Southeastern Bahamas Coral Reef & Island Survey

Rapid Ecological Assessment Report

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Front cover: Background - Samana Cay (Photo by S. Schill); Foreground - Elkhorn coral, cushion star, golden crinoid, and queen conch (photos by S. Voegeli).

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List of Acronyms

AGRRA	Atlantic and Gulf Rapid Reef Assessment
BREEF	Bahamas Reef Environmental Educational Foundation
CBF	Caribbean Biodiversity Fund
CCI	Caribbean Challenge Initiative
GPS	Global Positioning System
IUCN	International Union for the Conservation of Nature
MPA	Marine Protected Area
REA	Rapid Ecological Assessment
REEF	Reef Environmental Education Foundation
TNC	The Nature Conservancy

Executive Summary

Coral reef ecosystems in the Bahamas are valuable biological and economic resources, providing food security, a major source of marine biodiversity and high cultural and tourism attraction value. The reefs of the Southeastern Bahamas are among the least studied reefs in the country and therefore are a substantial gap in the environmental and ecological knowledge for the Bahamas. These reefs play an important role in the recruitment dynamics, serving as larval sources and sinks for the ecologically and commercially important species such as spiny lobster, conch and Nassau grouper occurring in the Exuma Land and Sea Park and areas in the central and southern Bahamas. Consequently, it is important to provide protection to this area of The Bahamas as there are relatively few anthropogenic impacts in these southern areas due to their remoteness and the small populations on the inhabited islands.

Figure E1. Map of the Commonwealth of The Bahamas indicating the REA survey area

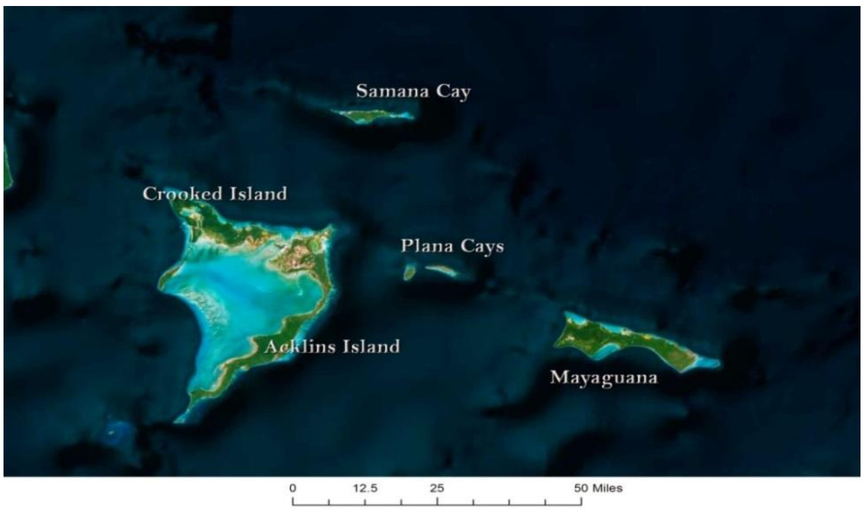


Figure E2. REA survey area in the Southeastern Bahamas.

The purpose of the rapid ecological assessment (REA) survey was to assess the condition of the reef ecosystem as well as determine the condition of flora and fauna of the land areas. The scientists were divided into three teams in order to conduct the REA:

- Coral Reef Survey Mapping Team – to collect information on benthic communities, coral communities and condition and fish abundance and diversity.
- Benthic Habitat Mapping Team – to collect GPS-referenced bathymetric profiles and underwater video samples of benthic habitats to create detailed maps from high resolution satellite imagery indicating depth and benthic habitat coverage.
- Terrestrial Team – to assess the composition and condition of the flora and fauna (e.g., flamingos, hutias) on the islands surveyed.

Ten scientists (see participants list) surveyed the areas on and around East Plana Cay, West Plana Cay, Samana Cay, Mayaguana, Acklins Island and Crooked Island during a period of 8 days (February 20-27, 2013). The assessment activities included:

- 138 individual scuba dives
- 23 Atlantic and Gulf Rapid Reef Assessment (AGRRA) reef survey sites
- approximately 375 individual reef and benthic transects
- over 1200 fish belt transects
- approximately 25 REEF Fish Surveys
- 1,707 individual coral colonies surveyed
- 460 m^2 coral surveyed
- 13,800 m^2 fish transects surveyed
- 9200 benthic cover points assessed
- 18 hours underwater video captured
- 850 Underwater photos captured
- 362 Benthic habitat underwater video camera samples
- 272.1km(170 linear miles) of baythmetric mapping (at 3pts/second)
- 85 km (53 linear miles) coastal vegetation surveyed

The marine surveys revealed large areas of *Dendogyra cylindrus* (pillar coral) which is recorded as being rare in The Bahamas, as well as large stands of *Acropora palmata* (elkhorn coral), which were found to be in good condition and other localized areas with high coral cover. In particular, massive stands of relict *Acropora* were found on the north side of the islands that were oriented east-west (e.g. Samana Cay and East Plana Cay).The macroalgal cover was moderate to high and there was overall low abundance of herbivorous and commercially significant fish (e.g., grouper). Fish were more abundant near the shelf wall on all islands and cays and Crooked and Acklins had significantly more fish with higher overall biodiversity. There was a lack of seagrass areas near the smaller islands due to the limited shelf size and high exposure to strong physical forces. Overall, this assessment revealed the reefs of the Southeastern Bahamas to be in good condition, although with signs of overfishing. The overfishing was indicated by the almost complete absence of commercially important species, e.g. spiny lobster, queen conch and Nassau grouper in areas where heavy fishing pressure was suspected. The land surveys indicated that near pristine conditions existed in most areas of the survey islands with little evidence of major anthropogenic effects. There was evidence of a significant hutia population on East Plana Cay, and several adult and juvenile flamingos were observed on West Plana Cay.

The Southeastern Bahamas Islands are an important link between the Bahamian island chains to the north and the Inaguas to the south, as well as further south into the Turks and Caicos and Caribbean Basin. Results from this rapid ecological assessment have provided informative and insightful findings that will benefit our understanding of this unique remote area as well as help develop measures to ensure its protection for future generations. Preliminary findings include:

- *Pristine islands provide critical 'land to sea' habitat for flamingos, hutia and other biota*
- *The Southeastern Bahamas support unique, extensive and healthy coral reefs*
- *These reefs are highly vulnerable to any further loss of herbivory*
- *The fish communities are threatened by overfishing and lack of nursery habitat*
- *Spawning aggregations are likely present in Southeastern Bahamas*
- *Lionfish are present even at remote reefs*
- *A new reserve in the SE Bahamas will fill a key gap in the current Bahamas network*

Island	**Biodiversity**	**Human use**
Samana	Pristine terrestrial habitat, no invasive plants Unique east-west orientation New unique *Acropora palmata* 'relict' reef type discovered Sea turtle nesting habitat Large cave inhabited by significant bat colony Low fish biomass, especially commercial fish Lack of nursery habitat, but numerous land blue holes	Fishermen and cascarilla bark harvesters camps Illegal fishing by foreign vessels
East Plana	Pristine terrestrial habitat, uninhabited by people, no invasive plants Stable population of hutia, only endemic Bahamian land mammal Flamingos and an osprey nest observed Unusual east-west island orientation New unique *Acropora palmata* 'relict' reef type discovered Aggregations of Bermuda chub, possible spawning aggregation Lack of mangrove and seagrass nursery habitat Low fish biomass, especially commercial fish	Illegal fishing by foreign vessels
West Plana	Terrestrial habitat in good condition Extensive healthy coral reef wall along western side Unusual exposed rock platform extending 2 km north More than 10 lagoons with landlocked mangrove habitat Few seagrass beds, lack of nursery habitat Flamingo population (adults and juveniles) Sandy beach habitat western side of island, possible sea turtle nesting	Fishermen and cascarilla bark harvesters camps Goats on island may alter vegetation Illegal fishing by foreign vessels
Mayaguana	Several large bays Vast nursery habitat with seagrass & mangroves High variety of healthy coral reef types Groupers displaying spawning behavior Several predicted grouper spawning aggregations Numerous conch and lobster Several predatory fish like sharks and barracudas	Moderately developed island
Acklins/ Crooked Islands	Extensive tidal creek, mangrove and seagrass nursery habitat Abundant lobster and conch Unusual high relief mount coral reef providing 'oasis' habitat Numerous sharks, large predatory fish, schooling fish Southern stingray aggregation Groupers displaying spawning behavior Several predicted spawning aggregation sites	Small human population, subsistence fishing

Table E1. Biodiversity features and human use of Southeastern Bahamian Islands.

Summary

- The Samana and Plana Cays are among the most isolated of the Bahamian islands. These remote cays are government-owned Crown land and have no or very low human use. Mayaguana and Acklins/Crooked Islands have small to moderate human population densities where mostly subsistence fishing occurs.

- Inclusion of this area into the Bahamian-wide marine reserve network would create an ecological corridor and complete an important gap from north to south. Located near the southeastern edge of the Bahamas territory, these islands link the northern Bahamian island chain to the Inaguas, Turks and Caicos and into the Caribbean Basin.

- Terrestrial habitats of Samana and Plana are pristine and provide critical 'land to sea' ecosystem connections for numerous species. Endemic hutia depend on undisturbed habitat on E. Plana Cay. Resident flamingos and other birds nest, roost and feed among the various forests, lagoons and mangroves. Sea turtles rely on the sandy beaches for nesting. A large bat colony resides in one of the Samana caves.

- Outstanding and unique coral reefs in the Southeastern Bahamas provide habitat and shelter for a high diversity of marine organisms. The extent of available, quality reef habitat could support higher biomass of fish, conch and lobster if illegal fishing was eliminated and populations were allowed to rebound. However, reefs here are vulnerable to any further loss of herbivory, particularly due to illegal fishing of parrotfish.

- Southeastern Bahamas are an important source of larvae to northern Bahamian islands like Cat Island, Long Island, and San Salvador.

- Fish rely on the unique promontories for spawning. Several groupers were displaying spawning behaviors and numerous habitats were predicted to be potential spawning aggregation sites on Acklins/Crooked and Mayaguana. Large aggregations of Bermuda chub, believed to be spawning, were observed along East Plana Cay and Mayaguana.

- Extensive mangrove, seagrass, bays and tidal creeks of Acklins/Crooked Island and Mayaguana provide important nursery habitat. Robust populations of lobster and conch and an aggregation of stingrays were found along Crooked Island. Flocks of flamingos, coots, ducks, and other birds waded among the mangrove lagoons. The pristine tidal flats of Acklins/Crooked Island are home to large numbers of bonefish and are the basis for an economically important fly fishing tourism business.

- The Southeastern Bahamas Islands are adjacent to an important humpback whale migration route and the islands act as 'stepping stones' for migratory birds.

- A new reserve in the SE Bahamas can allow for more surveillance and enforcement, which will reduce illegal fishing and increase national security.

Recommendations

In recent years, coral reef ecosystems worldwide have been in great decline due to overfishing, pollution, and global climate change. Much of the world's reefs are already severely damaged, and approximately 60% of the reefs will be lost by 2030 if actions are not taken to recover and protect them. While the islands and reefs of the Southeastern Bahamas are in good condition and likely some of the best in the Bahamas, they remain particularly vulnerable to human impacts.

These risks include:

- Illegal fishing of vulnerably low fish populations may cause a collapse of fish populations if not protected quickly.
- Remote location makes it challenging to prevent illegal fishing and/or challenging to implement conservation and management efforts.
- Overharvesting of key nursery habitats of fish, conch and lobster may decimate important stocks.
- Overfishing of grouper spawning aggregations may lead to ecologically or locally extinct populations.
- Dependence on nearby reef areas for fish, coral and other biota sources (e.g., Turks and Caicos) that may not receive adequate protection may result in a depletion of larval sources and disruption of ecological connectivity.
- Unplanned infrastructure and invasive species may destroy intact terrestrial ecosystems.

The Southeastern Bahamas REA survey area has several factors that make it a good candidate for implementing effective conservation measures and establishing a protected area or reserve. The area is quite remote and the anthropogenic impacts are few. Several of the cays do not have resident human populations and the inhabited islands have populations that are quite small. The Southeastern Bahamas would also meet the criteria for setting up and maintaining MPA networks established by the international Union for the Conservation of Nature (IUCN, 2007) including:

- Adequacy - ensuring that the sites have the size, shape, and distribution to ensure the success of selected species.
- Representability - protection for all of the local environment's biological processes
- Resilience - the resistance of the system to natural disaster, such as hurricanes or flood.
- Connectivity- maintaining population links across nearby MPAs.

Thus, it is recommended that this area should be considered for inclusion into the Bahamas National Park System as a “land and sea” park. The area would protect *adequate* and *representative* habitats by including all types habitats (terrestrial habitat, sandy beaches, tidal creeks, wetlands, mangroves, seagrasses, sandy bottoms, patch reefs, spur and grooves hard bottoms, fore reefs, wall reefs, deep oceanic areas, sea mounts). Natural *resilience* would be incorporated by including appropriate niche spaces and nursery areas for all life stages of resources in the protected area. The protected area would also have positive impacts locally and Bahamas-wide if established because of the *connectivity* and linkage to the existing Inagua protected area system to the south, as well as the Exuma Cays Land and Sea Park to the north. This MPA designation could improve the surveillance and enforcement activities against illegal fishing as other stakeholders would become more actively involved.

Conservation recommendations include:

1. Establish a land and sea reserve in the Southeastern Bahamas, particularly around the Plana and Samana Cays. Implementing protective measures will a) fill a major ecological gap in the Bahamas National Park System, b) protect nationally important biodiversity, and c) provide an ecological corridor from north to south.

2. Decrease illegal fishing from other countries in the southeastern Bahamas. Investigate the use of Unmanned Aerial Vehicles (UAVs) to monitor fishing activity and acquire ecological data in a comparatively cost effective manner.

3. Remove goats on West Plana to prevent the island from losing its largely intact and pristine forest cover. Prohibit the practice of releasing feral goats and other invasive species on small islands.

4. Protect parrotfish to maintain herbivory on reefs. Consider legislation to ban the harvesting of parrotfish as Belize and Bonaire have recently implemented.

5. Safeguard spawning aggregations of reef fish. Identify and further protect through zoning all reef fish spawning aggregations and implement consistent seasonal closures for species like Nassau grouper during their critical spawning migrations.

6. Control invasive lionfish. Consider creating incentives to promote the harvest and consumption of lionfish through sustainable market-based solutions.

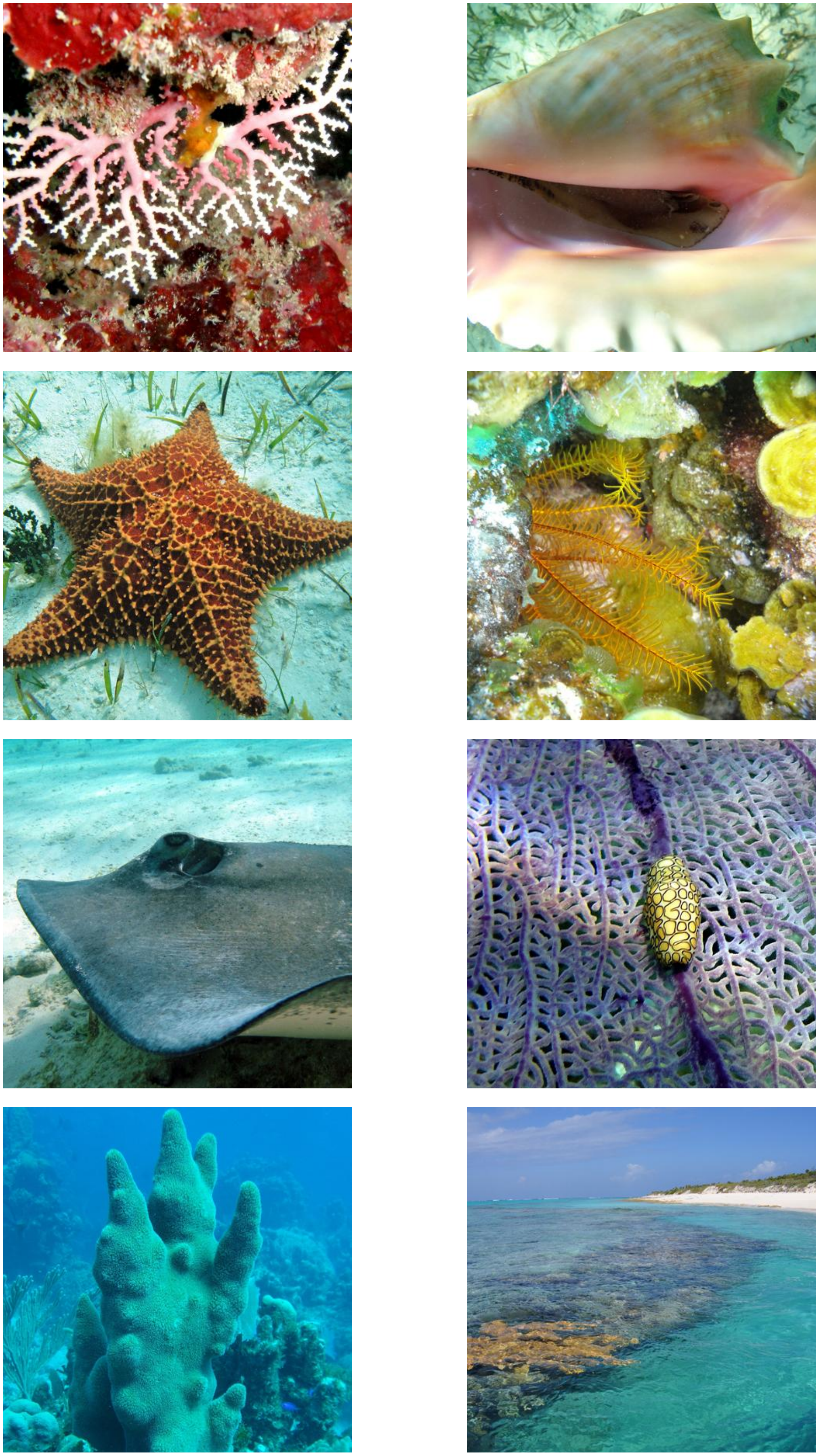
7. Involve stakeholders in conservation planning to balance natural resource management with sustainable economic development. Conduct a stakeholder assessment of the SE Bahamas to better understand current usage, stakeholder conservation priorities, and economic value of the area. This should include residents, recreational fisherman, tourists, and cruisers. Consider developing microfinance stimulus programs to promote ecotourism, lionfish harvesting and conch and lobster population enhancement projects. Collaborate with stakeholders to identify appropriate measures for subsistence, sport, and commercial fishing as well as no-take areas.

8. Protect terrestrial habitats to preserve important “land to sea” habitat connections for hutia, flamingos, bats, and other biota. No substantial infrastructure developments or mining/extractive activities should be allowed on the Plana Cays or Samana Cay. Sustainable development practices should be adopted for Mayaguana and Acklins/Crooked Island.

9. Promote additional scientific investigations of the region focusing on shark and sport fish populations, grouper aggregations, nursery habitats and ecological connectivity.

10. Engage communities by creating opportunities for people to participate in environmental stewardship and encouraging environmentally friendly practices.

