

The Global Reef Expedition:

Bahamas 2011

Marine Research Activities Undertaken at:
Cay Sal Bank, Great Inagua, Little Inagua,
Hogsty Reef, and Andros Island



Report to the
Bahamas Department of Marine Resources (Fisheries)
in fulfillment of Research Permit: MAF/FIS/17



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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 (Appendix I). Professional videographers accompanied the Science Team on the Cay Sal and Inagua missions. The M/Y Golden Shadow was used as the research platform, with small vessels (catamarans, twin V, tenders) deployed for groundtruthing and SCUBA assessments. The Goldeneye seaplane was used for aerial surveys of the three regions.

The research included habitat mapping and characterization of coral reef community structure. Habitat mapping efforts included acquisition of WorldView 2 (WV2) Satellite Imagery, aerial reconnaissance and photography, and detailed groundtruthing using a small catamaran. Groundtruthing focused on continuous bathymetry measurements, drop camera videos, sediment sampling, and low frequency sonar to profile the seafloor's sub-bottom, all linked into to a geographic positioning system (dGPS). SCUBA assessments focused on 1) characterization of the benthos, including substrate type and cover and biomass 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, coral recruitment patterns, prevalence of diseases and other stressors, patterns of coral reef recovery, and physical and oceanographic parameters. A detailed research project on the effects of herbivory in controlling algal populations was undertaken during the first and second mission. Research to characterize coral diseases, with emphasis on dark spots disease, was conducted. Disease prevalence and impacts were quantified and tissue/skeleton samples of eight species of scleractinian corals were collected during the August and October missions. Additional physical parameters including salinity, temperature and current profiles were measured. KSLOF established a Legacy Site on Cay Sal Bank and Great Inagua. Each site (10 m X 10 m) was permanently marked with four stainless steel rebars, photographed using a high resolution digital SLR camera, and all corals were assessed; temperature loggers were also deployed at the Legacy Site on Cay Sal Bank.

A total of 23,407 sq km of WV2 and RapidEye satellite imagery was acquired for the 5 areas. Continuous bathymetry was recorded over a 572 km track and 1157 drop camera videos were taken. The researchers completed 1003 dives for a total of 842 hrs and 52 min bottom time, with surveys conducted to a maximum of 30 m depth. Products and information resulting from this mission include 1) high resolution habitat maps depicting twelve marine habitats at a 6 m resolution and three-dimensional bathymetric maps for shallow (0-25 m depth) habitats; 2) sub-bottom profiles of the underlying substrate; 3) a detailed characterization the coral reef community structure, including the biomass of reef fishes, population dynamics of coral, benthic attributes of reef habitats, threats and resilience indicators; 4) a better understanding of rates of algal growth and role of herbivorous fishes in regulating algal populations; and 5) characterization of a prevalent coral disease (dark spots disease). All of the imagery, maps and information are being compiled into a GIS database and a detailed *Atlas of Bahamian Shallow Marine Habitats* is under development.

Research areas

The research involved three missions covering Cay Sal Bank, Great Inagua, Little Inagua, Hogsty Reef, Andros Island and Abaco Island (Fig. 1). Due to bad weather during the October 2011 mission, only a portion of the proposed survey area around Andros Island was completed, and no research was conducted off Abaco Island.

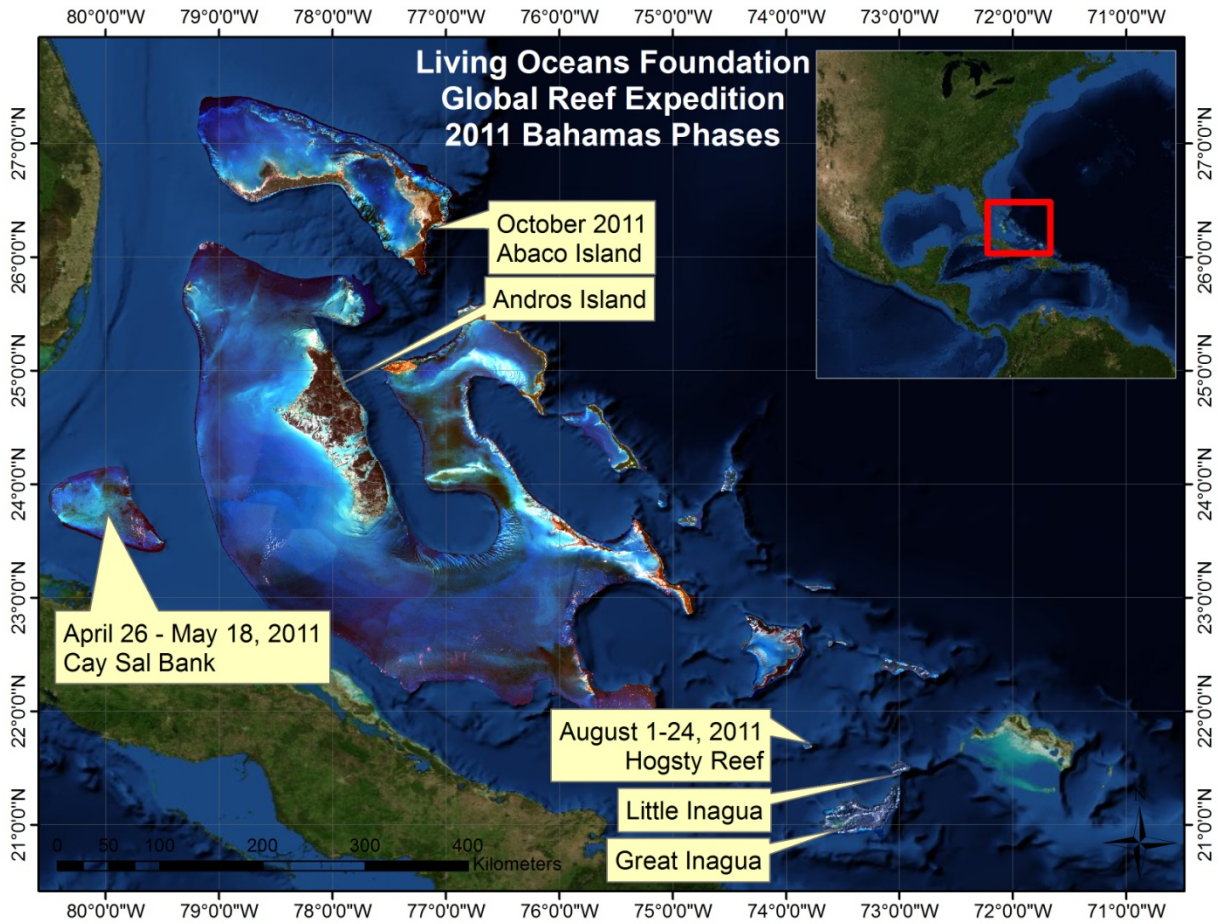


Fig. 1. Proposed study locations.

General methodology

Satellite imagery

A set of 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 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-m² 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 satellite was limited in the depths for which it could observe the seafloor. In the clearest waters, observations up to depths of 45 m are possible. However, satellite observations were generally limited to a depth of 25 m during the field campaign due to turbidity. The fine spatial resolution of the images allowed seafloor features, such as reef structures, seagrass meadows, and sand flats, to be identified prior to surveying of an area. This informed the dive teams' sampling site selection. The ground-truth team used the scenes in conjunction with a differential GPS device (dGPS) to 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 will be 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 (hereto after referred to as a drop-cam; Figure 2) gathered video on the benthic composition at each survey site. At these points, the drop-cam was held from the survey boat 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 geospatial 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 limited length of the tether cable (50 m). The acquired videos will be used in the creation of the benthic habitat maps by providing the necessary information for developing the habitat classification scheme and training of classification models.

Acoustic depth soundings

Depth soundings were gathered along transects between survey sites using Hydrobox, a single-beam acoustic transducer, developed by Syqwest. The instrument emitted 3 pings per second. Depths are estimated based on the time the return-pulse's reaches the sounder's head. The depth estimates were recorded by the Hydrobox software on a field laptop aboard the survey vessel. Geospatial data were simultaneously acquired by a dGPS unit and recorded in the bathymetric file. The soundings will be used to train a water-depth derivation model, which is

based on the spectral attenuation of light in the water column, that will be applied to the WV2 satellite imagery. Final topographic maps have the same spatial resolution as satellite imagery.

Acoustic sub-bottom

Profiles of the seafloor's sub-bottom was gathered along transects using the Stratabox acoustic sounder, also developed by Syqwest. Similar to the bathymetric soundings, the sub-bottom profile emits an acoustic ping which reflects off the seafloor. However, the pulse has a lower 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; it was recorded in the SEG Y 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 slope's angle; steeper slopes resulted in shorter transect lines.

Coral community structure, population dynamics and health.

A belt transect, 10 m long and 1 m wide, is used to record the number, size and condition of colonies of all coral species for colonies larger than 4 cm diameter. A one meter bar, marked in 1 cm increments is used to measure the maximum diameter, width (perpendicular to the diameter), height, and amount of mortality. Each coral is identified to species, measured and assessed for condition. 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 such as snails (*Coralliophila abbreviata*) and fireworms (*Hermodice carunculata*). 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 is assigned. Diseases were identified according to Bruckner 2010b and Raymundo et al. 2008, and included yellow band disease (YBD), white plague (WP), black band disease (BBD), red band disease (RBD), Caribbean ciliate infection (CCI), dark spots disease (DSD) and white band disease (WBD). The data sheet for recording coral observations is shown in Appendix II

Recruitment

Sampling for corals smaller than 4 cm is done using a minimum of five 0.25 m² quadrats per transect, with each quadrat located at fixed, predetermined intervals (e.g. 2, 4, 6, 8, 10 m), alternating between right and left side of the transect. Recruits were identified in both point intercept surveys and belt transects. Recruits were divided into two sizes: corals up to 2 cm diameter and 2-3.9 cm diameter. In addition, all corals settling on dead skeletal surfaces of colonies identified within the belt transects were recorded separately, with a single measure of diameter and an estimate of percent mortality made for those recruits exhibiting partial mortality.

Benthic cover

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 was recorded every ten 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.. Gorgonians are recorded as sea fan or branching/encrusting gorgonian. Sponges 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) with certain dominant taxa recorded to genus (e.g. *Microdictyon*, *Lobophora*, *Dictyota*, *Styopodium*, *Sargassum*, *Peyssonnelia*). Nuisance invertebrate species were recorded to genus or higher taxonomic level; these include: tunicate (*Trididemnum*), encrusting gorgonian (*Erythropodium*, *Briareum*), colonial anemone (*Palythoa*), encrusting or bioeroding sponge (*Cliona langae/aprica* complex, *Cliona delitrix*, *Anthosigmella*), and hydrozoan coral (*Millepora*). The data sheet for point intercept surveys is shown in Appendix III.

Fish assessments

On each reef two divers completed a minimum of six 30 X 2 m belt transects to assess the community structure of the reef fish assemblages. All species were identified and their size is 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 (88 species). The emphasis was on herbivores (parrotfish, surgeonfish, chubs, damselfish), invertebrate feeders and larger piscivores. Parrotfish were also separated into initial phase and terminal phase fishes. A total of 170 species are included in the assessment. A data sheet with all species listed is shown in Appendix IV.

