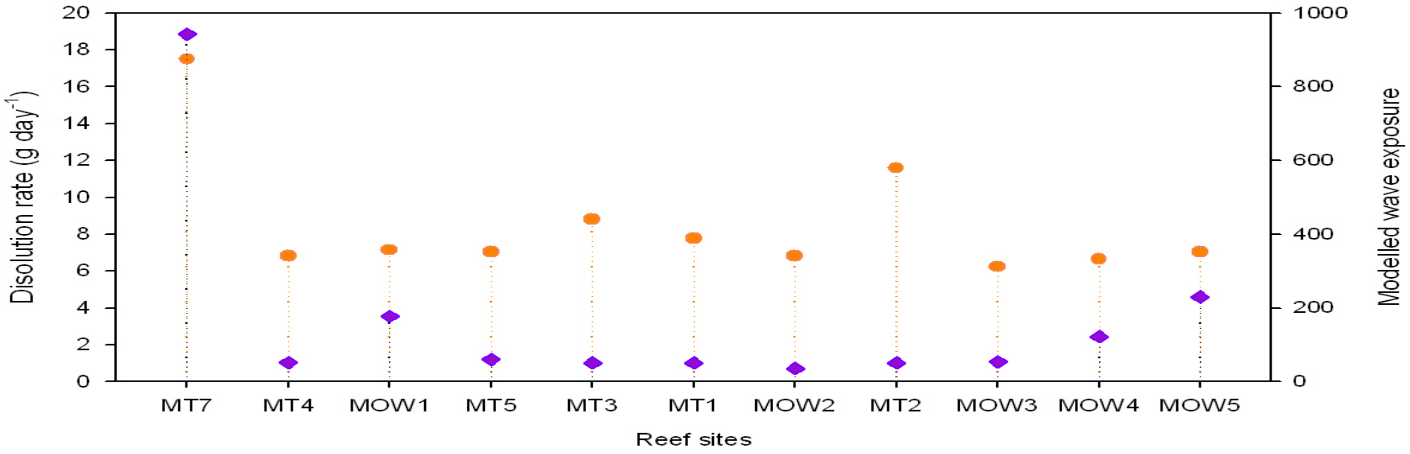


Fig. 41. Orange dotted lines scaled on the *left y axis* indicate the mean dissolution rate of the gypsum moulds at each site (during 5 days) as an indicator of the relative amount of water flow. Purple dotted lines scaled on the *right y axis* indicate the wave exposure as modeled using the wind and fetch algorithm.

Light

Mean daily light intensity experienced outside the cages were similar among most sites (Fig. 42). Only site MT7 seemed to be subjected to higher light intensity perhaps reflecting that this site was the shallowest among all (8 m).

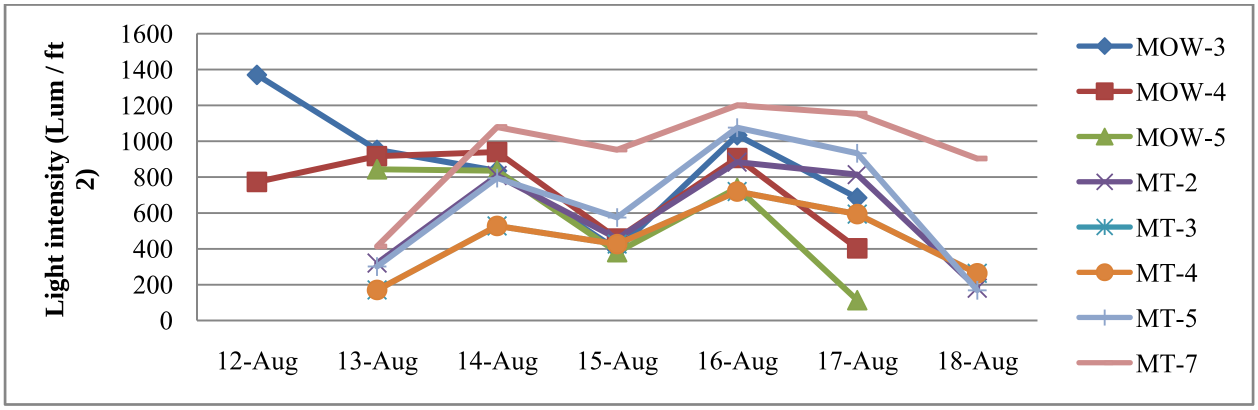


Fig. 42. Mean daily light intensity (Lum ft^2) captured by the HOBO sensors installed on the reef bottom at the study sites. Note that some sites are missing because sensors were lost from their attaching point due to their positive buoyancy.

Effect of the cages in light intensity

As the cages constituted a physical barrier separating the tile from its external environment, these were expected to reduce the amount of water flow in the immediate surroundings of the tiles and the amount of light that reached their upper surface, and it was necessary to quantify the magnitude of such effects. In average, cages were found to reduce the mean light intensity received by the tiles by 17 % of the light intensity that reaches the adjacent uncaged substrate (Fig 43).

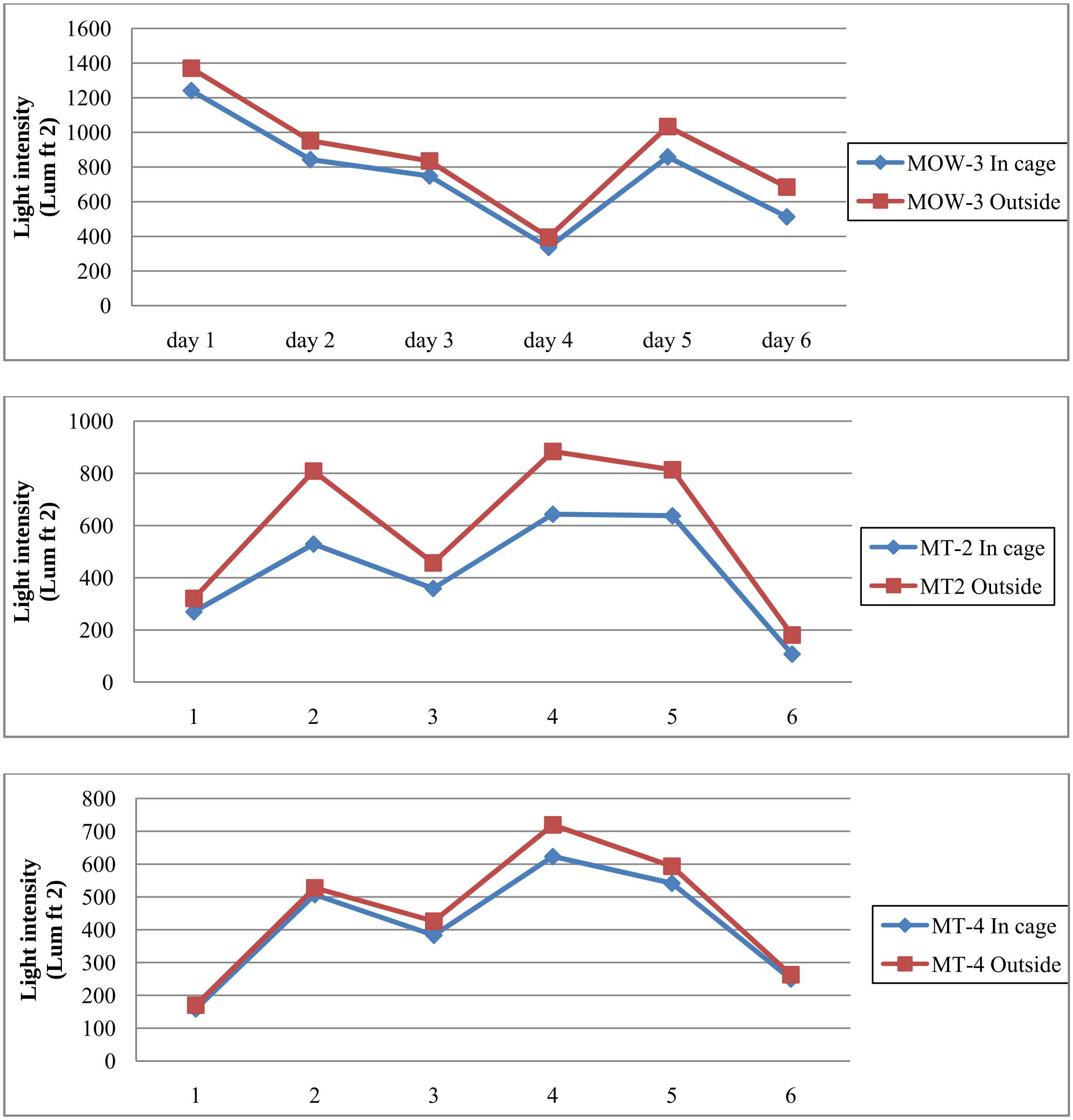


Fig. 43. Mean daily light intensity (Lum ft^2) captured by the HOBO sensors installed inside a cage and on the reef bottom outside the cage in three of the study sites. Top: MOW-3, middle: MT-2, and bottom: MT-4.

Effect of the cages on water flow

The experiment run in Little Inagua to quantify the reduction of water flow around the tile caused by the presence of the cage indicated that, in average, gypsum moulds outside the cages lost 0.05 g more every hour compared to those inside the cages (Fig. 44a). Additionally, the effect of the cages in the water flow could be tested in 3 of the experimental sites of Great Inagua (MOW7, MOW5 and MT4). At these sites gypsum moulds set outside the cages lost 0.8 g more every day compared to the moulds installed inside the cage (Fig 44b). The decrease in water flow caused by the presence of the cages was minimal.

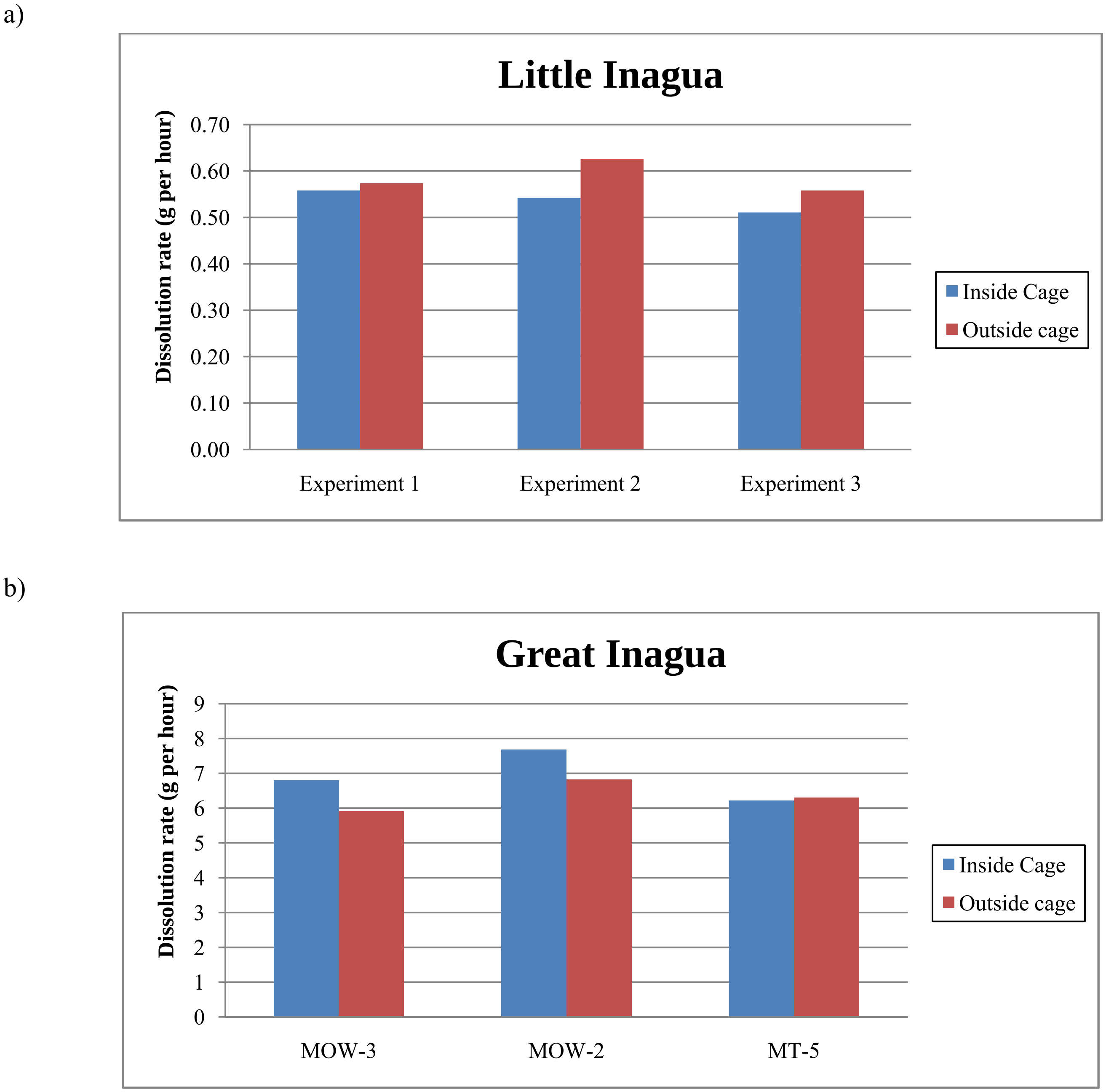


Fig 44. Comparison of the dissolution rate of gypsum moulds inside and outside of cages on Little Inagua (a) and Great Inagua (b).

Reef fish assessments

Quantitative assessments of reef fish were conducted by two divers using the AGRRA methodology and species list (belt transects, 30 m X 2 m wide) and additional surveys for herbivores were done by one researcher examining 4 m X 30 m area within the 12 study sites that corresponded to the herbivore study.

Herbivorous reef fish community

A total of 10 species of roving herbivorous reef fish (3 acanthurids and 7 scarids) were commonly encountered during these surveys, with four additional parrotfish species seen infrequently (blue, midnight, blue lip and redfin). An additional 7 species of damselfish were frequently observed (Appendix 2). All survey sites in the Inagua region had a higher diversity of herbivorous fish compared to Cay Sal. Most of these sites also had very high topographic complexity that appeared to correlate with moderately high densities of scarids and acanthurids (Fig. 45).

Parrotfish biomass was higher on Great Inagua as compared to Hogsty Reef and Little Inagua (Fig. 46). Overall, this was due to three species. The redband parrotfish (*Sparisoma aurofrenatum*) was the most common of the parrotfishes present in all survey sites. The princess parrotfish (*Scarus taenipterus*) was on average the most abundant species per site (4 individuals 120 m^{-2}). The largest species of parrotfishes (*Sparisoma viride* and *Scarus vetula*) accounted for the largest mean biomass per site (967 g 120 m^{-2} and 686.2 g 120 m^{-2}). The blue tang (*Acanthurus coeruleus*) was the most common of the surgeonfishes present in all survey sites. The ocean surgeonfish (*A. bahianus*) was on average the most abundant species of surgeonfish per site (up to six individuals 120 m^{-2} at MOW5). Both *A. bahianus* and *A. coeruleus* had the largest mean biomass per site among surgeonfishes. Fewer doctorfish were seen. The density and biomass by species are shown in Table 6 and 7.

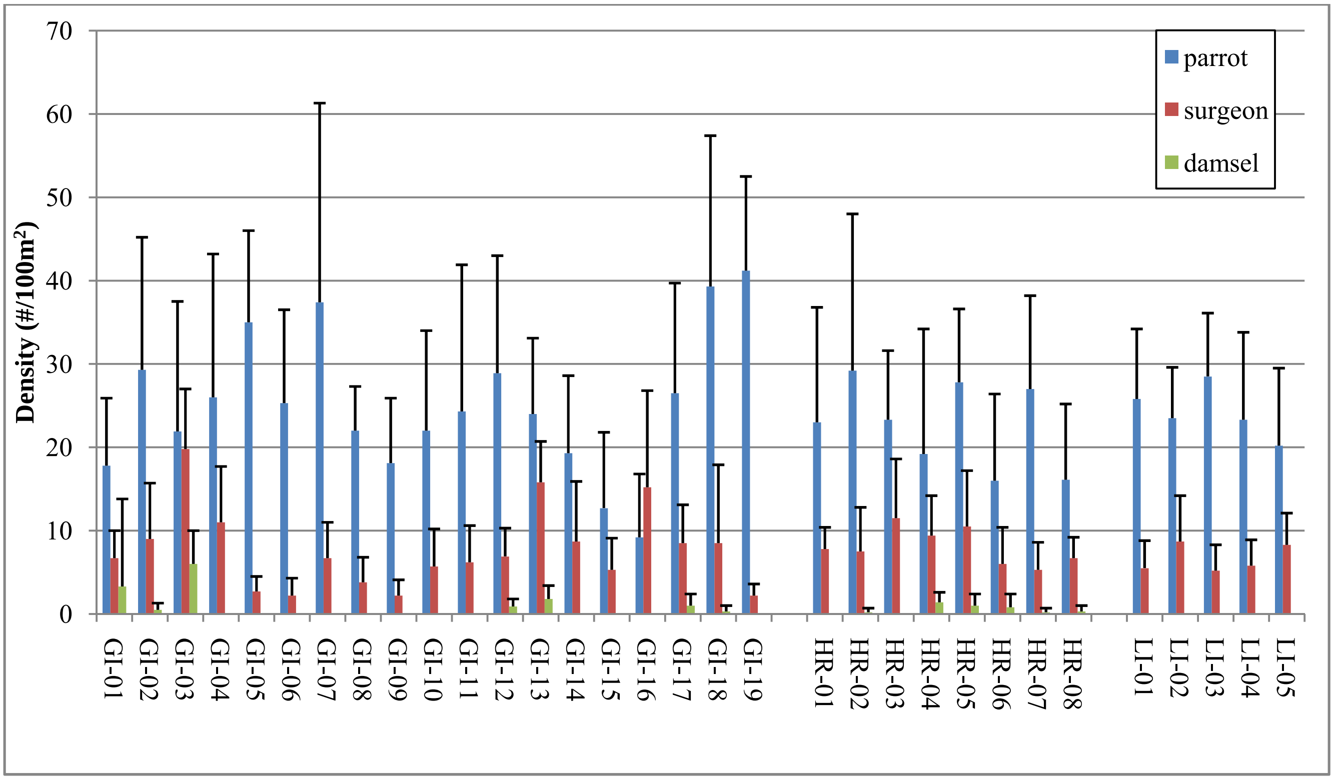


Fig. 45. Density (number per 100 sq. meter) of herbivores on Great Inagua, Hogsty Reef and Little Inagua. The mean and standard error are presented for all species of parrotfish (blue), acanthurids (red) and damselfish (green), pooled by site.

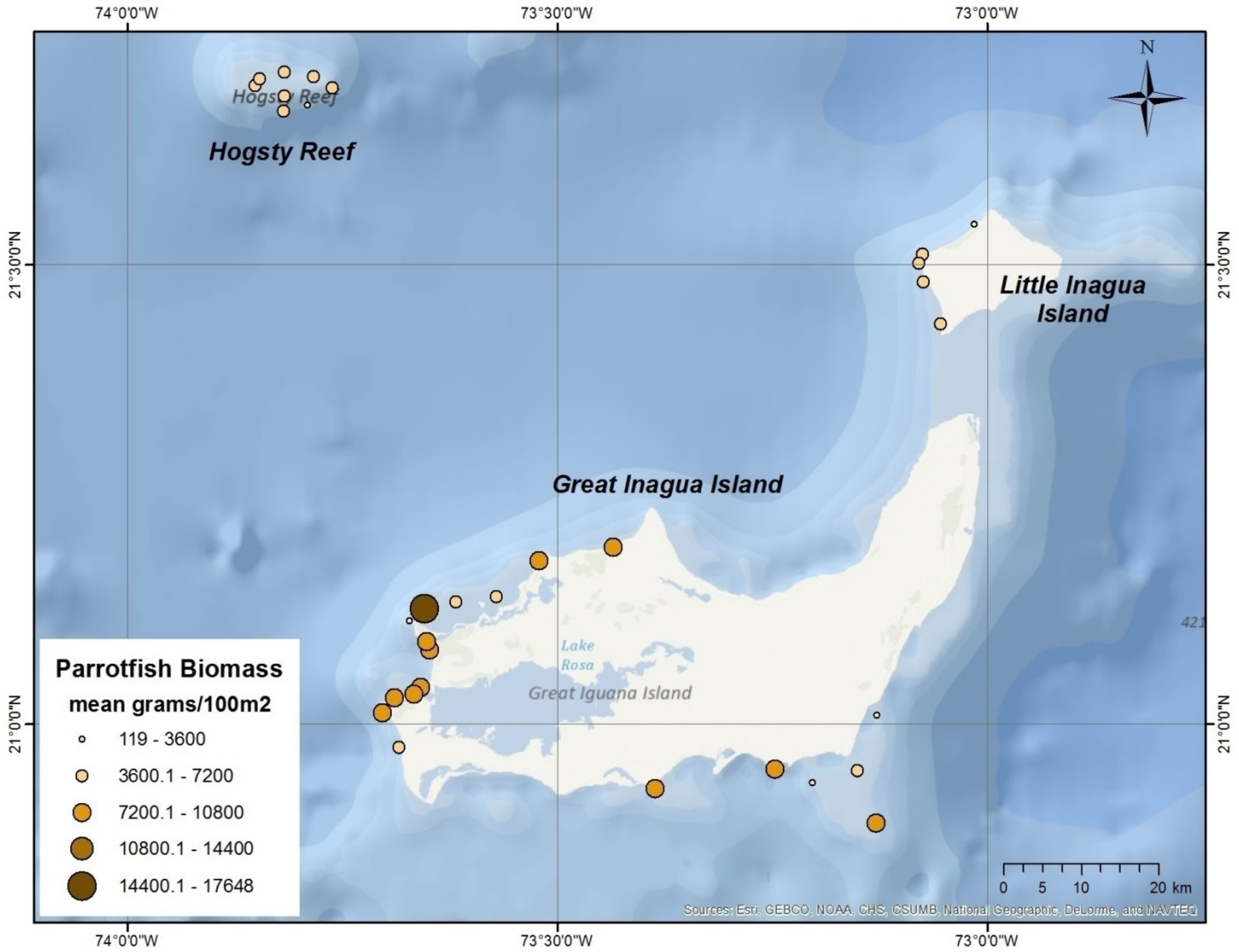


Fig. 46. A map showing the biomass of parrotfish at the sites examined in Great Inagua. Little Inagua and Hogsty Reef. The larger circles and darker colors represent the highest biomass.