The area’s ecological biodiversity and connectivity importance reinforce the need to provide conservation protection to the Southeastern Bahamian Islands. While this REA has provided initial insights into the extent and condition of the region’s terrestrial and marine resources, additional opportunities exist to further understand and develop measures to safeguard this unique area for future generations.



Left column: Rose lace coral (top); Reticulated cushion star (middle); Southern stingray (middle); Pillar coral (bottom). Right column: Queen conch (top); Golden crinoid (middle); Flamingo tongue grazing on sea fan (bottom). Photos – S. Voegeli.








Left column: Samana Cay cave (top); Coastal arch (middle); *Pithecellobium keyense* (Rams Horn) (middle); Osprey chick, East Plana (bottom). Right Column: Blue hole, E. Plana Cay (top), Samana Cay sandy beach (middle); *Euphorbia gymnonota* (middle). Flamingos, West Plana (bottom). Photos by E. Freid.

Chapter 1 – Introduction
Bahamas overview

The Commonwealth of The Bahamas is an archipelagic nation that is commonly said to be formed of “more than 700 islands and 2000 rocks and cays”. The chain of islands extends from southeast of the Florida peninsula on the North American continent to just north of the island of Hispaniola in the Caribbean Sea (Figure 1). The land mass of the islands covers about 13,939 km^2 while the marine area encompasses almost 500,000 km^2. The Bahamas lies between 20° and 28° N latitude and 72° and 80° W longitude. The country is made up of low lying limestone islands with ridges up to about 20m high. The highest point in the country is Mount Alvernia, located on Cat Island, which reaches a height of 63 m.

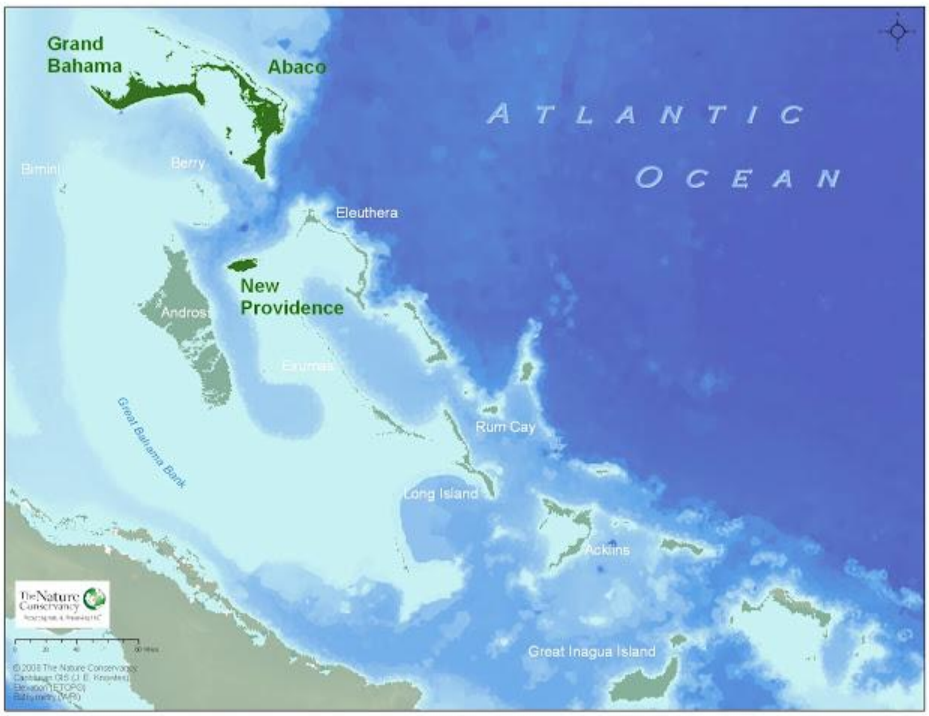


Figure 1. Map of the Commonwealth of The Bahamas.

The climate of The Bahamas is subtropical to tropical, with an annual average high temperature of 28.8° C and an annual average low temperature of 20.8° C. This average temperature range makes The Bahamas a very attractive tourist destination during the winter months in North America.

The total population was estimated at 351,461 (2010 National Census) with 70% (246,329) being located on the island of New Providence where the capital city, Nassau, is found. The other islands which have substantial populations include Grand Bahama (51,368), Abaco (17,224), Eleuthera (including Harbour Island and Spanish Wells) (11,515), Andros (7,490) and Exuma (6,928), for islands with populations greater than 5,000 resident individuals.

Annually, over 4 million tourists (2.5 million on cruise ships) visit the Bahamas, mostly in Nassau and Freeport (Spalding 2004). Fishing is important socially, culturally and economically to Bahamians. The fishing industry contributes on average about 2.5% to the GDP with over 9,000 individuals employed in the sector, 95% as fishermen (Linton et al. 2002). Most of the commercial fishing takes place on the shallow banks of the Bahamas. The most important commercial species are lobster (*Panulirus argus*), queen conch (*Strombus gigas*), and scalefish (e.g., groupers, snappers). Fisheries exports were valued at US$74.1 million in 1999 (95% of which was lobster) and Bahamian landings of lobster are 4th in the world (after Australia, Brazil and Cuba) (Linton et al. 2002). The Bahamas is rich in biodiversity (Appendix 2).

Bahamian coral reefs

The Bahamas are well known for their crystal clear blue waters, coral reefs, productive seagrass beds, and intricate mangrove forests. Fringing and barrier coral reefs are found around most islands on the north and east windward coasts and around bank edges and are often adjacent to steep or vertical walls (Figure 2). Coral reefs cover 1,987 km^2 (2.2%) of the Great Bahama Bank and 324 km^2 of the Little Bahama Bank (Woodley et al. 2000). The longest reef system is found along Andros Island and extends more than 200 km.

Coral reefs are very important in the marine environment and play an important role in protecting shorelines from storms and surges. Coral reefs act to stabilize the shoreline by reducing the effects of these powerful forces on the inshore seagrass and mangrove areas, as well as on the manmade structures placed near or on the shore. The reduction of erosion due to storms is a very important benefit gained from the presence of reef areas. The reef is the foundation of complex food webs, providing support for a large diversity of fish, algae, sponges, soft corals and other invertebrates which take refuge and find niche spaces within the structure of the reef. These webs exhibit a balanced relationship between predator and prey species that keep the marine ecosystem diverse. Another important contribution of coral reefs is that water clarity and improved quality results from the removal of particulates from the water column by the filter feeding process used in corals and sponges.

Figure 2. Map showing locations of coral reefs in The Bahamas.

Bahamas Coastal Resource Management and Marine Protected Areas (MPAs)

There are three main government and non-government entities responsible for coastal resource management and conservation in the Bahamas:

- **The Department of Marine Resources,** within the Ministry of Agriculture and Marine Resources, is responsible for fisheries management, establishment of marine fisheries reserves and coral reef monitoring.
- **The Bahamas National Trust,** a non-government organization, mandated under the National Trust Act of 1959, has the legal authority to manage the national parks of the country. The Royal Bahamas Defense Force provides enforcement support for the national parks.
- **The Bahamas Environment, Science and Technology (BEST) Commission** is responsible for developing legislation to protect the environment and issues permits for development.

The Bahamas has taken innovative and proactive steps to protect and conserve the coastal marine resources that are an important part of their cultural heritage.

The Bahamas had an early start in establishing marine protected areas, establishing the Exuma Cays Land and Sea Park as the first marine park in the Caribbean in 1958. This park has been fully protected as a “no-take” zone since 1985. Following this, several other marine parks have been established across The Bahamas (Figure 3), in the following locations:

- Abaco
- Bimini
- Berry islands
- Central Andros
- Exuma (Cays and mainland)
- Little Inagua
- New Providence
- Pelican Cay
- Peterson Cay
- Tilloo Cay
- Walker’s Cay

To protect commercially significant marine species, the Government of the Bahamas developed a system of fishery reserves, declaring six areas for the protection of lobster, conch and Nassau Grouper. In addition, the use of SCUBA or compressed air is prohibited while harvesting fish, conch, lobster, or other marine species. Overfishing in many other parts of the Caribbean is related in part to the use of SCUBA while fishing.

Beginning in 1999-2000, the Department of Marine Resources initiated closures of Nassau Grouper fishing during spawning season. Three fish spawning aggregation sites are protected including one at High Cay off the coast of Central Andros and two sites off the east coast off Long Island. The taking, landing, processing, selling and offering for sale of fresh Nassau Grouper is prohibited from the first of December to the end of February throughout the Bahamas.

In 2002, the Bahamas Government made a significant effort to conserve natural resources by creating 10 new National Parks to protect more than 700,000 acres of marine and terrestrial areas, nearly doubling the size of its National Park System. Five national parks were established on Andros Island, including West Side National Park, Andros Barrier Reef Park (two areas), Blue Holes National Park, and Crab Replenishment National Park.

In 2012, the Bahamas made a landmark accomplishment by expanding the West Side National Park from 286,080 acres to 1.2 million acres – one of the largest marine reserves in the Caribbean. West Side National Park protects key habitat for conch, bonefish, and West Indian flamingos and is an important nursery area for numerous fish species. It now includes northwestern areas of Williams and Billy Islands and Turner Sound; important mangrove and creek areas of Loggerhead, Pelican and Deep Creek; a lake system, Cabbage Creek and Sandy Cay in the South Bight.

However, a marine protected area gap exists in the south-eastern Bahamas, in the area around Crooked and Acklins Islands (see figure 3). There is limited scientific knowledge regarding the local ecosystems and communities that reside in the area. It is important that the area be assessed so that science based decisions can be made for the proper management of the area. This research cruise had the purpose of supplying the scientific information needed to fill the knowledge gap.

Figure 3. Map showing location of designated protected areas in The Bahamas.

Threats to Bahamian Coral Reefs

The Caribbean contains 10 percent of the world's coral reefs as well as a great biodiversity of fish and marine mammals and substantial areas of mangrove forests along the coastlines. In countries like The Bahamas, where the entire national population can be said to reside within the coastal zone, the value of a healthy marine and coastal environment cannot be understated. Tourism, the greatest contributor to the Bahamian economy, is highly impacted by the state of these resources, which are under constant threat from coastal development, pollution, overfishing and climate change.

As tourism has increased in The Bahamas, demands for additional infrastructure in coastal zones has also increased, leading to greater dredging activities, especially for dock, port, canal and channel constructions, and the resulting sedimentation which can negatively affect the reef ecosystem. Coastal development in The Bahamas often includes the removal of wetlands and mangrove areas which can reduce littoral nursery areas, thereby reducing the habitat and food sources available for juveniles of many commercially important species that eventually would settle on the offshore reef. Further, coastal development, particularly around Nassau, has also resulted in increased and chronic nutrient and sediment runoff into the marine environment, both negatively affecting the coral reefs through eutrophication, algal blooms and the smothering the coral polyps, respectively. In some areas, these events can also reduce the penetration of light through the water column, thereby reducing or preventing photosynthesis by the symbiotic zooxanthellae resident within the coral tissues. Physical damage to Bahamian reef areas, due to anchoring in popular diving and fishing areas, or from ship groundings, has reduced the reef complexity and structure through breakage and scouring in some areas.

Fishing has also affected coral reef ecosystems through the removal of particular types of fish. The existing balance of piscivores to invertivores to herbivores may be altered, reducing the resilience of the reef to natural and anthropogenic disturbances. Overfishing, especially illegal fishing activities, are a major threat in this remote area. It is reported that many fishing vessels from the Dominican Republic frequently harvest fishery resources in this area. Significant quantities of spiny lobster are exported to the US and consumed locally in the Dominican Republic but there are no known commercially viable stocks in that country. The unwieldy process of arrests, seizures and prosecution of poachers, along with the costs of supporting the vessels and crew while in custody, is not a deterrent. Generally, if foreign fishing vessels are arrested in The Bahamas only a small fine is levied and the vessels themselves are not typically confiscated, allowing vessel operators to continue profitable poaching operations after replacing any confiscated fishing gear.

The condition of corals in the Caribbean region has dramatically declined over the past three decades. Historically, two of the most devastating events to impact Caribbean coral reefs occurred in the 1980's. In 1983, a lethal disease outbreak decimated over 90% of the herbivorous sea urchin, *Diadema antillarum*, and a region-wide recovery has not been observed (Lessios 1988). The loss of these key algae-eating urchins allowed macroalgae to increase and overgrow corals in many reefs. A separate disease outbreak in the 1980's is believed to be the primary cause for mass mortality of elkhorn (*Acropora palmata)* and staghorn (*A*. *cervicornis*) corals - the principal framework builders of shallow reefs. The population collapse of both *Diadema* and acroporid corals and their subsequent inability to recover have had significant impacts on the structure and functioning of Caribbean coral reefs (Hughes 1994). However, it is not fully understood how and to what extent these early disease epidemics affected populations of *Diadema* sea urchins and acroporid corals on Bahamian coral reefs.

More recently, there has been in an increase in the number of coral bleaching events related to more frequent and longer lasting elevated sea surface temperature events. The Bahamas has experienced several recent coral bleaching events. The most significant one occurred in 1998 and caused unprecedented coral mortality and subsequent disease along Andros Island's coral reefs and was responsible for the largest coral reef decline on Andros Island in the past 10 years (Kramer and Kramer 2010). Less severe coral bleaching events occurred in 2005 and 2007, although sea surface temperatures and resultant impacts varied in the different reef regions due to the large geographic size of the Bahamas.

Of growing concern is the ecological impacts associated with the introduction of exotic lionfish, *Pterois* sp., which were first reported in the Bahamas between 2001-2002. Along Andros Island, lionfish did not appear in significant numbers until 2007, but since then, lionfish biomass has increased as juveniles observed in 2007 matured to larger fish (Kramer and Kramer 2010). The impact of lionfish on trophic dynamics of the Bahamas coral reefs is likely to be significant, particularly since they have high reproductive rates, are voracious feeders, and have no known predators.

Destructive fishing practices and the aquarium fish trade often damage reef structure and disrupt the ecological balance between reef species. Coral mining for construction, jewelry and souvenirs result in reef destruction and increased sedimentation, loss of fish habitat and long recovery times as corals are formed over hundreds to thousands of years.

Sea-level rise is of particular importance to low-lying island states like The Bahamas. An estimated one meter sea level rise in The Bahamas would impact approximately 5% of the land area (613 sq km). If only the land that lies 1 km from the ocean is considered, where most people live, the percentage impacted goes up to 10%. The Bahamas has an estimated 1,051 km^2 of mangroves (44% would be impacted by 1-meter sea-level rise); 113 km^2 of beach (16% would be impacted); and 997 km^2 of coral reef. Estimates have been calculated using an ASTER 30-meter digital elevation model and marine features mapped from satellite imagery (Appendix 2). Red=high threat, yellow=medium threat, and blue= lower threat levels (Fig. 4).

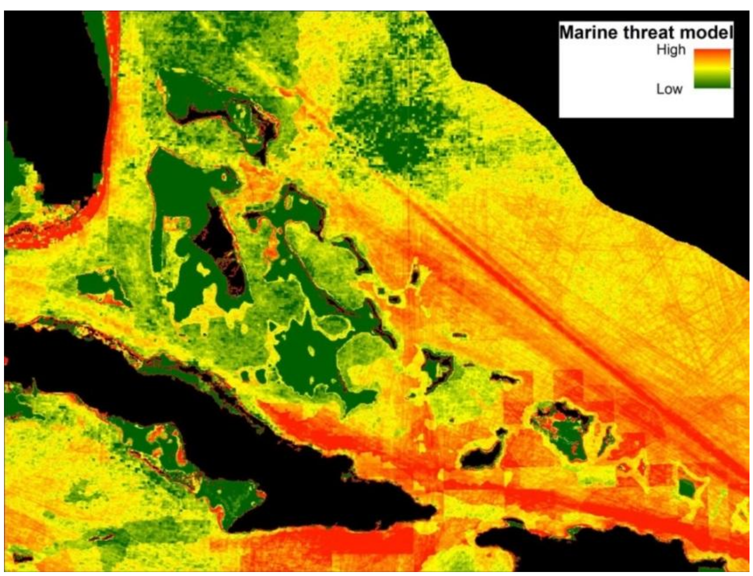


Figure 4. Map showing marine threat model in The Bahamas due to climate change.

Chapter 2 - Survey Methodology
Survey area

The Southeastern Bahamas is described as being remote primarily because it is relatively difficult to gain access to, the amenities are few, the islands are either uninhabited or have very small populations and a mainly subsistence existence is the norm for the area. The islands within the survey area included East Plana Cay, West Plana Cay, Samana Cay, Mayaguana, Acklins Island and Crooked Island (Figures 5, 6).

East and West Plana Cays

These small cays are uninhabited and the sole remaining endemic Bahamian land mammal, the hutia, can be found on East Plana Cay. The rabbit-sized hutia was previously thought to have been extinct, but was first studied on the cay in 1966. Since then the hutia has been transplanted to the Exuma Cays. The Plana Cays are located about 475 km southeast from Nassau.

Samana Cay

This relatively large cay is also uninhabited. It is said to be the largest uninhabited cay in The Bahamas. Evidence of previous long term residents on the cay have been recorded; pottery shards and other artifacts ascribed to Lucayan Indians around to the time of Columbus and the ruins of a settlement from the first half of the 20th century. Residents of Acklins Island periodically visit Samana Cay for a few weeks at a time in order to farm and collect cascarilla bark which grows abundantly on the cay. Samana Cay is about 16 km long and is up to 3 km wide and has an area of about 45 km^2. This cay is well vegetated and has many ponds, and is surrounded by well-developed reef systems. The cay is also known internationally to have a very good fishery for pelagic species.

Mayaguana

Mayaguana is the eastern-most island in The Bahamas. It has an area of about 280 km^2 and had a population of 277 individuals at the time of the 2010 National Census. There are three settlements on the island, the largest being Abraham’s Bay on the south coast while Betsy Bay and Pirate’s Well are located on the north coast. The island is located about 560 km southeast of the Capital of Nassau, on New Providence Island. Farming and fishing are the primary activities on this isolated island. There is only one “resort” located in Pirate’s Wells but several other small guest houses are available. The island is known for its laid back and relaxed atmosphere. Bonefishing, scuba diving and seaside activities are enjoyed here by the very few arriving visitors.

Acklins and Crooked Islands

These islands are located about 440 km southeast of Nassau and encircle a shallow bank known as the Bight of Acklins. Acklins Island has a total population of 565 individuals while Crooked Island has 330 residents (2010 National Census).The main towns on these islands are Spring Point on Acklins Island and Colonel Hill on Crooked Island. As in Mayaguana, fishing and farming are the main occupations for the residents. Bonefish guiding for tourists is also available with both near shore and deep-sea fishing charters. Crooked Island was the site for the first Post Office in The Bahamas at Pitt’s Town, and the Marine Farms Fortress, an ancient British fort ruin, is also located there, overlooking the Crooked Island Passage.

Figure 5. Map of the Commonwealth of The Bahamas indicating the REA survey area.