Herbivorous reef fish (3 species of surgeonfish and 12 species of parrotfish, Table 1) were counted using 8 belt transects of 30 x 4 m per site. Total length (TL) was visually estimated and life phase was noted for every individual within the transect. Mean total density (individuals 120 m⁻²) and biomass (g 120 m⁻²) as well as per family and species was calculated among transects for each reef site.

Photo-documentation

Extensive photographic documentation of reef habitats and individual colonies in various states of health were taken during surveys. At each site an overview of the reef was taken from above at four compass points and then representative shots of the bottom were taken. Representative photographs of individual colonies located along belt transects with lesions, including signs of disease, predation, physical damage, and overgrowth, were also taken. One set of photo-quadrats, each 0.25 m long was taken on each reef along the same transect as that used for the point intercept survey at 2, 4, 6, 8 and 10 m.

Coral Sampling

Coral tissue and skeleton samples were collected from *Montastraea annularis* (complex), *Diploria strigosa* and *D. labyrinthiformis*, *Siderastrea siderea*, *Agaricia agaricites*, *Stephanocoenia intersepta*, *Madracis mirabilis* and *Agaricia agaricites* at Hogsty, Great Inagua, Little Inagua, and Andros for coral disease studies. The samples were small (1-4 cm diameter) cores carefully removed using a coring tool for massive/plating coral species and branch fragments up to 4 cm in length with clippers for *Madracis*. Samples were removed primarily from diseased corals exhibiting dark spots disease (one sample at the disease interface and one remote sample, 10-20 cm from the diseased tissue), with one control colony sampled per affected species in each area. Samples were preserved in Z-fix for histological analysis. In addition mucus samples using a cotton swab were collected from the diseased portion of the colony for RNA analysis of the microbial community. These were preserved in small vials and frozen. All samples are being processed and analyzed at the University of Michigan.

Corallivores

All coral eating snails (*Coralliophila abbreviata*) were collected from affected colonies located within the coral belt transects. These were measured and sexed. Snails were discarded after measurements were completed.

Algal growth and herbivory

Cylindrical cages made of PVC coated wire mesh, with hexagon mesh weave (1 inch) were deployed on Great Inagua for five days and then removed. These were secured to the reef substratum by hammering metallic fence staples across the mesh flaps of the cage. Each cage contained one coral tile, suspended 20 cm above the substrate. Water flow was measured in each of the survey sites by quantifying the dissolution rate of 3 small gypsum moulds (Fig 4) attached to the outside of the experimental cages for the duration of the experiment. Light intensity was measured in each of the survey sites using one light sensor (HOBO Pendant temp/light UA-002-64) per site, attached to a 3 pound lead weight with cable ties.

Cay Sal Bank

An aerial assessment of Cay Sal Bank was undertaken on March 24, 2011 (Fig. 2). The purpose of this was to identify key areas for groundtruthing surveys and to obtain aerial photographs of the land masses and shallow underwater features. Field research was conducted on Cay Sal Bank from April 26-May 16, 2011. The research team joined the Golden Shadow in Freeport, Bahamas; a changeover of some local participants occurred on May 2, 2011. The Golden Shadow used eight anchorages all located in sandy areas at the perimeter of the bank (Fig. 4) and small boats were deployed to conduct research.

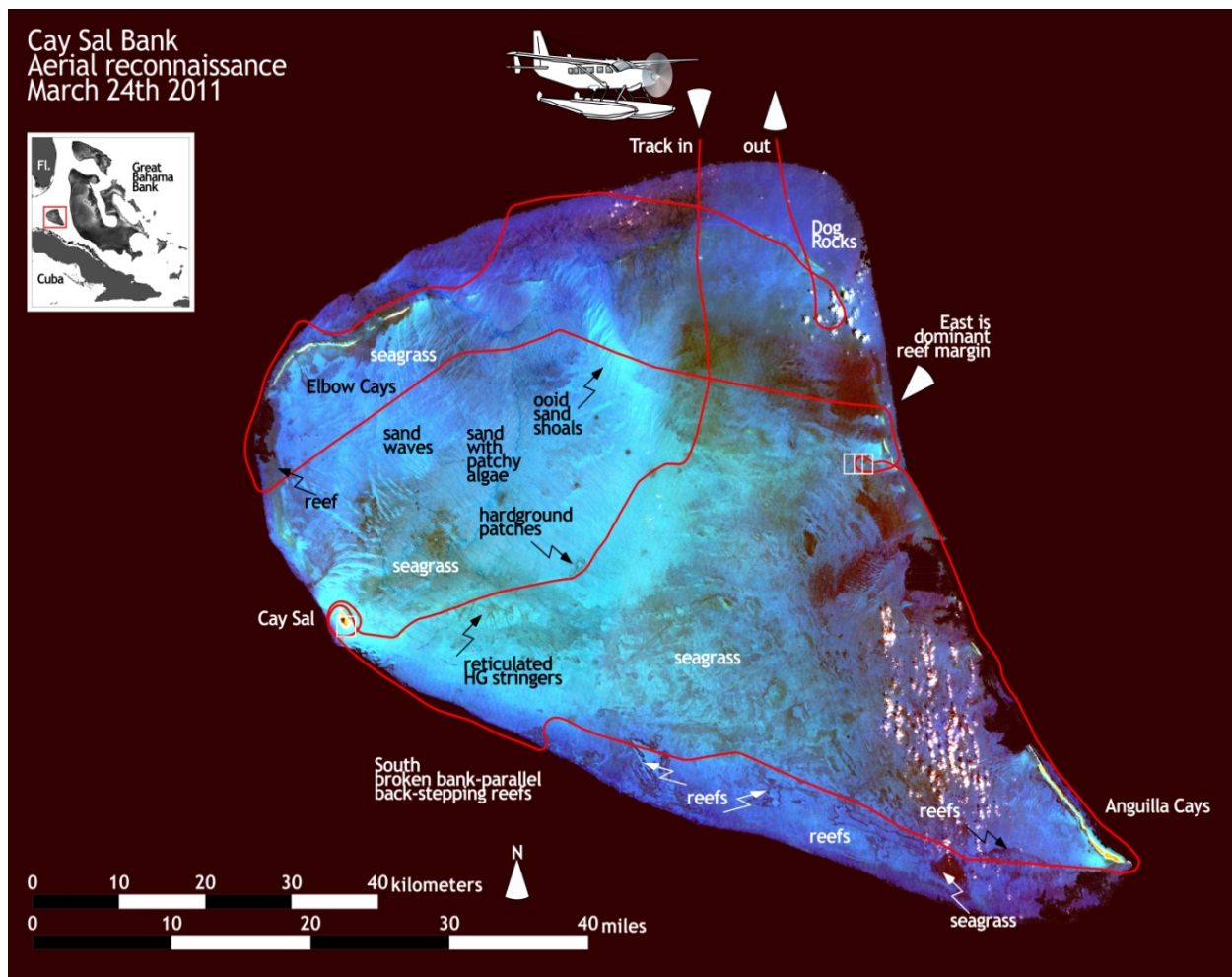


Fig. 2. Track of the Goldeneye Seaplane during aerial reconnaissance of the site, 03/24/2011.

Habitat mapping

A total of 5979 sq km of WV2 satellite imagery was acquired for Cay Sal Bank. The groundtruthing team covered a total distance of over 1100 km from depths of 0.50 m to 138 m to obtain detailed information on the characteristics of the shallow marine habitats. (Table 1). Sub-bottom profiles (26) were collected along the northern, eastern, and southern drop-offs, over both filled and unfilled blue holes, and over the sand shoals in the north-central interior of the platform.

Parameter	Number
Linear distance traveled:	1102.1 km(684.8 m)
Drop camera videos	565 videos (typically 30 to 60 seconds long; up to 2 minutes for unique features)
Sediment samples	79
Bathymetric points along tracks:	1,908,173
Sub-bottom profile tracks	26

Table 1. Number of samples taken by the groundtruthing team.

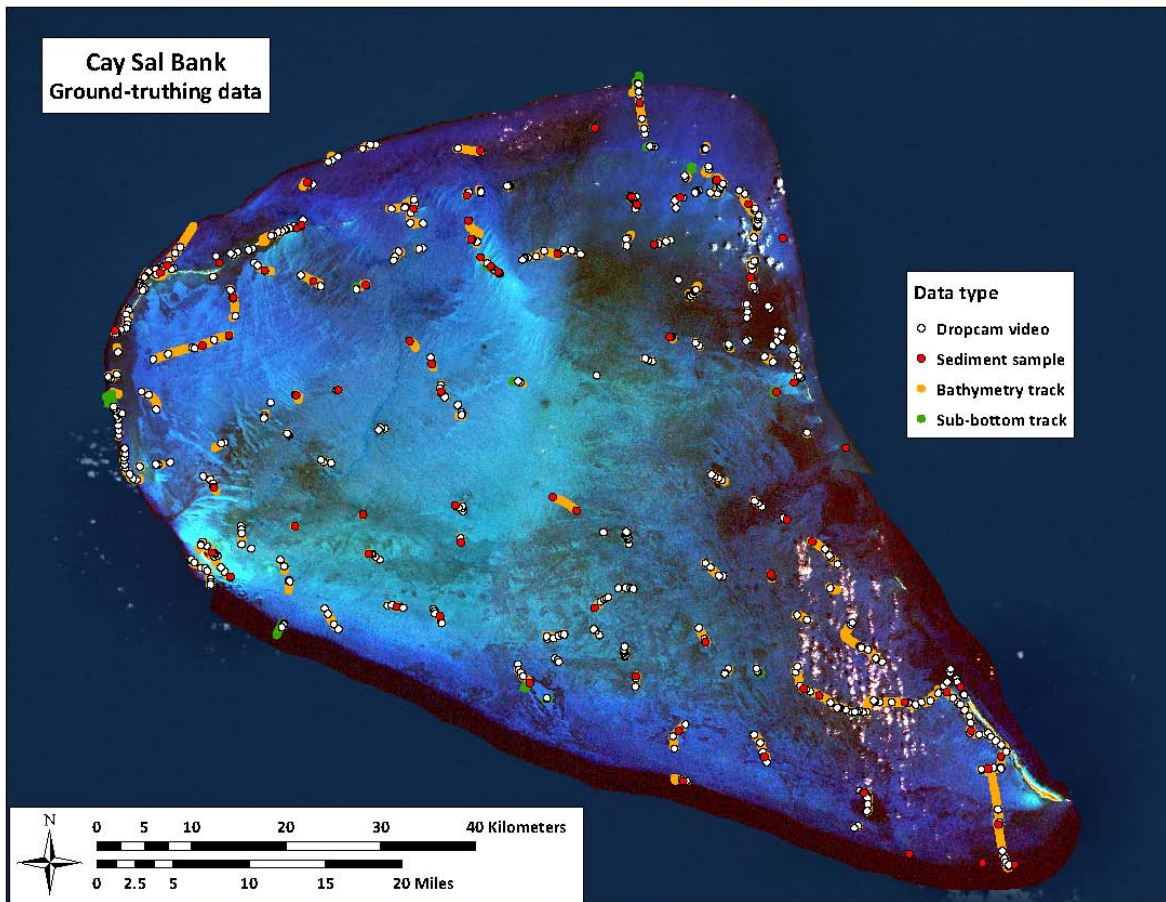


Fig. 3. Survey track of the groundtruthing team. Continuous bathymetry (yellow dots) was run along the entire track. Locations of Sediment samples (red dots), drop camera videos (open circles) and sub-bottom profiles (green dots) are superimposed onto this track.