Relationship between fish density and biomass and primary productivity

Within the 12 sites examined in Great Inagua, comparisons between algal productivity and herbivore biomass were made. Density and biomass of all herbivorous reef fish combined and of acanthurids were not significantly related to primary productivity (Fig. 47). Because most sites along the west coast of Great Inagua were similar in terms of wave exposure and therefore primary productivity, it is possible that other environmental variables, such as rugosity or the percent cover of algae or live coral could have acted as stronger drivers of the fish community structure. The only apparent significant relationship occurred between primary production and the density of parrotfishes (Fig. 47c). Parrotfish density increased linearly as primary production increased. This relationship was strong and significant ($R^2= 0.83$, $p < 0.001$) only if one of our exposed sites with relatively high productivity (MT1) but unusually low density of parrotfishes (5.0 ind. 120 m^{-2}) was excluded from the analysis (Fig 47c). It is unclear what could have driven the low density of parrotfishes in MT1. Although no clear linear relationship occurred between primary production and the biomass of surgeonfish, it was clear that on places where productivity did not exceed 0.4 g m^{-2} day^{-1} the biomass of acanthurids was always low (< 88 g 120 m^{-2}, Fig 47f), whereas on those sites were productivity ranged between 0.4 - 0.7 g m^{-2} day^{-1} acanthurid biomass ranged more widely, reaching the highest values (976 g 120 m^{-2}) in MT3.

Table 6. Mean density (individuals 120 m^{-2}) and standard error (in parenthesis) of each herbivorous species in 12 study sites on the east coast of Great Inagua.

Families	**Sites**											
	Man of War Bay					**Mathew Town**						
Species	**MOW-1**	**MOW-2**	**MOW-3**	**MOW-4**	**MOW-5**	**MT -1**	**MT-2**	**MT-3**	**MT-4**	**MT-5**	**MT-6**	**MT-7**
Acanthuridae												
Acanthurus bahianus	4.1	-	0.3	0.3	5.6	2.9	0.7	-	0.5	0.5	3.7	4.6
	(0.8)	-	(0.2)	(0.2)	(0.8)	(0.9)	(0.3)	-	(0.3)	(0.3)	(0.4)	(1.6)
Acanthurus chirurgus	0.25	-	-	-	0.6	0.4	0.2	-	-	0.1	-	0.5
	(0.3)	-	-	-	(0.6)	(0.3)	(0.2)	-	-	(0.1)	-	(0.3)
Acanthurus coeruleus	0.6	7.0	0.5	1.0	1.8	2.9	8.2	1.4	0.7	0.9	0.3	2.4
	(0.3)	(6.0)	(0.3)	(0.4)	(0.8)	(0.6)	(5.3)	(0.5)	(0.3)	(0.4)	(0.2)	(0.3)
Total (Surgeonfish)	**5.0**	**7.0**	**0.8**	**1.3**	**8.0**	**6.1**	**9.0**	**1.4**	**1.2**	**1.5**	**4.0**	**7.5**
	(1.0)	(6.0)	(0.3)	(0.3)	(1.5)	(1.3)	(5.1)	(0.5)	(0.4)	(0.5)	(0.4)	(1.8)
Scaridae												
Sparisoma aurofrenatum	2.9	3.0	1.7	1.0	2.8	1.4	1.2	1.3	2.5	2.3	1.8	1.1
	(0.5)	(0.4)	(0.5)	(0.3)	(0.7)	(0.6)	(0.3)	(0.5)	(1.0)	(0.6)	(0.5)	(0.3)
Sparisoma chrysopterum	-	0.2	-	0.2	0.2	0.1	0.2	0.4	0.3	0.1	-	0.5
	-	(0.2)	-	(0.2)	(0.2)	(0.1)	(0.2)	(0.3)	(0.3)	(0.1)	-	(0.3)
Scarus iserti	0.5	2.5	4.0	0.3	-	-	0.7	3.0	1.2	0.4	6.2	9.1
	(0.3)	(1.1)	(1.4)	(0.3)	-	-	(0.5)	(1.0)	(1.0)	(0.3)	(1.9)	(6.0)
Sparisoma rubripinne	-	-	-	-	0.2	-		0.3	-	-	-	0.1
	-	-	-	-	(0.2)	-		(0.2)	-	-	-	(0.1)
Scarus taeniopterus	6.4	2.7	0.7	3.2	2.8	2.9	6.7	4.6	5.5	4.5	5.0	-
	(1.5)	(1.1)	(0.2)	(1.1)	(1.3)	(0.9)	(1.2)	(1.0)	(1.4)	(1.3)	(1.5)	-
Sparisoma viride	1.4	3.2	1.7	2.3	1.4	0.8	2.0	2.3	1.0	1.9	1.2	1.6
	(0.5)	(0.7)	(0.3)	(0.4)	(0.4)	(0.3)	(0.6)	(0.6)	(0.4)	(0.4)	(0.7)	(0.5)
Scarus vetula	0.9	1.7	2.5	1.5	-	0.3	1.7	2.4	1.5	3.3	2.5	1.4
	(0.2)	(0.7)	(0.3)	(0.7)	-	(0.2)	(0.4)	(0.6)	(0.5)	(0.7)	(1.2)	(0.3)
Total (Parrotfish)	**12.0**	**13.2**	**10.5**	**8.5**	**7.4**	**5.4**	**12.3**	**14.3**	**12.0**	**12.4**	**16.7**	**13.9**
	(2.0)	(1.9)	(1.0)	(1.5)	(2.1)	(1.1)	(1.5)	(1.4)	(2.1)	(0.9)	(2.4)	(1.3)
Total (Herbivores)	**17.0**	**20.2**	**11.3**	**9.8**	**15.4**	**11.5**	**21.3**	**15.7**	**13.2**	**13.9**	**20.7**	**21.4**
	(2.9)	(5.2)	(1.1)	(1.3)	(2.6)	(0.9)	(0.7)	(1.8)	(2.2)	(1.1)	(2.5)	(1.7)

Table 7. Mean biomass (g 120 m^{-2}) and standard error (in parenthesis) of each herbivorous species in 12 study sites on the east coast of Great Inagua

Families	**Sites**											
	Man of War Bay					**Mathew Town**						
Species	**MOW-1**	**MOW-2**	**MOW-3**	**MOW-4**	**MOW-5**	**MT -1**	**MT-2**	**MT-3**	**MT-4**	**MT-5**	**MT-6**	**MT-7**
Acanthuridae												
Acanthurus bahianus	171.5		16.6	24.5	273.0	148.5	26.2		19.3	13.0	159.4	118.1
	(40.9)		(10.9)	(17.9)	(29.2)	(50.6)	(13.3)		(13.2)	(9.5)	(25.8)	(42.3)
Acanthurus chirurgus	100.4				133.5	248.0	14.8			16.5		58.1
	(100.4)				(133.5)	(174.0)	(14.8)			(16.5)		(30.3)
Acanthurus coeruleus	85.4	585.8	35.1	72.7	65.2	159.5	918.3	68.5	37.8	48.4	14.1	109.7
	(44.8)	(509.2)	(22.6)	(33.0)	(41.5)	(37.0)	(769.5)	(19.9)	(19.6)	(22.5)	(9.0)	(23.9)
Total (Surgeonfish)	**357.2**	**585.8**	**51.7**	**97.2**	**471.6**	**556.0**	**959.3**	**68.5**	**57.0**	**77.9**	**173.5**	**285.8**
	(111.1)	(509.2)	(19.9)	(27.8)	(143.9)	(223.2)	(760.7)	(19.9)	(20.5)	(35.0)	(23.5)	(71.0)
Scaridae												
Sparisoma aurofrenatum	384.1	308.6	151.5	107.8	284.1	229.0	141.8	201.9	231.3	305.1	168.4	236.6
	(109.6)	(134.2)	(68.0)	(41.2)	(65.7)	(119.5)	(35.8)	(65.9)	(96.6)	(76.5)	(72.7)	(94.0)
Sparisoma chrysopterum		107.7		34.3	85.8	148.7	79.6	171.0	101.7	73.3		250.2
		(107.7)		(34.3)	(85.8)	(148.7)	(79.6)	(119.9)	(101.7)	(73.3)		(126.3)
Scarus iserti	35.4	109.4	179.6	66.3			24.1	140.8	80.5	42.7	269.7	221.6
	(21.5)	(55.1)	(54. 5)	(66.3)			(23.7)	(67.6)	(67.4)	(32.4)	(77.9)	(97.3)
Sparisoma rubripinne					127.7			128.0				226.8
					(127.7)			(82.8)				(226.8)
Scarus taeniopterus	325.2	175.8	55.9	285.3	187.7	228.8	426.9	253.9	248.2	211.4	337.4	
	(73.7)	(79.2)	(27.5)	(129.7)	(100.2)	(74.0)	(74.6)	(55.1)	(72.0)	(41.1)	(116.0)	
Sparisoma viride	620.4	1807.1	494.1	1578.9	986.7	621.2	1097.6	1130.7	656.8	976.3	366.8	1269.8
	(253.3)	(517.0)	(212.9)	(257.8)	(280.5)	(234.3)	(391.9)	(241.5)	(226.5)	(253.2)	(228.4)	(383.9)
Scarus vetula	357.1	627.7	954.7	974.9		494.7	1165.1	748.7	722.4	1094.4	414.0	680.5
	(212.5)	(259.3)	(251.3)	(507.8)		(343.0)	(336.0)	(194.3)	(280.1)	(316.8)	(167.1)	(165.9)
Total (Parrotfish)	**1722.2**	**3136.2**	**1835.7**	**3047.5**	**1672.0**	**1722.3**	**2935.2**	**2775.0**	**2040.8**	**2703.2**	**1556.3**	**2885.5**
	(250.5)	(686.3)	(302.5)	(528.9)	(346.1)	(548.2)	(379.1)	(255.7)	(459.9)	(493.6)	(259.2)	(716.5)
Total (Herbivores)	**2079.5**	**3722.0**	**1887.4**	**3144.8**	**2143.6**	**2278.3**	**3894.5**	**2843.5**	**2097.8**	**2781.1**	**1729.9**	**3171.3**
	(258.5)	(747.1)	(291.7)	(529.5)	(319.7)	(546.0)	(848.2)	(249.5)	(451.0)	(478.6)	(263.1)	(702.4)

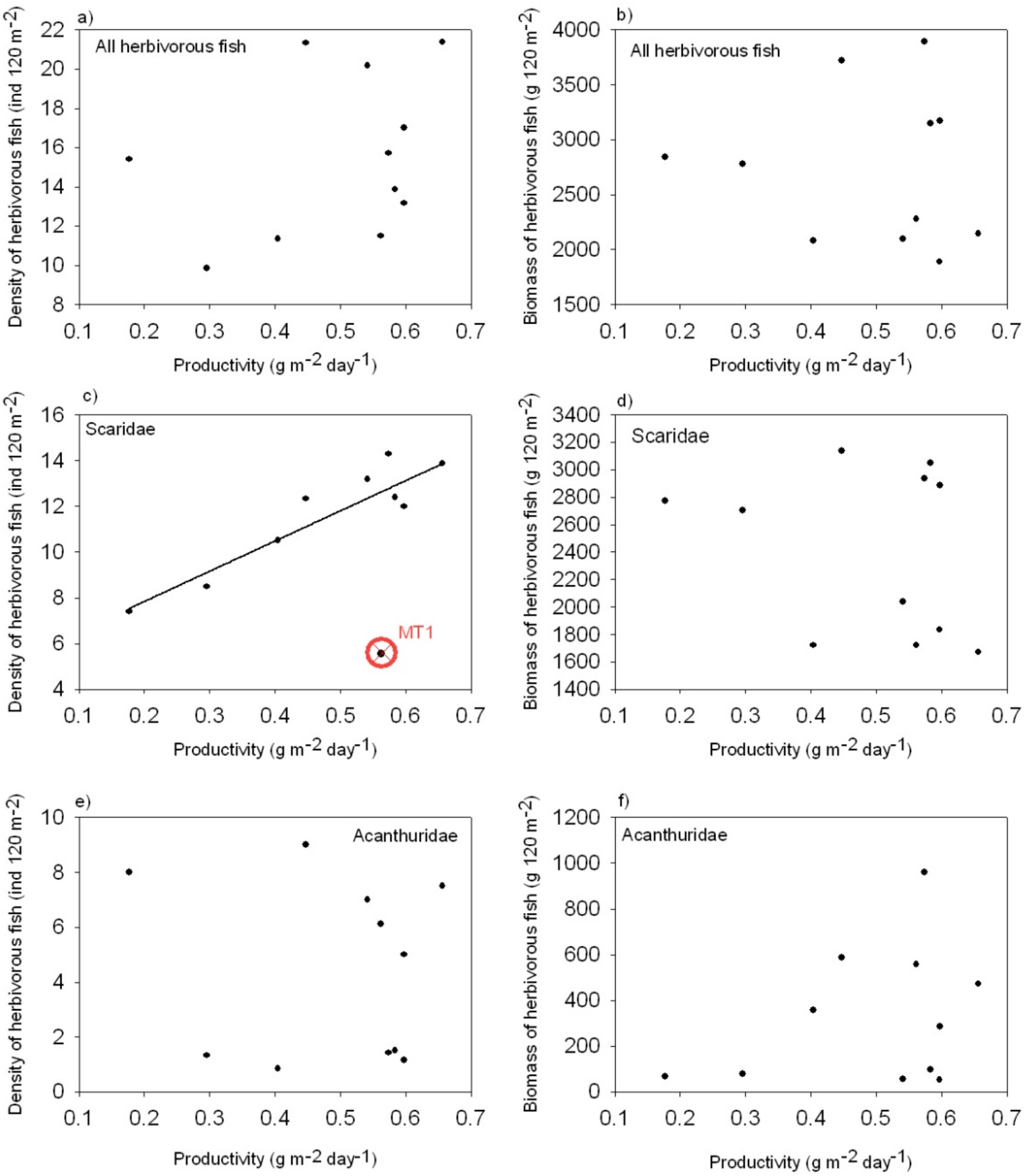


Fig. 47. Mean primary productivity (*x axis*) *vs*. mean density (*y axis* of panels on the left) and biomass (*y axis* of panels on the right) of scarids (c, d), acanthurids (e, f) and all herbivores combined (a, b). In panel c the outlier dot corresponding to site MT1 has been removed to visualize the relationship followed by all other sites.

Predatory reef fishes

A comparison of the density of fish functional groups are presented for all fore reef sites (Fig. 48-50). Two outliers (GI-03, HR-08) are presented separately because these were reef crest and lagoonal sites respectively (Fig. 53). In general, the density of top predators was fairly low (< 5 fish/100m^2), with exception of a few sites that had large schools of snapper. (Fig. 47) Most invertivores also occurred in low numbers with exception of wrasses (Fig. 49-50).

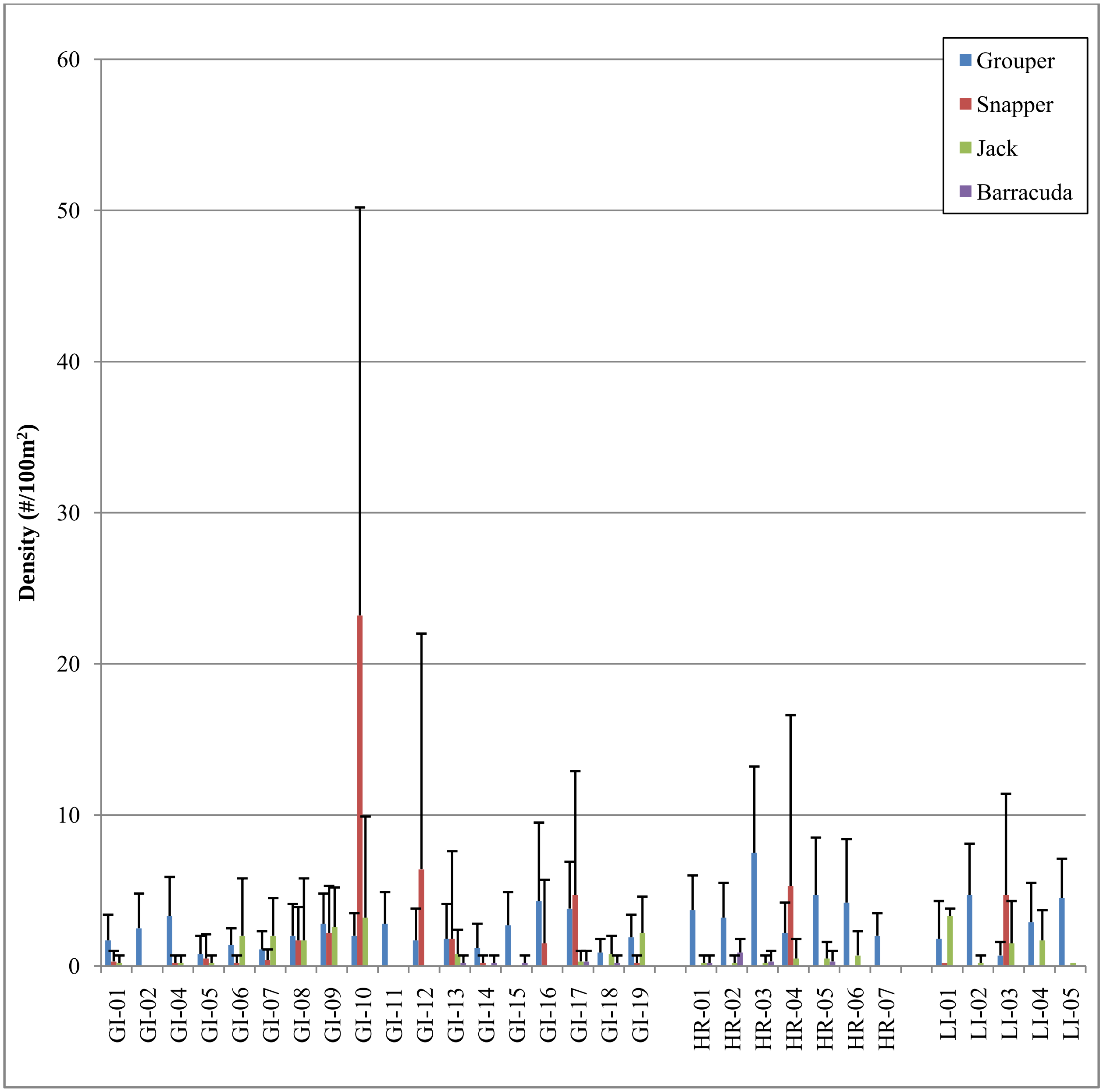


Fig. 48. Density of top predators (number of fish per 100 sq. m) on fore reef sites in Great Inagua, Hogsty Reef and Little Inagua reported as mean and standard error. All species within each functional group are pooled.