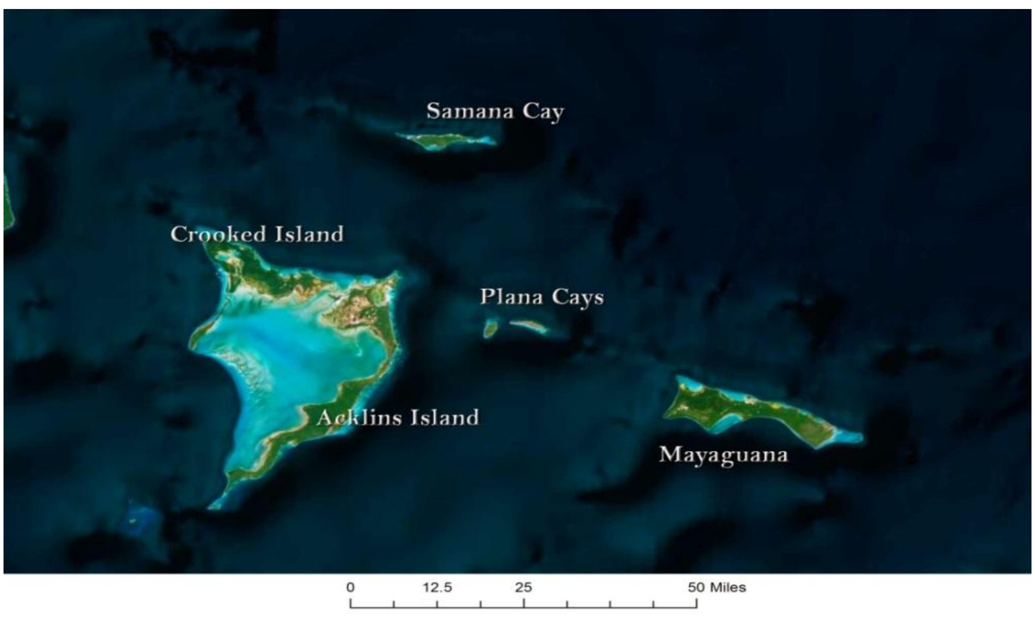


Figure 6. Close-up of REA survey areas.

Survey Method

The Rapid Ecological Assessment (REA) is useful for gathering data about the major biological features of the reef. Its purpose is to document the biodiversity within the reef habitat and note the interactions between the species present. It documents the basic state of the reef components (algae, corals, fish, and invertebrates) and compiles a species inventory for the area during comprehensive surveys. Because the method can collect sufficient data for a general assessment of the reef flora and fauna during a single dive it is particularly useful for remote areas like the Southeastern Bahamas. The Southeastern Bahamas REA had three teams of scientists to make a thorough assessment of the area being studied. The teams included the 1) Coral Reef Team dedicated to assessing benthic composition and cover, coral population structure and condition and fish community structure, 2) Marine Mapping Team to conduct video and bathymetric transects of reef areas, and 3) Terrestrial Team to assess the flora and fauna onshore. In addition, a marine connectivity and coral larvae transport model was completed by Schill et al. (2012) for the Caribbean Basin and Gulf of Mexico and results specific for East and West Plana Cays, Samana Cay, Mayaguana, and Acklins Islands are provided.

Coral Reef Survey Dive Teams

The Coral Reef Survey Team used Atlantic and Gulf Rapid Reef Assessment (AGRRA) survey methods (http://www.agrra.org) to assess the overall reef condition. The goals of AGRRA are to complete the regional assessment of the health of coral reefs throughout the Western Atlantic, to analyze the results and develop a database so as to establish a practical scale of comparative reef condition, and to promote the transfer of this information to a wider audience including the general public, resource managers, government officials, policy makers, tourist operators, and students.

A part of the benthic team specifically assessed the current benthic algal states by recording the benthic cover under points at 10-cm intervals on each of six, 10-m long transect lines per site (Figure 7). The heights of the macroalgae in at least two transects were measured and all recruit and small corals within each of five, 25 cm square quadrats which were placed at 2 m intervals along each transect line were identified and counted. In addition, the benthic algae team also counted all of the long-spined urchins, spiny lobster, queen conch, lionfish and trash within a 1 m wide belt centered on each transect line.

The other part of the benthic team was focused on coral and assessed the size and overall condition of corals greater than 4 cm diameter in two 10 m by 1 m belt transects per site. An estimate of the partial and type of coral mortality and bleaching condition was also determined.

The fish survey dive team also used AGGRA protocols to assess the abundance and diversity of the fish populations at the dive sites. This was done by counting and recording the size of the fish species listed in the AGRRA sheets in 10, 30 m long by 2 m wide belt transects per site. The maximum reef relief was also measured at six regularly spaced intervals (i.e., every 5 m) along each transect. The fish survey team also assessed reef fish species richness by conducting a roving diver census at each dive site. This was done using Reef Environmental Education Foundation (REEF) methodology (http://www.reef.org) and forms, recording the species and density of each fish observed during the dive.

The reef survey dive sites (Figures 8-12) were selected through the use of recent IKONOS (4X4m) and Worldview-2 (2X2m) high resolution satellite imagery. Contrast stretching of the satellite imagery was done prior to the surveys to enhance reef features and identify important representative reef features to be sampled around each of the islands. In addition, snorkel tows were conducted to further identify and select representative sites. The survey sites mainly consisted of fore reef habitats between 10 – 15 m deep due to rough weather, except for a few shallower sites. For Acklins and Crooked islands, two sites (A1 and A2) were selected based on areas that were identified as potential spawning aggregation sites. In total, comprehensive surveys were made at 23 sites by scuba divers: five dives were made at West Plana cay, four at East Plana cay, six at Samana Cay, five at Mayaguana and three at the northern coasts of Acklins and Crooked Islands. Appendix 5 has more information on the geology and Appendix 6 includes results from the REEF roving diver fish surveys.

Figure 7. Scientist recording benthic cover along transect line (photo – S. Voegeli).

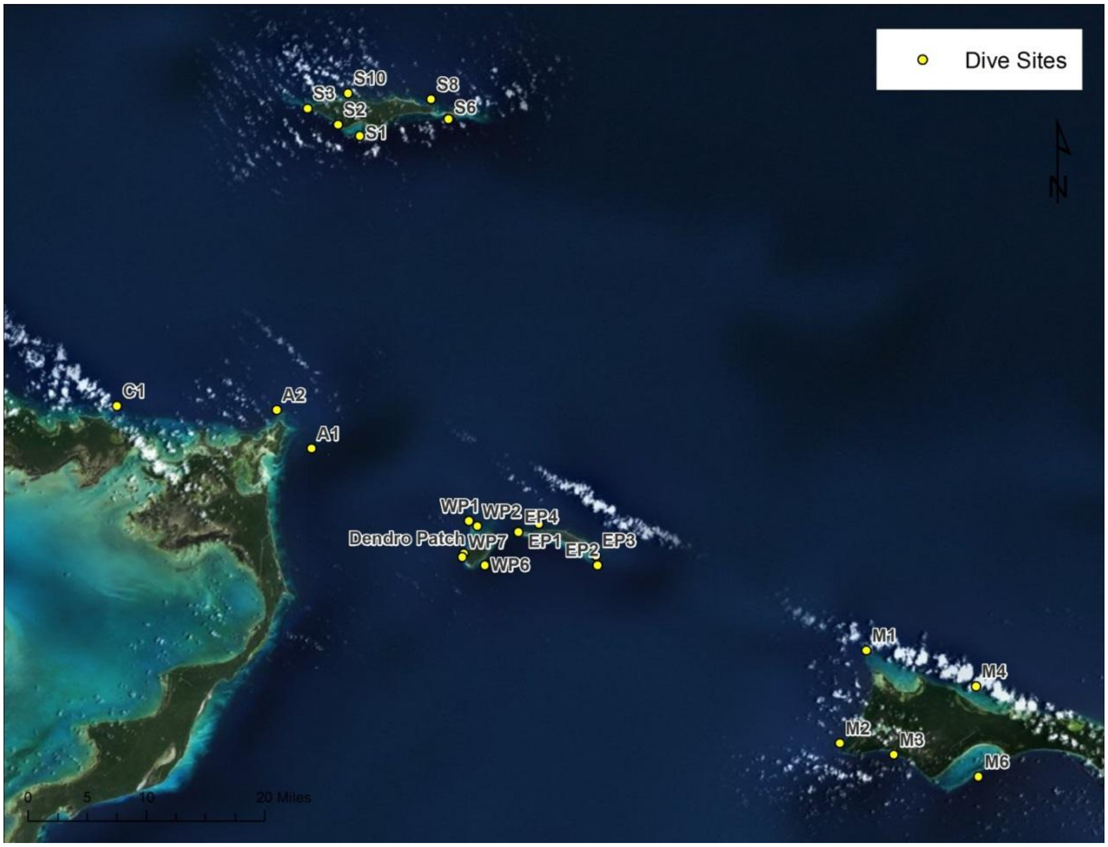


Figure 8. Distribution of all the dive survey sites sampled during the REA.

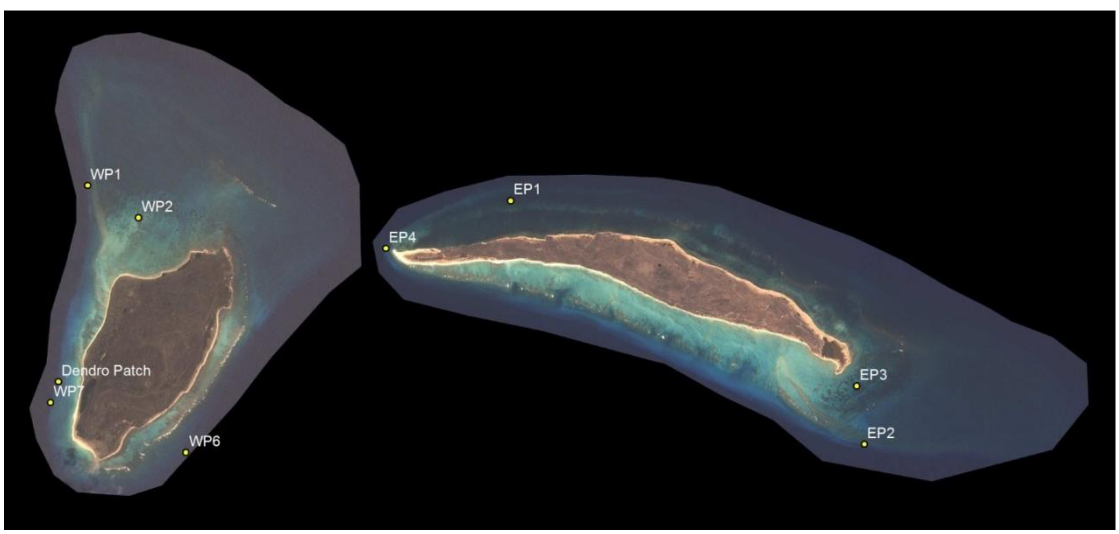


Figure 9. Distribution of dive survey sites sampled around East and West Plana Cays.

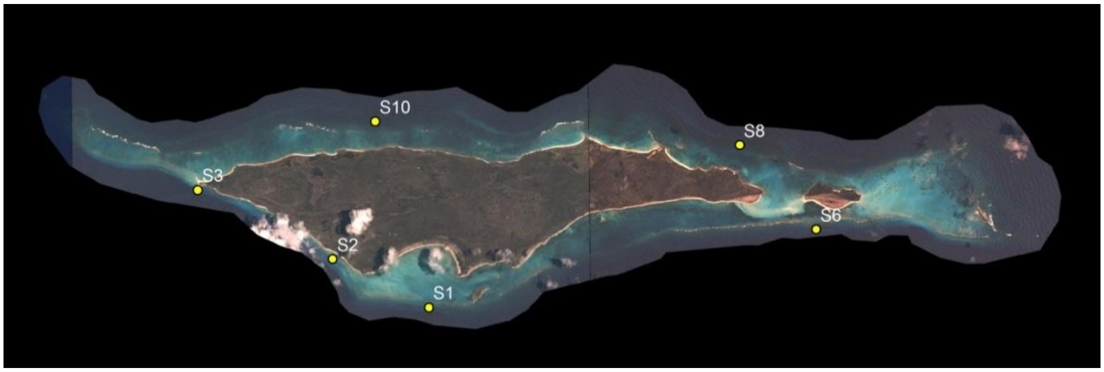


Figure 10. Distribution of dive survey sites sampled around Samana Cay.

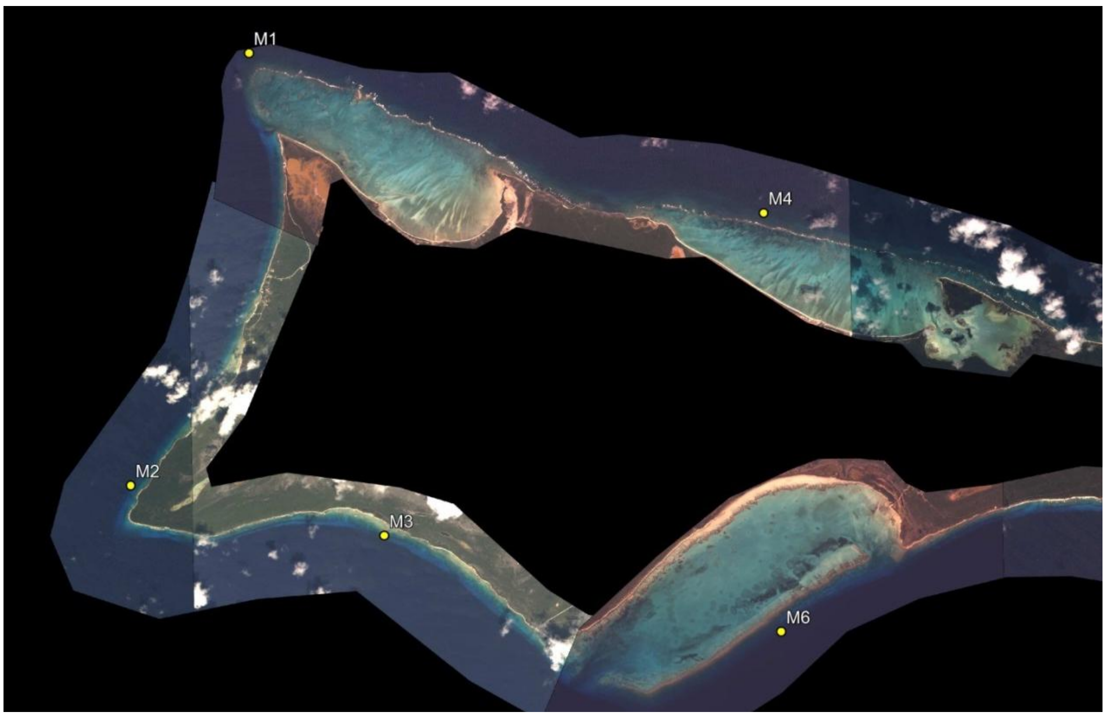


Figure 11. Distribution of dive survey sites sampled around Mayaguana.

Figure 12. Distribution of dive survey sites sampled around Acklins and Crooked Islands.

Marine Mapping Team

The mapping team deployed an underwater video system coupled with GPS and a depth sounding device. Ground survey consisted of accurately positioned videos of the seafloor, as well as continuous survey of the water depth; this provided both the data necessary for habitat mapping, but also a historical archive of reef conditions. The mapping software Fugawi™ was used to interrogate satellite imagery in real time and carefully position the survey vessel over ground targets. A SeaViewer Sea-Drop™ underwater video camera (SeaViewer.com), angled slightly downwards, with 100 feet (30.5 m) of cable was used. Position data were gathered using a Garmin GPSmap® GPS (Figure 13) with a positional accuracy of <3 m (95% typical). Date, time, speed, heading, and position were embedded in each video using a SEA-TRAK™ GPS Video Overlay which was then saved as a compressed MPEG file. The videos were viewed in real time on a laptop to allow the user to control a smooth flight approximately 1 m above the seafloor. A point-feature shapefile was created at each drop location using ESRI ArcPad software to facilitate subsequent video analysis. Water depth data were measured using a Garmin GPSmap® transducer (Figure 19). Depth readings from the transducer were collected as a continuous string and combined with GPS position data in Fugawi™. These data were processed further using a script written in Matlab™ to determine the depth of each ground control video based on the nearest sounding at time of capture. The entire survey system was wired to allow data to be collected, overlaid, and stored on a single laptop, all powered from a 12-volt battery (Schill et al., 2011).

The GPS location and bathymetric data collected at each sample point will permit the matching of the underwater video samples and bathymetry to the same location on the satellite image. Light reflection and depth patterns found in the satellite imagery will be analyzed and modeled for each benthic habitat class. Since each depth and habitat type reflect light differently across each scene, these patterns can be modeled to map the entire nearshore in depths less than 30 m. The mapping team also used satellite images to select representative areas for their broad scale survey of all the reef and benthic habitats around each of the islands in the study area. This team used 45° boat transect lines towards and away from the coastline across appropriate depth isobaths to capture the benthic video data. Figures 14-21 and Appendix 3 show locations and tracks of underwater video sampling sites and bathymetric surveys for individual islands.

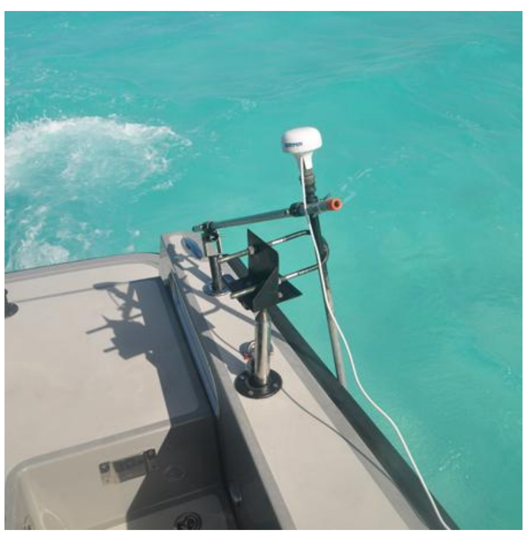


Figure 13. Photograph of GPS antenna and Depth Sounder units used for collecting data for the benthic habitat and bathymetric surveys (photo – S.Schill).

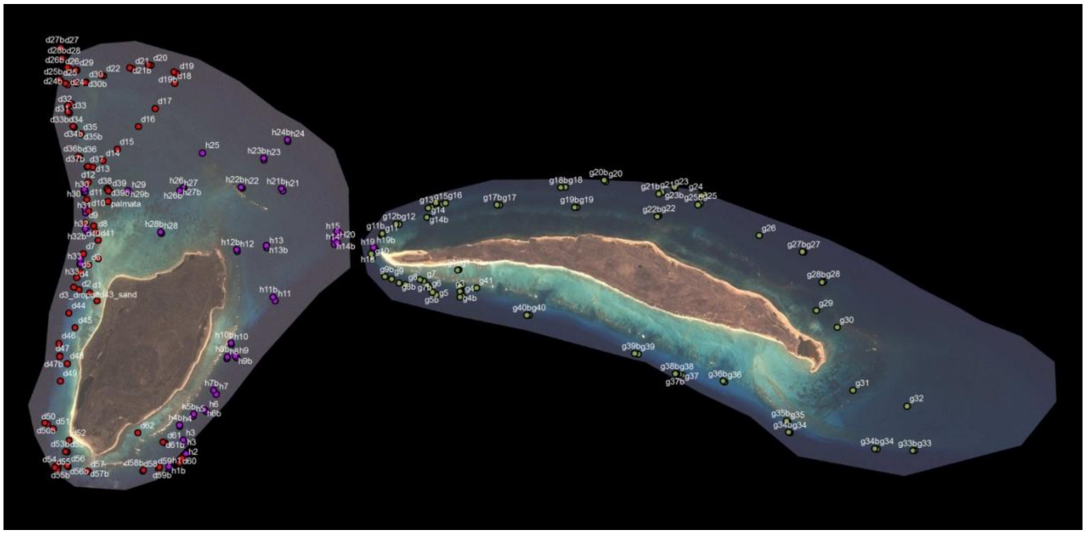


Figure 14. Distribution of underwater video camera surveys for East and West Plana Cays.