Coral Reef Assessments

The research team examined the coral reef community composition in 39 locations for a total of 512 dives (392 hrs, 15 min). In total, 31 locations were fore reef sites and 8 were lagoonal sites (Fig 4). The sites ranged in depth from 7-25 m (Table 1). The team examined the benthic composition and cover, coral population structure and condition, and fish composition, size structure and biomass. Benthic surveys included 318 transects; each 10 m transect contained 100 points. For coral surveys a total of 153 transects were completed. These contained 4586 corals. Coral recruits were assessed on 39 reefs, within 4230 quadrats, each 0.25 m² in size. A total of 363 fish transects, each 30 m in length were completed. Transects had a mean density of 68 fish/100m² (fore reef) and 83 fish/100m² (lagoonal sites) for the target list of 88 species. Additional fish transects (30 m X 4 m, n=8 per site) targeting 11 species of roving herbivores were completed at 22 sites. Data sheets are shown in Appendix 2-4.

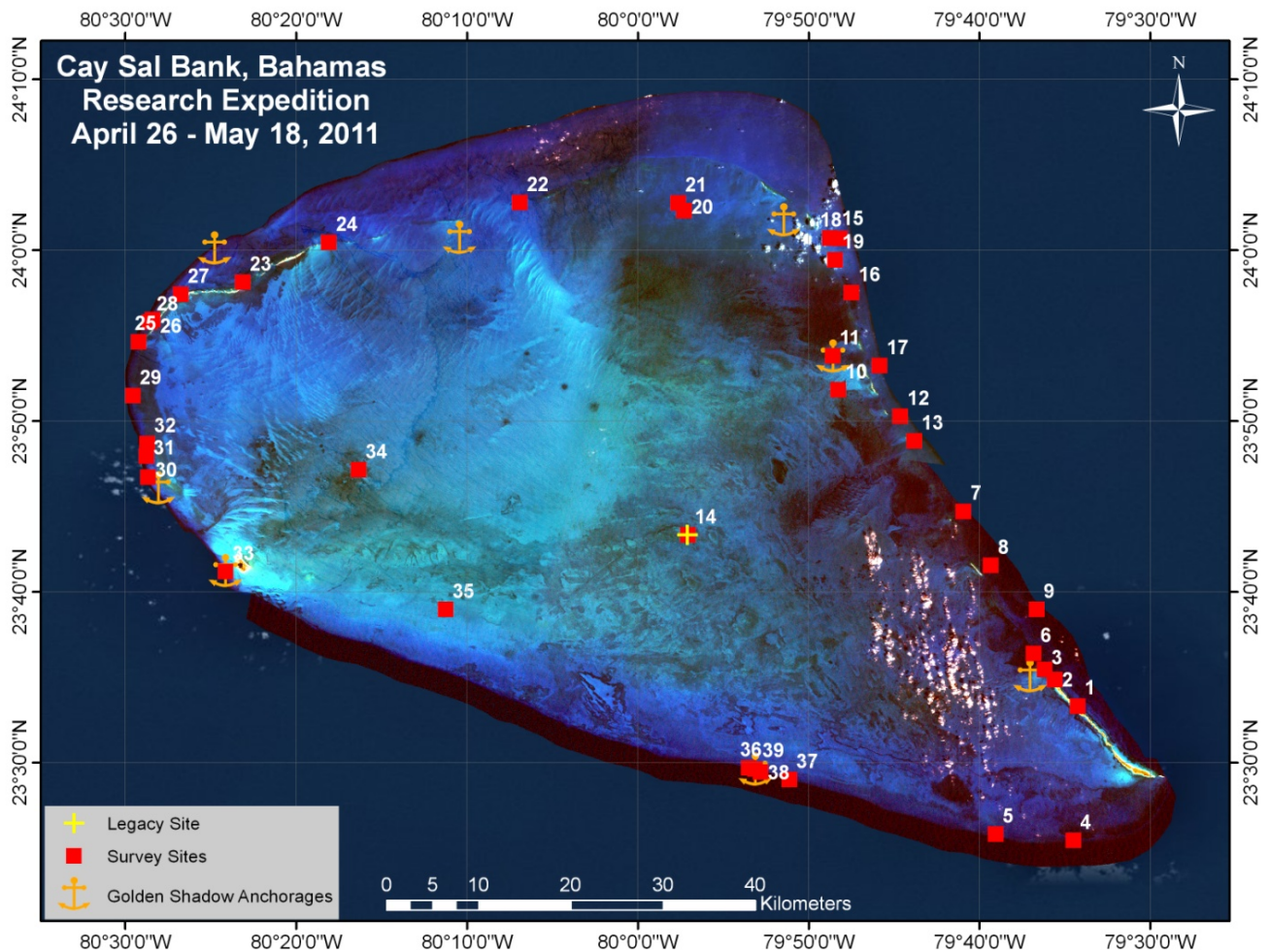


Fig. 4. Location of SCUBA assessments on Cay Sal Bank.

Table 2. Location, date and depth of 39 sites assessed on Cay Sal Bank using SCUBA.

Long_W	Lat_N	Site	Name	Date	Depth (m)
79.570550	23.555210	1	Cay Sal 1, Anguilla Cays 1	4/28/2011	7.5
79.592820	23.580890	2	Cay Sal 2, Anguilla Cays 2	4/28/2011	11.0
79.602980	23.590690	3	Cay Sal 3, Anguilla Cays 3	4/28/2011	8.0
79.574600	23.424040	4	Cay Sal 4	4/29/2011	14.0
79.650460	23.430120	5	Cay Sal 5	4/29/2011	13.0
79.613550	23.606390	6	Cay Sal 6, Anguilla Cays 4	4/29/2011	9.5
79.681910	23.745190	7	Cay Sal 7	4/30/2011	15.0
79.655290	23.692570	8	Cay Sal 8	4/30/2011	14.5
79.610620	23.649300	9	Cay Sal 9	4/30/2011	13.5
79.804160	23.863820	10	Cay Sal 10, Blue Hole 1	5/1/2011	10.0
79.809580	23.896960	11	Cay Sal 11, Damas Cays 1, Anchor 2	5/3/2011	10.8
79.743580	23.837940	12	Cay Sal 12, Damas Cays 2	5/4/2011	14.0
79.729930	23.814050	13	Cay Sal 13, Damas Cays 3	5/4/2011	15.0
79.950850	23.722300	14	Cay Sal 14, inner reef	5/4/2011	4.2
79.803330	23.865000	10	Cay Sal 10, Blue Hole 1	5/4/2011	10.0
79.802620	24.011540	15	Cay Sal 15, Dog Rocks 1	5/5/2011	13.0
79.791110	23.958700	16	Cay Sal 16	5/5/2011	17.6
79.763730	23.887320	17	Cay Sal 17, Damas Cays 4	5/5/2011	13.8
79.804560	23.864170	10	Cay Sal 10, Blue Hole 1	5/7/2011	11.0
79.812130	24.011950	18	Cay Sal 18, Dog Rocks 2	5/8/2011	13.5
79.807270	23.990490	19	Cay Sal 19	5/8/2011	11.5
79.954610	24.038410	20	Cay Sal 20, Dog Rocks 3	5/8/2011	13.0
79.954830	24.038910	20	Cay Sal 20, Dog Rocks 3	5/9/2011	12.0
79.960500	24.046080	21	Cay Sal 21, Dog Rocks 4	5/9/2011	13.0
80.115080	24.046640	22	Cay Sal 22, Dead Man's Cays 1	5/9/2011	10.5
80.385220	23.968980	23	Cay Sal 23, Elbow Cays 1	5/10/2011	13.0
80.301270	24.007870	24	Cay Sal 24, Elbow Cays 2	5/10/2011	9.0
80.48680	23.91085	25	Cay Sal 25, Elbow Cays 3	5/11/2011	17.0
80.47313	23.93244	26	Cay Sal 26, Elbow Cays 4	5/11/2011	14.5
80.44592	23.95722	27	Cay Sal 27, Elbow Cays 5	5/11/2011	10.0
80.47625	23.92997	28	Cay Sal 28, Elbow Cays 6	5/12/2011	16.0
80.49263	23.85814	29	Cay Sal 29	5/12/2011	13.8
80.477650	23.778630	30	Cay Sal 30, Rampidas Reef 1	5/13/2011	25.0
80.47932	23.79921	31	Cay Sal 31, Rampidas Reef 2	5/13/2011	14.0
80.47852	23.81126	32	Cay Sal 32, Rampidas Reef 3	5/13/2011	13.0
80.40205	23.68629	33	Cay Sal 33, Cay Sal Island	5/14/2011	17.0
80.272320	23.785840	34	Cay Sal 34, inner bommies	5/14/2011	9.0
80.18733	23.64939	35	Cay Sal 35	5/15/2011	7.0
79.89154	23.49485	36	Cay Sal 36, southern escarpment	5/15/2011	13.0
79.851940	23.483460	37	Cay Sal 37, southern escarpment	5/15/2011	13.0
79.87989	23.49066	38	Cay Sal 38, southern wall	5/16/2011	25.0
79.8853	23.49395	39	Cay Sal 39, Anchor 8	5/16/2011	16.0

Targeted research was conducted on herbivory, including assessments of herbivorous fish population structure and biomass, characterization of algal functional groups and algal biomass, evaluation of patterns of feeding by herbivorous fishes and invertebrates, and deployment of video cameras (10 per site) to document fish behavior. A CTD profile (salinity, temperature and depth profile) was collected for each site. A current meter was deployed for a 48 hour period off the eastern end (near site 3).

Algal heights were measured along 4 of the belt transects used to count herbivorous reef fish. At the end of a typical fish census the surveyor rolled back the 30-m measuring tape. The tape was used as a guide for the surveyor to stop every 5 meters and take at least 10 measurements of the algae present under the tape. Algae were measured to the nearest millimeter using a plastic ruler and macroalgae in particular were identified to a genus level. Additional measurements of algal height were taken within each quadrat used to assess coral recruits (n=5 measures/quadrat).

Photographic documentation of sites included habitat shots, phototransects (each 10 m length; minimum 2 per site) and photoquadrats (0.25 m², minimum 10 per reef).

To capture the feeding behavior of the herbivorous fish community undisturbed by the presence of divers, 10 high-definition video cameras (GO-PRO Hero 1080) were deployed in each reef site and held stationary on the bottom using 2-pound lead weights. A diver switched the cameras on between 11:30 and 12:00 h showing a white board with the date, time, reef site name and the height of the mound or promontory where the camera was placed. Each camera was set at least 5 m apart from every other and programmed to film continuously over an area of at least 1 m² of predominantly grazeable reef substrata (e.g. hard bottom covered algal turfs, encrusting coralline algae or macroalgae). Once all cameras were switched on, all divers exited the water. Cameras were switched off and retrieved back to the surface for footage downloading and battery recharging between 15:30 and 16:00 h.

At site 14, a Legacy Site was established. A 10 m X 10 m area was permanently marked with four stainless steel rebars. All corals were assessed within the area and overlapping high resolution photographs were taken to allow creation of a mosaic. Two temperature meters were deployed; these can log sea bottom temperature for up to five years.