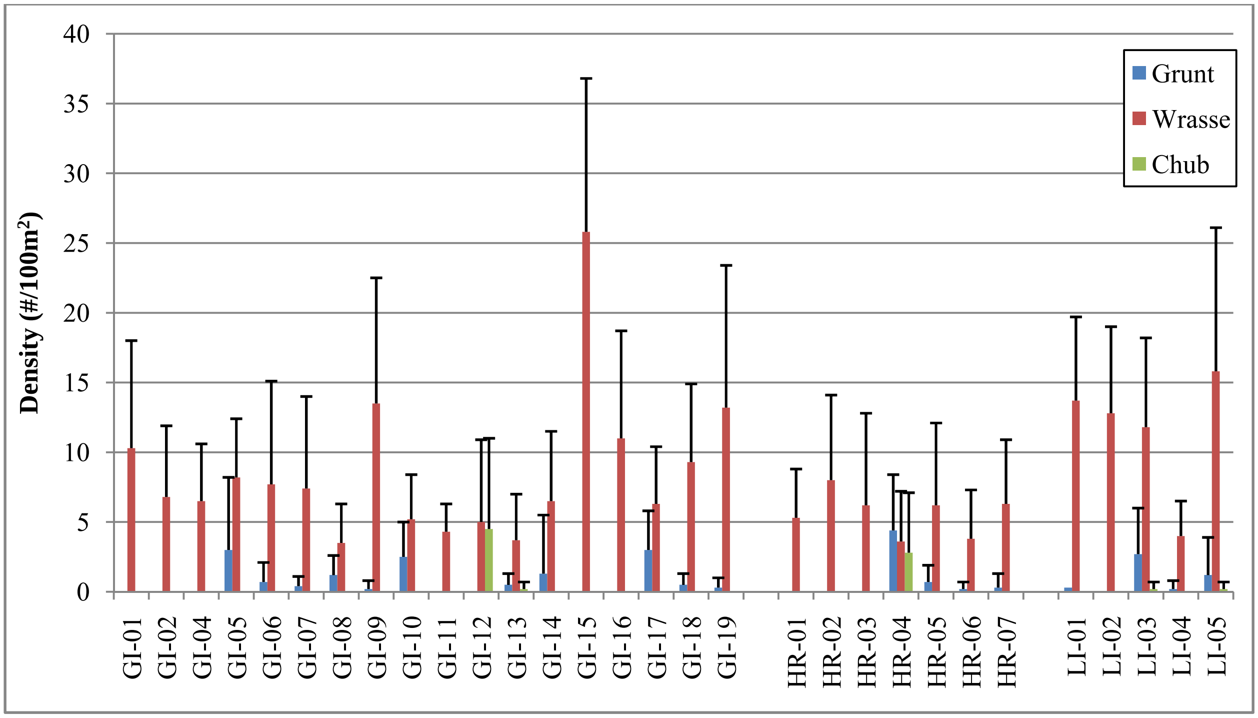


Fig. 49. Density of grunts, wrasses and chubs (number of fish per 100 sq. m) on fore reef sites in Great Inagua, Hogsty Reef and Little Inagua reported as mean and standard error. All species within each functional group are pooled.

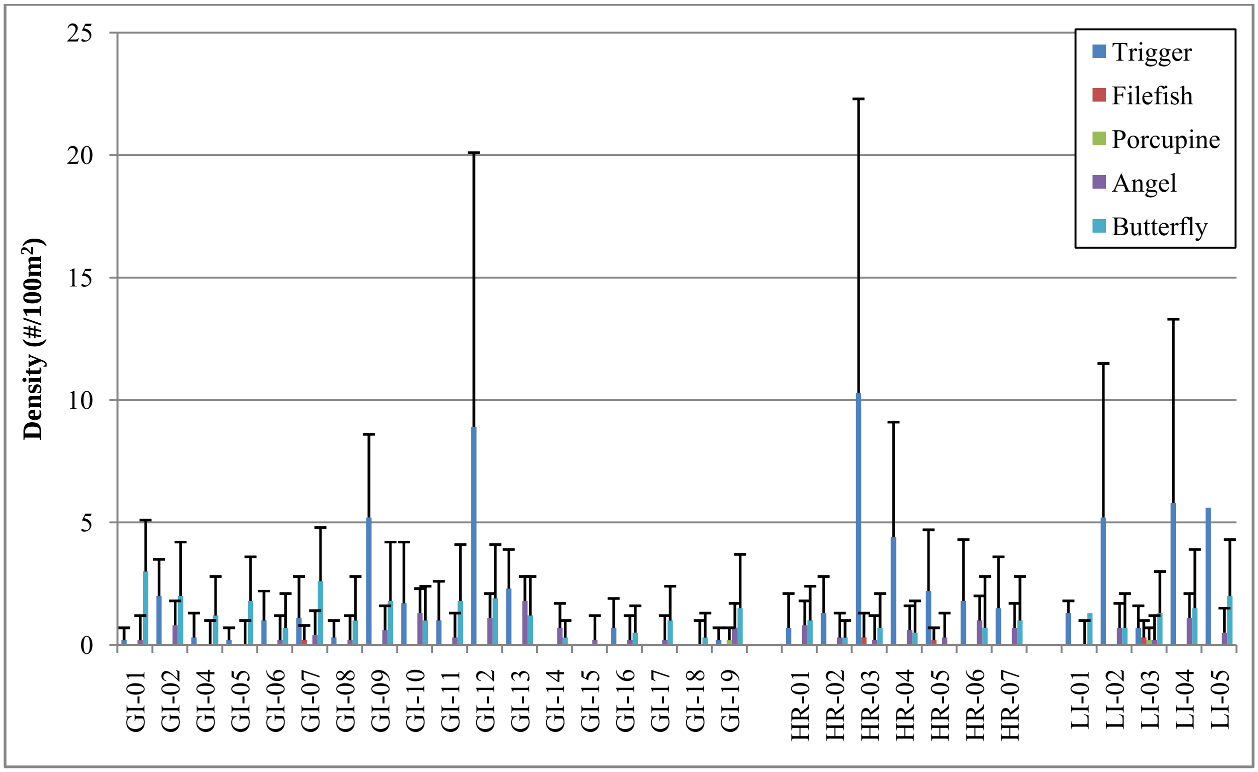


Fig. 50. Density of invertebrate feeders (number of fish per 100 sq. m) on fore reef sites in Great Inagua, Hogsty Reef and Little Inagua reported as mean and standard error. All species within each functional group are pooled.

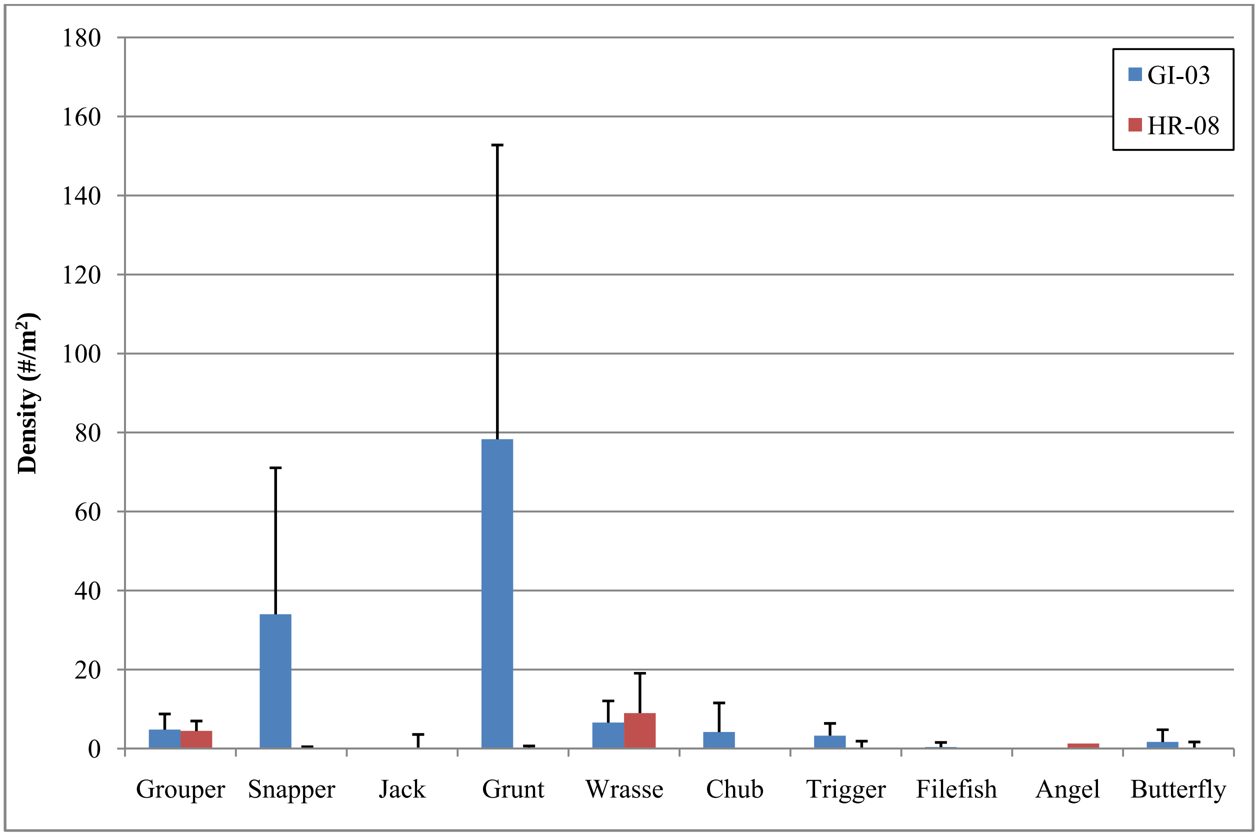
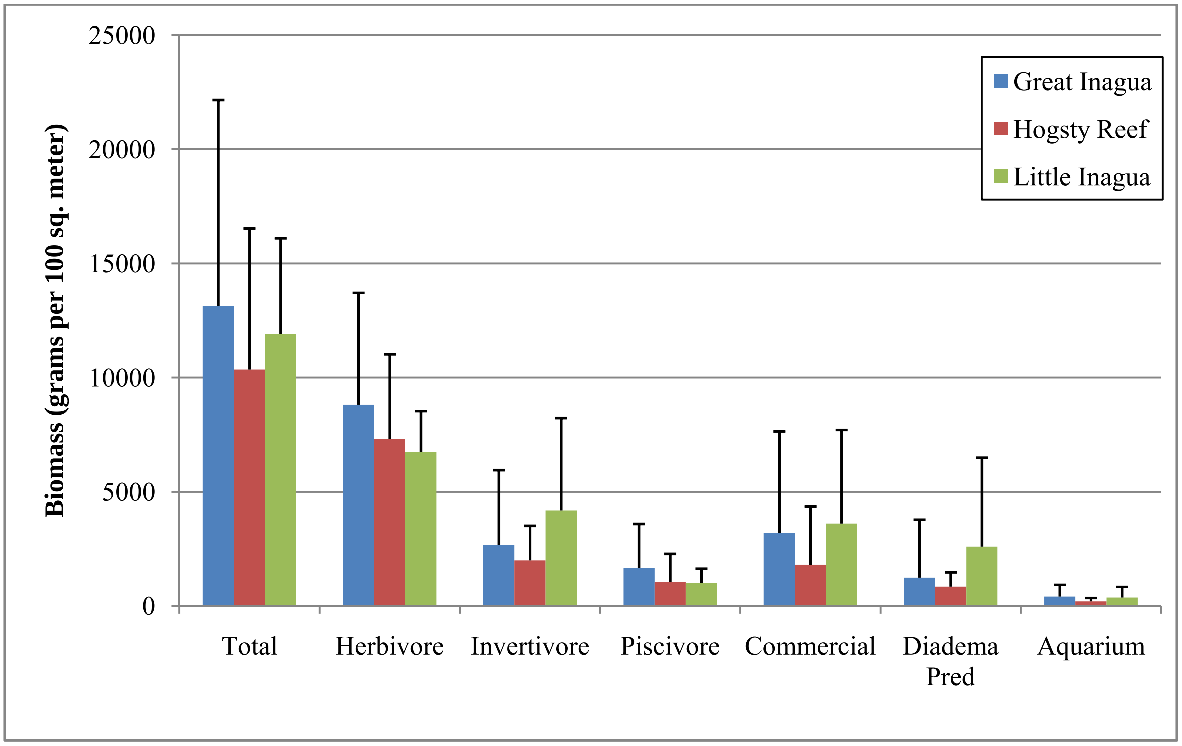


Fig. 51. Density of predatory fishes (number of fish per 100 sq. m) identified in the reef crest (GI-03) and lagoon (HR-08) on Great Inagua and Hogsty Reef. All species within each functional group are pooled.

Biomass of reef fishes

The biomass of fishes, grouped into functional groups, showed differences between sites and locations. Total biomass was highest on Great Inagua, mainly due to a higher biomass of herbivore and piscivores (Fig. 52a). The biomass of all functional groups, except herbivores, was also lower or equal to the biomass on Little Inagua.

A further examination of these same functional groups within Cay Sal, Inagua and Andros reveals significant differences between the fish communities on fore reef sites (Fig. 52b). Overall biomass of fish (all AGRRA species) was highest on Andros, followed by Inagua. Predatory fish, including piscivores and invertebrate feeders were also most abundant on Andros, followed by Cay Sal, with the lowest biomass on Inagua sites. In contrast, herbivore biomass was substantially higher in Inagua. Some of the differences between Andros sites and the other two locations may be depth related, as fore reef sites were shallower (mean = 8.8 m) than Cay Sal and Inagua (mean=13.1 and 14.5 respectively).



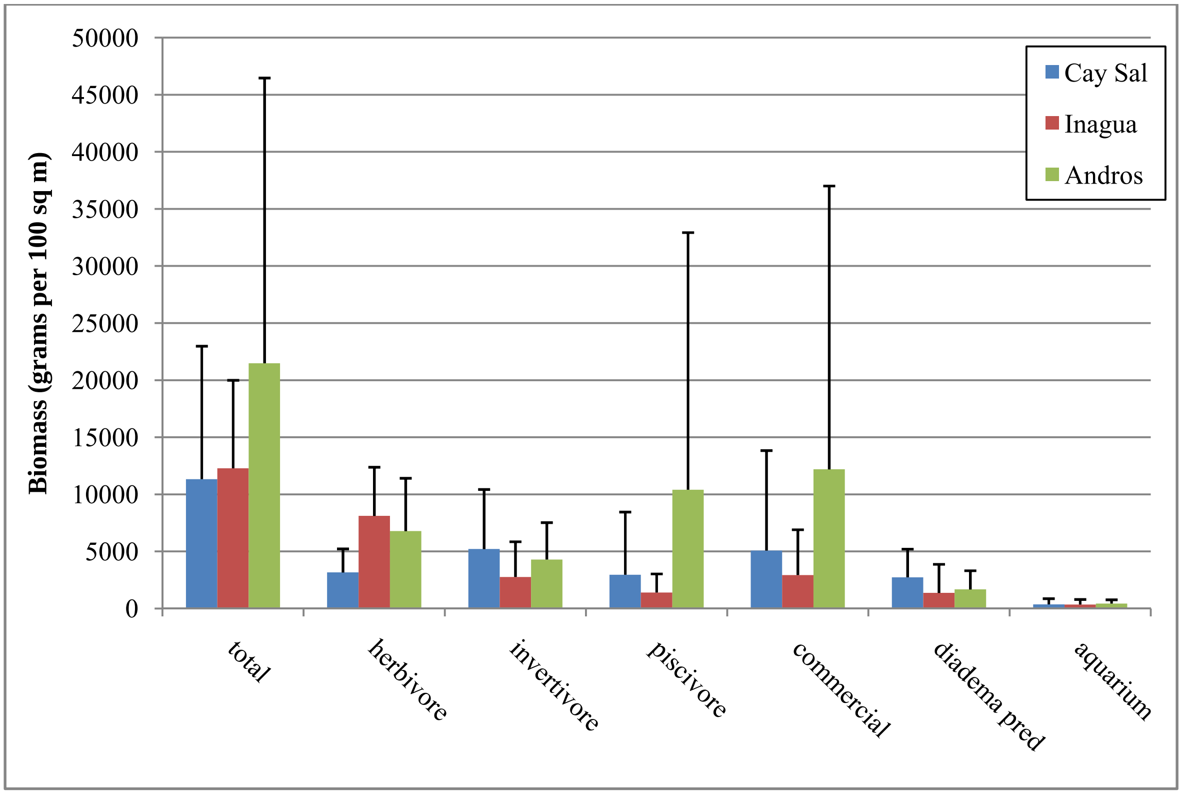


Fig. 52. Biomass of reef fishes (grams per 100 sq. meters) for all species (total), herbivores, invertebrate feeders, piscivores, commercially important species, Diadema predators and aquarium ornamentals for Great Inagua, Hogsty Reef and Little Inagua (top) and for Cay Sal, Inagua region (3 locations pooled) and Andros.

Invasive species

The invasive lionfish *Pterois volitans* was observed at low densities (1-5 fish per dive) in several fore reef locations. The highest numbers (5) were identified on GI-05, GI-08 and LI-01. No other non-native species were documented.

Fig. 53a. *Pterois volitans* lionfish on a shallow reef in Great Inagua.

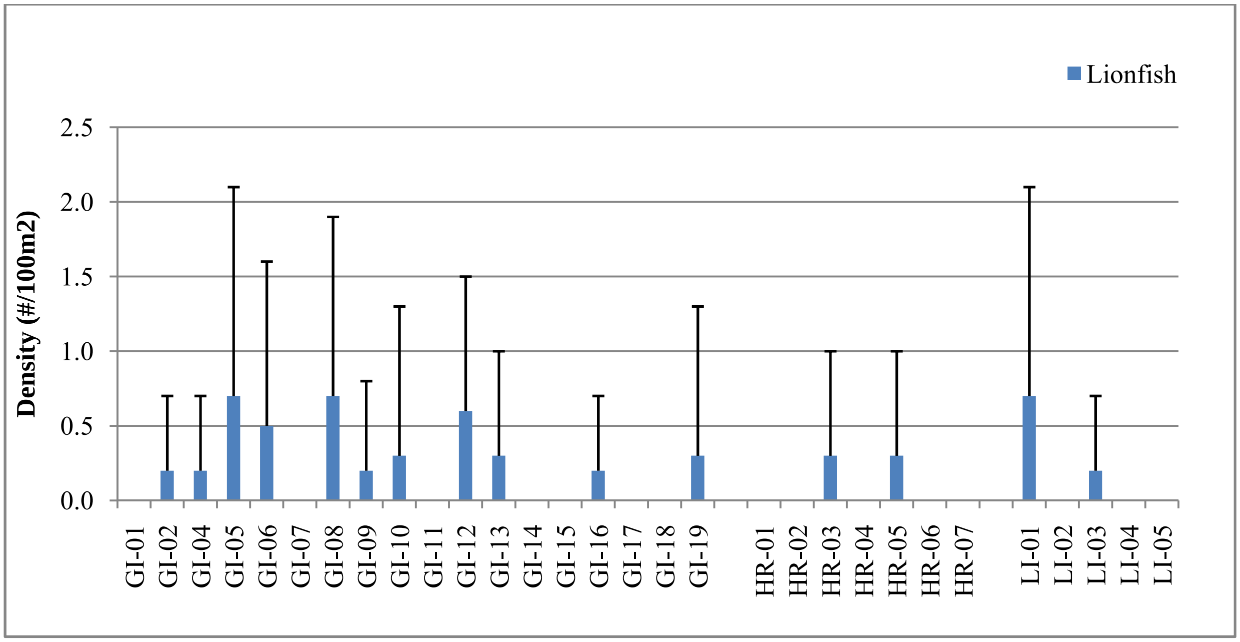


Fig. 53b. Density of the invasive predatory lionfish (number of fish per 100 sq. m) on fore reef sites in Great Inagua, Hogsty Reef and Little Inagua, reported as mean and standard error. This species was not observed in the reef crest or lagoon.

Comparisons among coral reef attributes

An initial comparison between reef attributes and fish population structure was undertaken to determine if specific parameters were interrelated. Initially, percent cover of macroalgae, turf algae and live coral was compared to total fish abundance, and abundance of herbivores. There is no correlation between percent cover of macroalgae, turf algae or coral and total fish abundance (# of fish per m^2) and (Fig. 54a) or abundance of herbivores (Fig. 54b).