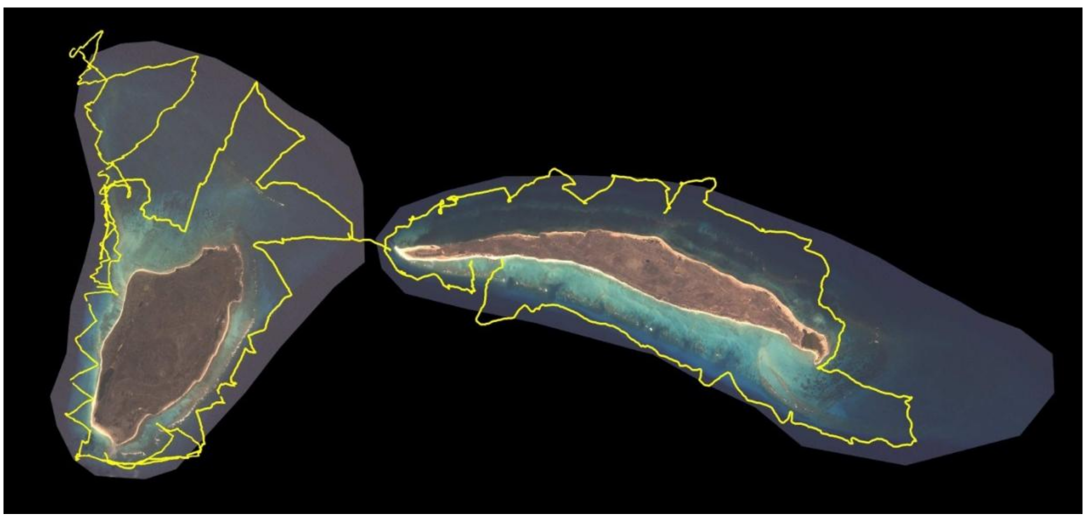


Figure 15. Tracks of bathymetric surveys for East and West Plana Cays.

Figure 16. Distribution of underwater video camera surveys for Samana Cay.

Figure 17. Tracks of bathymetric surveys for Samana Cay.

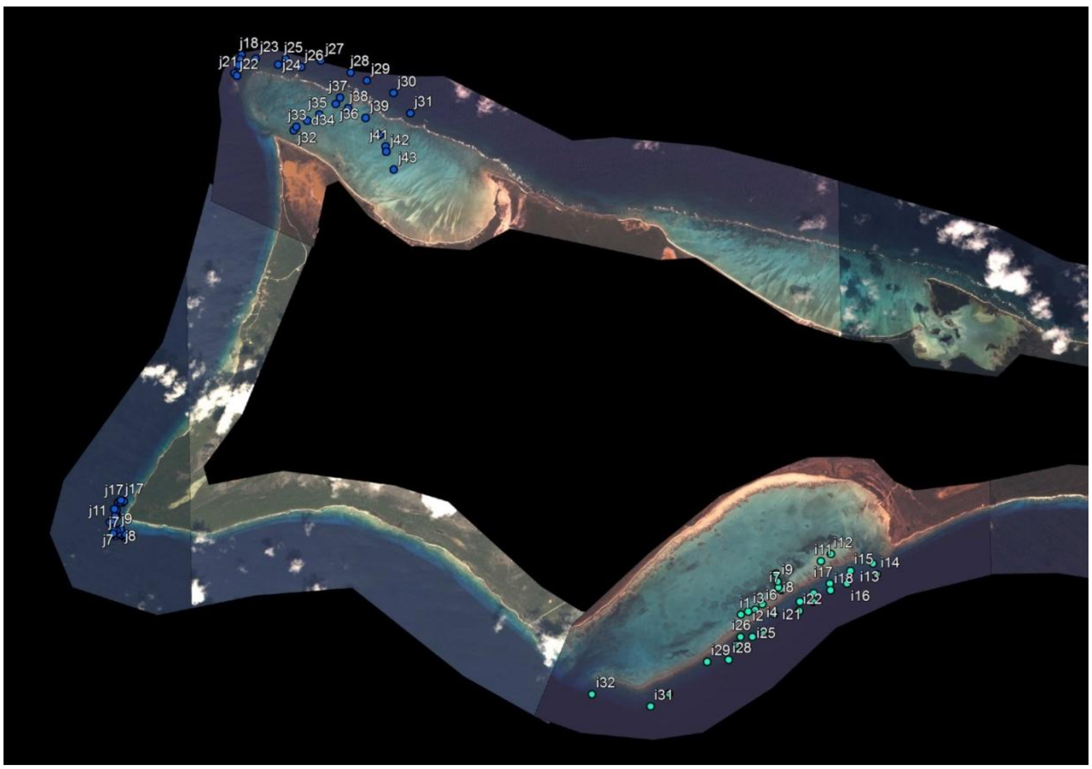


Figure 18. Distribution of underwater video camera surveys for Mayaguana.

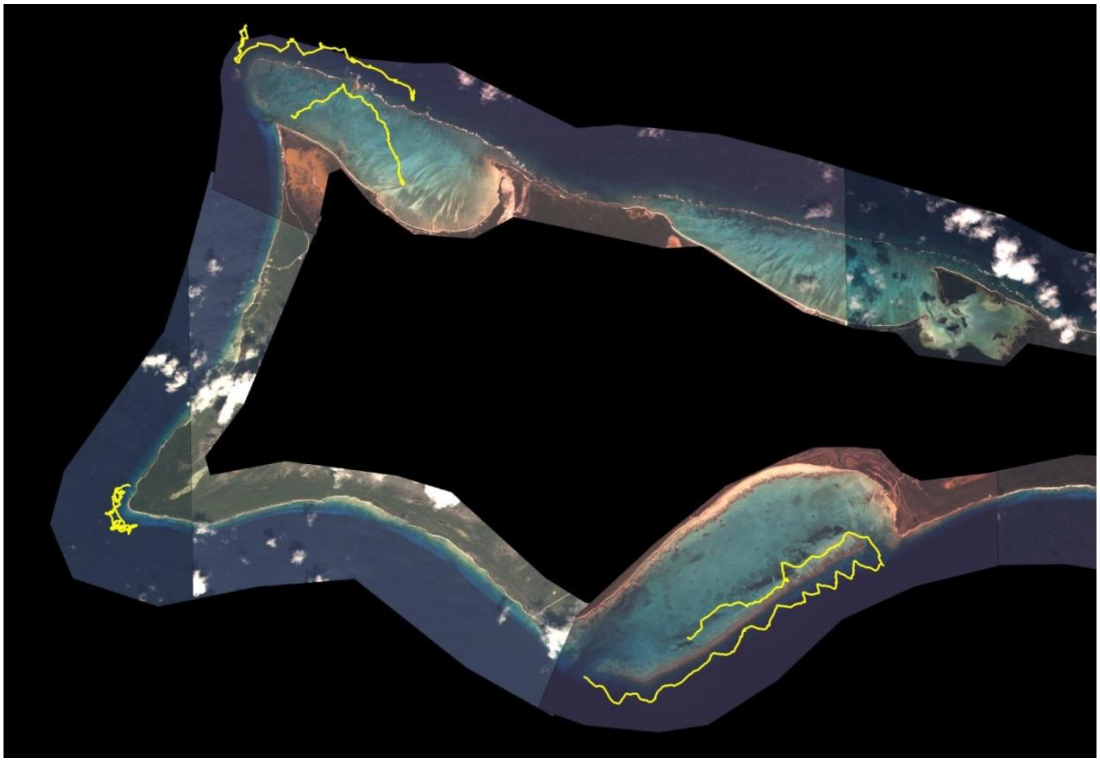


Figure 19. Tracks of bathymetric surveys on Mayaguana.

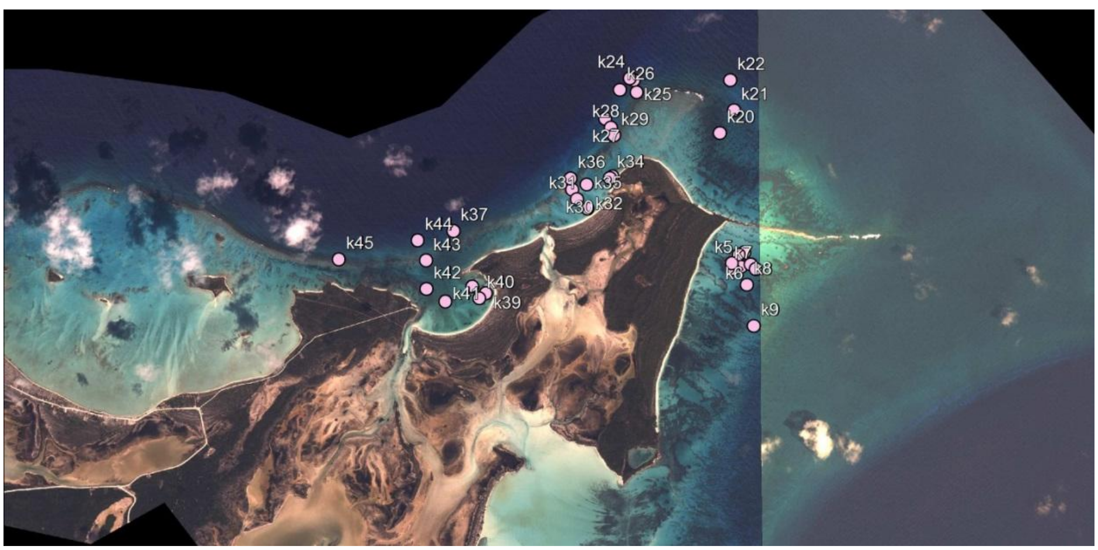


Figure 20. Distribution of underwater video camera surveys for Acklins Island.

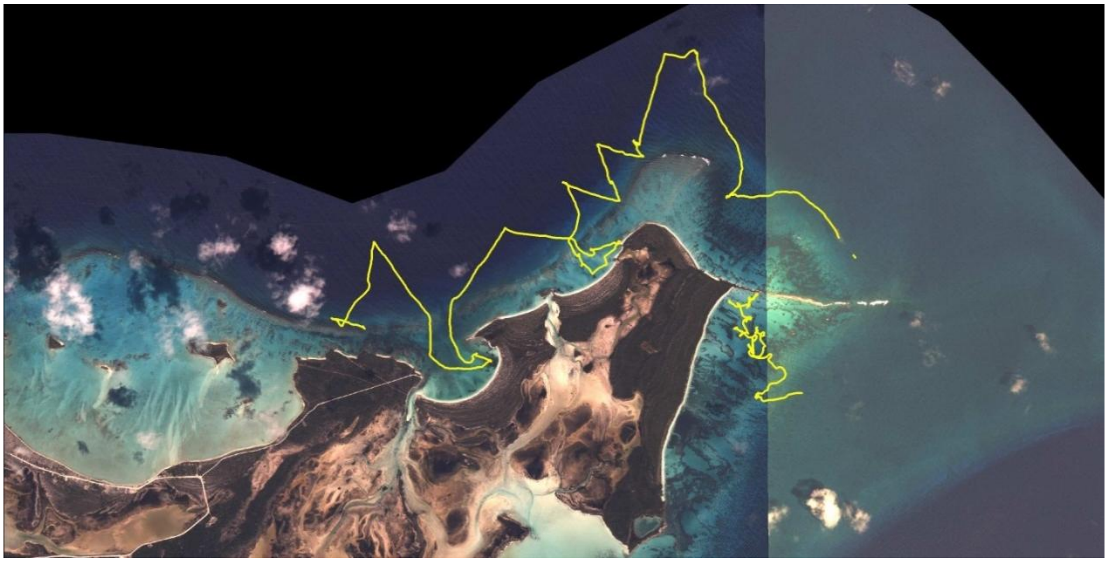


Figure 21. Tracks of bathymetric surveys for Acklins Island.

Terrestrial Team

The terrestrial team used walking transects to assess general plant diversity, habitat type and structure, coastal quality assessment, invasive plant status as well as any general information (e.g., hutia, birds, blueholes). A Garmin 60 CSX GPS unit was used to record transect waypoints and coordinates of specimens of particular interest. (See attached terrestrial report in Appendix 4). Terrestrial surveys were conducted on East and West Plana Cays, Samana Cay and on Mayaguana (Figures 22-24, Appendix 4). Less survey time was spent on Mayaguana and Acklins/Crooked Islands due to time constraints.

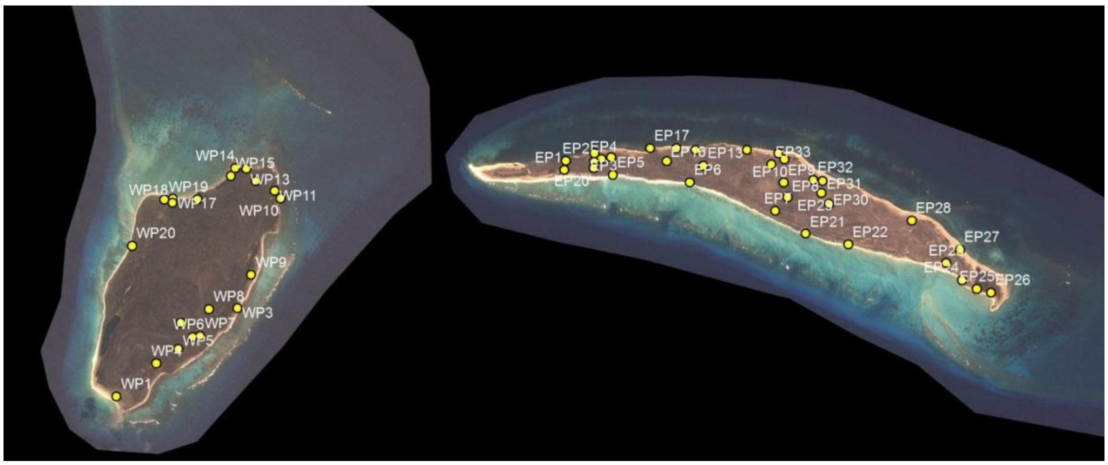


Figure 22. Distribution of terrestrial survey sites on East and West Plana Cays.

Figure 23. Distribution of terrestrial survey sites on Samana Cay.

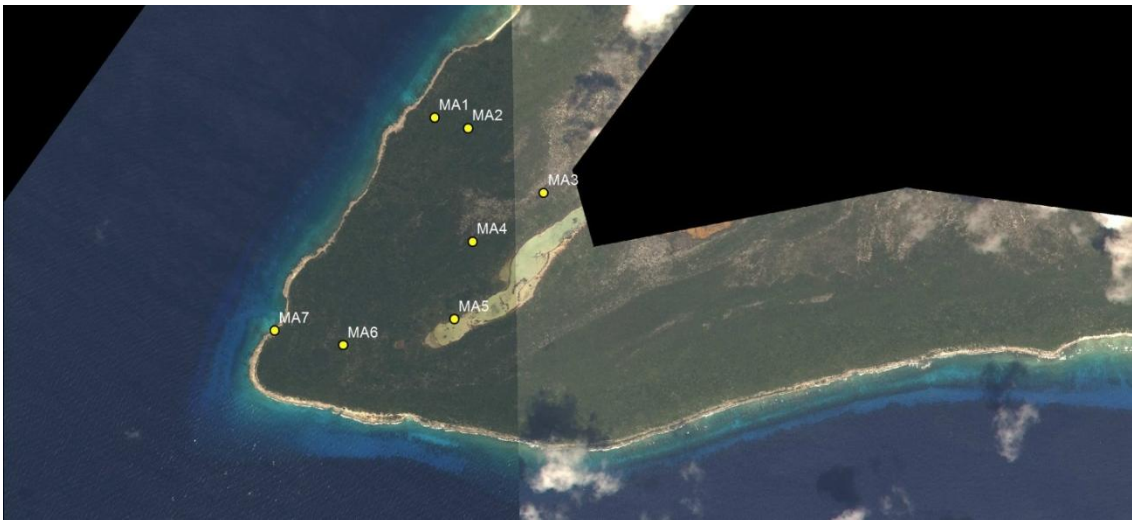


Figure 24. Distribution of terrestrial survey sites on Mayaguana Island.

Marine connectivity model

A marine connectivity and coral larvae transport model was completed by Schill et al. (2012) for the Caribbean Basin and Gulf of Mexico. As part of the REA for the South-eastern Bahamas, we present the results of the connectivity model for East and West Plana Cays, Samana Cay, Mayaguana, and Acklins Islands. The marine connectivity and larval transport models produced explore research questions such as, "Following a spawning event, where do coral larvae go? And "Where is settlement and recruitment most likely to occur?" These are important questions to investigate in order to determine how reefs and islands depend on one another for their long-term survival and reproduction. To help answer these questions, a regional ocean connectivity model (8x8km) was developed for the Caribbean Basin and Gulf of Mexico, integrating the ocean current information in NOAA's Real-Time Ocean Forecast System (RTOFS) [http://polar.ncep.noaa.gov/ofs/]. Findings from the connectivity model are provided in the Results section and further explanation of the methodology is found in Appendix 9.

Chapter 3. Survey Results

Terrestrial Results

West Plana Cay

A total of 8.5 hours was spent conducting groundtruthing transects and revealed 58 vascular plant species. The main habitats were Coastal (e.g., *Coccothrinax argentata* woodlands and *Uniola paniculata* herbland), Dry Broadleaf Evergreen Formation - Shrubland/Dwarf Shrubland (Mixed species Shrubland, (*Erithalis fruticosa* shrubland, and *Strumpfia maritima* dwarf shrubland) and Wetlands (*Laguncularia racemosa* Shrubland, *Rhizophora mangle* Shrubland, and *Batis/Sporobolus/Salicornia* herbland)

There were no invasive plants on the island but there were goats, chickens, and at least one dog. Based on the good condition of the vegetation, the goats are likely a relatively recent introduction. Over all diversity was good and would be likely higher given more survey time. The coastline vegetation and structure was intact but not very suitable for sea turtle nesting because the sand dunes are very steep, except for a few locations on the western and eastern sides of the island. There are blueholes that show connection to the sea. A wetland on the southern side had a group of 7 flamingos (4 adults and 3 juveniles). The island is frequented by fishermen and cascarilla barkers.

East Plana Cay

Over 18 hours of transect survey time were conducted on East Plana Cay and 44 vascular plant species were observed. Habitats were mainly Coastal (*Ambrosia hispida* herbland), Rocky shore (*Coccothrinax argentata* woodlands), DBEF (Shrubland (mixed species), Dwarf Shrubland (*Strumpfia maritima* or *Croton/Foresteria* or *Phyllanthus epiphyllanthus* dominated) and Wetland (*Avicennia germinans* Shrubland and *Batis maritima* herbland).