Great Inagua, Little Inagua, Hogsty Reef

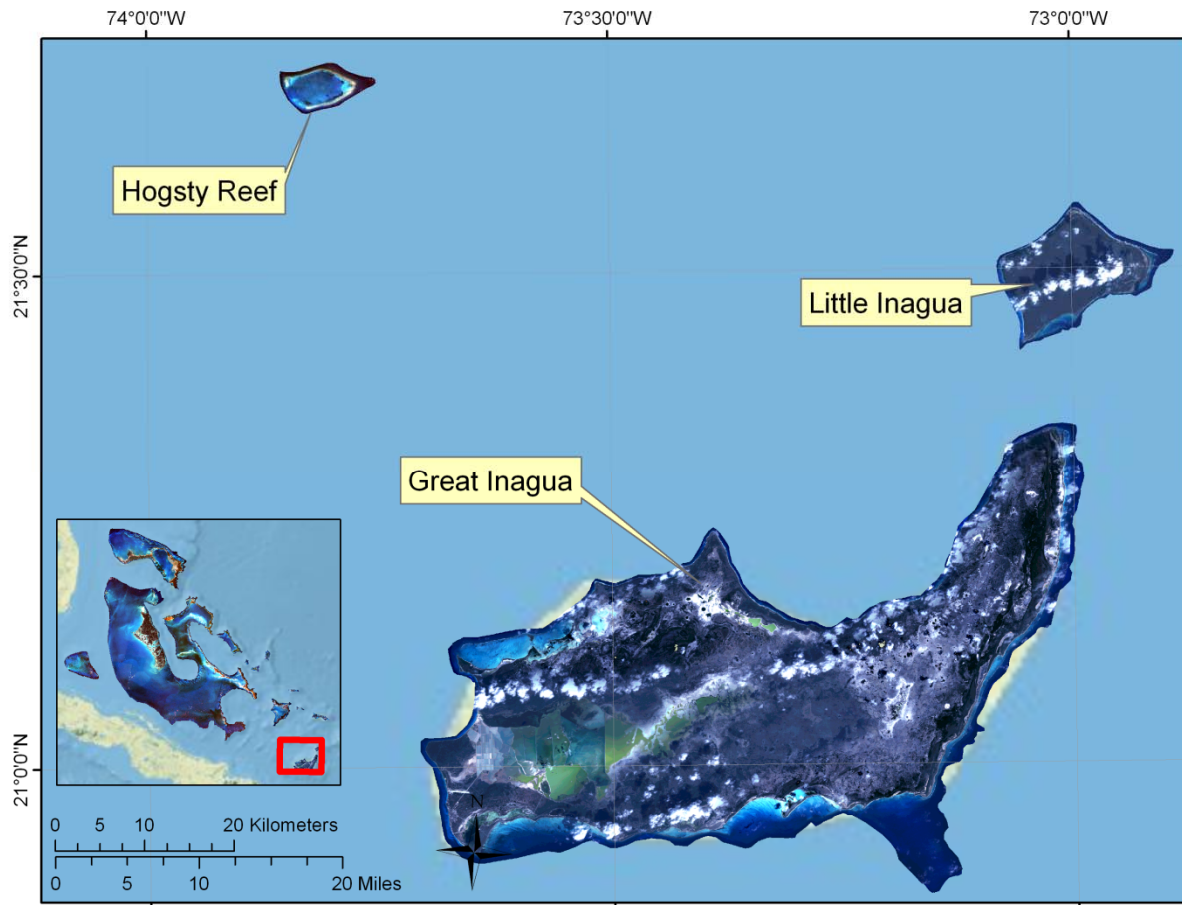


Fig. 5. Location of Great Inagua, Little Inagua and Hogsty Reef in the southern Bahamas.

An aerial assessment of this region was undertaken on June 30, 2011. The purpose of this was to identify key areas for groundtruthing surveys and to obtain aerial photographs of the land masses and shallow underwater features for each area. Field research was conducted from Aug. 6-Aug. 21, 2011. The research team joined the Golden Shadow in Nassau, Bahamas on August 1, but had to delay the start of the mission due to Tropical Storm Emily. The mission also ended two days early due to Hurricane Irene. The Golden Shadow used one anchorage at the western end of Hogsty, one at the western end of Little Inagua and two off Great Inagua (Fig. 11-13) and small boats were deployed to conduct research.

Groundtruthing

Hogsty Reef (09 Aug – 11 Aug 2011)

Benthic videos ($n = 137$), acoustic depth soundings ($n = 436,893$), and a single sub-bottom profile were collected at Hogsty Reef (Fig. 6, 7). Sampled depths ranged from 0.48 m to 44.47 m. The sub-bottom profile was collected at the mouth of the lagoon along the western flank.

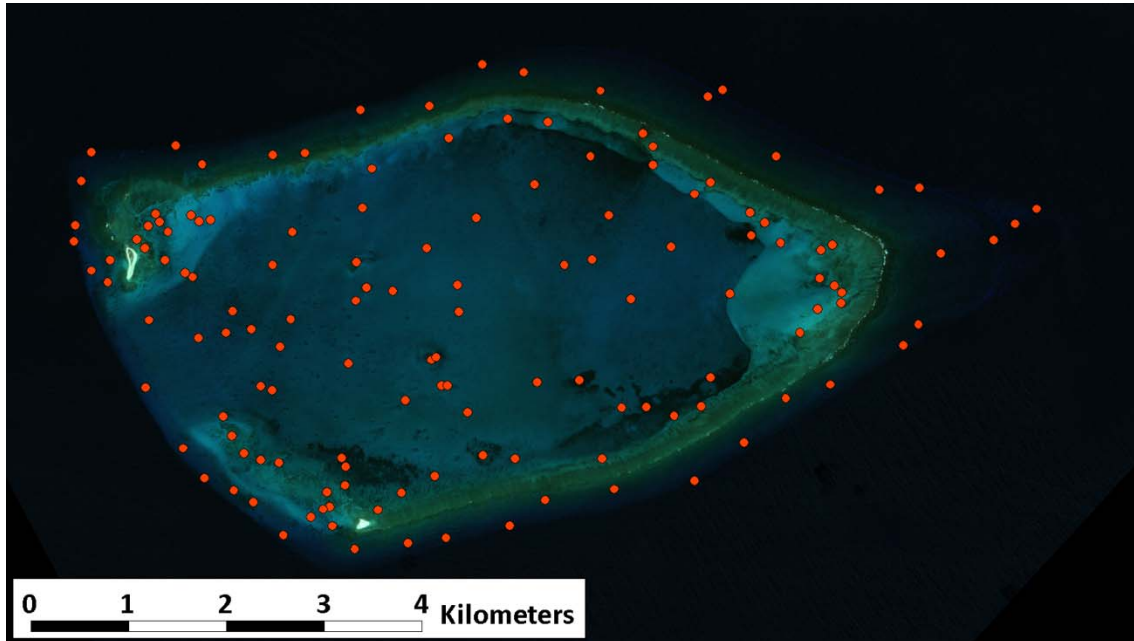


Fig. 6: Locations where drop-cam videos were acquired at Hogsty Reef.

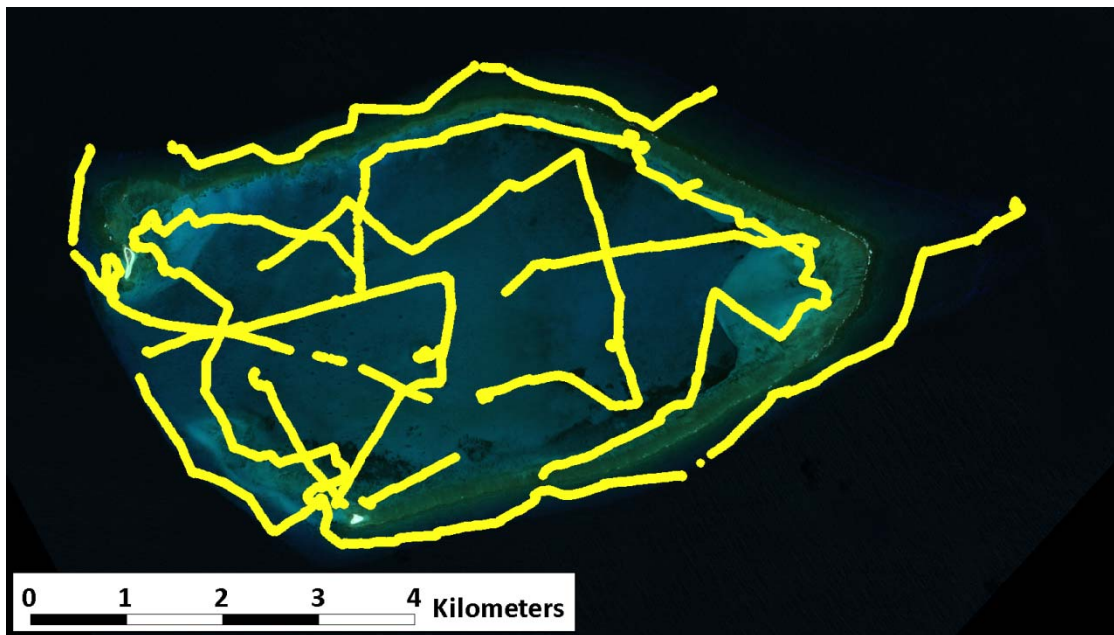


Fig. 7: Tracks along which acoustic depth soundings were acquired at Hogsty Reef.

Great Inagua (06 Aug – 08 Aug; 12 Aug – 16 Aug 2011)

Benthic videos ($n = 288$) and acoustic depth soundings ($n = 735,140$) were collected along a 168 km long track around Great Inagua (Fig. 8,9). Sampled depths ranged from 0.54 m to 70.37 m. 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.

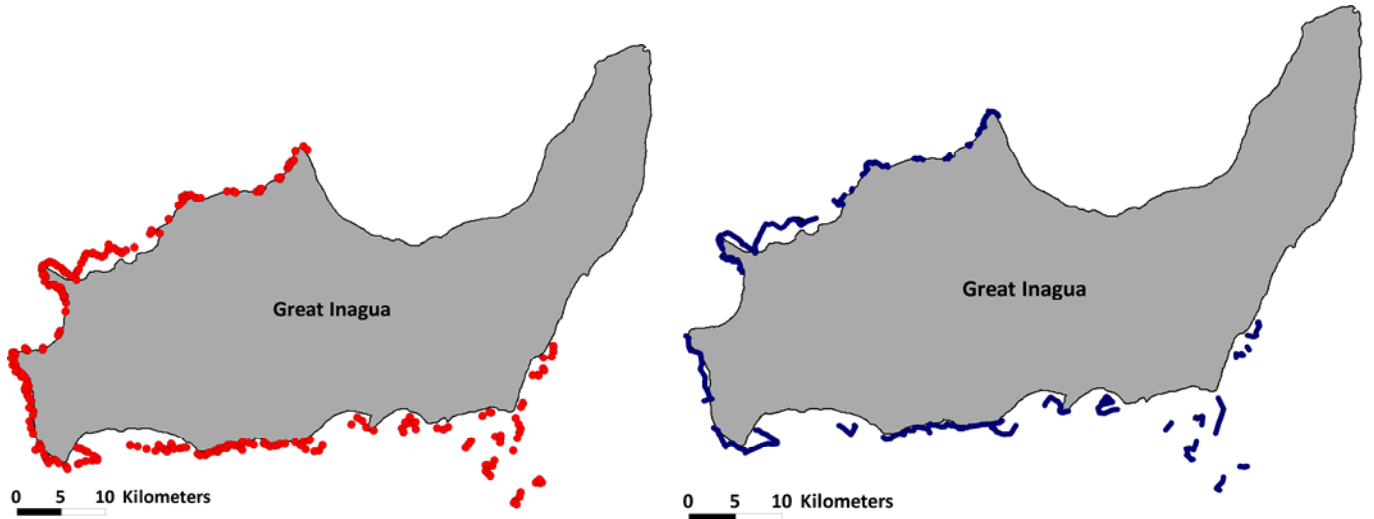


Fig. 8: Locations where drop-cam videos were acquired (red dots, left image) and tracks along which acoustic depth soundings (blue line, right image) were acquired around Great Inagua.