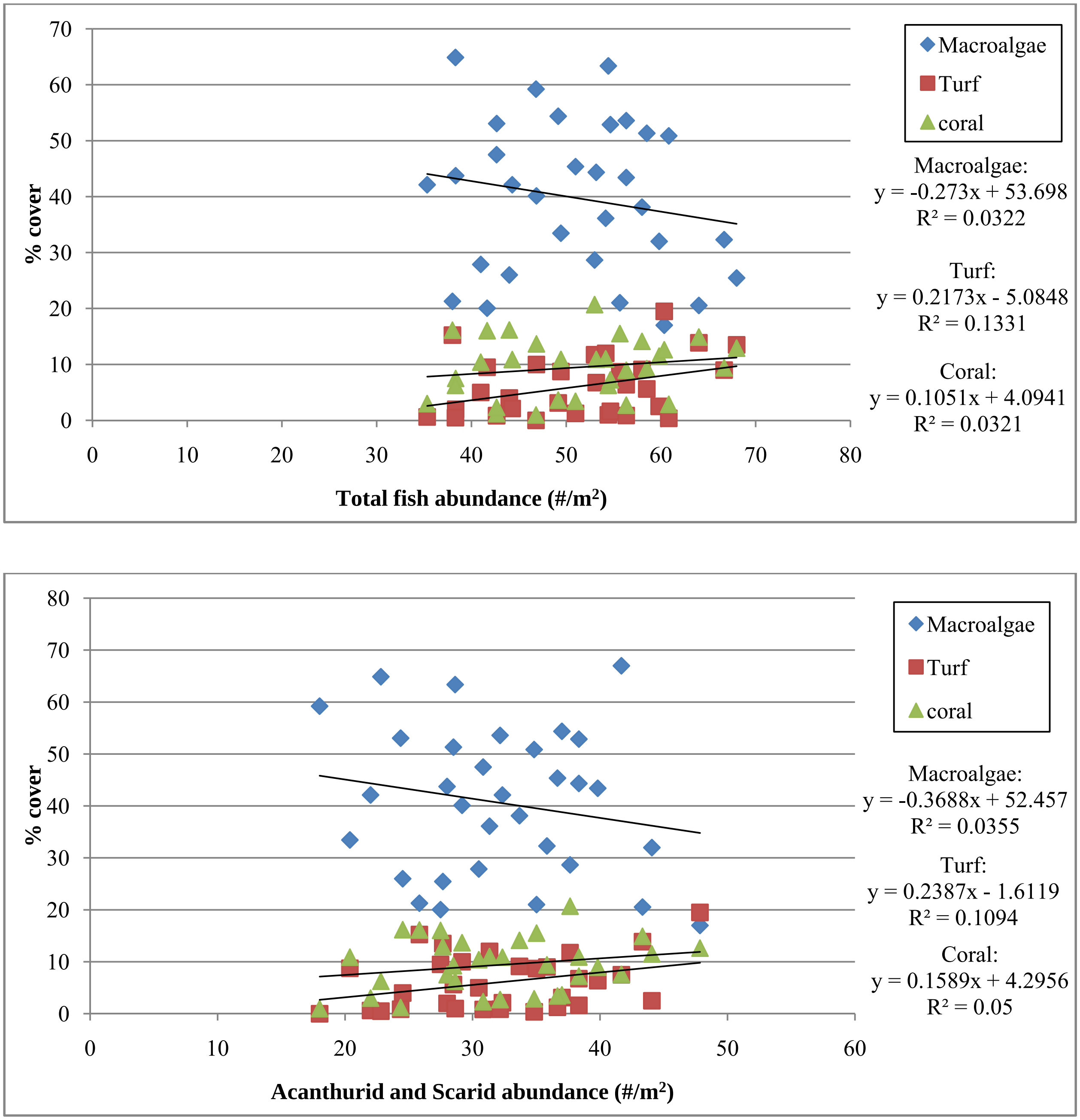


Fig. 54. Relationship between percent cover of macroalgae (blue diamond), turf algae (red square) and coral (green triangle) and total fish abundance (top figure) and herbivore abundance (bottom). Each point represents a single site in Great Inagua, Hogsty Reef and Little Inagua.

When looking at parrotfish and surgeonfish density separately, the trends are opposite. Increasing density of parrotfish is correlated with a decrease in cover of macroalgae and an increase in cover of turf algae and coral, although the R^2 values are fairly low (Fig 55a). Interestingly, an opposite trend is seen with surgeonfish density (Fig. 55b).

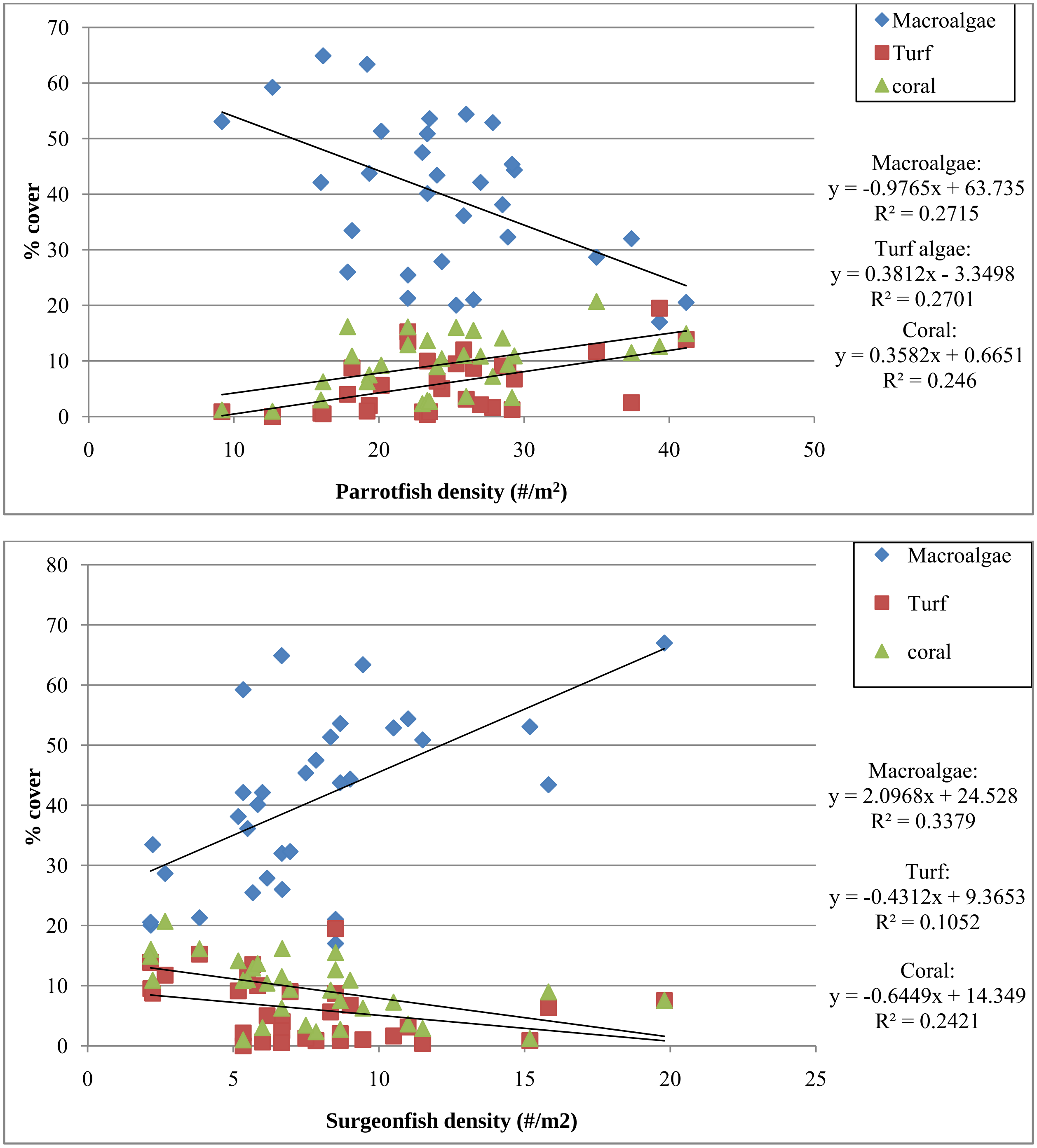


Fig. 55. Relationship between percent cover of macroalgae (blue diamond), turf algae (red square) and coral (green triangle) and parrotfish abundance (top figure) and surgeonfish abundance (bottom). Each point represents a single site in Great Inagua, Hogsty Reef and Little Inagua.

Examination of the same benthic parameters with fish biomass showed no significant trend for total fish biomass (Fig. 56a), herbivore biomass (Fig. 56b), parrotfish biomass (Fig. 57a) or surgeonfish biomass (Fig 57b).

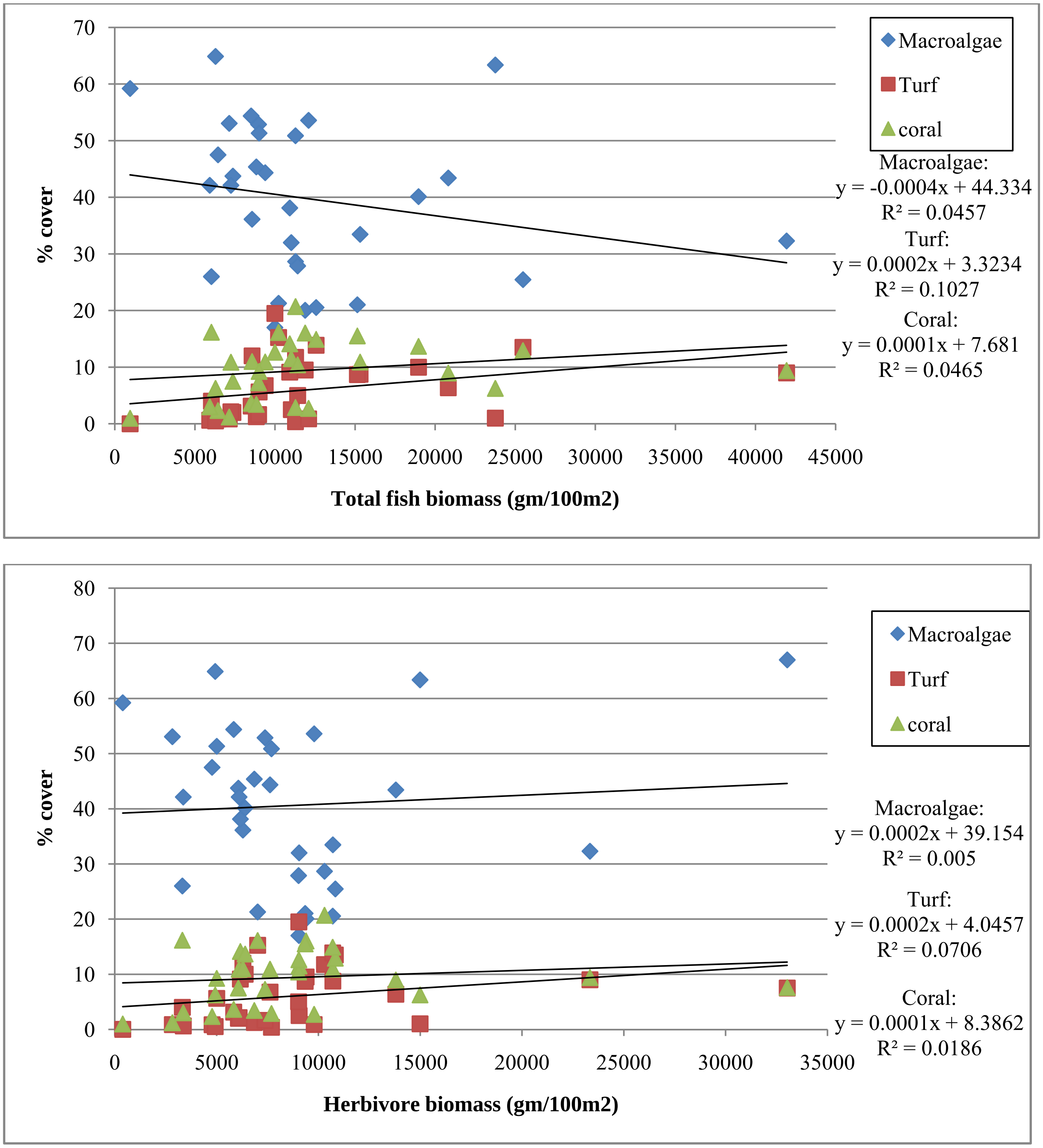


Fig. 56. Relationship between percent cover of macroalgae (blue diamond), turf algae (red square) and coral (green triangle) and total fish biomass (top figure) and herbivore biomass (bottom). Each point represents a single site in Great Inagua, Hogsty Reef and Little Inagua.

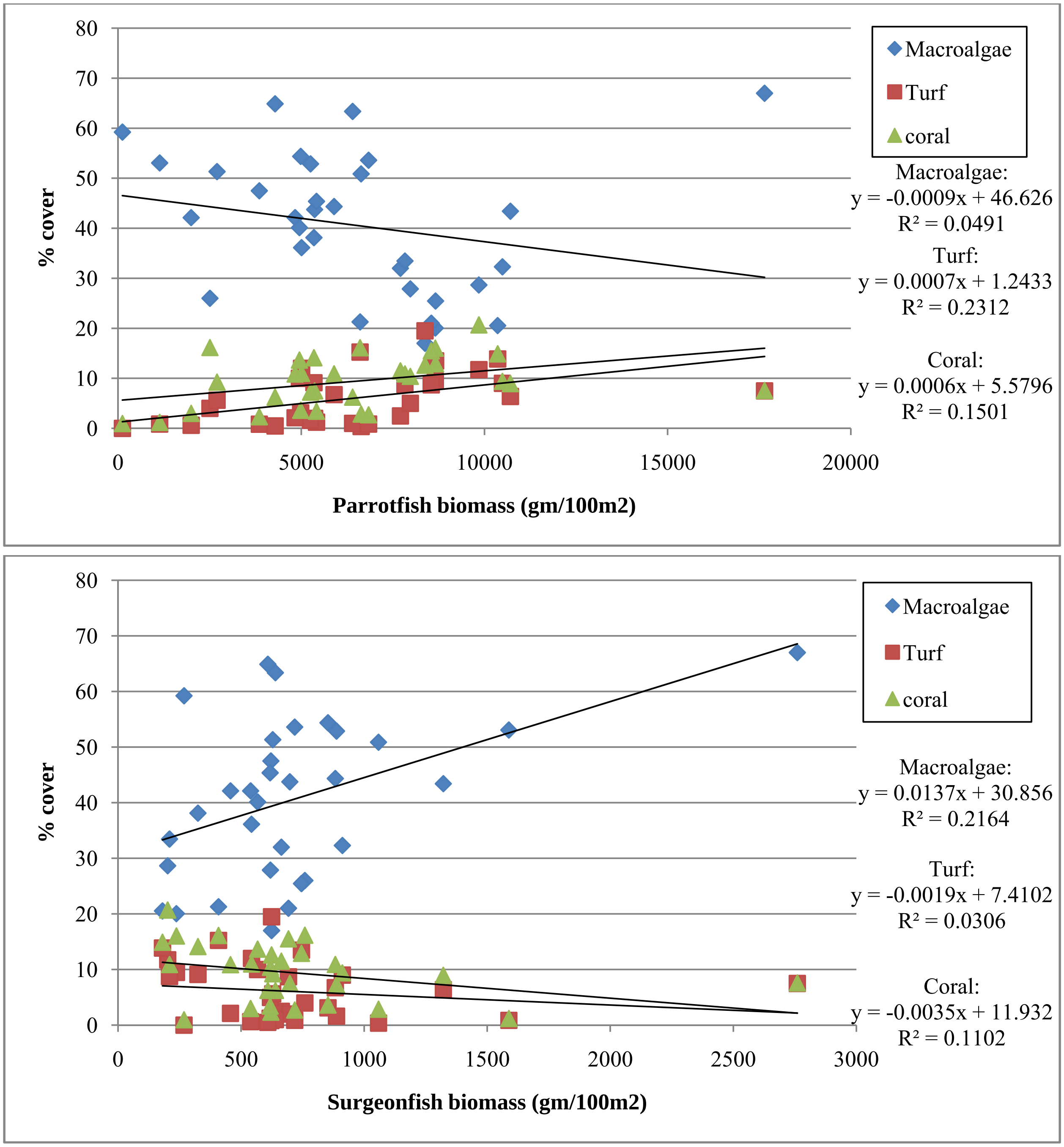


Fig. 57. Relationship between percent cover of macroalgae (blue diamond), turf algae (red square) and coral (green triangle) and parrotfish biomass (top figure) and surgeonfish biomass (bottom). Each point represents a single site in Great Inagua, Hogsty Reef and Little Inagua.

An additional comparison between average reef relief (rugosity; height from the reef substrate to the top of the coral heads) and fish density (Fig. 58a) and fish biomass (Fig. 58b) showed no significant relationships for all species pooled, parrotfish or surgeonfish.

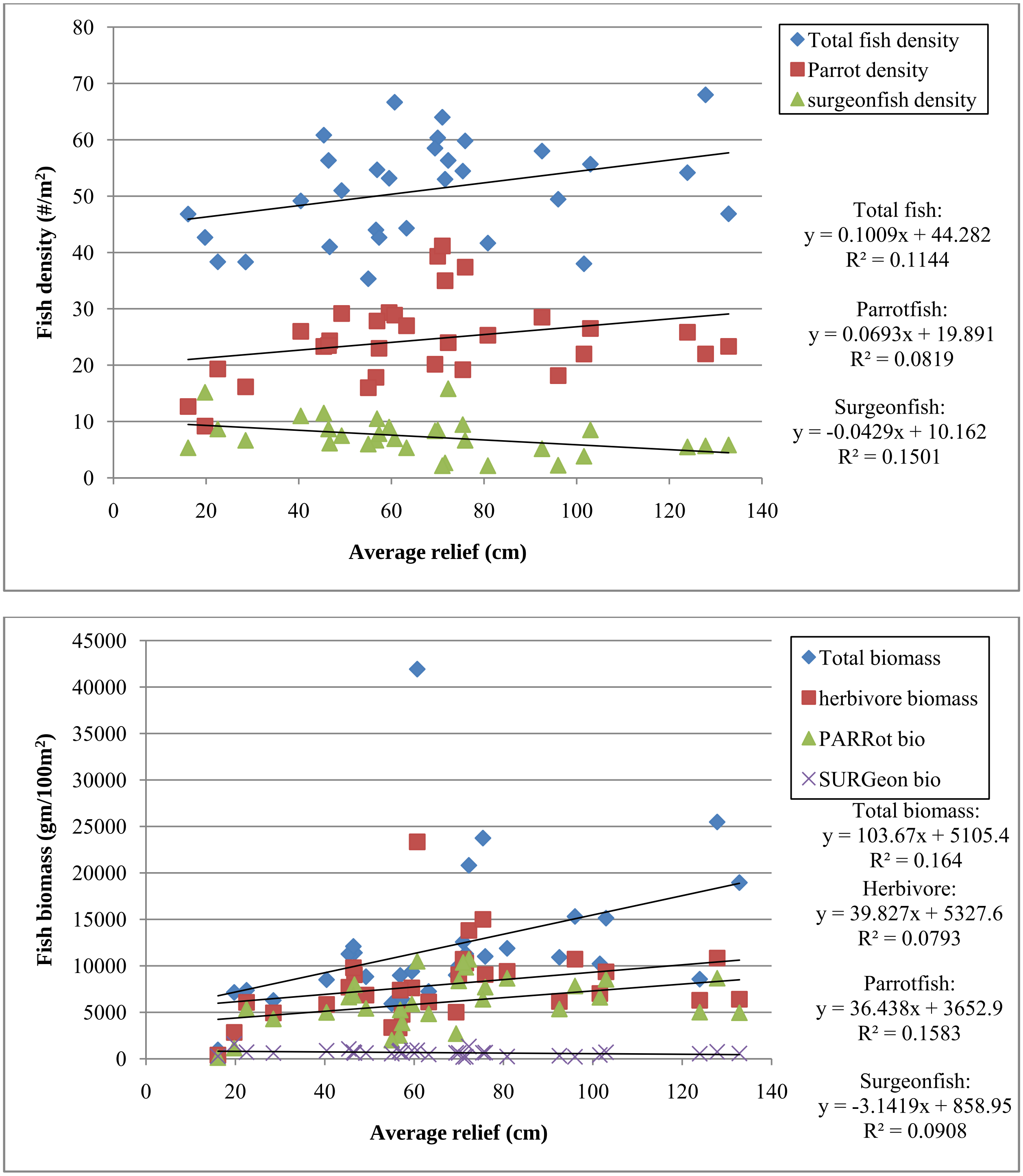


Fig. 58. Relationship between the average relief and the density of reef fishes (top figure) and biomass of fishes (bottom figure) for all species, herbivores, parrotfish and surgeonfish pooled for Great Inagua, Little Inagua and Hogsty Reef.

The density of coral recruits also was not correlated to overall fish density or density of herbivores (Fig. 59).