The only endemic Bahamian land mammal, the hutia, was documented and populations are believed to be doing well. There are no invasive plants and no other non-native animals. The vegetation was intact but diversity was lower than comparable islands. Habitats were homogenous. Habitats were the same as reported by Clough and Fulk (1971) but more species were observed in this survey. This difference may be due more to the surveyors in the late 1960's not being trained botanists or widely familiar with the species of the Bahamas rather than changes in the flora of the island. No shoreline was good for sea turtle nesting as there was no dune with low slope toward ocean, but instead consisted of exposed rock along the water's edge. There are several blue holes many connected to the ocean, one had shrimp in it. A wetland on the northern edge had a single flamingo in it.

Samana Cay

A total of 17 hours of transect time was conducted and 116 vascular plant species were observed. Primary habitats included Coastal (*Uniola paniculata* herbland), Rocky Shore, DBEF (Open pavement: exposed flat limestone, typically high in cacti and Forest/Shrubland (mixed species), and Wetlands (*Conocarpus erectus* Shrubland/Woodland, *Laguncularia racemosa* shrublands). Vegetation was in great condition and there were no invasive plants. The shoreline has great beaches for sea turtle nesting. People live on island collecting cascarilla bark. There was at least one large cave with a significant bat population, and possibly a second cave.

Additional information and photos of habitat types are found in Appendix 4.

Coral reef results

The coral reef dive research team surveyed 23 reefs during 8 days (February 20-27, 2013) (Figures 8-12), of which 21 were fore reefs and 2 were patch reefs. Rough weather prevented the survey of shallow, exposed reefs. The scientists assessed reef structure, benthic composition and cover, coral population structure and condition, and fish composition, size structure and biomass.

Samana and Plana Cays

The Samana and Plana Cays are small, fairly isolated islands in the south-eastern Bahamas with narrow shelves and high exposure to north Atlantic seas. Coral growth has flourished over time around these islands and dominates the overall benthic habitat assemblages. It is suspected that the islands were once larger than they are today and have experienced differential erosion from waves as sea level rose and flooded these banks some 6000-8000 years ago. A “ridge” some 0.5-1km from today’s present shoreline is thought to be a relict shoreline. When present, this ridge serves as a solid substrate for coral growth (crustose corraline algae, *Millepora*, and some *Acropora palmata* and *A. cervicornis)* and provides some protection from the Atlantic swells. The southern and western sides of the islands now appear to be prograding (building) outwards by the reworking and redistribution of sand. The narrow inner lagoons located shoreward of the “ridge” are primarily composed of shifting sand which is not yet stabilized enough to allow seagrasses and mangroves to be established. As a result, there is very limited nursery habitat present on the smaller islands (Plana, Samana Cays).

A unique type of coral reef habitat was found on the north sides of both Samana and East Plana Cays, these were termed “relict *Acropora* forests”. These habitats consisted of massive coral “trees” and are thought to be thousands of years old with trunks 2-6 m in diameter at their base, and extending up to 10 m towards the surface with live *Millepora* or *Acropora* capping about half of them. Thousands of these “trees” were found along the north central and western coasts of the cays (Figure 25). These coral formations are thought to arise from a combination of factors, including the east-west facing aspect of the islands and the narrow shelf which combine to produce a wave “shadow” along the northern coast which protects the coral structures from direct wave impacts. Figures 25-28 show images of the elkhorn coral “trees”.

Steep drop-offs characterize the southern and western sides of all three islands. Sand with occasional patch reefs dominates these coasts with a narrow coral “lip” 10-30m in width that suddenly plunges as a wall to great depths. The condition of corals along these drop-offs was generally good to excellent with high coral cover in many places and with abundant large colonies of the fairly rare *Dendrogyra cylindrus* and *Eusimilia fastigiata*. Low macroalgal growth and fairly high herbivore biomass also characterize these reefs. Northern and eastern shelves around the cays have gradual slopes with extensive rubble fields and no steep coral walls. Coral cover was lower and macroalgal abundance (particularly *Turbinaria* and *Dictyota*) was higher. An aggregation of Bermuda chub were found along East Plana, possibly for spawning.

Overall benthic habitat complexity around these islands was low to moderate. Dense seagrass areas (*Thalassia* and *Syringodium*) were only found around the south-central section of Samana Cay and was virtually absent from the Plana Cays. Mangrove forests were only found in land-locked coastal salt ponds. The relatively exposed nature of the shelves of these islands and the abundant sand (thought to be coming from erosion of both the island and surrounding reefs) contributes to lower habitat complexity.

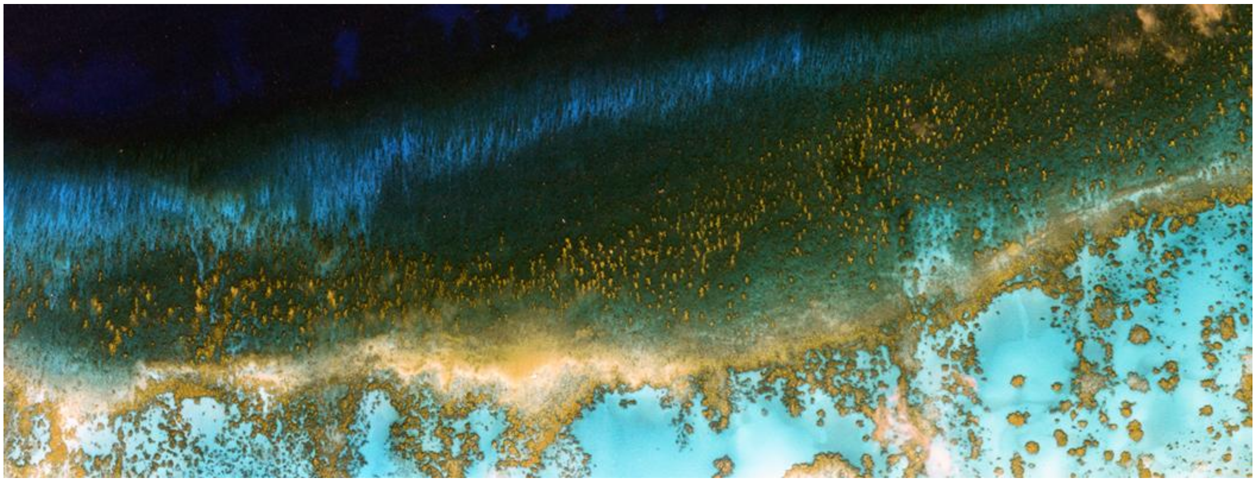


Figure 25. Worldview-2 satellite image subset showing a large area of dense relict *Acropora* forest on the north side of Samana Cay.

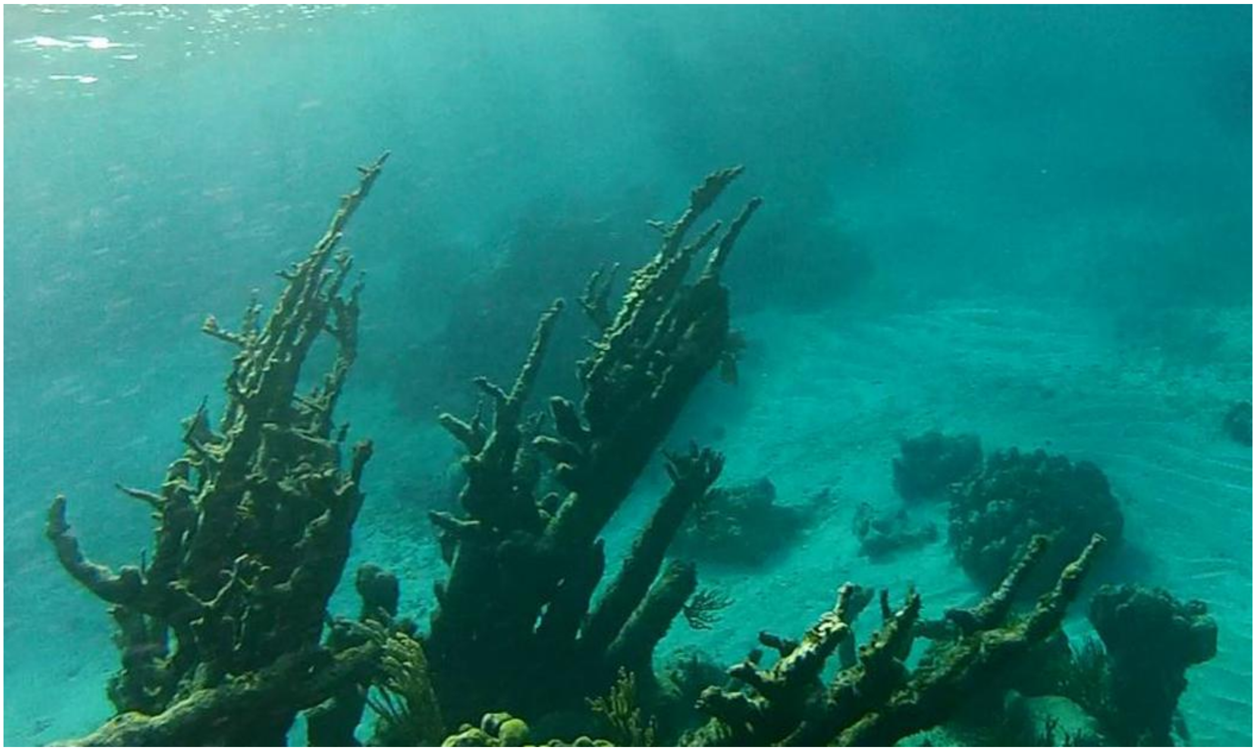


Figure 26. Photograph of *Acropora palmata* from Samana Cay (photo – S.Schill).

Figure 27. *Acropora palmata* colonies, living and dead, on south side of Samana Cay.

Figure 28. *Acropora* colonies along Samana Cay (photo – S.Schill).

Mayaguana

Mapping efforts focused on the southern, western and northwestern sides of Mayaguana since only two survey days were available. A wide variety of reef and benthic habitat types were found associated with their location, wave exposure and proximity to a bay or land promontory. Abraham's Bay, a large bay along the south coast, had calm waters and extensive meadows of short, sparse seagrass (mainly *Thalassia*). Seaward of Abraham's Bay, there was a gentle sloping, low relief spur and groove with mostly small-sized corals and carpets of net algae. Just west of Abraham's bay along the south coast of Dean's Bay was an extensive fore reef with numerous large healthy platy *Montastraea* corals cascading down a steep wall higher coral cover and fish diversity. Mayaguana's western edge contained semi-low relief spur and groove reefs covered with numerous corals, gorgonians and sponges. North of Betsy Bay at the NW promontory, tall (~40 ft high) finger-like spur and groove reefs occurred with smaller-sized corals and numerous gorgonians and sponges likely due to the strong currents and high wave energy common here. Shoreward were sparse seagrass and sand. The north coast had very high wave energy and lower fore reef development. Near Little Bay on the north, site M4 was a shallow (15 ft) spur and groove reef of old relict *Acropora palmata*, with the tops of spurs covered by bare crustose coralline algae and small-sized corals (mostly *Porites*, *Agaricia*, and more *Millepora* than other survey islands). Pillar coral was quite common and *Diadema* were found.

Unlike the Samana and Plana Cays, this area had a higher diversity and abundance of fish, especially commercially important species like Nassau grouper and snappers. Several Nassau groupers were observed in spawning colors, indicating that there was probably a spawning aggregation site nearby. In addition, several large Caribbean reef sharks and barracuda were seen. Many conchs and lobster were also observed. Large areas of seagrass and tidal creeks around Mayaguana provide nursery habitat for juveniles and may be the reason for increased schooling fish, lobster and conch. Another possible factor is that Mayaguana is an inhabited island with a significant population and infrastructure. Illegal foreign fishermen may avoid populated areas like Mayaguana where they may be observed and reported to the authorities.

Acklins and Crooked Island

The two survey locations on Acklins were selected because they were predicted to be possible spawning aggregation sites. Spur and groove reefs had large sand channels dissecting them. Several standing dead *A. palmata* were found with many new living colonies of *A. palmata* crusts recolonizing the dead areas. Pillar coral was observed in moderate abundance. A highlight from the survey included one spur with several large standing dead *A. palmata* colonies that hosted numerous large schools of fish such as grunts, parrotfishes, and squirrelfish, suggesting the relict coral forests are important as they provide habitat and shelter for fish and other biota. Gravid female Nassau groupers (~60 cm in size) and numerous other Nassau and tiger groupers and several large barracudas were seen. This should be a good site to revisit during the peak grouper spawning aggregation time. Similar to Mayaguana, there were numerous Caribbean reef and nurse sharks present. This area has an extensive network of tidal creeks and nursery areas comprised of seagrasses and mangroves.

The Crooked Island survey site was a unique reef structure not previously observed in the survey area. It consisted of an isolated large round "'mount" rising >10m high surrounded by barren sand areas with sparse seagrass. The reef shape created an oasis effect attracting hundreds of schooling fish. Fish abundance was quite high and dense schools of grunts and parrotfishes swarmed the reef. Small corals and abundant gorgonians and sponges covered the mount surface. Numerous crevices were filled with many spiny lobster. Groupers and snappers were seen around the reef base in deeper waters and several sharks and one sea turtle were observed.

Site	Date	Latitude	Longitude	Zone	Depth	# Benthic Transects	# Coral Transects	# Fish Transects
Acklins/Crooked Island (A1)	02/27/13	22.70538	-73.81745	FORE	15.0	4	2	10
Acklins/Crooked Island (A2)	02/27/13	22.74920	-73.86005	FORE	12.0	4	2	10
Acklins/Crooked Island (C1)	02/27/13	22.75370	-74.05579	FORE	15.6	4	2	9
Mayaguana (M1)	02/26/13	22.47680	-73.13799	FORE	15.1	4	2	10
Mayaguana (M2)	02/25/13	22.37172	-73.17038	FORE	15.2	4	2	10
Mayaguana (M3)	02/25/13	22.35870	-73.10405	FORE	16.3	4	2	9
Mayaguana (M4)	02/26/13	22.43622	-73.00340	FORE	7.1	4	2	6
Mayaguana (M6)	02/25/13	22.33405	-73.00025	FORE	16.4	4	2	9
E. Plana Cay (EP1)	02/23/13	22.62012	-73.53858	FORE	8.6	4	2	10
E. Plana Cay (EP2)	02/24/13	22.57360	-73.46725	FORE	14.4	4	2	10
E. Plana Cay (EP3)	02/24/13	22.58460	-73.46868	PATCH	2.7	4	2	10
E. Plana Cay (EP4)	02/24/13	22.61133	-73.56403	FORE	8.5	4	2	10
W. Plana Cay (DP)	02/20/13	22.62370	-73.63078	FORE	13.7	3	2	8
W. Plana Cay (WP1)	02/20/13	22.62370	-73.62452	FORE	10.6	4	2	6
W. Plana Cay (WP2)	02/20/13	22.61757	-73.61423	PATCH	1.9	3	2	9
W. Plana Cay (WP6)	02/23/13	22.57335	-73.60500	FORE	14.7	4	2	10
W. Plana Cay (WP7)	02/23/13	22.58293	-73.63245	FORE	18.5	3	2	8
Samana Cay (S1)	02/21/13	23.05857	-73.75800	FORE	6.6	4	2	12
Samana Cay (S10)	02/22/13	23.10675	-73.77261	FORE	8.7	4	2	10
Samana Cay (S2)	02/21/13	23.07128	-73.78478	FORE	12.7	4	2	12
Samana Cay (S3)	02/21/13	23.08940	-73.82238	FORE	11.9	4	2	11
Samana Cay (S6)	02/22/13	23.07783	-73.64955	FORE	8.8	4	2	10
Samana Cay (S8)	02/22/13	23.09980	-73.67068	FORE	8.5	4	2	10

Table 1. Location of 23 sites surveyed in Southeastern Bahamas using SCUBA.

Benthic composition

Reef Substrate Relief

Reef relief averaged 74 cm in height for all reefs combined (Figure 29). Sites EP4 (173), Site S10 (151 cm), and S8 (128 cm) had the highest average reef relief. Maximum heights ranged from 50 cm (Site M6) to 1000 cm (Site S3), with an average maximum height of 381 cm. By island, reefs had higher average reef relief on Samana Cay (106 cm) and East Plana Cay (94 cm). When maximum relief was examined, Acklins & Crooked Islands (550 cm max) and Samana Cay (512 cm) had highest maximum reef relief.

Benthic cover

Cover of reef constructors, including live coral cover (LCC), crustose coralline algae (CCA), and newly dead coral (NDC) is shown for each site as a series of stacked bars (Figure 30). Live coral cover averaged 12%, with a range of 5 to 38%. Crustose coralline algae averaged 7%, ranging from 1 to 31%. Eight of the 23 sites had higher than average crustose coralline algae (e.g., 31% at M4) and was higher on Mayaguana and Acklins & Crooked Islands. Similarly, cover of reef competitors is shown in figure 30 (bottom), including aggressive invertebrates (AINV), cyanobacteria (CYA), calcareous macroalgae (CMA) and macroalgal mix (MA). The percent of reef covered by aggressive invertebrates (0.3%), cyanobacteria (0.7%), calcareous macroalgae (5%), and macroalgal mix (0.1%) was low. Turf algae (TA) were prevalent on many of the reef sites, averaging 31%, with range of 3 to 63% cover. Reef constructors on all reefs combined averaged 20%, reef competitors was 34%, and turf algae 31%. Only four of the 23 sites had a greater proportion of constructors versus competitors (Sites M4, EP2, DP, and S3.).

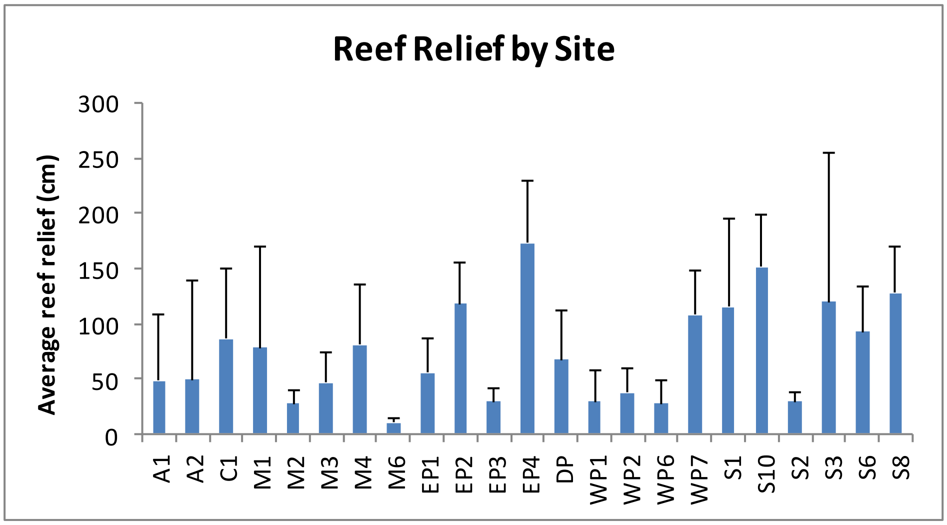
Fleshy macroalgae were more prevalent than cyanobacteria and aggressive invertebrates on all reef types. Fleshy macroalgae ranged from 5 to 53%, with an average of 29%. Cyanobacteria and aggressive invertebrates were low on all reefs. Other encrusting and erect sessile invertebrates (OINV) occupied an average of 4% of the reef bottom (range of 0.3 to 11%), with 10 of the 23 sites having higher than average OINV. OINV were more abundant on Mayaguana and Acklins & Crooked Island.