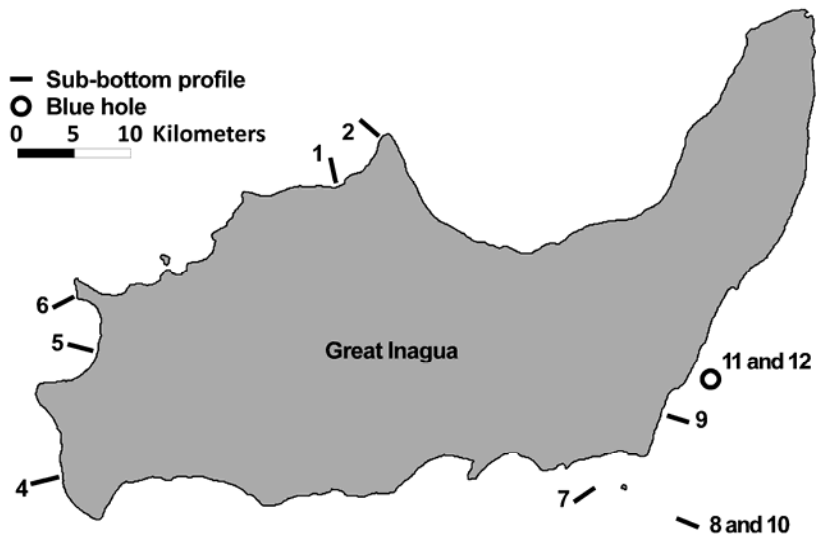


Fig. 9: Locations of the acoustic sub-bottom profiles off Great Inagua.

Little Inagua (20 Aug – 21 Aug 2011)

Benthic videos ($n = 64$) and acoustic depth soundings ($n = 262,986$) were collected along a 59 km track around Little Inagua (Fig. 10). Sampled depths ranged from 0.35 m to 58.33 m. A total of three sub-bottom profiles were collected, each along a different coast: the eastern, western, and southern coasts.

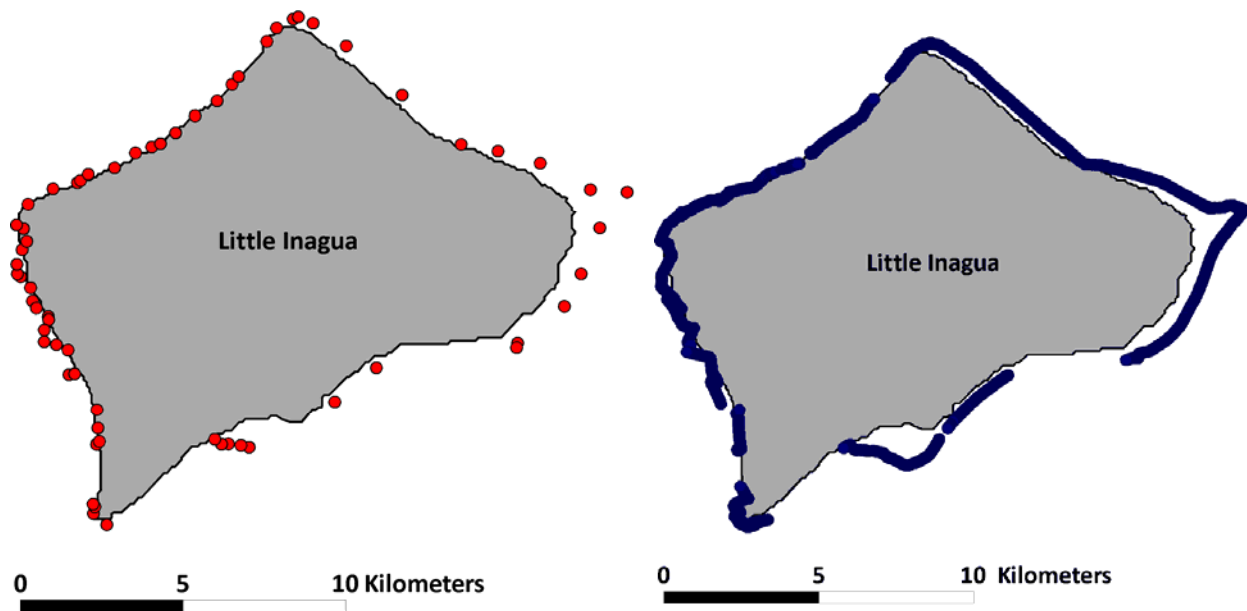


Fig. 10: Locations where drop-cam videos were acquired (red dots, left image) and tracks along which acoustic depth soundings were acquired (blue line, right image) around Little Inagua .

Coral Reef Assessments

SCUBA assessments of coral reef habitats were conducted at Great Inagua (19 locations, 242 dives; total bottom time = 218 hrs, 25 min), Little Inagua (5 locations, 41 dives, total bottom time = 34 hrs, 19 min) and Hogsty reef (8 locations, 110 dives; total bottom time = 96 hrs, 5 min). Due to high seas, no dives were completed on the exposed northeastern and southeastern end of Great Inagua and Little Inagua.

In total, 30 locations were on the fore reef, 1 was in the reef crest and 1 was a lagoonal site (Fig 11-13). The sites ranged in depth from 4.5-18.9 m (Table 1). The team examined the benthic composition and cover, coral population structure and condition, and fish composition, size structure and biomass. Benthic surveys included 255 transects; each 10 m transect contained 100 points. A total of 39 benthic transects were completed on Little Inagua, 67 on Hogsty Reef and 149 on Great Inagua. For coral surveys a total of 98 transects were completed, 12 on Little Inagua, 27 on Hogsty Reef and 59 on Great Inagua. These contained 3179 corals. Coral recruits were assessed within 3035 quadrats (each 0.25 m² in size). Coral recruitment and algal biomass was assessed in 530 quadrats on Little Inagua, 825 on Hogsty Reef and 1680 on Great Inagua.

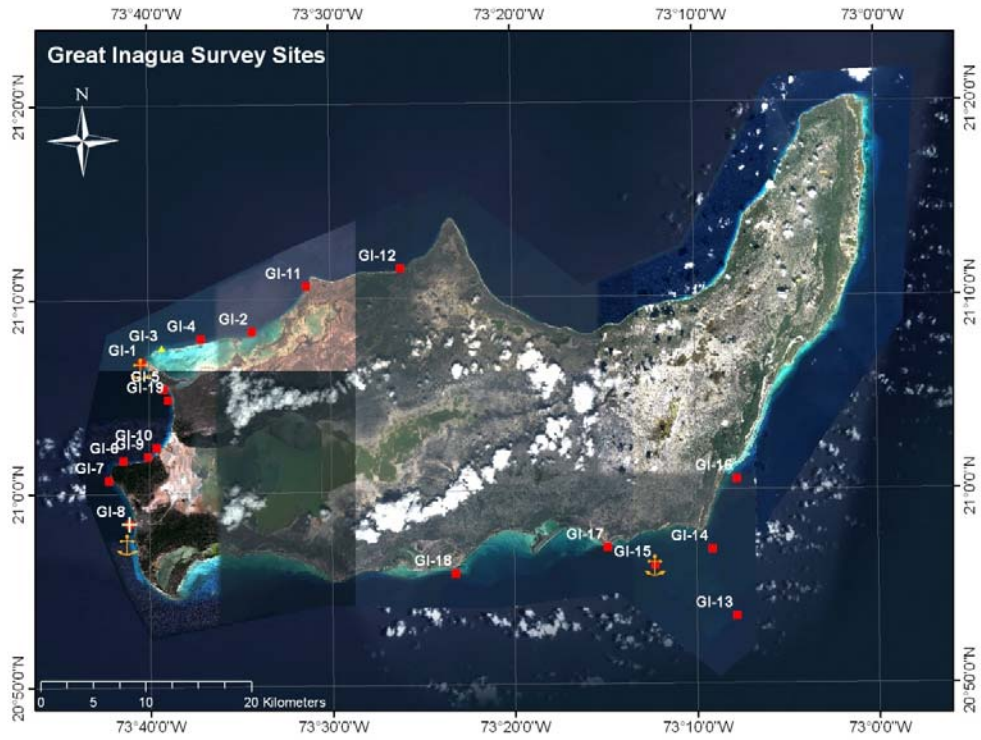


Fig. 11. Location of SCUBA assessments around Great Inagua

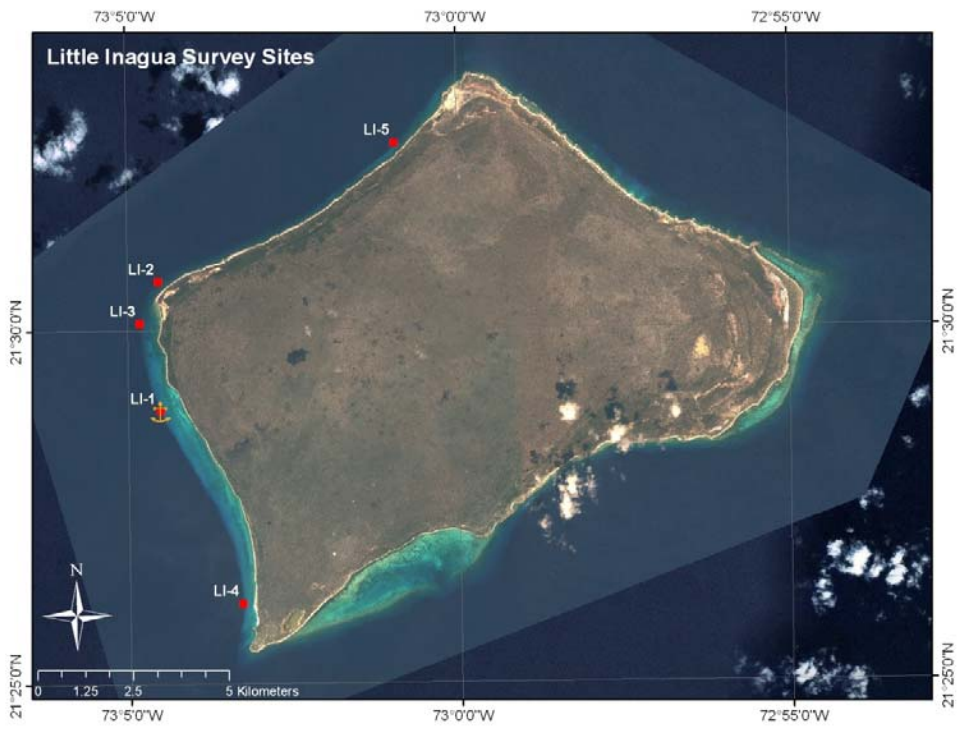


Fig. 12. Location of SCUBA assessments around Little Inagua.