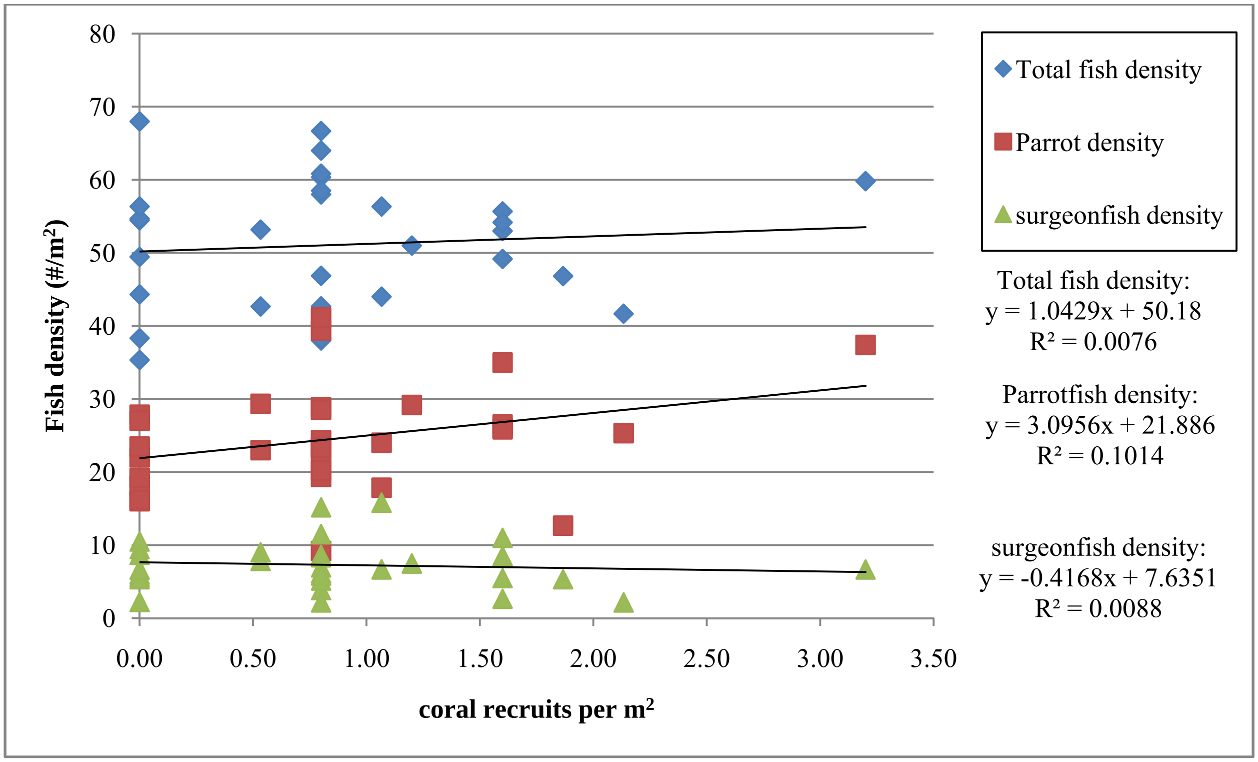


Fig. 59. Relationship between the number of coral recruits per square meter and the density of reef fish. The density of all species pooled (blue diamonds), parrotfish (red squares) and surgeonfish (green triangles) are presented. Each point represents a single location in Great Inagua, Hogsty Reef or Little Inagua.

Resilience assessment

Biological indicators

A reef health index was calculated for each dive site using seven specific biological indicators assessed during the field surveys (Fig. 60). The grades were calculated by converting the mean for each indicator into a rank of 1 (critical) to 5 (very good). Seven parameters, grouped into two categories, were used in this assessment. The first category is a *Coral Index*, comprised of coral cover, coral disease prevalence and coral recruitment. The second category is a *Reef Biota Index*, comprised of a macroalgal index, herbivorous fish abundance (parrotfish and surgeon fish only), commercial fish abundance (grouper and snapper only), and *Diadema* abundance. Threshold values for each rank were based on data ranges presented in the Healthy Reef Initiative (2008) report (summarized below in table 8). The ranked scores of the three *Coral* measures and the four *Reef Biota* measures and these two sub-indices were then averaged to calculate an integrated reef health index. This approach was applied to the MesoAmerican reef system in 2008 (see: www.healthyreefs.org). A simplified reef health index was used to categorize these same reefs in 2012. This approach uses only four parameters (coral cover, macroalgal index, herbivore abundance and commercial fish abundance) and each was weighted equally. A comparison is presented using the Inaguas data in Fig. 61.

Table 8. Threshold values used to determine the ranks.

INDICATORS	VERY GOOD (5)	GOOD (4)	FAIR (3)	POOR (2)	CRITICAL (1)
Coral cover (%)	≥40	20.0-39.9	10.0-19.9	5.0-9.9	<5
Coral recruitment (#•m^2)	≥10	5.0–9.9	3.0–4.9	2–2.9	<2
Coral disease prevalence (%)	<1	1.1–1.9	2.0–3.9	4.0–6.0	>6
Fleshy macroalgae cover (%)	0-0.9	1.0-5.0	5.1-12.0	12.1-25	>25.0
Key herbivorous fish (g•100 m^2)	≥3480	2880-3479	1920-2879	960-1919	<960
Key commercial fish (g•100 m^2)	≥1680	1260-1679	840-1259	420-839	<420
Diadema abundance (#•m^2)	>2.5	1.1–2.5	0.5–1.0	0.25–0.49	<0.25

This analysis may prove useful in comparing sites and regions, and it provides a target for conservation, however it must be viewed with caution. The values presented in table 8 were developed by a scientific review committee based on their experience, perspectives and data and they represent "*a compromise position between grading for the ideal "pristine" reef conditions and what we can realistically hope to achieve in modern times and conditions*." Critical considerations include the most appropriate variables to using and the appropriate weighting of these variables. As seen in Fig. 61, changes in the number of variables used and the weighting can result in drastically different grades of health. Using the simplified health index, 52% of the sites increase by 1 grade (from poor to fair or fair to good) and one site declines by one grade (poor to critical; GI-15). Increases were seen in Great Inagua (mean= 2.9 vs. 3.3) and Little

Inagua sites (2.9 vs 3.4), while no difference was noted for Hogsty (mean= 2.4) (Fig. 61). In addition, multiple sites in Great Inagua and Little Inagua went from good to very good.

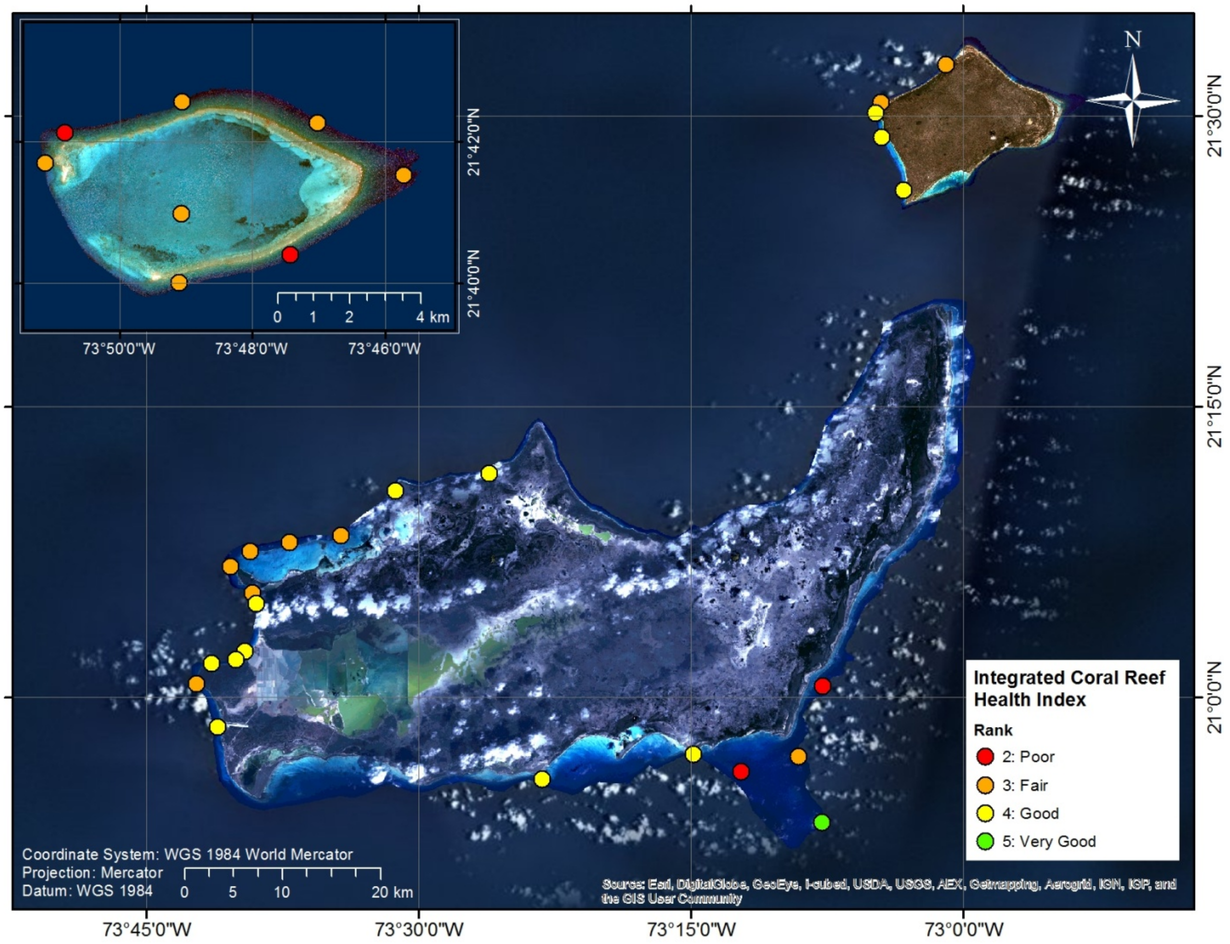


Fig. 60. Integrated coral health index for dive sites assessed on Great Inagua, Little Inagua and Hogsty Reef.

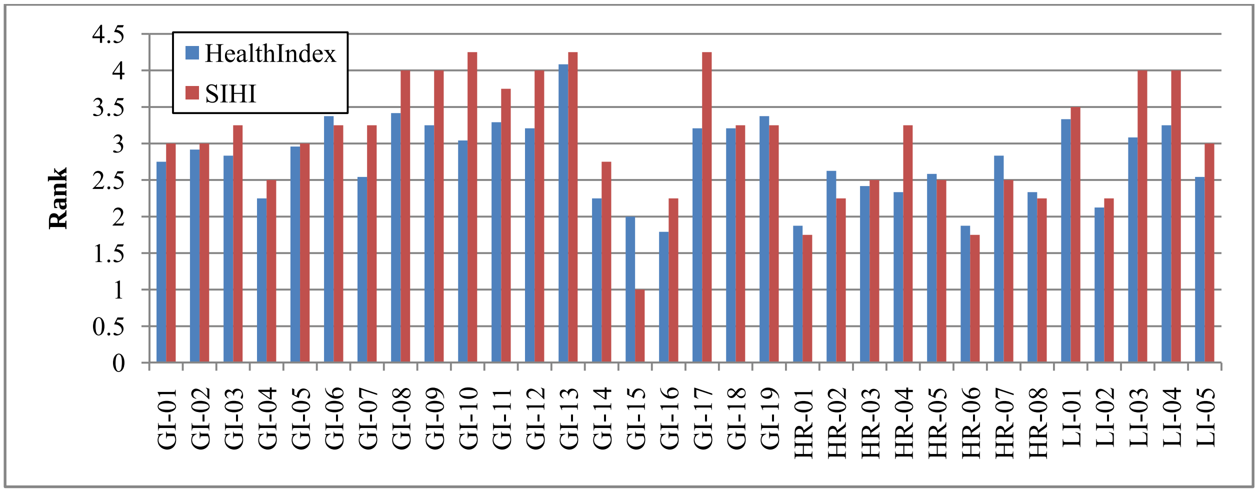


Fig. 61. Comparison of the ranks using the health index presented in Fig. 60 (blue) and a simplified health index based on four equally weighted measures (red).

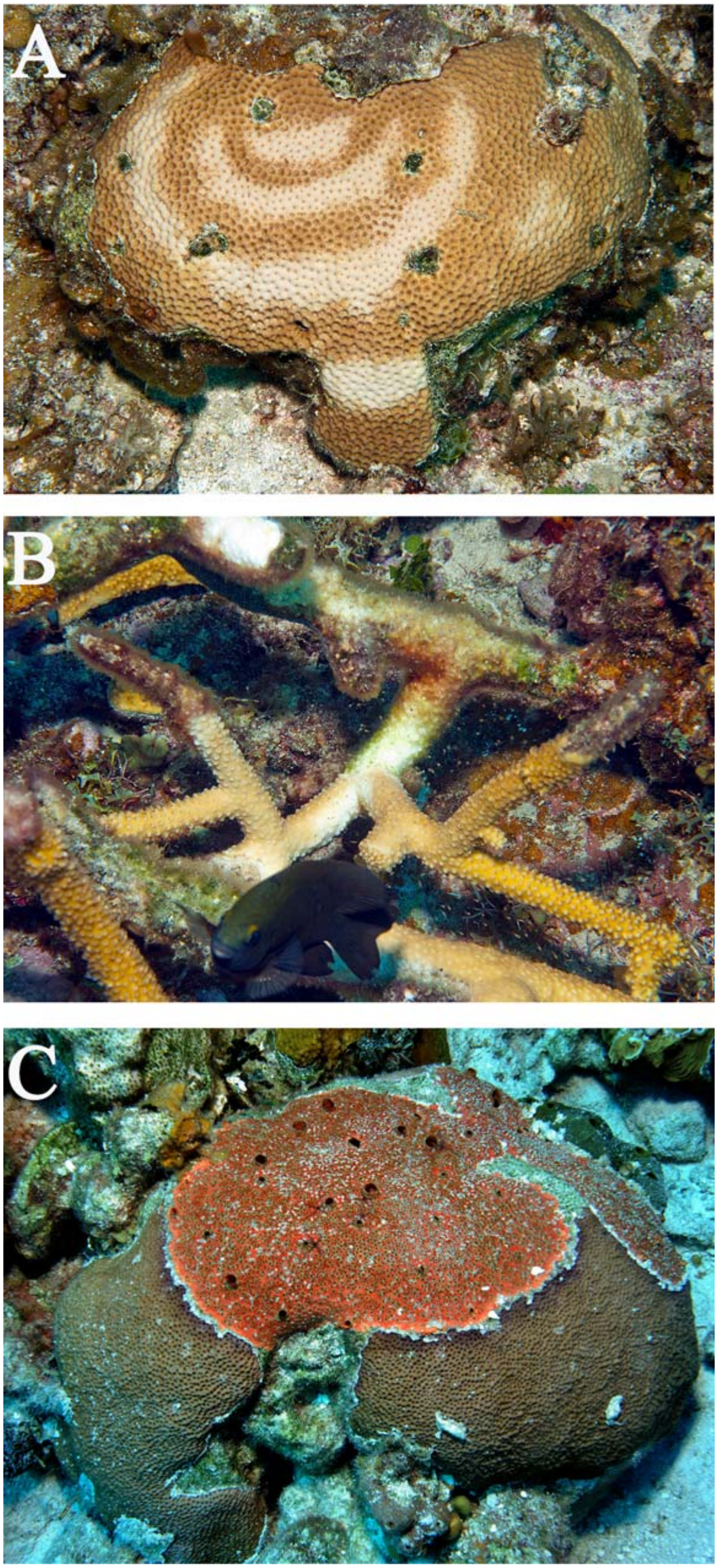


Fig. 62. Examples of biotic stressors affecting reefs in the Inaguas. A. Coral bleaching was generally minimal. Shown is a *Siderastrea siderea* colony with patchy bleaching. B. Three spot damselfish (*Stegastes planifrons*) create algal lawns on corals. While these fish may help propagate certain corals such as *A. cervicornis* through bioerosion of the bases of the branches, if the corals are already stressed and the fish repeatedly bites at the coral, it may undergo tissue sloughing and mortality as seen here. C. Encrusting and bioeroding sponges can outcompete, overgrow and bioerode corals. In the Inaguas, the clionid sponges were commonly observed on corals especially the red *Cliona delitrix* seen here overgrowing a *S. siderea* colony.

While an overall rank of reef health provides a quick snapshot of the reefs that are in the best shape and those that are in a state of decline, it is also important to take a closer look at individual indicators in order to understand specific factors that are of most concern. In general the ranks for five of the variables were fairly similar among the three regions (Fig. 63). Coral cover and macroalgae were identified as "critical" or "poor" in the majority of the sites in all three regions, with significantly lower ranks for both at Hogsty Reef. One cause of this may be due to the unusually low numbers of *Diadema*. Urchins were rare or absent from most sites, indicating that recovery from the 1982-1983 epizootic has not yet occurred. A moderate number of recruits and low prevalence of disease were positive attributes of these reefs, illustrating the potential for improvement in coral cover in future years. The highest overall scores (good to very good) were seen for herbivorous fish populations, which may help reduce macroalgal abundances, thereby enhancing substrate quality and the potential for additional recruitment and increases in coral condition. Most reefs on Great Inagua and Little Inagua also had fair to good populations of commercially valuable groupers and snappers, while these species were less common on Hogsty Reef, suggesting that illegal fishing may be occurring.

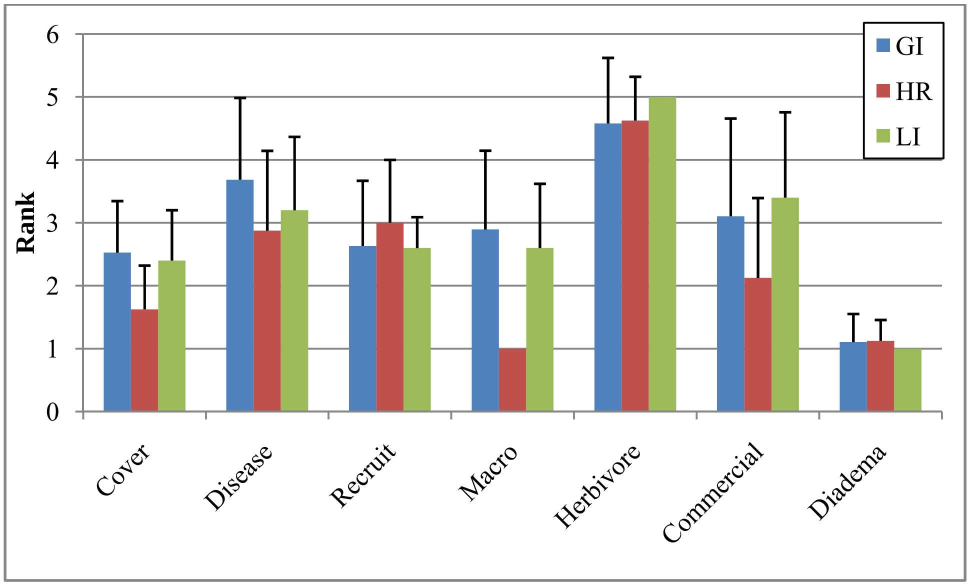


Fig. 63. Mean rank for each of the seven parameters for Great Inagua (blue), Hogsty Reef (red) and Little Inagua (green).

Physical indicators

Relief (height from the reef substrate to the top of the corals) is an important indicator of the amount of available habitat and refuge for motile organisms. The sites examined during this study varied considerably, with the lowest relief overall at Hogsty sites (mean=53 cm) and the highest at Great Inagua (93 cm). Great Inagua and Little Inagua had several very high relief sites (>100 cm), while all sites on Hogsty were between 30-80 cm (Fig. 64).

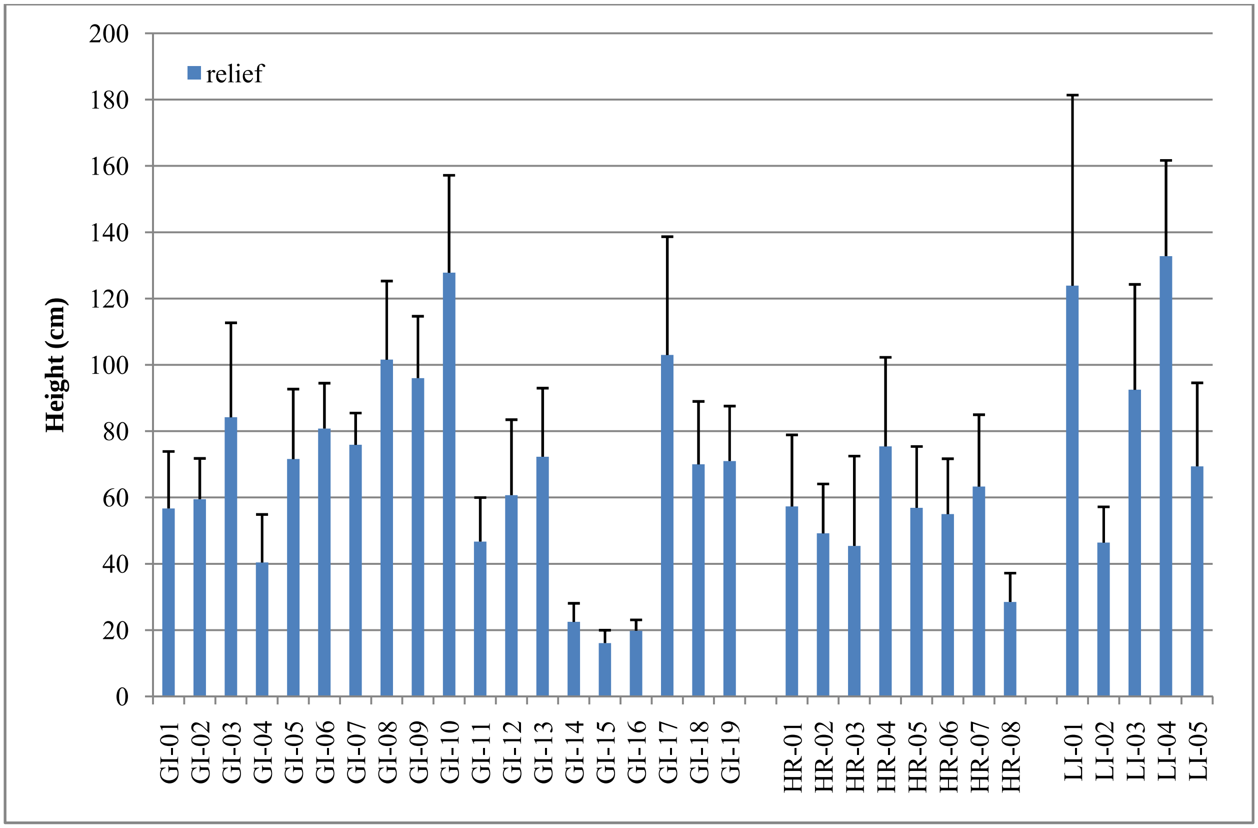


Fig. 64. Mean relief for coral reef sites assessed off Great Inagua, Hogsty Reef, and Little Inagua.