Live Coral Cover

Live coral cover averaged 12%, with a range of 5 to 38% (Figure 31). Sites with higher than average coral cover were EP2, EP4, WP7, S1, S2, S3, and S6. Live coral cover was higher on East Plana and Samana Cays (all sites averaged by island).

Coral Recruitment

The number of coral recruits averaged 2 recruits per m^2, with a range of 0 to 7 recruits/m^2 (Figure 32), Two sites (A2, WP1) had no recruits observed in transects, while 9 of the 23 sites had higher than average recruits. By island, West Plana had the highest recruits, while very few were observed on Acklins & Crooked Island. Only 7 species of coral recruits <2 cm in size and 15 coral species of large recruits (size 2-4 cm) were observed. *Porites astreoides* and *Agaricia* (*Undaria) agaricites* were the most common recruit seen (Table 2).



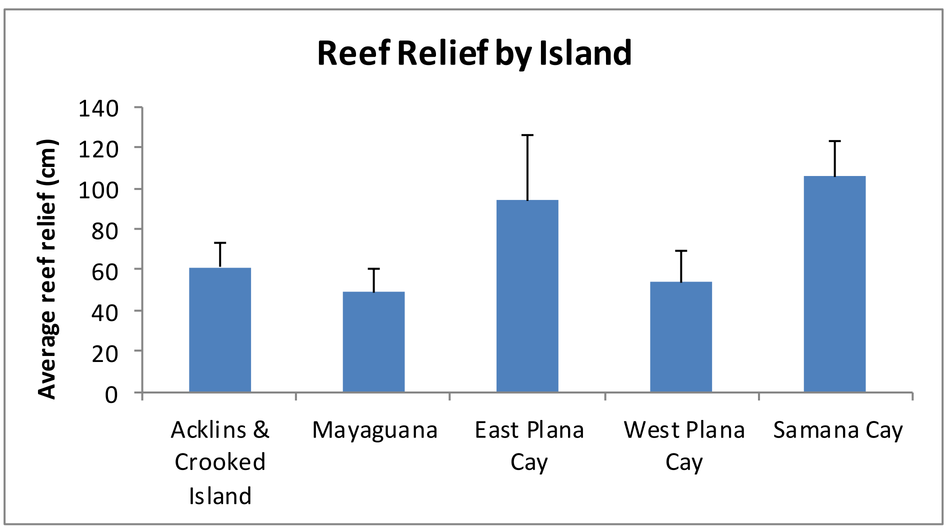


Figure 29. Mean reef relief (and standard error) by site (top) and island (data pooled by island).

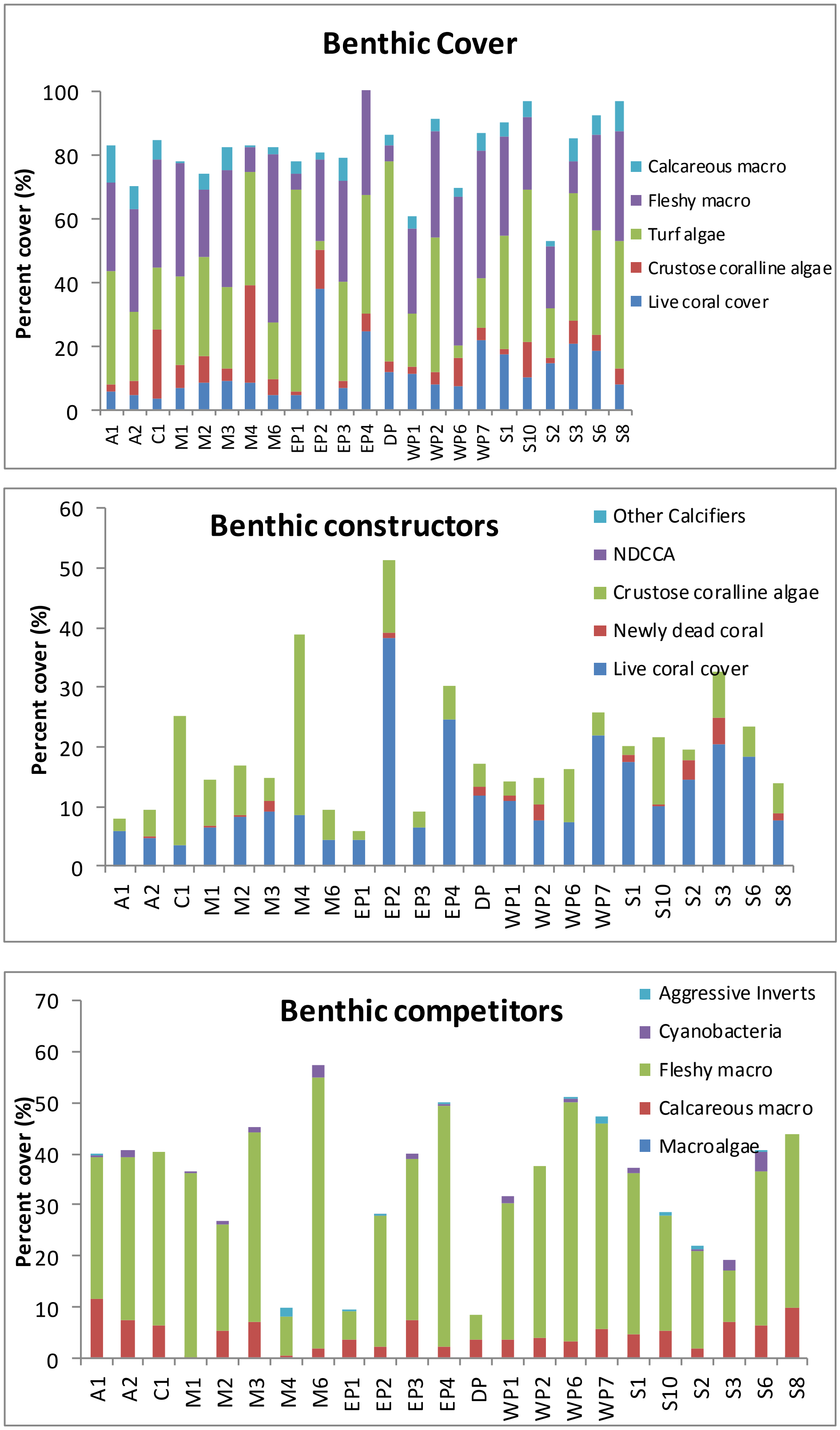
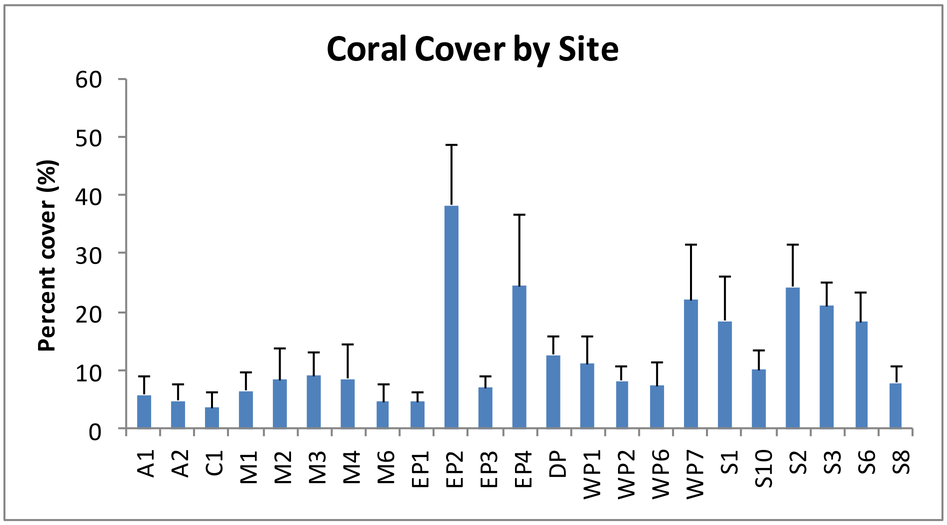


Figure 30. Benthic cover (top), benthic constructors (middle), and benthic competitors (bottom).



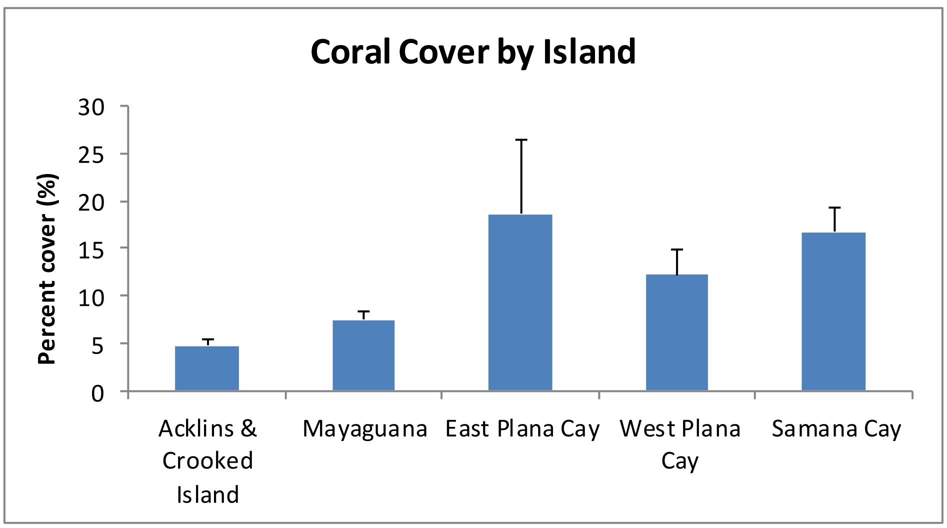
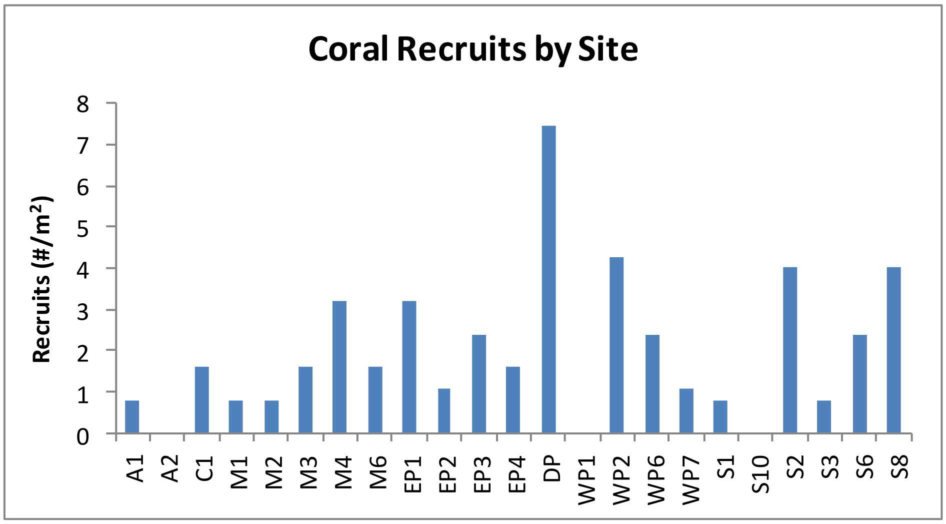


Figure 31. Mean live coral cover (+se) by site and by island.

Species	NR	%	#/m2
Porites astreoides	24	47.06%	0.89
Undaria agaricites	11	21.57%	0.41
Siderastrea siderea	4	7.84%	0.15
Unknown species	4	7.84%	0.15
Favia fragum	3	5.88%	0.11
Porites porites	2	3.92%	0.07
Eusmilia fastigiata	1	1.96%	0.04
Porites sp.	1	1.96%	0.04
Siderastrea radians	1	1.96%	0.04

Species	NR	%	#/m2
Undaria agaricites	63	36.21%	2.34
Porites astreoides	43	24.71%	1.60
Porites porites	23	13.22%	0.86
Siderastrea siderea	20	11.49%	0.74
Favia fragum	3	1.72%	0.11
Manicina areolata	3	1.72%	0.11
Dichocoenia stokesii	2	1.15%	0.07
Diploria labyrinthiformis	2	1.15%	0.07
Eusmilia fastigiata	2	1.15%	0.07
Madracis auretenra	2	1.15%	0.07
Madracis decactis	2	1.15%	0.07
Montastraea cavernosa	2	1.15%	0.07
Orbicella annularis	2	1.15%	0.07
Unknown species	2	1.15%	0.07
Agaricia sp.	1	0.57%	0.04
Meandrina meandrites	1	0.57%	0.04
Siderastrea radians	1	0.57%	0.04

Table 2. Abundance (NR) of small coral recruits (<2 cm) (top) and larger coral recruits (2-4 cm) (bottom).



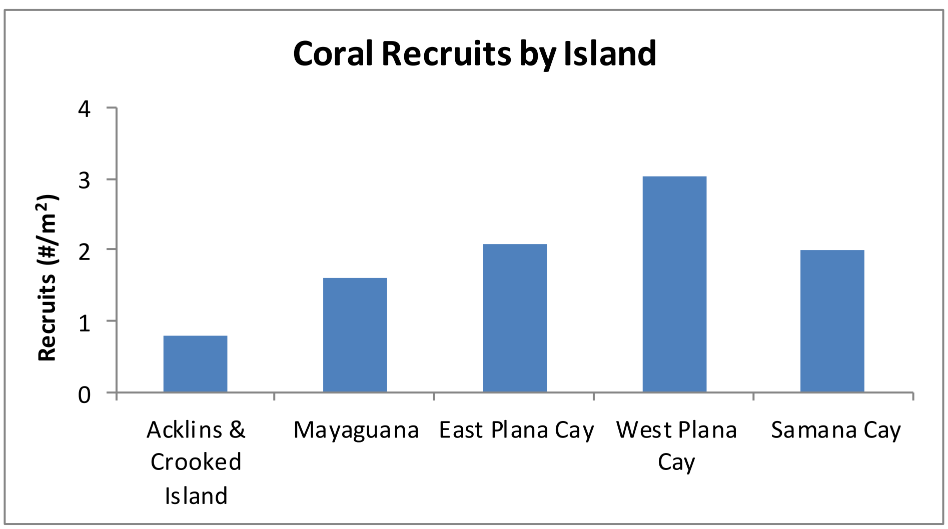


Figure 32. Mean abundance of small corals <2cm in size (+se) by site (top) and island (bottom).

Coral Communities

A total of 1,651 corals that were 4 cm or larger in diameter were assessed along belt transects (1,653 total, but 2 were <4cm). Survey transects contained 38 scleractinian coral species (two were) hydrozoan corals (Table 3). The most predominate coral species included *Agaricia (Undaria) agaricites* (19%), *Porites astreoides* (17%), *Montastraea annularis* and *M. faveolata* (12%), and *Siderastrea siderea* (11%) (Figure 33). Coral density averaged 4 coral colonies per m^2, with a range of 2 to 5 colonies per m^2 (Figure 33). Coral density was lowest at site S8 (2.1 corals/m^2) and C1 (2.8 corals/m^2) and highest at EP4 (5.4 corals/m^2) and WP7 (5.3 corals/m^2). Coral density was similar among the islands. An exception was Acklins and Crooked Island, which had lower number of corals per meter.

Coral size

Corals ranged in size from 3 to 300 cm in diameter, with an average of 22 cm (Figure 34). Coral heights ranged from 1 to 220 cm in height, with an average of 13 cm. Largest diameter corals included *Acropora palmata* (86 cm average size), *Colpophyllia natans* (79 cm), *Dendrogyra cylindrus (*49 cm), and *Montastraea* species (40-46 cm). These species also had the tallest heights. *Acropora palmata* had the widest coral (300 cm) and *Montastraea faveolata* had the tallest coral observed in belt transects. One colony of *Dendrogyra cylindrus* outside of a belt transect was >300 cm in height.

Coral mortality

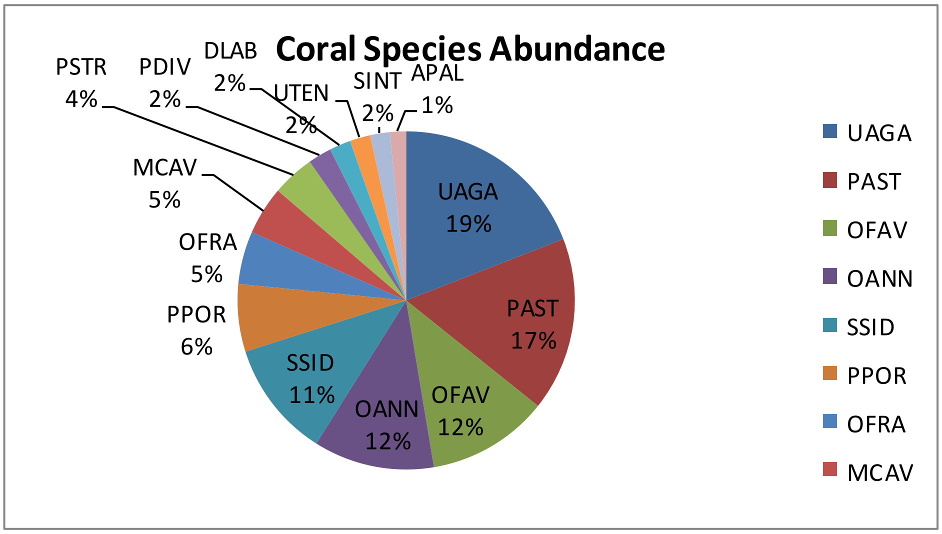
Recent coral mortality (occurring within the last 5 days) was very low (1% average all sites combined), but ranged from 0 to 6% (S2) at individual sites (Figure 35). Among islands, Samana Cay had slightly higher recent mortality than the other islands. Old mortality occurring more than (one month prior to surveys) averaged 19%, ranging from 11 to 29%. Samana Cay had slightly higher old mortality than the other islands (all sites combined by island). Of the 1,651 corals, only 99 individual corals or 6% of the total coral population were standing dead (100% coral mortality but still in 'growth' form. Standing dead ranged from 0 to 14 % of the population. Mayaguana (8% of all corals), East Plana (7%), and Samana (6%) had slightly higher levels of standing dead corals than Acklins & Crooked Island and West Plana. *Acropora palmata* had the greatest number of standing dead colonies (60% of colonies surveyed); although this is expected as this species retains its 'signature' of standing longer than other species. Other species with standing dead colonies were *C. natans*, *Montastraea* species, and *P. porites*. *Montastraea franksi*, *D. labrynthiformis*, *A. palmata*, *M. annularis*, and *S. siderea* had recent mortality 1-3%. *Montastraea* species and *D. labrynthiformis* had old mortality between 20-29%.