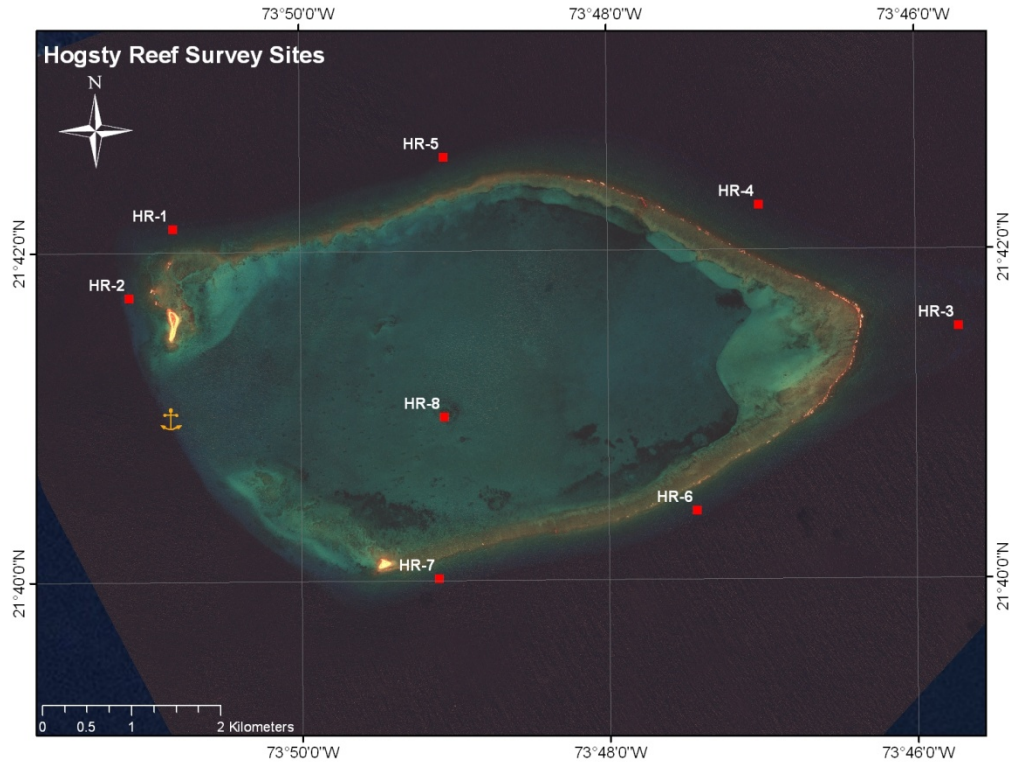


Fig. 13. Location of SCUBA assessments on Hogsty Reef.

A total of 306 fish transects, each 30 m in length, were completed. This included 49 on Little Inagua, 77 on Hogsty Reef and 191 on Great Inagua. Transects had a mean density of 52 fish/100m² (fore reef), 181 fish/100m² (reef crest) and 38 fish/100m² (lagoonal sites) for the target list of 88 species. Additional fish transects (30 m X 4 m, n=8 per site) targeting 11 species of roving herbivores were completed at all 30 sites. Total length (TL) was visually estimated and life phase was noted for the fish listed below:

Family	Species
Acanthuridae	<i>Acanthurus tractus</i>
	<i>Acanthurus chirurgus</i>
	<i>Acanthurus coeruleus</i>
Scaridae	<i>Scarus taeniopterus</i>
	<i>Scarus iserti</i>
	<i>Scarus vetula</i>
	<i>Scarus guacamaia</i>
	<i>Scarus coeruleus</i>
	<i>Sparisoma aurofrenatum</i>
	<i>Sparisoma viride</i>
	<i>Sparisoma rubripinne</i>
	<i>Sparisoma radians</i>
	<i>Sparisoma atomarium</i>

Table 4. Location, date and depth of 32 sites assessed on Great Inagua, Little Inagua and Hogsty Reef using SCUBA

Site	Island	Date	Lat_N	Long_W	Depth_m
GI-1	Great Inagua	8/6/2011	21.112410	73.672710	18.00
GI-2	Great Inagua	8/7/2011	21.138840	73.571520	11.60
GI-3	Great Inagua	8/7/2011	21.125590	73.654720	3.00
GI-4	Great Inagua	8/8/2011	21.132903	73.618659	16.00
GI-5	Great Inagua	8/8/2011	21.089570	73.652510	9.00
HR-2	Hogsty Reef	8/9/2011	21.695000	73.852000	12.00
HR-1	Hogsty Reef	8/9/2011	21.702000	73.847000	11.00
HR-3	Hogsty Reef	8/10/2011	21.692100	73.762020	18.00
HR-4	Hogsty Reef	8/10/2011	21.704480	73.783610	17.00
HR-5	Hogsty Reef	8/10/2011	21.709420	73.817710	11.00
HR-8	Hogsty Reef	8/11/2011	21.683170	73.817770	5.00
HR-7	Hogsty Reef	8/11/2011	21.666860	73.818470	12.00
HR-6	Hogsty Reef	8/11/2011	21.673580	73.790470	13.00
GI-8	Great Inagua	8/12/2011	20.973790	73.684740	9.00
GI-7	Great Inagua	8/12/2011	21.011520	73.703640	11.00
GI-6	Great Inagua	8/12/2011	21.028540	73.690210	12.00
GI-9	Great Inagua	8/13/2011	21.031890	73.667540	15.00
GI-10	Great Inagua	8/13/2011	21.039340	73.659720	13.00
GI-11	Great Inagua	8/14/2011	21.177470	73.521470	9.00
GI-12	Great Inagua	8/14/2011	21.192410	73.435320	10.00
GI-15	Great Inagua	8/15/2011	20.935350	73.204070	13.00
GI-14	Great Inagua	8/15/2011	20.948550	73.151500	14.00
GI-13	Great Inagua	8/15/2011	20.891640	73.129650	17.00
GI-16	Great Inagua	8/16/2011	21.009120	73.128970	14.00
GI-17	Great Inagua	8/16/2011	20.950750	73.247720	8.50
GI-18	Great Inagua	8/16/2011	20.929300	73.386670	11.00
GI-19	Great Inagua	8/17/2011	21.080230	73.648860	15.00
LI-1	Little Inagua	8/18/2011	21.480960	73.075150	10.00
LI-3	Little Inagua	8/19/2011	21.501690	73.080150	17.00
LI-2	Little Inagua	8/19/2011	21.511390	73.075390	16.00
LI-4	Little Inagua	8/20/2011	21.435660	73.054910	18.00
LI-5	Little Inagua	8/20/2011	21.543700	73.015750	19.50

Algal growth and herbivory studies

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. 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 (Fig. 14). 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.



Fig. 14. (1) 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.

In July 2011 the racks were recovered and cut in fragments using an electric saw, ensuring that each tile remained screwed on to 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.

12 reefs within the 7-12 m depth contour were selected and marked along the west coast of Great Inagua for this study (Fig 15). At each of these sites 6 tiles were deployed and protected from the impact of large grazers (> 10 cm TL) with cylindrical cages made of PVC coated wire mesh, with hexagon mesh weave (1 inch). Cages were secured to the reef substratum by hammering metallic fence staples across the mesh flaps of the cage.

Coral tiles were suspended inside the cages 20 cm above the substratum (Fig. 16). Caged tiles were left in the experimental reefs for 5 full days. After the incubation period, caged tiles were retrieved from each reef. All tiles were extracted from the cages, detached from the PVC pipes, and carefully stored at freezing temperature.

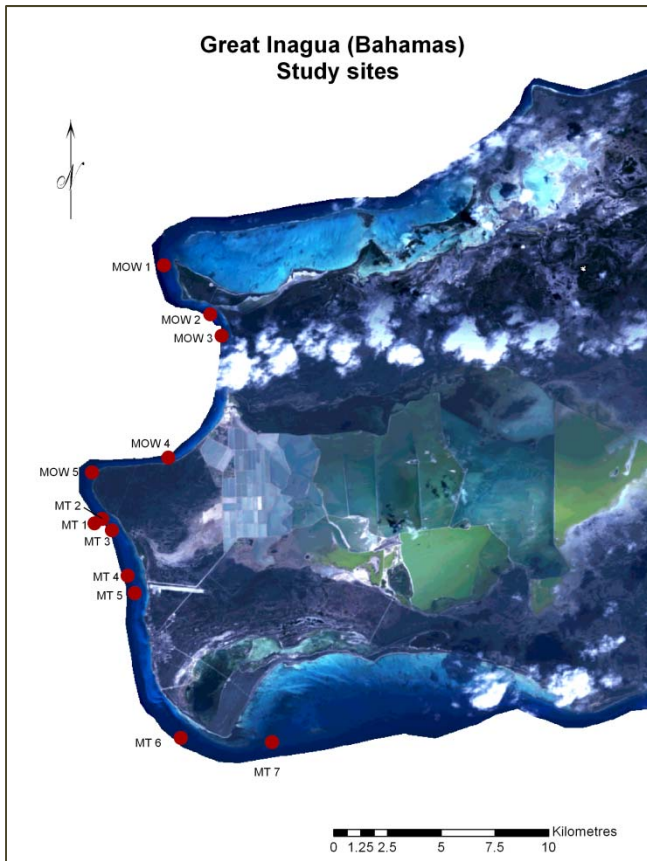


Fig. 15. Map of Great Inagua (Bahamas) indicating the location of the 12 study sites where caged tiles were deployed.



Fig. 16. Caged tile in the reef site MT4 in Mathew Town (Great Inaguas, Bahamas).

Photographic documentation of the reefs included habitat images, species photos and phototranssects. A minimum of two 10 m X 1 m phototranssects were taken on each reef. In addition, a minimum of 10 photoquadrats (0.25 m²) were taken on each reef.