Anthropogenic Indicators

Coastal waters throughout the Caribbean are affected by declining water quality due to land-based sources of pollution and sedimentation associated with agriculture, coastal development, sewage discharge, industrial pollution and other coastal activities. Fortunately, land-based threats are minimal due to the low human population density of the Inagua region. Perhaps the only potential source of direct stress to the reefs, which is extremely localized, is from the salt production facility at the eastern end of Great Inagua.

Concurrently, marine-based threats, such as overfishing and destructive fishing, marine debris and discharge of oil and other pollutants by large vessels threatens the ecological functioning of the reefs by altering food webs and damages the habitats these species rely on. While reports of illegal fishing exist, no fishing gear or vessels were observed during the study. These reefs are, however, vulnerable to overfishing due to the scarcity of certain nursery habitats, deep water separating reef areas, and large distances from potential external sources of recruits. It is extremely important that the available nursery habitats (primarily grassbeds) are maintained and protected from human impacts.

DISCUSSION

The Global Reef Expedition's assessments of the Inagua region resulted in the development of a GIS database containing: 1) satellite imagery of the region; 2) high resolution habitat maps and bathymetric maps; 3) photographic and video documentation, including phototransects; and 4) data layers on the benthic attributes, coral community structure and fish community. A comparative analysis of the community structure and health of reef environments was conducted in the three locations. For corals, detailed information relevant to the understanding of the status of coral populations and their life-history and potential future trajectories was obtained. Other benthic attributes examined include the condition of the substrate, as indicated by the type and amount of each functional group of algae, which can dictate survival and recovery of coral populations following disturbance. Fish assessments provide additional information on the health of the ecosystem, level of human pressures, and ability for the system to withstand change and promptly recover following disturbance.

Coral community structure

Most of the reef communities examined in this study had low cover of corals. On average, from 5-10% of the substrate was colonized by live coral, with only five sites identified (all in Great Inagua) with more than 15% live coral cover. Numerically, the most abundant corals were *Agaricia agaricites, Siderastrea siderea, Porites astreoides*, and the *Montastraea annularis* complex (respectively), followed by *M. cavernosa* and *P. porites*. More than half of these corals exhibited partial mortality, although the amount of partial mortality varied considerably depending on the species and the colony size. In general, the long-lived massive species had higher amounts of partial mortality (e.g. *M. annularis* complex), but these were also larger and presumably older (see below).

Colony size (length, width and height) was a key parameter measured for all corals 4 cm or larger. Size is an important indicator of health, as it encodes its fitness, survival through preceding life-stages and assigns each coral a function within the population according to life-stage, for example whether it is reproductively active or not. Size is often key to an organism's role in the ecosystem and has important evolutionary implications. The sum of all individuals per life stage, if the stages are determined by sizes, leads to a size-frequency distribution. Size-distributions encode much of a population's history and are regularly used for making predictions about a population's future trajectory or to evaluate the effects that certain mortality levels and anthropogenic agents (exploitation by fisheries, pollution, etc.) may have. Size-frequencies can also be used to make inferences about past and future coral population dynamics (Bak and Meesters, 1998; Meesters et al., 2001; Zvuloni et al., 2008).

The size distribution of organisms can vary and is determined by differences in: settlement, initial size, different growth rates due to genetic or environmental effects and mortality. These variables in turn are influenced by a host of biotic and abiotic factors such as predation, disturbances, competition, currents, settlement rates, temperature stress and many more. These factors can act in a systematic or random way. Different combinations of these factors might produce similar distributions, as might interactions with other biological or abiotic mechanisms.

Reefs throughout the Caribbean were traditionally dominated by large, long-lived massive corals in the genus *Montastraea*. Throughout their range, they have undergone a marked decline primarily from disease linked to recent bleaching events (Bruckner and Hill 2009). These species were still one of the dominant corals on the reefs in the Inaguas, although they have been greatly reduced in abundance. It is clear from the size frequency analysis that the colonies of these species in the largest size-class outnumber corals of the middle size classes and smallest size classes. Skewness to the right is caused by corals "stacking up" in the greatest size classes, due to the marked longevity of corals. Such a phenomenon is not unexpected and is observed in other organisms with analogous life-history strategies, such as rainforest trees (Condit et al., 2000). In these size-classes, corals enter into a size refuge where disease or predation cannot easily kill the entire colony. Nevertheless, substantial amounts of the skeletal surfaces of most of these larger colonies were devoid of tissue (Fig. 65).

Fig. 65. Large (1+ m) colony of *Montastraea faveolata* that is completely live and a colony of *M. annularis* on the left that had partially died but has a few small ramets (lobes) that are still live.

Corals in the smaller size-classes can be produced in two ways: by growth from recruits or by skeletal fission in the bigger size-classes. These smaller colonies are especially critical if a population that has been disturbed is likely to persist. The *M. annularis* complex is clearly not recruiting, and the presence of dead colonies, high amounts of partial mortality on survivors, and absence of small and medium sized corals is indicative of a downward trajectory. While the loss of the largest colonies of these species in the Inaguas may further hamper reproductive output, the tiny remnants were showing high rates of survival and modest regrowth. Although decades will be required to restore populations to their larger size, it is likely that these remnants will have a higher survival than recruits. If efforts are made to preserve the integrity of these reefs (e.g. by protecting herbivores through establishment of MPAs; re-establishment of *Diadema* populations) these communities may still rebound through resheeting and continued growth, and ultimately once they surpass a minimum size can begin sexually reproducing once again.

Contrary to this, shorter-lived corals (especially brooding corals in the genus *Agaricia* and *Porites*) were encountered very frequently in the small and medium size classes, suggesting that enough corals in the smaller sizes are produced to maintain a population. Because these species showed little mortality and high recruitment, this is indicative of a population on a sustainable trajectory. The other most important reef builders (*Acropora*) have declined throughout the wider Caribbean. Isolated thickets of these species in good condition were found and some areas contained modest numbers of individual colonies. While recruits of these species were also rare, the populations could quickly expand through fragmentation, which is highly likely in these locations given the high wave energy some sites (especially windward sides of Little Inagua and Great Inagua and all of Hogsty Reef) (Fig. 66).

Fig. 66. Large areas of reef were covered by macroalgae and had very little live coral cover. In some locations, small colonies and recruits are successfully settling and surviving, such as that seen on the shallow fore reef on Hogsty Reef shown here. Two small *Acropora cervicornis* colonies, *P. astreoides*, and *P. porites* are present.

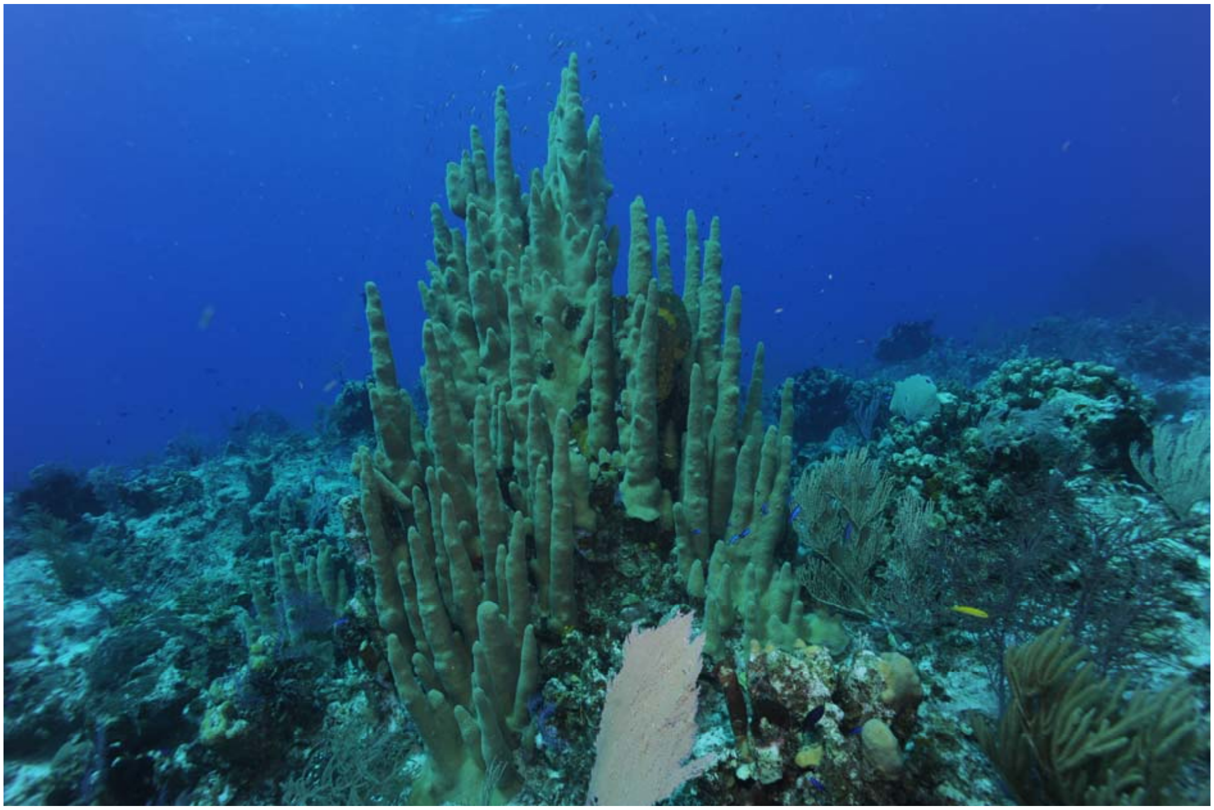


Fig. 67. Hogsty Reef had some unusual coral assemblages, such as a high number of very large pillar corals (*Dendrogyra cylindricus*) on the fore reef slope (top image) and large aggregations of finger corals (*Porites porites*) within shallow back reef and reef crest habitats (lower image).

Fish populations

Reef fish populations in the three locations included most of the common Caribbean species, with exception of certain species of grunts and snapper that were completely absent. Also, eels, filefish, hogfish, and several groupers (black, rock hind, yellowfin) were very rare (Fig. 68). The absence or rarity of certain fishes may be due to the scarcity of mangrove nursery habitats. The overall biomass of fishes was higher than that recorded on Cay Sal, but lower than on Andros. This was mainly due to higher number of predatory fish, including piscivores and invertebrate feeders present on Andros, where there is more high relief *Montastraea* habitat as well as extensive shallow seagrass beds and mangrove habitats. Invasive species (lionfish) were present, but in lower numbers than elsewhere in the Bahamas.

Recommendation: Establish fishery reserves in key coral areas to prevent exploitation of certain top predators and reduce illegal fishing.

The low abundance of species that rely mangroves and grassbeds for a portion of their lives illustrates the potential vulnerability of these fishes. Their presence suggests emigration of juveniles and/or adults from some distant location, but it is likely that these populations are very vulnerable to disturbance, such as fishing pressure. The long distance and presence of deep water surrounding these areas may delay recovery of a species that becomes depleted, with cascading impacts on other interdependent species. Because of this, it is critical that fishing pressure is maintained at low levels and efforts are made to preserve the available nursery habitats (e.g. shallow lagoonal grassbeds on Hogsty).

Fig. 68. One of the most abundant groupers seen in the Inaguas is the Nassau grouper, although most reefs only contained one or two individuals and juveniles were not observed. This species has been overfished throughout the Caribbean and few locations remain with healthy populations.

What was unique about this region was the abundance and biomass of herbivores which was substantially higher than Cay Sal and Andros. This was mainly due to four parrotfish: the redband parrotfish (*Sparisoma aurofrenatum*; Fig. 69), the princess parrotfish (*Scarus* *taenipterus*), the stoplight parrotfish (*Sparisoma viride*), and (*Scarus vetula*); and two surgeonfish: the blue tang (*Acanthurus coeruleus*) and the ocean surgeonfish (*A. bahianus*).

Fig. 69. Herbivores such as the red band parrotfish were very abundant in the Inaguas.

Recommendation: Protect herbivorous parrotfishes and surgeonfishes from fisheries harvest.
In other Caribbean locations, herbivorous parrotfish and surgeonfishes have become targets of subsistence fishing as other higher trophic level fishes have been depleted. In some regions, their numbers are rapidly dwindling and the biomass is also declining also due to the removal of the largest, most ecologically relevant individuals. Fishing of these species should be avoided altogether because 1) the critical role they play in maintaining high quality substrates through consumption of algae; and 2) the absence of other herbivores (e.g. *Diadema*) that could help control fleshy algae biomass and cover.

Benthic communities

Although herbivorous fishes were very common, coral cover remained exceedingly low and macroalgal abundance was very high. In particular, an unusually high cover of the green fleshy algae *Microdictyon* was present at most sites, and this was competing with corals (Fig. 70). Other dominant algae included *Dictyota* and *Lobophora*, all of which carpeted substrates, colonized the margins of corals and were observed overgrowing corals (Fig. 71). While it is unlikely that this is related to nutrient input, it may be so successful due to 1) large amounts of available substrate generated over the past few decades due to coral die-offs associated with mass bleaching events and disease outbreaks; and 2) extremely slow recovery of the keystone herbivore, *Diadema antillarum*. Given the unusually high number of parrotfishes and surgeonfishes, it is unlikely that the fishes alone will be able to control and/or reduce macroalgae cover/biomass. This is of concern because the high cover of macroalgae may be one factor limiting the settlement and survival of coral larvae, and hence the ability for coral populations to rebound.

Recommendation: Conduct research on Diadema with a focus on strategies to reintroduce urchins to key sites in the Inaguas, with the goal of establishing local breeding populations.

Recovery of *Diadema* appears to be a critical step in restoring habitat quality, as existing herbivorous fish populations, albeit healthy, do not appear to be controlling the proliferation of

Microdictyon. In the majority of the sites examined there was a near absence of the sea urchin *Diadema antillarum.* Following the die-off in the early 1980s, this species has likely undergone an allee effect whereby too few individuals remained in the Inaguas to ensure successful reproduction. Even if the few remaining urchins spawn, fertilization of gametes is unlikely to occur if urchins are at too low a density, and local recruitment is unlikely. The effective recovery of these species is likely to require an external (upstream) source of larvae, unless strategies are developed to successfully reintroduce the species and reestablish local breeding populations.

Fig. 70. Green fleshy algae (*Microdictyon*) covered much of the reef substrate and colonized dead areas on stony corals such as this colony of *M. annularis*. The coral is also affected by disease.

Recommendation: Conduct research on nuisance species such as certain sponges and cnidarians to determine factors responsible for their proliferation and options to reduce their prevalence.

Other nuisance species that monopolize substrates, overgrow corals and hamper recruitment were present but generally at low abundances. This primarily included the brown clionid sponges, the red *Cliona delitrix*, the encrusting tunicate *Trididemnum*, encrusting soft corals and colonial anemones (*Palythoa, Erythropodium*) and a few other species. In Great Inagua, there was also a localized occurrence of high numbers of a black sponge (*Svenzea zeai*) on several reefs (Fig. 72). These sponges were aggressively overgrowing corals. While the factors responsible for their proliferation are unknown, it is possible that this species could proliferate in areas of high wave exposure through fragmentation.

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Fig. 71. Reef wall at Hogsty Reef that is dominated by fleshy macroalgae and only contains small corals and scattered gorgonians.

Fig. 72. A reef in Great Inagua with a high abundance of the black sponge, *Svenzea*.

Legacy Site

The Inagua region contained a number of high value coral reefs and associated habitats. Several of these were flourishing coral communities that contained endangered species of corals which had not declined to the degree seen in other Caribbean localities and/or were showing promising signs of recovery. Many of the reef communities are very exposed, and subject to high wave energy and frequent storm damage. Given the extensive numbers of dead corals, still in growth position, and large numbers of colonies with tiny live tissue remnants, these reefs are also likely have also been affected by past large-scale acute disturbances such as coral reef bleaching events and disease outbreaks. They have not, however become completely degraded - the presence of living tissue remnants on larger colonies, many showing stages of resheeting suggests the systems are resilient and can rebound. Nevertheless, without protection from human activities, these reefs may be very vulnerable to future degradation and recovery may be delayed or hampered. Because of the remote nature of these reef environments, some of the unusual biological and geological attributes, and the low human population density of the region, these are key resources that warrant further protection.

Recommendation: Implement a monitoring program on reefs in the Inaguas.

Protection of these resources should include a multipronged approach, ranging from1) measures to reduce the potential for overfishing and illegal fishing, with emphasis on the protection of certain species critical to the health of the reefs (e.g. herbivores); 2) potential experimental manipulations to speed up the recovery of species that have declined from region-wide disturbances and control potential nuisance species (e.g. coral nurseries targeting fast growing acroporids, *Diadema* reintroductions, removal of invasive and pest species such as lionfish); and 3) broad scale conservation measures such as no-take marine protected areas to conserved breeding populations of commercial species and enhance the resilience of the coral communities. Any new management measures and experimental approaches also require follow-up monitoring. The Living Oceans Foundation provided a tool to assist in spatial management such as marine zoning and designation of MPAs (habitat maps). We also conducted rapid reef assessments to understand the current condition of these reefs and threats they face. These surveys focused on key indicators controlling reef health and provide information on population dynamics that can aid in predicting possible future trajectories of the reefs.

Through these assessments, we identified one location that is reminiscent of Caribbean reefs of 20-30 years ago. This area was dominated by a mixed coral assemblage with very high cover of living coral. It was a high relief site that had an unusually large and intact population of *A. cervicornis* and *M. annularis,* and was perhaps the largest remaining population of these corals in the Inaguas region. We selected this as a KSLOF legacy site and permanently marked the perimeter of the site with stainless steel rebar to allow relocation and future monitoring. The entire area was photographed which will allow a reference for future changes (Fig. 73).

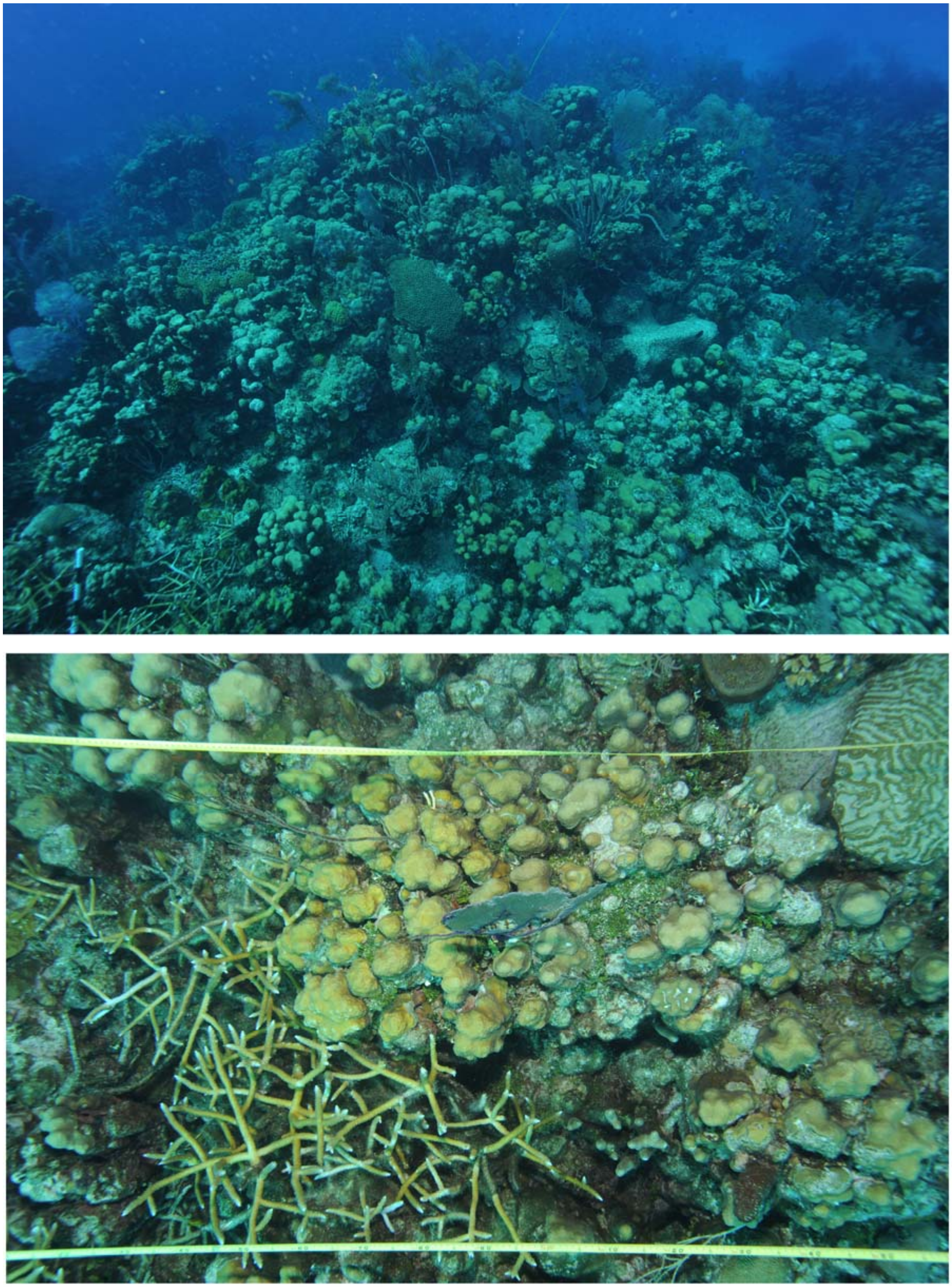

Fig. 73. KSLOF Legacy Site established on Great Inagua. Top photo shows the high relief coral habitat. Bottom photo is a planar view of a portion of the site showing the high abundance of *Montastraea annularis* and *Acropora cervicornis*.