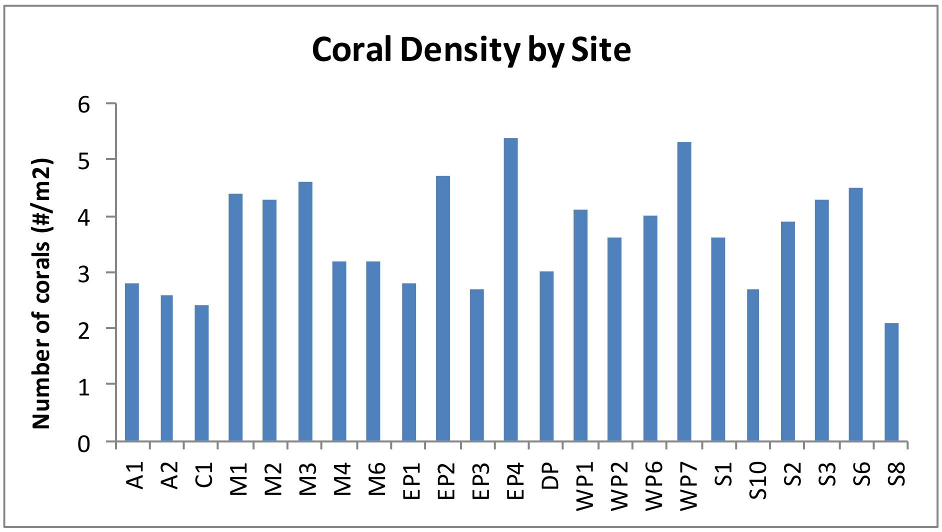
Coral bleaching and disease

None of the corals had signs of bleached tissue, which is not unexpected since surveys were conducted in the cooler winter months of February. Only one coral had a potential disease, dark spot disease, at site S1.

Species	Abbr	N
Undaria agaricites	UAGA	272
Porites astreoides	PAST	237
Orbicella faveolata	OFAV	166
Orbicella annularis	OANN	165
Siderastrea siderea	SSID	159
Porites porites	PPOR	92
Orbicella franksi	OFRA	72
Montastraea cavernosa	MCAV	66
Pseudodiploria strigosa	PSTR	58
Porites divaricata	PDIV	32
Diploria labyrinthiformis	DLAB	29
Undaria tenuifolia	UTEN	28
Stephanocoenia intersepta	SINT	27
Unknown species	UNKN	27
Acropora palmata	APAL	22
Eusmilia fastigiata	EFAS	20
Madracis auretenra (mirabilis)	MAUR	20
Millepora complanata	MCOM	19
Meandrina meandrites	MMEA	18
Madracis decactis	MDEC	15
Millepora alcicornis	MALC	14
Favia fragum	FFRA	13
Colpophyllia natans	CNAT	9
Dichocoenia stokesii	DSTO	9
Dendrogyra cylindrus	DCYL	8
Undaria humilis	UHUM	8
Siderastrea radians	SRAD	7
Acropora cervicornis	ACER	6
Helioseris cucullata	HCUC	5
Pseudodiploria clivosa	PCLI	5
Meandrina jacksoni	MJAC	4
Mycetophyllia ferox	MFER	4
Isophyllia rigida	IRIG	3
Mussa angulosa	MANG	3
Manicina areolata	MARE	2
Mycetophyllia aliciae	MALI	2
Mycetophyllia sp.	MYCE	2
Scolymia sp.	SCOL	2
Meandrina sp.	MEAN	1
Mycetophyllia lamarckiana	MLAM	1
Solenastrea bournoni	SBOU	1
Total # corals		1653

Table 3. Abundance of coral species observed (all sites pooled).





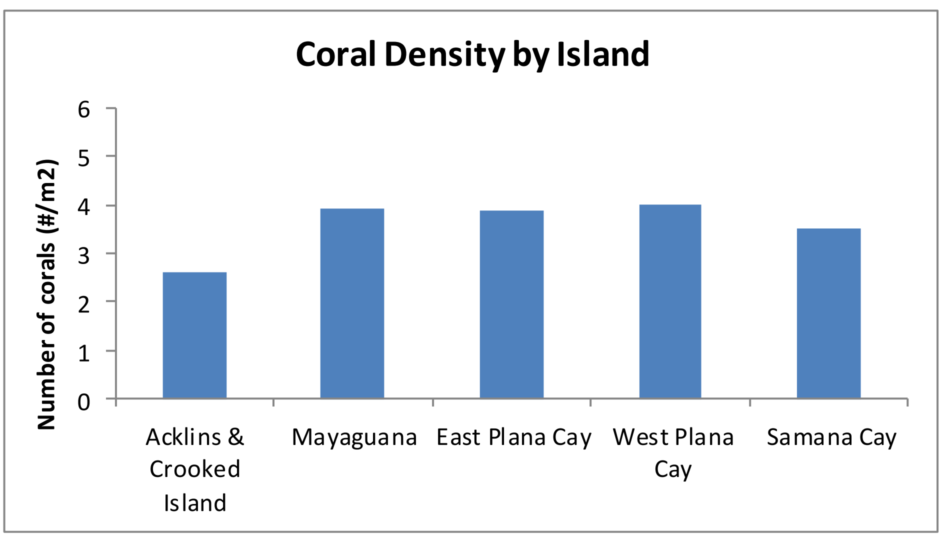
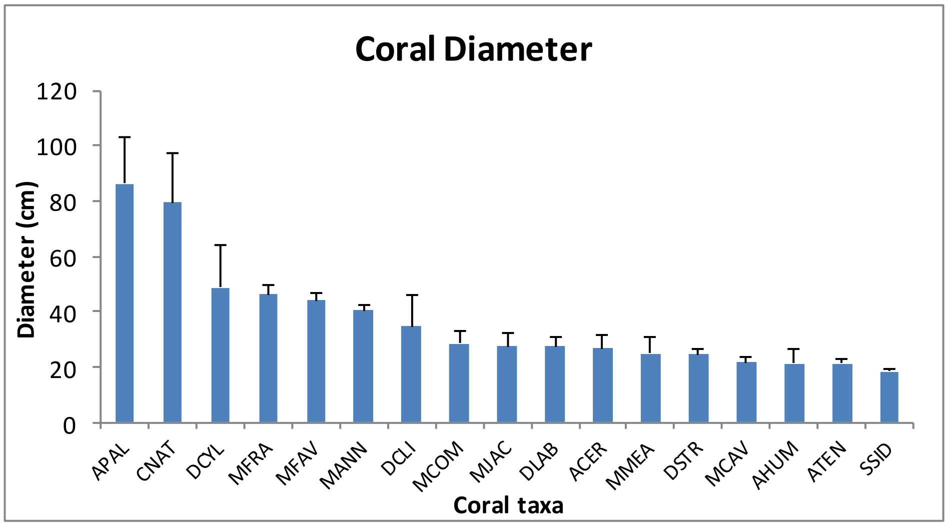


Figure 33. Abundance of reef building coral species observed along belt transects for all sites combined (top), by site (middle), and by island (bottom).



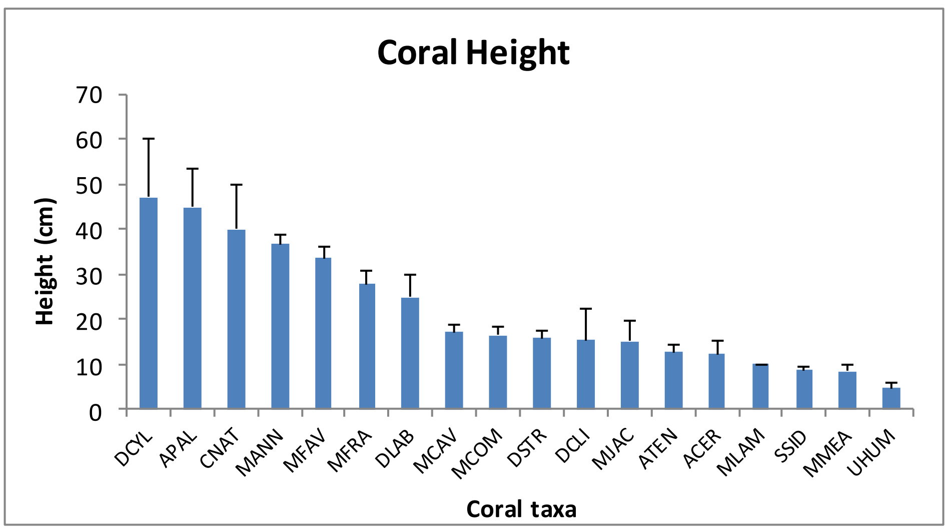
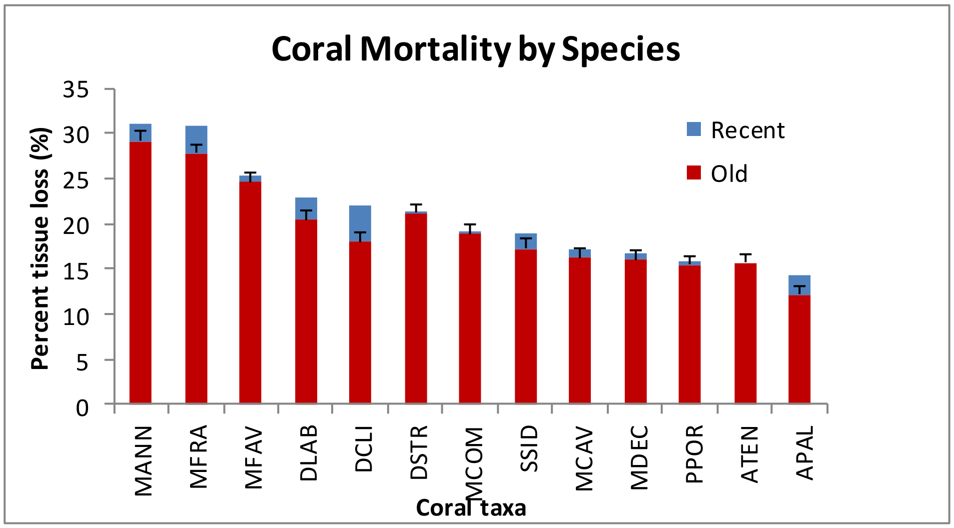
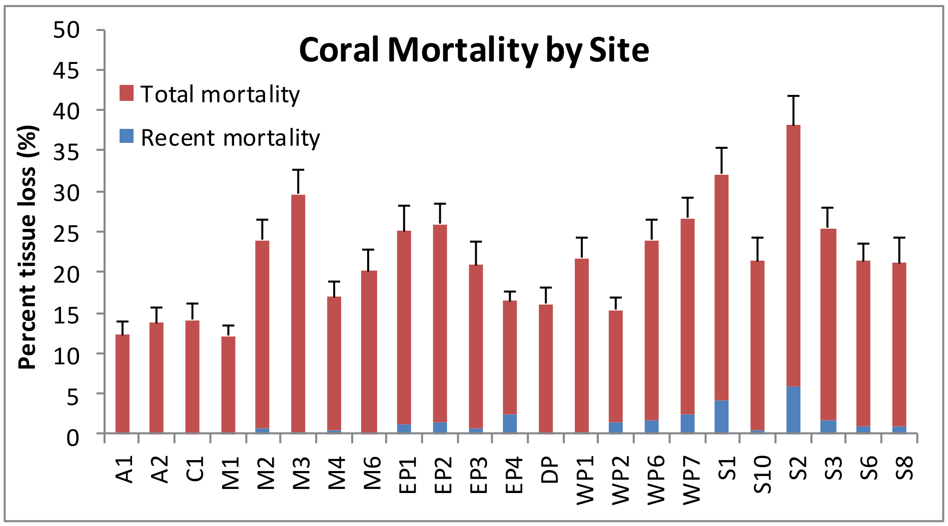


Figure 34. Mean diameter (top) and mean height (+se) for coral species, listed from largest to smallest.





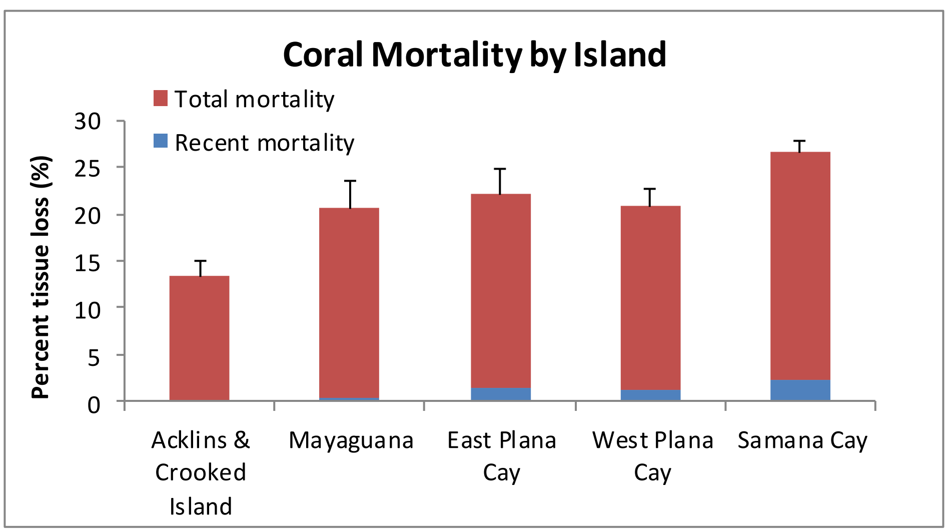


Figure 35. Mean (+se) amount of partial mortality observed on live corals by species (top), by site (middle) and island (bottom).

Algae
Fleshy macroalgae ranged from 5 to 53%, with an average of 29% (Figure 36). Fleshy macroalgae was similar among the four islands, although slightly lower on the east/west lying islands of East Plana and Samana Cay. The predominant macroalgae was green net algae, *Microdictyon*, although most of this was observed decaying due to natural winter seasonal decay. Several of the sites had very little macroalgae, due in part to high wave or currents. Although macroalgae was the dominant organisms covering many sites, crustose coralline alga underlying macroalgae was also a dominant component. The herbivorous sea urchin, *Diadema antillarum*, was not abundant and only found along belt transects at 9 of the 24 survey sites (with none on patch reefs). At sites where it was observed, *Diadema* abundance was very low (0.25-0.33 individuals/10m^2).

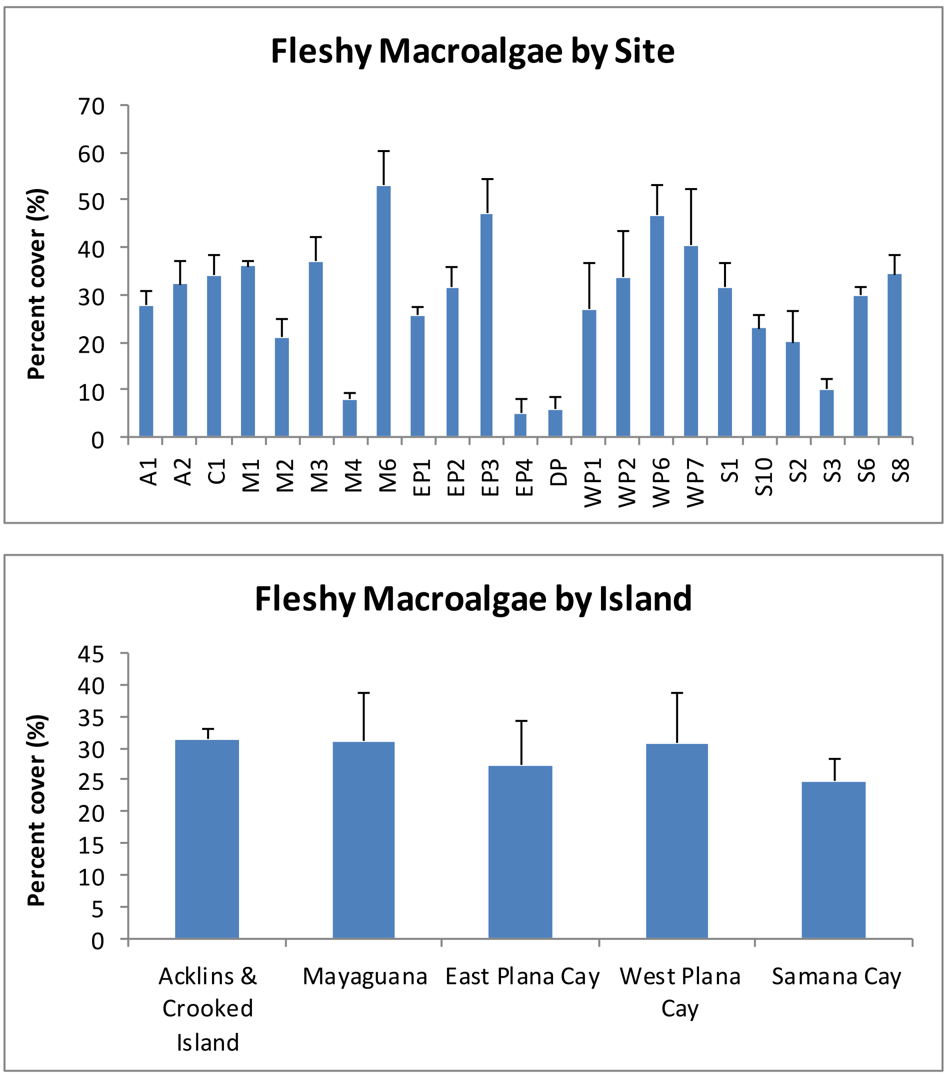


Figure 36. Benthic cover of fleshy macroalgae by site (top) and by island (bottom).

Fish Communities

There were 53 species of fish in 17 functional groups observed along belt transects (Figure 37). A total of 4,784 individual fish were identified within all transects and assessed for density, size structure and biomass. The most abundant fish groups were parrotfishes (26% of fish counted), wrasses (20%), grunts (16%), surgeonfishes (15%), and seabasses (7%). Yellowhead wrasses were the most abundant species observed (18% of all fish observed), followed by French grunt (11%), blue tang (8%), and princess parrotfish (7%). A list of all species observed in belt transects is shown in Table 4 and commercially significant fish in Table 5.

Fish Size

Figure 38 shows the size distribution of the more common species, grouped into four functional groups (seabass, snapper, grunt and parrotfish), shown as the percent of the total number of fish of that functional group. The majority of fish in these functional groups were small in size, with most (42%) occurring in the 6-10 cm size class or 11-20 cm size class (34%).

Average seabass size varied slightly among the islands ranging from 9 cm average total length in Acklins & Crooked Islands to 14 cm in West Plana Cay. Only 6% of the seabass population was greater than 21 cm in length, compared to seabass observed in other areas of the Bahamas which had 65% of seabass population greater than 21 cm. Only 5 of the 346 seabass observed were greater than 40 cm in total length. Snapper were only observed at 11 of the 23 sites and were notably absent from West Plana Cay (only 1 of 5 sites had snapper present in belt transects), Samana (only 2 of 5 sites had snapper present), and Mayaguana (1 of 4 sites had snapper present). Snapper were larger in size, with 34% of population in the 11-20 cm size class and 21% in the 31-40 cm size class, although few snapper were seen. Snapper size varied among the islands, with an average of 18 cm in length (range 8 to 36 cm). Compared among the islands, snappers were smaller on Mayaguana (11.8 cm), Samana (12 cm in length), and West Plana (16 cm average length). Slightly larger snappers were observed on East Plana (25 cm average) and Acklins & Crooked (18 cm). Parrotfish average size was 11 cm and was similar among sites (range 7 to 15 cm) and islands (range 11-12 cm).