Andros Island

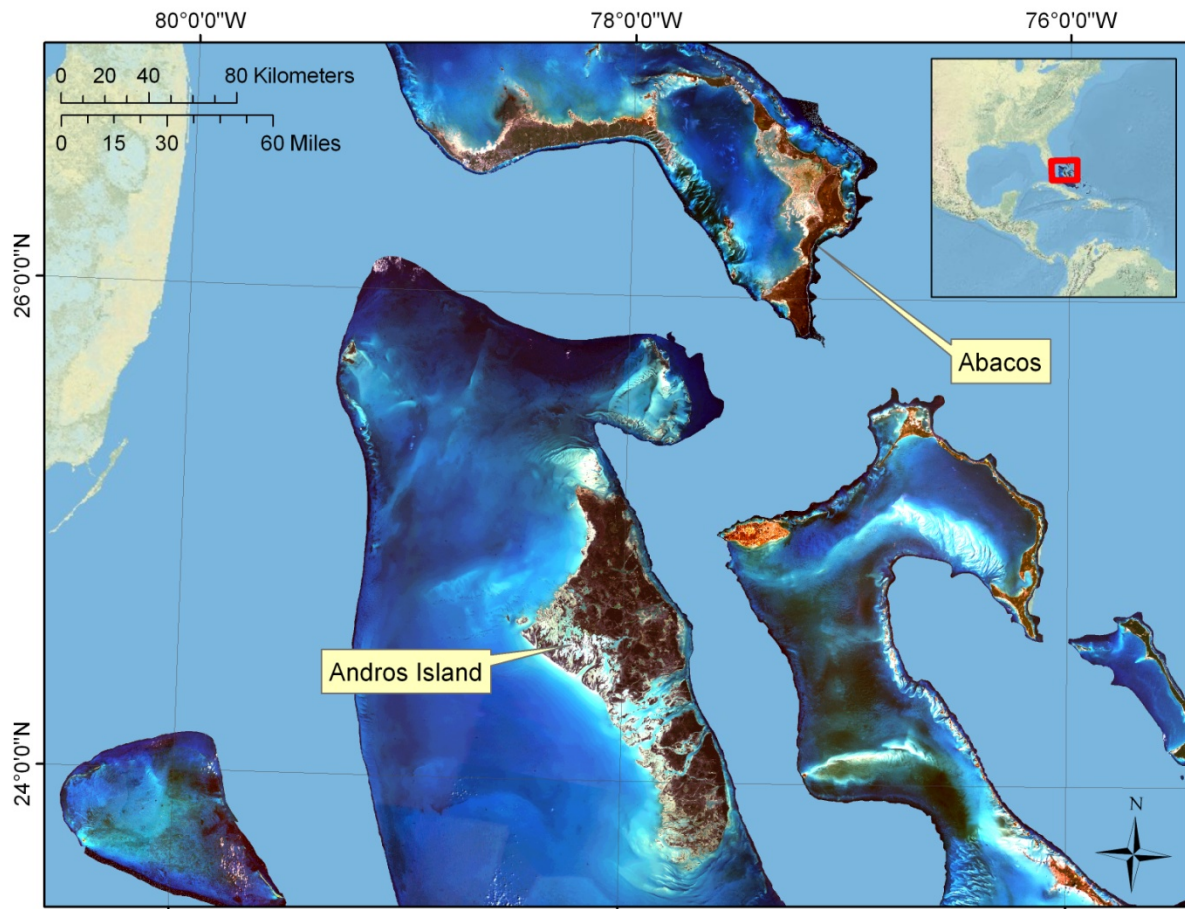


Fig. 17. Location of Andros Island.

An aerial assessment of Andros Island was undertaken on Sep. 1, 2011. The purpose of this was to identify key areas for groundtruthing surveys and to obtain aerial photographs of the land masses and shallow underwater features. Field research was conducted at the southern end of Andros Island and off Berry Island from Oct. 1-Oct 5, 2011. The research team joined the Golden Shadow in Nassau, Bahamas. The mission was aborted on 10/6/11 due to inclement weather. The Golden Shadow used two anchorages, one at the southern end of Andros and one off Berry Island. No suitable anchorages could be located further north, due to the narrow barrier reef, absence of sand-bottom communities on the seaward side of the reef crest and close proximity of deep water. Small boats were deployed to conduct research.

Habitat mapping

Through a project implemented by the Nature Conservancy and NCRI, a habitat map for the Andros Barrier reef were created using approximately ~13,918 sq km of RapidEye imagery (5 m spatial resolution, 4 band imagery; Fig 18). The habitat map (Fig. 19) was developed without detailed groundtruthing. During the KSLOF mission, we completed groundtruthing for the southern end of Andros Island to aid in validating the identified habitat types and their locations. A total distance of 69 km of continuous bathymetry was acquired and 103 drop cam videos were collected.



Fig. 18. RapidEye imagery of Andros Island.

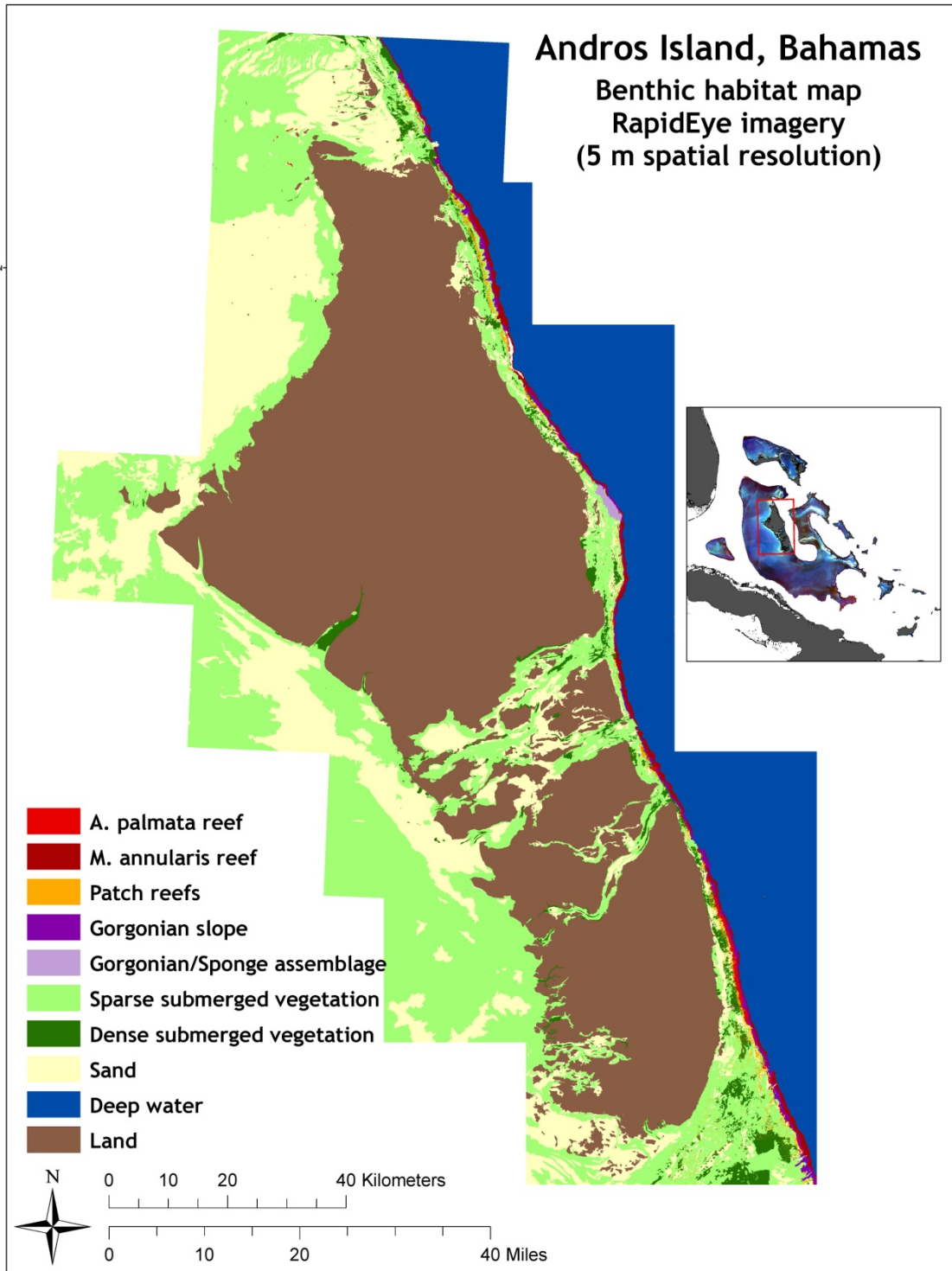


Fig. 19. Habitat map for Andros Island reef systems.

Coral Reef Assessments

SCUBA assessments of coral reef habitats were conducted off the southern end of Andros (n=7 sites) and north of Andros near Berry Island (n=3 sites) (Fig. 20; Table 5). A total of 98 dives (101 hrs, 48 min) were completed.

The team examined the benthic composition and cover, coral population structure and condition, and fish composition, size structure and biomass. Benthic surveys included 92 point intercept transects; each 10 m transect contained 100 points. For coral surveys a total of 45 belt transects (10 m X 1 m) were completed. These contained 1946 corals. Coral recruits were assessed within 460 quadrats, each 0.25 m² in size. A total of 95 fish transects, each 30 m X 2 m, were completed.

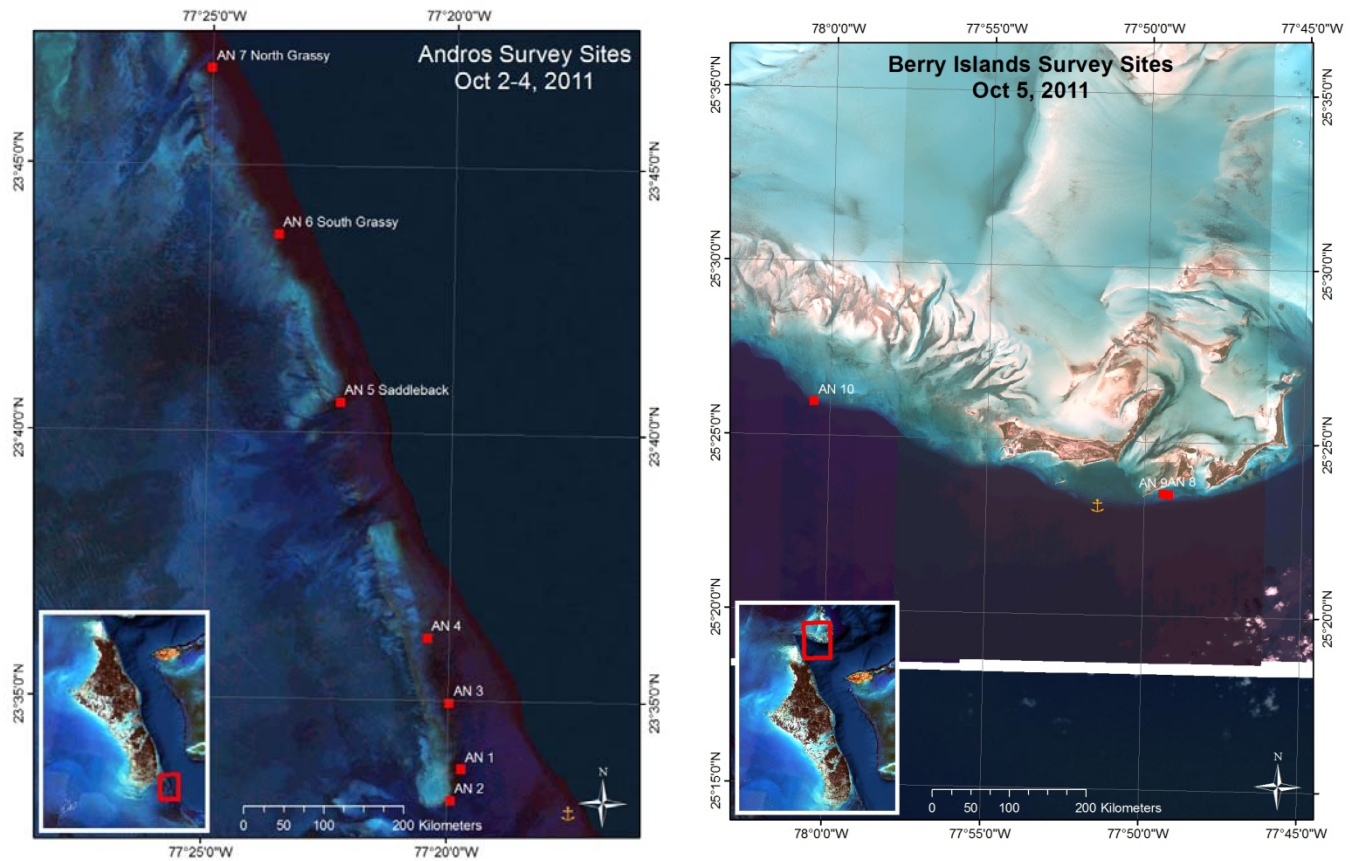


Fig. 20. Location of survey sites off southern Andros (left) and Berry Islands (right).