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Appendix Ia. Coral species checklist for Great Inagua, site 1-14.

Abbr	Species	GI-1	GI-2	GI-3	GI-4	GI-5	GI-6	GI-7	GI-8	GI-9	GI-10	GI-11	GI-12	GI-13	GI-14
ACER	*Acropora cervicornis*					x	x	x	x	x	x			x	
APAL	*Acropora palmata*			x											
AAGA	*Agaricia agaricites*	x	x	x	x	x	x	x	x	x	x	x	x	x	x
AFRA	*Agaricia fragilis*		x								x				
AHUM	*Agaricia humilis*	x				x									
ALAM	*Agaricia lamarcki*	x						x			x				
ATEN	*Agaricia tenuifolia*	x	x	x			x	x					x		
CNAT	*Colpophyllia natans*	x		x		x	x		x	x	x		x	x	x
DCYL	*Dendrogyra cylindrus*		x		x									x	
DSTO	*Dichocoenia stokesii*	x	x		x		x		x				x	x	x
DCLI	*Diploria clivosa*			x	x										x
DLAB	*Diploria labyrinthiformis*	x	x		x	x	x	x	x	x	x	x	x	x	
DSTR	*Diploria strigosa*		x	x		x			x	x	x		x	x	x
EFAS	*Eusmilia fastigiata*	x	x	x		x	x	x	x	x	x	x	x	x	x
FFRA	*Favia fragum*				x		x	x	x	x	x		x	x	
IRIG	*Isophyllastrea rigida*	x	x				x	x	x						
ISIN	*Isophyllia sinuosa*	x				x								x	
LCUC	*Leptoseris cucullata*					x			x	x		x		x	x
MDEC	*Madracis decactis*	x	x		x	x	x	x	x	x	x	x	x	x	x
MFOR	*Madracis formosa*														
MAUR	*Madracis mirabilis*		x			x			x	x	x			x	
MPHA	*Madracis pharensis*														
MARE	*Manicina areolata*	x		x	x	x									
MMEA	*Meandrina meandrites*	x	x		x	x	x	x	x	x	x	x	x	x	x
MALC	*Millepora alcicornis*	x	x	x	x	x	x	x	x	x	x		x	x	x
MCOM	*Millepora complanata*			x	x										
MANN	*Montastraea annularis*	x	x	x	x	x	x	x	x	x	x	x	x	x	x
MCAV	*Montastraea cavernosa*	x	x	x	x	x	x	x	x	x	x	x		x	x
MFAV	*Montastraea faveolata*	x	x	x	x	x	x	x	x	x	x	x	x	x	x
MFRA	*Montastraea franksi*	x				x		x	x	x	x				x
MANG	*Mussa angulosa*					x	x	x		x	x				
MALI	*Mycetophyllia aliciae*										x				
MFER	*Mycetophyllia ferox*					x			x		x				
MLAM	*Mycetophyllia lamarckiana*	x			x	x	x	x	x	x	x	x	x		
PAST	*Porites astreoides*	x	x	x	x	x	x	x	x	x	x	x	x	x	x
PBRA	*Porites branneri*														
PDIV	*Porites divaricata*		x	x		x		x						x	
PFUR	*Porites furcata*	x				x					x		x	x	
PPOR	*Porites porites*	x	x				x	x	x	x	x		x	x	x
SCUB	*Scolymia cubensis*	x						x	x						
SRAD	*Siderastrea radians*	x	x	x	x	x			x						
SSID	*Siderastrea siderea*	x	x	x	x		x	x	x	x	x	x	x	x	x
SINT	*Stephanocoenia intersepta*	x	x				x	x	x	x	x	x	x	x	

Appendix Ib. Coral species checklist for Great Inagua, site 15-20.

Abbr	Species	GI-15	GI-16	GI-17	GI-18	GI-19	GI-20
ACER	*Acropora cervicornis*					x	x
APAL	*Acropora palmata*						
AAGA	*Agaricia agaricites*	x	x	x	x	x	x
AFRA	*Agaricia fragilis*						
AHUM	*Agaricia humilis*						
ALAM	*Agaricia lamarcki*						
ATEN	*Agaricia tenuifolia*			x		x	
CNAT	*Colpophyllia natans*		x	x			
DCYL	*Dendrogyra cylindrus*		x				
DSTO	*Dichocoenia stokesii*	x	x	x	x		
DCLI	*Diploria clivosa*			x			
DLAB	*Diploria labyrinthiformis*	x	x	x	x	x	
DSTR	*Diploria strigosa*	x	x	x	x	x	
EFAS	*Eusmilia fastigiata*			x	x	x	
FFRA	*Favia fragum*	x		x			
IRIG	*Isophyllastrea rigida*				x		
ISIN	*Isophyllia sinuosa*			x			
LCUC	*Leptoseris cucullata*			x	x		x
MDEC	*Madracis decactis*	x	x	x	x	x	
MFOR	*Madracis formosa*						
MAUR	*Madracis mirabilis*					x	
MPHA	*Madracis pharensis*						
MARE	*Manicina areolata*						
MMEA	*Meandrina meandrites*	x	x		x	x	
MALC	*Millepora alcicornis*	x	x	x		x	
MCOM	*Millepora complanata*						
MANN	*Montastraea annularis*	x	x	x	x	x	x
MCAV	*Montastraea cavernosa*	x	x	x	x	x	
MFAV	*Montastraea faveolata*	x	x	x	x	x	x
MFRA	*Montastraea franksi*					x	
MANG	*Mussa angulosa*						
MALI	*Mycetophyllia aliciae*						
MFER	*Mycetophyllia ferox*						
MLAM	*Mycetophyllia lamarckiana*			x	x	x	
PAST	*Porites astreoides*	x	x	x	x	x	x
PBRA	*Porites branneri*						
PDIV	*Porites divaricata*	x		x		x	
PFUR	*Porites furcata*	x				x	
PPOR	*Porites porites*		x			x	x
SCUB	*Scolymia cubensis*			x			
SRAD	*Siderastrea radians*	x		x			
SSID	*Siderastrea siderea*	x	x	x	x	x	x
SINT	*Stephanocoenia intersepta*	x	x	x	x	x	

Appendix 1c. Coral species checklist for Hogsty Reef and Little Inagua.

Abbr	Species	HR-1	HR-2	HR-3	HR-4	HR-5	HR-6	HR-7	HR-8	LI-1	LI-2	LI-3	LI-4	LI-5
ACER	*Acropora cervicornis*					x						x		x
APAL	*Acropora palmata*					x								
AAGA	*Agaricia agaricites*	x	x	x	x	x	x	x	x	x	x	x	x	x
AFRA	*Agaricia fragilis*													
AHUM	*Agaricia humilis*													
ALAM	*Agaricia lamarcki*					x		x						x
ATEN	*Agaricia tenuifolia*			x		x		x						
CNAT	*Colpophyllia natans*									x				
DCYL	*Dendrogyra cylindrus*	x	x	x	x	x	x	x						
DSTO	*Dichocoenia stokesii*	x	x	x	x	x	x	x	x		x	x		
DCLI	*Diploria clivosa*	x				x								
DLAB	*Diploria labyrinthiformis*	x	x	x	x	x		x		x	x	x	x	x
DSTR	*Diploria strigosa*			x	x	x	x	x				x		
EFAS	*Eusmilia fastigiata*	x	x			x	x	x		x			x	x
FFRA	*Favia fragum*		x				x	x	x					
IRIG	*Isophyllastrea rigida*		x											
ISIN	*Isophyllia sinuosa*	x	x					x						
LCUC	*Leptoseris cucullata*	x	x		x		x	x	x		x			
MDEC	*Madracis decactis*	x	x	x	x	x	x	x		x	x	x	x	x
MFOR	*Madracis formosa*													
MAUR	*Madracis mirabilis*	x			x		x				x			x
MPHA	*Madracis pharensis*													
MARE	*Manicina areolata*	x												
MMEA	*Meandrina meandrites*	x	x	x		x	x	x		x	x	x		x
MALC	*Millepora alcicornis*		x	x	x		x			x	x	x	x	x
MCOM	*Millepora complanata*													
MANN	*Montastraea annularis*	x	x		x	x	x	x	x	x	x	x	x	x
MCAV	*Montastraea cavernosa*	x	x	x	x	x	x	x	x	x	x	x	x	x
MFAV	*Montastraea faveolata*	x	x	x	x	x	x	x	x	x	x	x	x	x
MFRA	*Montastraea franksi*					x				x			x	x
MANG	*Mussa angulosa*													
MALI	*Mycetophyllia aliciae*													
MFER	*Mycetophyllia ferox*													
MLAM	*Mycetophyllia lamarckiana*	x	x							x	x	x	x	x
PAST	*Porites astreoides*	x	x	x	x	x	x	x	x	x	x	x	x	x
PBRA	*Porites branneri*													
PDIV	*Porites divaricata*				x		x							
PFUR	*Porites furcata*		x	x	x	x	x		x	x		x	x	
PPOR	*Porites porites*		x	x	x	x	x	x	x	x	x	x	x	x
SCUB	*Scolymia cubensis*	x	x											
SRAD	*Siderastrea radians*	x	x		x						x	x		
SSID	*Siderastrea siderea*	x	x	x	x	x	x	x	x	x	x	x	x	x
SINT	*Stephanocoenia intersepta*		x	x	x	x		x	x	x	x	x	x	x

Appendix 2a. Fish species checklist for Great Inagua, sites 1-15.

Species	GI-1	GI-2	GI-3	GI-4	GI-5	GI-6	GI-7	GI-8	GI-9	GI-10	GI-11	GI-12	GI-13	GI-14	GI-15
ANGELFISH															
French				x			x								
Gray					x			x	x	x		x			
Queen	x						x			x			x		
Rock Beauty	x	x		x	x	x	x	x	x	x	x	x	x	x	x
BASSLETS															
Blackcap		x													
Fairy	x		x	x	x	x		x		x	x	x	x		
BLENNIES															
Redlip			x									x			
Roughhead				x			x	x	x			x		x	x
Saddled					x								x	x	x
Sailfin															
Seaweed															x
Secretary															
Spinyhead															
BOXFISH															
Honeycomb Cowfish					x		x		x	x		x		x	
Scrawled Cowfish															
Smooth Trunkfish											x		x	x	
Spotted Trunkfish	x			x	x		x								
BUTTERFLYFISH															
Banded		x	x					x			x		x	x	x
Foureye	x	x	x		x	x	x	x	x	x	x	x	x	x	
Longsnout							x					x			
Spotfin	x	x						x			x			x	x
CHROMIS															
Blue	x	x		x	x	x	x	x	x	x	x	x	x	x	x
Brown		x		x				x	x	x	x	x			
DAMSELFISH															
Beaugregory	x	x	x		x	x	x	x	x	x		x			
Bicolor	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cocoa		x	x	x	x	x	x		x			x			
Dusky	x		x		x										
Longfin		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Sergeant Major			x												
Threespot	x	x	x		x	x	x	x	x	x	x	x			
Yellowtail	x	x	x	x	x							x	x		
EEL															
Brown Garden									x	x					
Goldentail Moray		x													
Green Moray															
Spotted Moray				x											

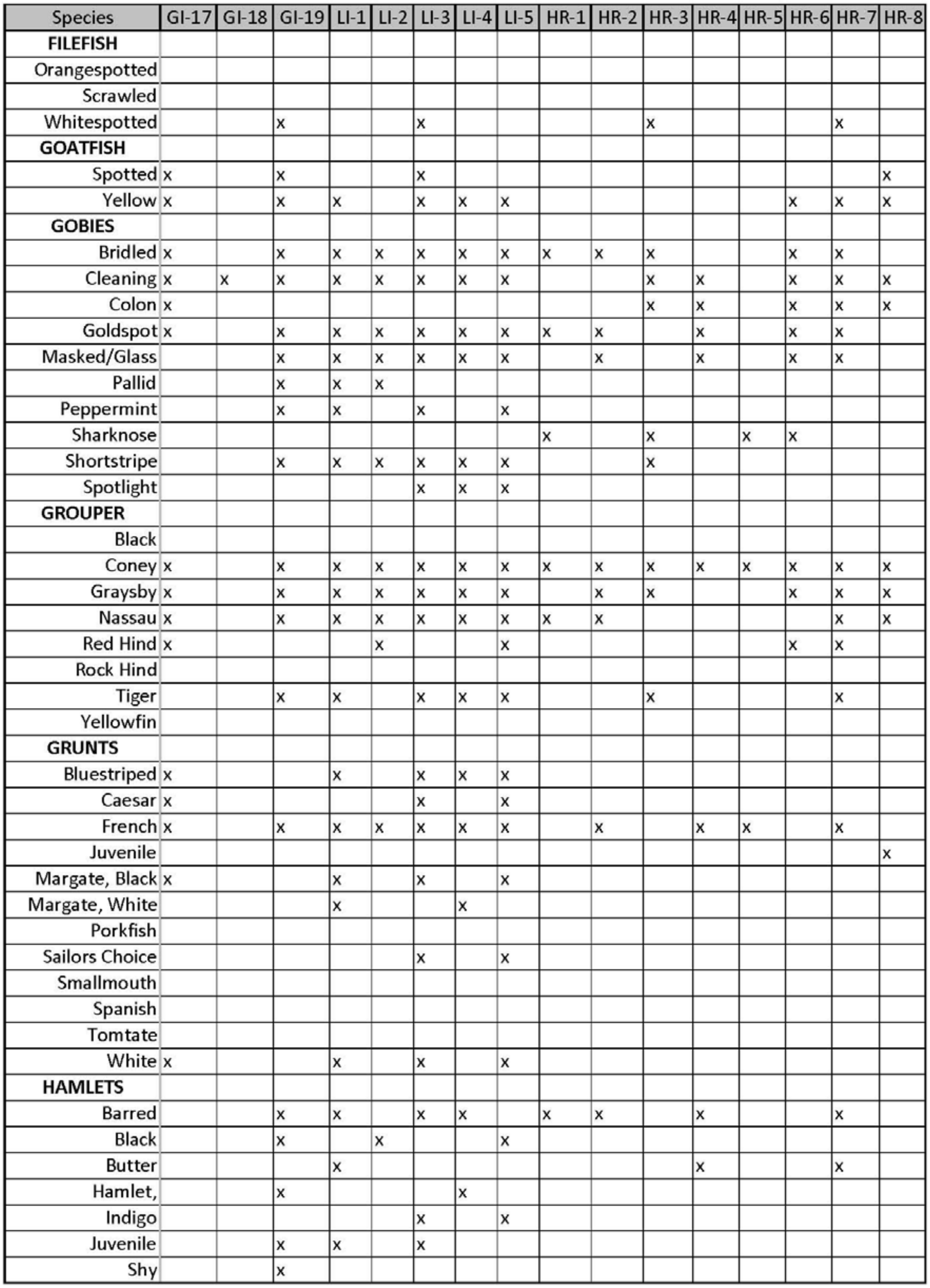
Appendix 2b. Fish species checklist for Great Inagua, site 16-19, Hogsty Reef and Little Inagua.

Species	GI-16	GI-17	GI-18	GI-19	LI-1	LI-2	LI-3	LI-4	LI-5	HR-1	HR-2	HR-3	HR-4	HR-5	HR-6	HR-7	HR-8
ANGELFISH																	
French									x	x							
Gray					x										x		
Queen				x	x		x	x	x						x	x	
Rock Beauty	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x
BASSLETS																	
Blackcap					x		x	x									
Fairy				x	x	x	x	x	x		x	x	x	x	x	x	x
BLENNIES																	
Redlip																	
Roughhead																x	x
Saddled	x					x							x	x	x	x	x
Sailfin	x																
Seaweed																	
Secretary																x	
Spinyhead		x															
BOXFISH																	
Honeycomb Cowfish						x	x		x	x		x					x
Scrawled Cowfish																	
Smooth Trunkfish												x					
Spotted Trunkfish					x		x						x			x	
BUTTERFLYFISH																	
Banded	x				x			x	x				x		x		
Foureye				x	x	x	x	x	x		x		x		x	x	
Longsnout					x		x		x			x	x	x	x	x	
Spotfin	x			x					x							x	
CHROMIS																	
Blue	x				x	x	x	x	x	x	x	x	x	x	x	x	x
Brown	x				x	x	x		x		x	x	x		x	x	
DAMSELFISH																	
Beaugregory					x			x									
Bicolor	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cocoa							x			x			x				
Dusky		x								x	x		x		x	x	
Longfin		x			x	x	x	x	x	x		x	x		x	x	x
Sergeant Major		x															
Threespot				x	x		x	x	x	x	x	x	x	x	x	x	
Yellowtail										x	x	x	x	x	x	x	x
EEL																	
Brown Garden								x									
Goldentail Moray																	
Green Moray								x	x								
Spotted Moray																	

Appendix 2c. Fish species checklist for Great Inagua, sites 1-16 (continued).