Table 5. Location, date and depth of 10 sites assessed off Andros Island using SCUBA.

Site	Date	Lat_N	Long_W	Depth
AN 1	10/2/2011	23.562020	-77.328540	10.0
AN 2	10/2/2011	23.552050	-77.332030	6.8
AN 3	10/3/2011	23.582530	-77.332860	7.0
AN 4	10/3/2011	23.602880	-77.340550	4.5
AN 5 Saddleback	10/3/2011	23.676190	-77.371330	7.5
AN 6 South Grassy	10/4/2011	23.728530	-77.393250	5.0
AN 7 North Grassy	10/4/2011	23.780300	-77.416800	8.0
AN 9, Berry Islands 1	10/5/2011	25.391580	77.820070	7.0
AN 8, Berry Islands 2	10/5/2011	25.391980	-77.823260	8.0
AN 10, Berry Islands 3	10/5/2011	25.432900	-78.008490	17.0

Additional Information

During the Expedition, KSLOF also gave talks at public meetings and at various locations for school groups. Numerous media interviews (radio, newspaper and TV) were conducted by the Executive Director and Chief Scientist. These resulted in numerous popular articles and broadcasts.

Acknowledgements

The Khaled bin Sultan Living Oceans Foundation is indebted to the science team for their hard work during the three research missions. Everyone contributed their expertise and time in completing these assessments, and all team members maintained a courteous and professional work effort, even when the weather did not cooperate. Special thanks for the logistical support and facilities provided by the Golden Shadow Officers and Crew, all of whom worked long hours leading up to the research project and each and every day of this mission to ensure the comfort and safety of our team, and contribute to the Khaled bin Sultan Living Oceans Foundation's mission of ocean conservation.

The gracious financial support and state-of-the art research ship provided by HRH Prince Khaled bin Sultan made this Expedition possible. We are forever grateful for his generosity and dedication to coral reef conservation, and his continued leadership role in the Global Reef Expedition.

The project could not have been completed without the assistance of the Bahamas National Trust, The Nature Conservancy and Department of Marine Resources, Bahamas. In particular, thanks to Tamica for logistical support; Eric Carey for assistance in convening several key meetings with Bahamian experts and organizations and for identifying key research sites and needs; and Roland Albury from the Department of Marine Resources, Ministry of Agriculture and Marine Resources for the assistance with the permit application process and the many changes we proposed throughout the project. Special thanks to Mrs. Linda Curtis for assistance with the CITES permits for coral collection. Dan Bobbie coordinated media interviews, press releases and other outreach activities.

We are extremely appreciative for the involvement and commitment of the local scientists from each of these essential Bahamian organizations. These young scientists demonstrated extensive knowledge and capabilities to lead future monitoring efforts in the Bahamas, and they should be encouraged to continue these efforts.

The research was conducted under permit MAF/FIS/17 issued by the Bahamas Department of Marine Resources, Fisheries.

Appendix I: Scientific Team and responsibilities

Name	Duty
Dr. Andrew Bruckner, KSLOF	Lead scientist; benthic assessments including coral, recruitment, coral disease, resilience
Capt Philip Renaud, KSLOF	Photo-documentation; recruitment quadrats
Amanda Williams, KSLOF	Point intercept transects; recruitment quadrats
Dr. Judith Lang, AGRRA	Coral assessments, algal assessments
Dr. Bernhard Riegl, NCRI	Coral assessments, recruitment, phototransects
Dr. Sam Purkis, NCRI	Groundtruthing
Jeremy Kerr, NCRI	Groundtruthing
Anesti Stathakopoulos, NCRI	Groundtruthing
Dr. Sonia Bejarano, University of Queensland	Herbivorous fish surveys, herbivory research, fish behavior
Ken Marks, AGRRA	Fish community structure along belt transects
Dave Grenda, Florida Aquarium	Fish community structure along belt transects
Alexandra Dempsey, NCRI	Point intercept transects; recruitment quadrats
Dr. Matti Kiupel, University of Michigan	Coral disease research
Liz Smith	Media/outreach
Kit VanWagner	Media/outreach
Jack Seubert	Media/outreach
Christian Clark, ROLEX Fellow	Coral reef assessments
Timothy Payne	Dive Safety Officer
Nick Cautin	Dive Safety Officer
Indira Brown, BMR	Roving fish surveys
Lindy Knowles, BNT	Fish transects
Leno Davis, TNC	Roving fish surveys
Alexio Brown, College of Bahamas	Roving fish surveys
Tavares Thompson, BNT	Roving fish surveys
Alannah Vellacott, College of Bahamas	Benthic and fish assessments
Alex Henderson, BNT	Roving fish surveys
Agnessa Lundy, TNC	Benthic assessments
Krista Sherman, BNT	Coral Assessments
Bill Mills/Charles Kinder	Video documentation, Cay Sal
Doug Allen/Curig Huws	Video documentation, Inaguas

The National Coral Reef Institute (NCRI)	3301 College Avenue, Fort Lauderdale-Davie, Florida 33314
The University of Queensland (UQ)	The University of Queensland, Brisbane, QLD 4072, Australia
University of Miami (RSMAS)	4600 Rickenbacker Causeway, Miami, FL 33149
Atlantic and Gulf Rapid Reef Assessment Program (AGRRA)	4600 Rickenbacker Causeway, Miami, FL 33149
Florida Aquarium	701 Channelside Drive Tampa, Florida 33602
University of Michigan	The University of Michigan, Ann Arbor, MI 48109
The Bahamas Department of Marine Resources (Fisheries)	Levy Building, East Bay St, Nassau, New Providence, The Bahamas
The Bahamas National Trust	P. O. Box N-4105, The Retreat, Village Road, Nassau, Bahamas
The Nature Conservancy, Bahamas	#6 Colonial Hill, Plaza Thompson Blvd. A, P.O. Box CB 11398, Nassau, New Providence, The Bahamas
The College of the Bahamas	Thompson Boulevard, P.O. Box N4912, Nassau, The Bahamas

Appendix 3: Benthic Assessment Datasheet

Surveyor:		Site:				Date:		Time:			Temperature: °C/ °F	
Compass Bearing:		Start Depth: ft/ m				End Depth: ft/ m			Quadrats			
Transect #:	0 m	1 m	2 m	3 m	4 m	5 m	6 m	7 m	8 m	9 m	#	≤ 2 cm Coral Recruits
0 cm											1	
10 cm												
20 cm											2	
30 cm												
40 cm											3	
50 cm												
60 cm											4	
70 cm												
80 cm											5	
90 cm												

Compass Bearing:		Start Depth: ft/ m				End Depth: ft/ m			Quadrats			
Transect #:	0 m	1 m	2 m	3 m	4 m	5 m	6 m	7 m	8 m	9 m	#	≤ 2 cm Coral Recruits
0 cm											1	
10 cm												
20 cm											2	
30 cm												
40 cm											3	
50 cm												
60 cm											4	
70 cm												
80 cm											5	
90 cm												

Compass Bearing:		Start Depth: ft/ m				End Depth: ft/ m			Quadrats			
Transect #:	0 m	1 m	2 m	3 m	4 m	5 m	6 m	7 m	8 m	9 m	#	≤ 2 cm Coral Recruits
0 cm											1	
10 cm												
20 cm											2	
30 cm												
40 cm											3	
50 cm												
60 cm											4	
70 cm												
80 cm											5	
90 cm												

Substrate codes

DC = dead coral
 RDC = recently dead coral
 BL = fully bleached
 HG = hardground
 R = rubble
 S = sand
 C = live coral
 I = invert

Coral codes

use first letter of genus
 and three letters of species

Condition

ID disease, predation, bleaching, other compromising feature

Algae codes

m = macroalgae
 t = turf
 cca=crustose coralline
 e = erect coralline
 cy = cyanobacteria
 TS = turf + sed.

Special algae

Dic = dictyota
 Lob = lobophora
 Mic = microdictyon
 Hal = halimeda
 Peys = Peyssonellia

Invert

Gorg = seafan
 Octo = soft coral
 Anem = anemone
 Paly = palythoa
 Tun = tunicate
 SP = sponge
 RSP = rope sponge
 TSP = tube sponge
 BSP = barrel sponge
 ESP = encrusting sponge

AINV = aggressive invert

Nuisance species

Eryth = Erythropodium
 Paly = Palythoa
 Clidel = Cliona delitrix
 Clio = Cliona (brown)
 Tridi = Trididemnum
 Chon=Chondrilla sponge

Appendix 4: Fish Assessment Datasheet

Surveyor:		Date:		Site Name:		AGRR Code:		Bottom Temp.: °C / °F					
Day #:	Site #:	Latitude:	Longitude:	Start Depth:	R / m	Day #:	Site #:	Latitude:	Longitude:				
Transect #:	Start Time:	Transect Comments:		Start Depth:	R / m	Transect #:	Start Time:	Transect Comments:					
Site Comments:		Site Comments:		Site Comments:		Site Comments:		Site Comments:					
Group	0-5 cm	6-10 cm	11-20 cm	21-30 cm	31-40 cm	> 40 cm	Group	0-5 cm	6-10 cm	11-20 cm	21-30 cm	31-40 cm	> 40 cm
Family	Angelish						Family	Angelish					
	Butterflyfish							Butterflyfish					
	Gunt							Gunt					
	Parrotfish							Parrotfish					
	Grouper/Hind							Grouper/Hind					
	Snapper							Snapper					
	Surgeonfish							Surgeonfish					
	Triggerfish							Triggerfish					
	Chub							Chub					
	Moray							Moray					
Species	Hogfish						Species	Hogfish					
	Puddingwife							Puddingwife					
	Slippery Dick							Slippery Dick					
	Spanish Hogfish							Spanish Hogfish					
	Yellowhead Wrasse							Yellowhead Wrasse					
	Orangespotted Filefish							Orangespotted Filefish					
	Scrawled Filefish							Scrawled Filefish					
	Whitespotted Filefish							Whitespotted Filefish					
	Jolthead Porgy							Jolthead Porgy					
	Pluma							Pluma					
	Saucereye Porgy							Saucereye Porgy					
	Sheepshead Porgy							Sheepshead Porgy					
	Balloontail							Balloontail					
	Porcupinefish							Porcupinefish					
	Bar Jack							Bar Jack					
	Permit							Permit					
	Bandtail Pufferfish							Bandtail Pufferfish					
	Great Barracuda							Great Barracuda					
	Spotted Trunkfish							Spotted Trunkfish					
	Yellowtail Damselfish							Yellowtail Damselfish					
	Lionfish							Lionfish					