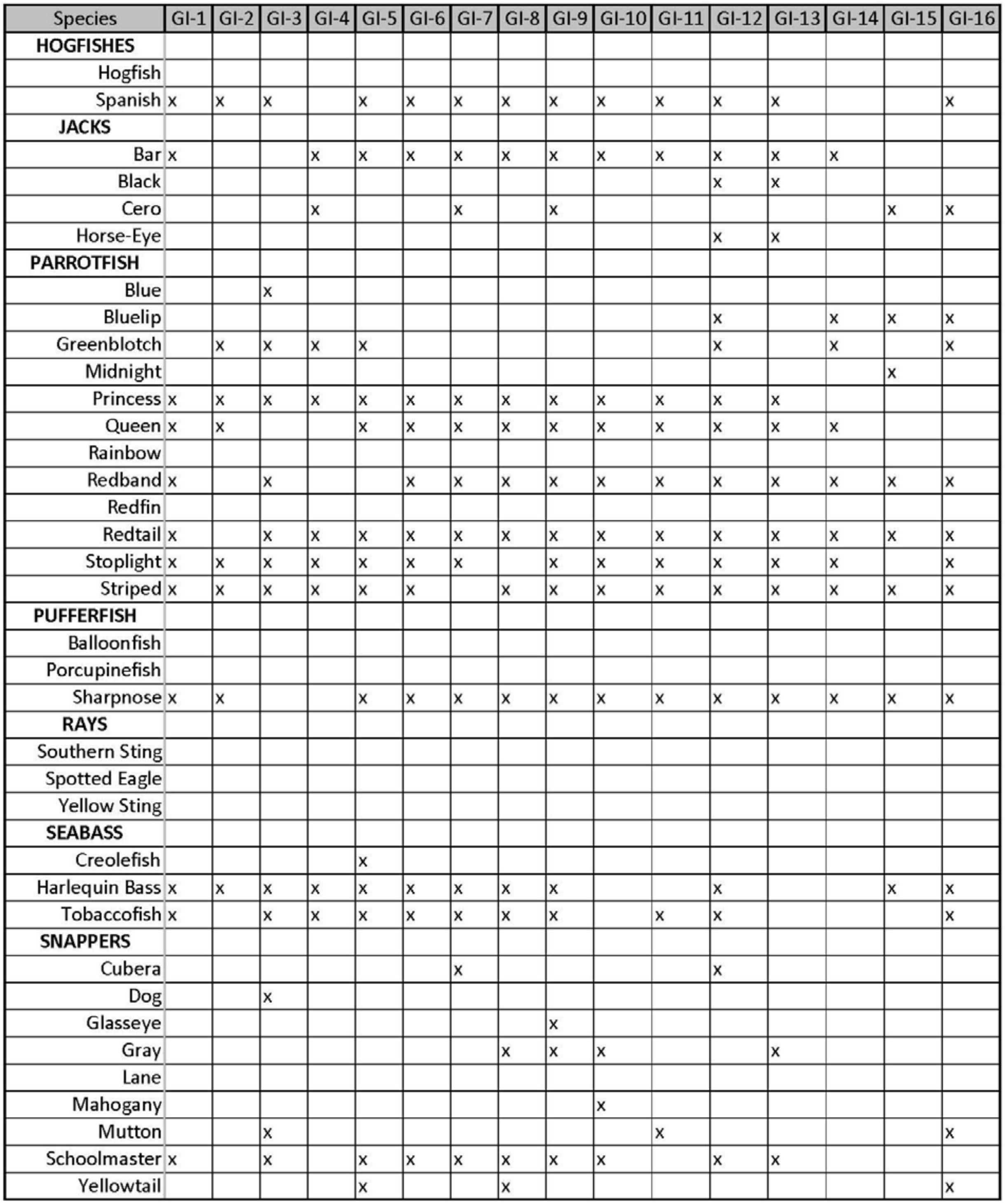
Species	GI-1	GI-2	GI-3	GI-4	GI-5	GI-6	GI-7	GI-8	GI-9	GI-10	GI-11	GI-12	GI-13	GI-14	GI-15	GI-16
FILEFISH																
Orangespotted															x	
Scrawled						x										
Whitespotted																
GOATFISH																
Spotted	x				x			x	x		x	x	x	x	x	x
Yellow	x				x	x	x	x	x	x						
GOBIES																
Bridled	x				x	x	x	x	x	x	x		x	x	x	
Cleaning		x		x	x	x	x	x	x	x	x	x		x	x	x
Colon	x	x	x	x	x				x		x					
Goldspot				x	x	x	x	x	x	x	x	x	x	x	x	x
Masked/Glass					x	x	x	x	x	x	x	x	x			
Pallid									x				x			
Peppermint							x		x			x				
Sharknose				x												
Shortstripe				x		x		x	x	x	x					
Spotlight																
GROUPER																
Black			x													
Coney	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Graysby	x	x	x		x	x	x	x	x	x	x	x	x	x		x
Nassau	x			x	x	x		x	x	x	x	x	x	x		x
Red Hind	x							x	x		x	x		x	x	x
Rock Hind		x		x			x									
Tiger						x		x	x	x	x	x	x			
Yellowfin				x												
GRUNTS																
Bluestriped						x	x	x	x	x						
Caesar							x	x	x	x						
French	x		x	x	x	x	x	x	x	x			x			
Juvenile																
Margate, Black			x													
Margate, White			x							x						
Porkfish																
Sailors Choice										x						
Smallmouth																
Spanish																
Tomtate																
White							x		x	x			x		x	
HAMLETS																
Barred	x	x	x	x	x			x								
Black																
Butter												x				
Hamlet,								x								
Indigo					x											
Juvenile																
Shy																

Appendix 2d. Fish species checklist for Great Inagua, Hogsty Reef & Little Inagua.



Species	GI-17	GI-18	GI-19	LI-1	LI-2	LI-3	LI-4	LI-5	HR-1	HR-2	HR-3	HR-4	HR-5	HR-6	HR-7	HR-8
FILEFISH																
Orangespotted																
Scrawled																
Whitespotted			x			x					x				x	
GOATFISH																
Spotted	x		x			x										x
Yellow	x		x	x		x	x	x						x	x	x
GOBIES																
Bridled	x		x	x	x	x	x	x	x	x	x			x	x	
Cleaning	x	x	x	x	x	x	x	x			x	x		x	x	x
Colon	x										x	x		x	x	x
Goldspot	x		x	x	x	x	x	x	x	x		x		x	x	
Masked/Glass			x	x	x	x	x	x		x		x		x	x	
Pallid			x	x	x											
Peppermint			x	x		x		x								
Sharknose									x		x		x	x		
Shortstripe			x	x	x	x	x	x			x					
Spotlight						x	x	x								
GROUPER																
Black																
Coney	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Graysby	x		x	x	x	x	x	x		x	x			x	x	x
Nassau	x		x	x	x	x	x	x	x	x					x	x
Red Hind	x				x			x						x	x	
Rock Hind																
Tiger			x	x		x	x	x			x				x	
Yellowfin																
GRUNTS																
Bluestriped	x			x		x	x	x								
Caesar	x					x		x								
French	x		x	x	x	x	x	x		x		x	x		x	
Juvenile																x
Margate, Black	x			x		x		x								
Margate, White				x			x									
Porkfish																
Sailors Choice						x		x								
Smallmouth																
Spanish																
Tomtate																
White	x			x		x		x								
HAMLETS																
Barred			x	x		x	x		x	x		x			x	
Black			x		x			x								
Butter				x								x			x	
Hamlet,			x				x									
Indigo						x		x								
Juvenile			x	x		x										
Shy			x													

Appendix 2e. Fish species checklist for Great Inagua, sites 1-16 (continued).



Species	GI-1	GI-2	GI-3	GI-4	GI-5	GI-6	GI-7	GI-8	GI-9	GI-10	GI-11	GI-12	GI-13	GI-14	GI-15	GI-16
HOGFISHES																
Hogfish																
Spanish	x	x	x		x	x	x	x	x	x	x	x	x			x
JACKS																
Bar	x			x	x	x	x	x	x	x	x	x	x	x		
Black												x	x			
Cero				x			x		x						x	x
Horse-Eye												x	x			
PARROTFISH																
Blue			x													
Bluelip												x		x	x	x
Greenblotch		x	x	x	x							x		x		x
Midnight															x	
Princess	x	x	x	x	x	x	x	x	x	x	x	x	x			
Queen	x	x			x	x	x	x	x	x	x	x	x	x		
Rainbow																
Redband	x		x			x	x	x	x	x	x	x	x	x	x	x
Redfin																
Redtail	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Stoplight	x	x	x	x	x	x	x		x	x	x	x	x	x		x
Striped	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x
PUFFERFISH																
Balloonfish																
Porcupinefish																
Sharpnose	x	x			x	x	x	x	x	x	x	x	x	x	x	x
RAYS																
Southern Sting																
Spotted Eagle																
Yellow Sting																
SEABASS																
Creolefish					x											
Harlequin Bass	x	x	x	x	x	x	x	x	x			x			x	x
Tobaccofish	x		x	x	x	x	x	x	x		x	x				x
SNAPPERS																
Cubera							x					x				
Dog			x													
Glasseye									x							
Gray								x	x	x			x			
Lane																
Mahogany										x						
Mutton			x								x					x
Schoolmaster	x		x		x	x	x	x	x	x		x	x			
Yellowtail					x			x								x

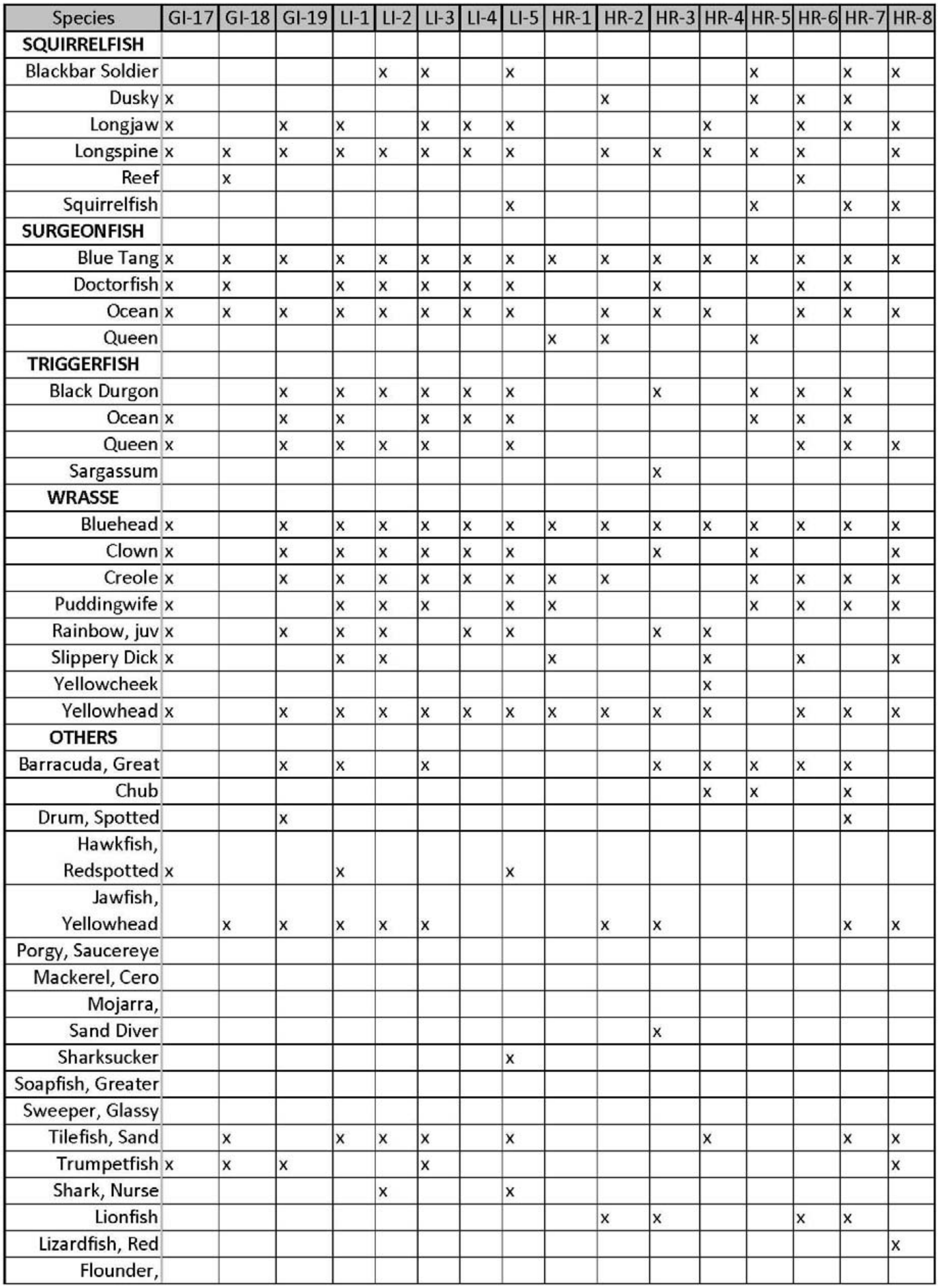
Appendix 2f. Fish species checklist for Great Inagua, site 17-19, Hogsty Reef and Little Inagua.

Species	GI-17	GI-18	GI-19	LI-1	LI-2	LI-3	LI-4	LI-5	HR-1	HR-2	HR-3	HR-4	HR-5	HR-6	HR-7	HR-8
HOGFISHES												x				
Hogfish												x				
Spanish	x		x	x	x	x		x	x	x			x	x	x	x
JACKS																
Bar	x		x	x	x	x		x					x	x	x	x
Black				x	x		x				x					
Cero	x		x													
Horse-Eye				x			x	x						x	x	
PARROTFISH																
Blue																
Bluelip																
Greenblotch		x	x	x	x	x		x	x	x	x	x		x	x	x
Midnight																
Princess	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Queen	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x
Rainbow																
Redband	x	x	x	x	x	x	x	x		x	x	x	x	x		x
Redfin	x	x														
Redtail	x	x		x	x	x	x	x	x		x	x		x	x	
Stoplight	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Striped	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
PUFFERFISH																
Balloonfish																
Porcupinefish			x													x
Sharpnose	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x
RAYS																
Southern Sting	x														x	x
Spotted Eagle																
Yellow Sting															x	x
SEABASS																
Creolefish				x	x									x		
Harlequin Bass	x	x	x	x	x	x	x	x		x	x	x		x	x	x
Tobaccofish			x	x	x	x		x	x	x					x	
SNAPPERS																
Cubera																
Dog	x															
Glasseye			x													
Gray																
Lane																
Mahogany	x															
Mutton	x															
Schoolmaster	x	x	x	x	x	x		x				x	x		x	x
Yellowtail	x											x				

Appendix 2g. Fish species checklist for Great Inagua, sites 1-16 (continued).

Species	GI-1	GI-2	GI-3	GI-4	GI-5	GI-6	GI-7	GI-8	GI-9	GI-10	GI-11	GI-12	GI-13	GI-14	GI-15	GI-16
SQUIRRELFISH																
Blackbar Soldier	x	x			x	x	x		x	x						x
Dusky																
Longjaw	x					x	x	x	x	x		x	x			
Longspine	x	x	x		x	x		x	x	x		x	x	x	x	x
Reef																
Squirrelfish	x							x	x	x	x	x			x	x
SURGEONFISH																
Blue Tang	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Doctorfish		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Ocean	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
Queen	x				x											
TRIGGERFISH																
Black Durgon		x	x		x	x	x		x	x	x	x	x			x
Ocean		x	x							x	x	x				
Queen			x			x		x	x		x		x	x	x	
Sargassum																
WRASSE																
Bluehead	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Clown		x	x			x	x	x		x	x	x	x	x	x	x
Creole	x					x	x	x	x	x	x	x	x			
Puddingwife		x	x			x				x	x	x	x			
Rainbow, juv				x		x	x	x	x	x	x	x	x	x	x	
Slippery Dick	x	x	x		x				x	x	x	x	x		x	x
Yellowcheek				x												
Yellowhead	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
OTHERS																
Barracuda, Great	x	x	x						x		x	x	x		x	
Chub			x	x												
Drum, Spotted								x				x				
Hawkfish, Redspotted				x			x				x				x	x
Jawfish, Yellowhead				x		x	x	x	x	x		x	x	x		
Porgy, Saucereye																
Mackerel, Cero								x		x						
Mojarra,																
Sand Diver																
Sharksucker																
Soapfish, Greater											x					
Sweeper, Glassy																
Tilefish, Sand	x			x	x	x	x	x	x	x	x	x	x	x	x	x
Trumpetfish						x	x	x	x	x	x	x	x	x		
Shark, Nurse			x													
Lionfish					x	x										
Lizardfish, Red						x										
Flounder,						x										
Razorfish, Green																

Appendix 2h. Fish species checklist for Great Inagua, site 17-19, Hogsty Reef and Little Inagua.



Species	GI-17	GI-18	GI-19	LI-1	LI-2	LI-3	LI-4	LI-5	HR-1	HR-2	HR-3	HR-4	HR-5	HR-6	HR-7	HR-8
SQUIRRELFISH																
Blackbar Soldier					x	x		x					x		x	x
Dusky	x									x			x	x	x	
Longjaw	x		x	x		x	x	x				x		x	x	x
Longspine	x	x	x	x	x	x	x	x		x	x	x	x	x		x
Reef		x												x		
Squirrelfish								x					x		x	x
SURGEONFISH																
Blue Tang	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Doctorfish	x	x		x	x	x	x	x			x			x	x	
Ocean	x	x	x	x	x	x	x	x		x	x	x		x	x	x
Queen									x	x			x			
TRIGGERFISH																
Black Durgon			x	x	x	x	x	x			x		x	x	x	
Ocean	x		x	x		x	x	x					x	x	x	
Queen	x		x	x	x	x		x						x	x	x
Sargassum											x					
WRASSE																
Bluehead	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x
Clown	x		x	x	x	x	x	x			x		x			x
Creole	x		x	x	x	x	x	x	x	x			x	x	x	x
Puddingwife	x			x	x	x		x	x				x	x	x	x
Rainbow, juv	x		x	x	x		x	x			x	x				
Slippery Dick	x			x	x				x			x		x		x
Yellowcheek												x				
Yellowhead	x		x	x	x	x	x	x	x	x	x	x		x	x	x
OTHERS																
Barracuda, Great			x	x		x					x	x	x	x	x	
Chub												x	x		x	
Drum, Spotted			x												x	
Hawkfish, Redspotted	x			x				x								
Jawfish, Yellowhead		x	x	x	x	x				x	x				x	x
Porgy, Saucereye																
Mackerel, Cero																
Mojarra,																
Sand Diver											x					
Sharksucker								x								
Soapfish, Greater																
Sweeper, Glassy																
Tilefish, Sand		x		x	x	x		x				x			x	x
Trumpetfish	x	x	x			x										x
Shark, Nurse					x			x								
Lionfish										x	x			x	x	
Lizardfish, Red																x
Flounder,																

Appendix 2i. Fish species checklist for Great Inagua, Little Inagua and Hogsty Reef.

Species	GI-1	GI-2	GI-3	GI-4	GI-5	GI-6	GI-7	GI-8	GI-9	GI-10	GI-11	GI-12	GI-13	GI-14	GI-15	GI-16
Razorfish, Green																
Chub, Bermuda/Yellow												x	x			
Lionfish, Red								x		x	x	x		x		x
Razorfish, Rosy									x		x					
Runner, Blue										x						
Bonnetmouth										x	x					
Cardinalfish,											x					
Cardinalfish, Barrred											x					
Bass, Lantern												x			x	x
Cherubfish													x		x	
Jawfish, Dusky														x		
Highhat																x
Soldierfish, Blackbar																
Sea Turtle, Hawksbill																
Sunshinefish																
Permit																
Boga																

Species	GI-17	GI-18	GI-19	LI-1	LI-2	LI-3	LI-4	LI-5	HR-1	HR-2	HR-3	HR-4	HR-5	HR-6	HR-7	HR-8
Razorfish, Green																x
Chub, Bermuda/Yellow				x	x	x										x
Lionfish, Red			x	x		x		x								
Razorfish, Rosy	x			x			x									
Runner, Blue	x			x			x									
Bonnetmouth								x								
Cardinalfish,					x			x								
Cardinalfish, Barrred								x								
Bass, Lantern																
Cherubfish																
Jawfish, Dusky																
Highhat																
Soldierfish, Blackbar	x															
Sea Turtle, Hawksbill				x		x										
Sunshinefish				x												
Permit				x												
Boga						x		x								

Appendix 3. Science team.

From left to right: Dr. Sam Purkis, CAPT Philip Renaud, Dave Grenda, Amanda Williams, Dr. Matti Kiupel, Krista Sherman, Dr. Sonia Bejarano, Alexandra Dempsey, Jeremy Kerr, Indira Brown, Dr. Judith Lang, Lindy Knowles, Nicholas Cautin, Dr. Bernhard Riegl, Agnessa Lundy, Doug Allan, Christian Clark, Curig Huws.

Name	Affiliation	Role
CAPT Philip Renaud	Living Oceans Foundation	Phototransects
Amanda Williams	Living Oceans Foundation	Benthic Surveyor/GIS
Dr. Bernhard Riegl	Nova Southeastern University	Coral Scientist
Dr. Sam Purkis	Nova Southeastern University	P.I. Remote Sensing/Mapping
Dr. Judith Lang	Atlantic and Gulf Rapid Reef Assessment	Coral Scientist
Dr. Sonia Bejarano	University of Queensland	Herbivore Research
Jeremy Kerr	Nova Southeastern University	Benthic Habitat Mapping
Alexandra Dempsey	Nova Southeastern University	Benthic Surveyor
Ken Marks	Atlantic and Gulf Rapid Reef Assessment	Fish Surveyor/AGRRA Data Manager
Dave Grenda	Reef Environmental Education Foundation	Fish Surveyor
Dr. Matti Kiupel	Michigan State University	Coral Pathologist
Indira Brown	Bahamas Department of Marine Resources	REEF Fish Identifier
Lindy Knowles	Bahamas National Trust	Fish Surveyor
Krista Sherman	Bahamas National Trust	Coral Surveyor
Tavares Thompson	Bahamas National Trust	Fish Surveyor
Agnessa Lundy	The Nature Conservancy	Benthic Surveyor
Christian Clark	Our World-Underwater Society	N. American Rolex Scholar/Science Diver
Kristen Van Wagner	Independent	Outreach

End note: Taxonomic revisions of corals

Since completion of these surveys, taxonomic revisions have been made for several corals. All of the taxa listed in this report use the previous nomenclature. The taxonomy has been revised using molecular tools for the following corals:

Nomenclature used in this paper (Veron 2000)	**New nomenclature (C Pinzon and Weil 2011; Budd et al. 2012)**
Diploria strigosa	*Pseudodiploria strigosa*
Diploria clivosa	*Pseudodiploria clivosa*
Montastraea faveolata	*Orbicella faveolata*
Montastraea annularis	*Orbicella annularis*
Montastraea franksi	*Orbicella franksi*
Isophyllastrea rigida	*Isophyllia rigida*
Meandrina meandrites	*Meandrina meandrites; Meandrina jacksoni*

Veron JEN (2000) *Corals of the world*, 3 vols. Townsville, Qld: Australian Institute of Marine Science.

Budd AF, Fukami H, Smith ND, Knowlton N (2012) Taxonomic classification of the reef coral family Mussidae (Cnidaria: Anthozoa: Scleractinia) *Zoological Journal of the Linnean Society*, 166: 465–529.

C Pinzon JH and Weil E (2011) Cryptic species within the Atlantic Caribbean Genus *Meandrina* (Scleractinia): a multidisciplinary approach and description of the new species *Meandrina jacksoni*. *Bulletin of Marine Science*. 87(4):823–853.