Total fish biomass

Total fish biomass was very low averaging 1,536 g/100m^2 (Figure 39). Total fish biomass was highest on Acklins and Crooked Island (2,808 g/100m^2). Only one site on Crooked Island had significantly higher biomass (C2).

Herbivorous Fishes

Twelve species of parrotfish were observed in belt transects, with the most abundant being princess, stoplight, striped and redband. Herbivorous fish biomass averaged 883 g/100m^2, varying by site (Figure 40). When data were pooled by island, East Plana (1,260 g/100m^2) and Samana Cay (1,054 g/100m^2) had higher herbivore fish biomass.

Commercial Fishes

Very few (only 13 species) commercially significant fish species were observed along belt transects, compared to the list of commonly seen commercial species (at least 29 species) (Fig 41). Only 6 species of seabass were assessed with coney being the most common. Other seabass species included grasby, black, Nassau, red hind, and tiger. Schoolmaster was the the most common snapper species and a few mahogany snappers were observed. Only 2 mutton and 2 yellowtail snappers were observed. Commercially significant fish biomass was low (460 g/100m^2 average all sites pooled) at all but one site, C1, which had significantly higher biomass (5,212 g/100m^2) (Figure 41).

Lionfish
Lionfish abundance was low, only 8 fish total were observed and were found at only 3 sites (M3, DP, S1) (Figure 42). The few lionfishes observed were fairly small in size with four of the fish being 6-10 cm in size and four in the 11-20 cm size class.

Reef Surveys
A total of 95 fish species were observed during the REEF roving diver fish surveys (Appendix 5). Mayaguana had the highest number of species observed although additional surveys and more bottom time are needed to fully characterize fish diversity and identify differences among reef types and islands. Some fish species were noticeably absent such as several grunts (no porkfish, smallmouth, Spanish), parrotfish (no blue, rainbow or redtail), and groupers (no black, yellowfin, yellowmouth).

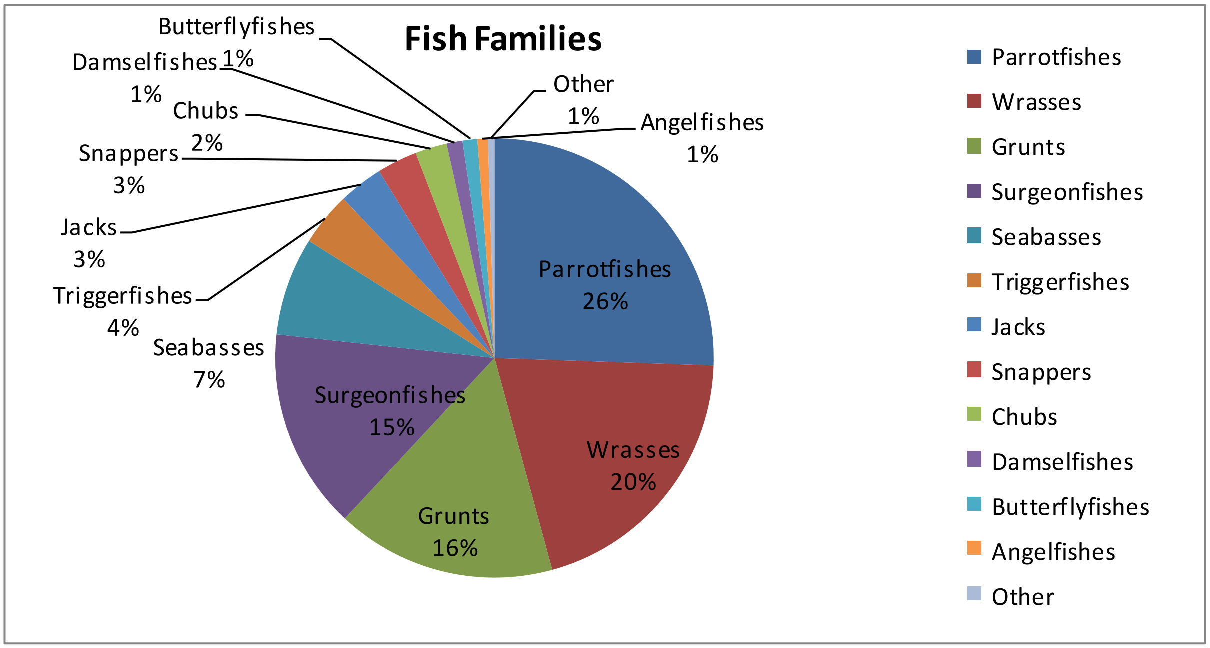
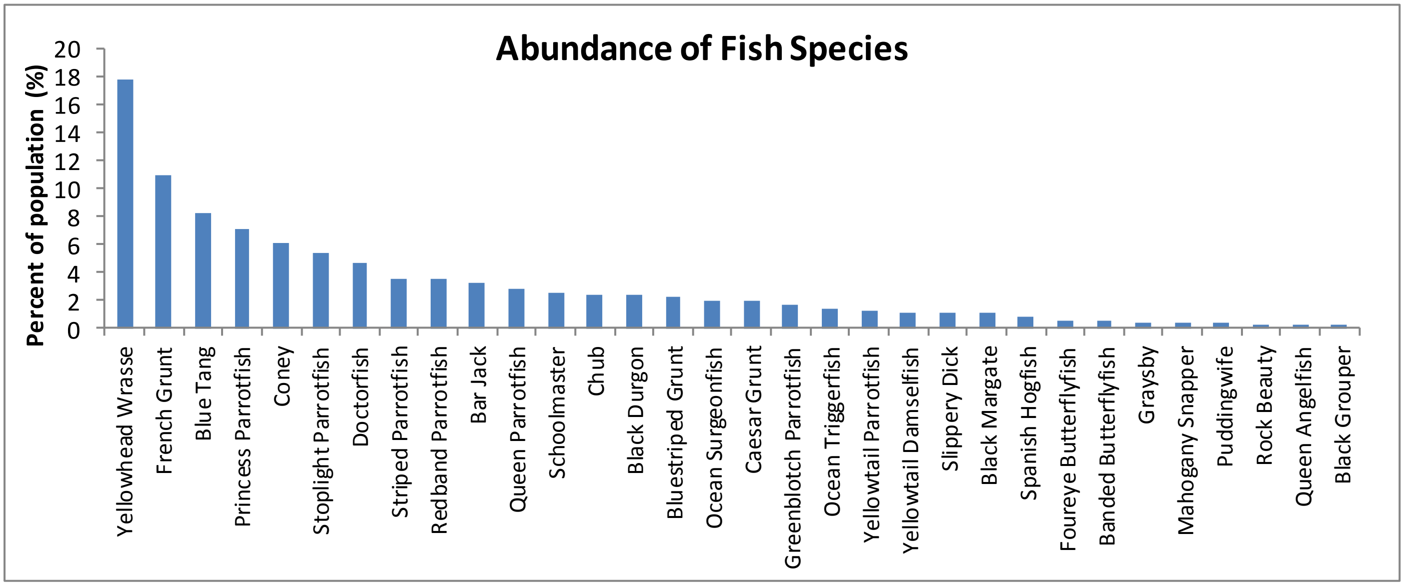


Figure 37. Abundance of fishes counted along belt transects, listed by family (all sites pooled).



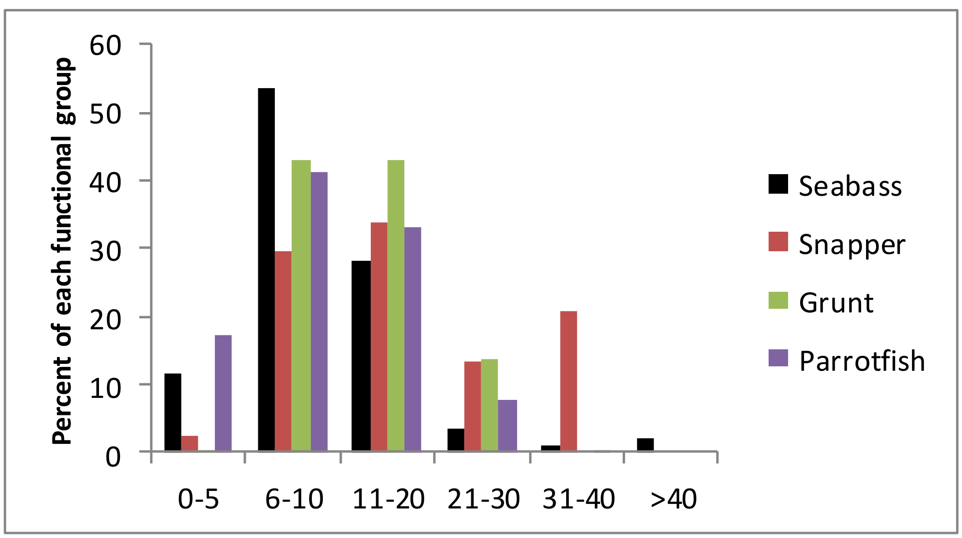


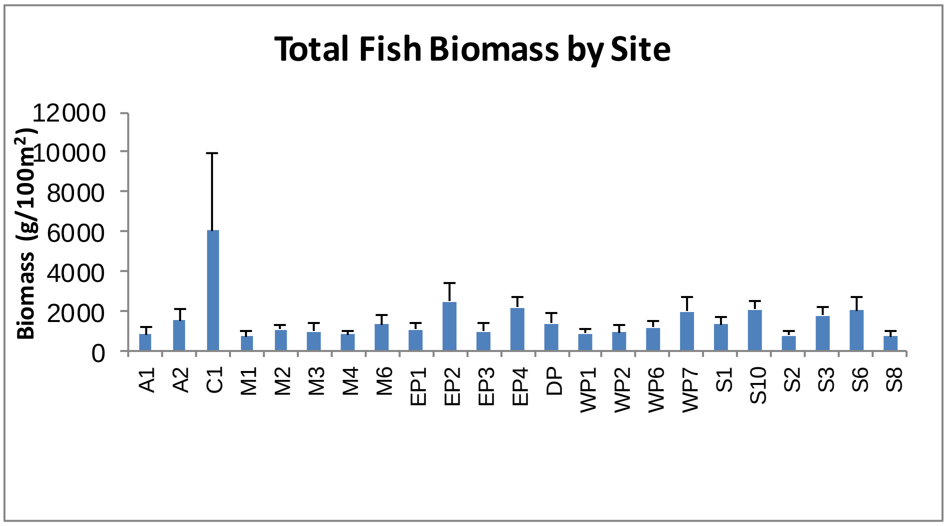
Figure 38.Total abundance of the dominant fish species, presented as percent of the population (top) and size structure of the dominant functional groups in each size group (bottom).

Total Number of Fish by Family		
Common	**Scientific**	**# of fish**
Angelfishes		**37**
Queen Angelfish	*Holacanthus ciliaris*	13
Rock Beauty	*Holacanthus tricolor*	15
Gray Angelfish	*Pomacanthus arcuatus*	7
French Angelfish	*Pomacanthus paru*	2
Barracudas		**8**
Great Barracuda	*Sphyraena barracuda*	8
Boxfishes		**1**
Spotted Trunkfish	*Lactophrys bicaudalis*	1
Butterflyfishes		**52**
Foureye Butterflyfish	*Chaetodon capistratus*	24
Spotfin Butterflyfish	*Chaetodon ocellatus*	4
Banded Butterflyfish	*Chaetodon striatus*	24
Chubs		**112**
Chub	*Kyphosus* spp.	112
Damselfishes		**56**
Yellow tail Damselfish	*Microspathodon chrysurus*	56
Filefishes		**5**
Whitespotted Filefish	*Cantherhines macrocerus*	5
Grunts		**775**
Black Margate	*Anisotremus surinamensis*	50
Caesar Grunt	*Haemulon carbonarium*	92
French Grunt	*Haemulon flavolineatum*	522
Cottonw ick	*Haemulon melanurum*	3
White Grunt	*Haemulon plumierii*	4
Bluestriped Grunt	*Haemulon sciurus*	104
Jacks		**157**
Bar Jack	*Caranx ruber*	157
Parrotfishes		**1222**
Juvenile Parrotfish	*Scarus / Sparisoma*	2
Midnight Parrotfish	*Scarus coelestinus*	2
Blue Parrotfish	*Scarus coeruleus*	1
Rainbow Parrotfish	*Scarus guacamaia*	1
Striped Parrotfish	*Scarus iseri*	172
Princess Parrotfish	*Scarus taeniopterus*	337
Queen Parrotfish	*Scarus vetula*	132
Greenblotch Parrotfish	*Sparisoma atomarium*	82
Redband Parrotfish	*Sparisoma aurofrenatum*	167
Redtail Parrotfish	*Sparisoma chrysopterum*	11
Yellow tail Parrotfish	*Sparisoma rubripinne*	58
Stoplight Parrotfish	*Sparisoma viride*	257
Porgies		**1**
Jolthead Porgy	*Calamus bajonado*	1
Scorpionfishes		**8**
Lionfish	*Pterois* spp.	8
Seabasses		**346**
Graysby	*Cephalopholis cruentata*	18
Coney	*Cephalopholis fulva*	291
Red Hind	*Epinephelus guttatus*	8
Nassau Grouper	*Epinephelus striatus*	10
Black Grouper	*Mycteroperca bonaci*	13
Tiger Grouper	*Mycteroperca tigris*	6
Snappers		**142**
Mutton Snapper	*Lutjanus analis*	2
Schoolmaster	*Lutjanus apodus*	120
Mahogany Snapper	*Lutjanus mahogoni*	18
Yellow tail Snapper	*Ocyurus chrysurus*	2
Surgeonfishes		**706**
Doctorfish	*Acanthurus chirurgus*	222
Blue Tang	*Acanthurus coeruleus*	391
Ocean Surgeonfish	*Acanthurus tractus*	93
Triggerfishes		**189**
Queen Triggerfish	*Balistes vetula*	12
Ocean Triggerfish	*Canthidermis sufflamen*	66
Black Durgon	*Melichthys niger*	111
Wrasses		**967**
Spanish Hogfish	*Bodianus rufus*	39
Slippery Dick	*Halichoeres bivittatus*	52
Yellow head Wrasse	*Halichoeres garnoti*	855
Puddingw ife	*Halichoeres radiatus*	18
Hogfish	*Lachnolaimus maximus*	3

Table 4. Total number of fish observed along belt transects.

Fish species considered commercially significant	
Black Margate	*Anisotremus surinamensis*
Pluma	*Calamus pennatula*
Ocean Triggerfish	*Canthidermis sufflamen*
Bar Jack	*Caranx ruber*
Coney	*Cephalopholis fulva*
Bluelip Parrotfish	*Cryptotomus roseus*
Rock Hind	*Epinephelus adscensionis*
Red Hind	*Epinephelus guttatus*
Dusky Grouper	*Epinephelus marginatus*
Red Grouper	*Epinephelus morio*
Nassau Grouper	*Epinephelus striatus*
White Margate	*Haemulon album*
French Grunt	*Haemulon flavolineatum*
Mutton Snapper	*Lutjanus analis*
Schoolmaster	*Lutjanus apodus*
Blackfin Snapper	*Lutjanus buccanella*
Cubera Snapper	*Lutjanus cyanopterus*
Gray Snapper	*Lutjanus griseus*
Dog Snapper	*Lutjanus jocu*
Mahogany Snapper	*Lutjanus mahogoni*
Lane Snapper	*Lutjanus synagris*
Black Grouper	*Mycteroperca bonaci*
Yellowmouth Grouper	*Mycteroperca interstitialis*
Gag	*Mycteroperca microlepis*
Scamp	*Mycteroperca phenax*
Tiger Grouper	*Mycteroperca tigris*
Yellowfin Grouper	*Mycteroperca venenosa*
Yellowtail Snapper	*Ocyurus chrysurus*
Permit	*Trichonotus falcatus*

Table 5. List of fish species considered commercially significant. Not all species were observed along belt transects.



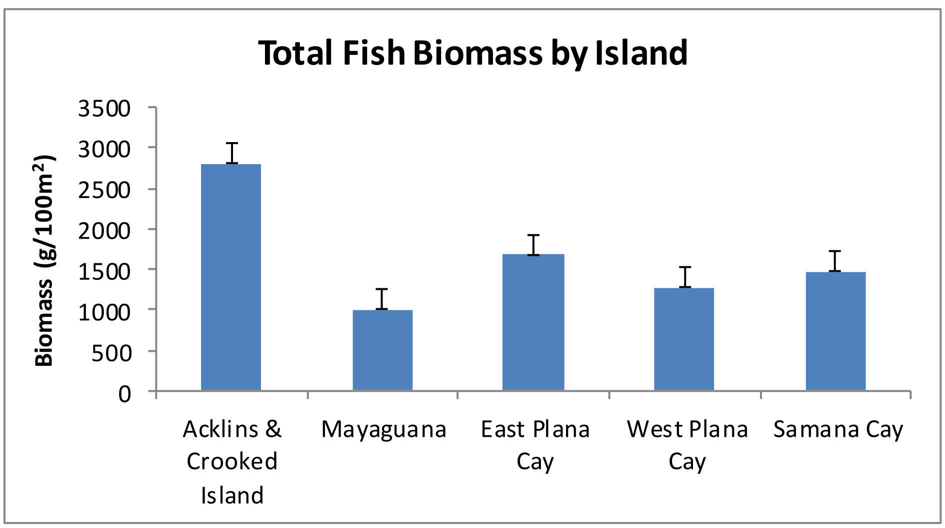
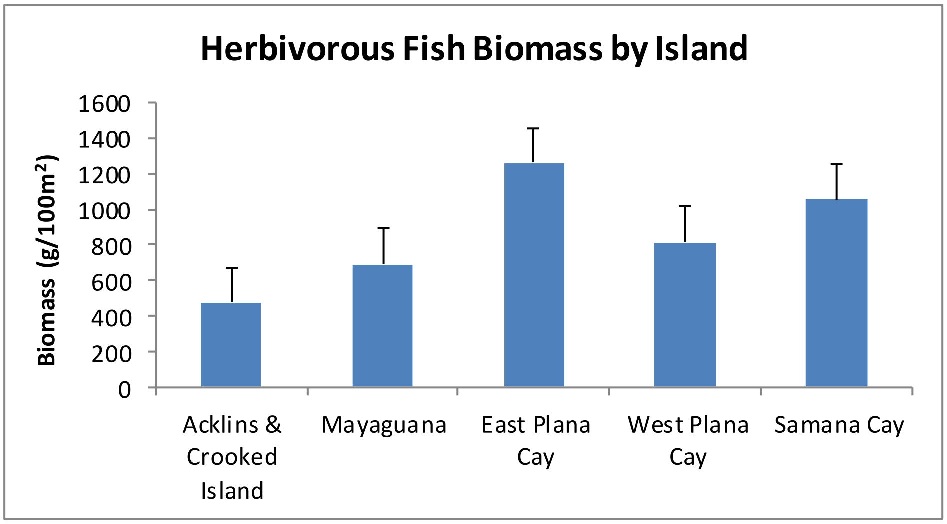


Figure 39. Mean total fish biomass (+se) by site (top) and by island (bottom).



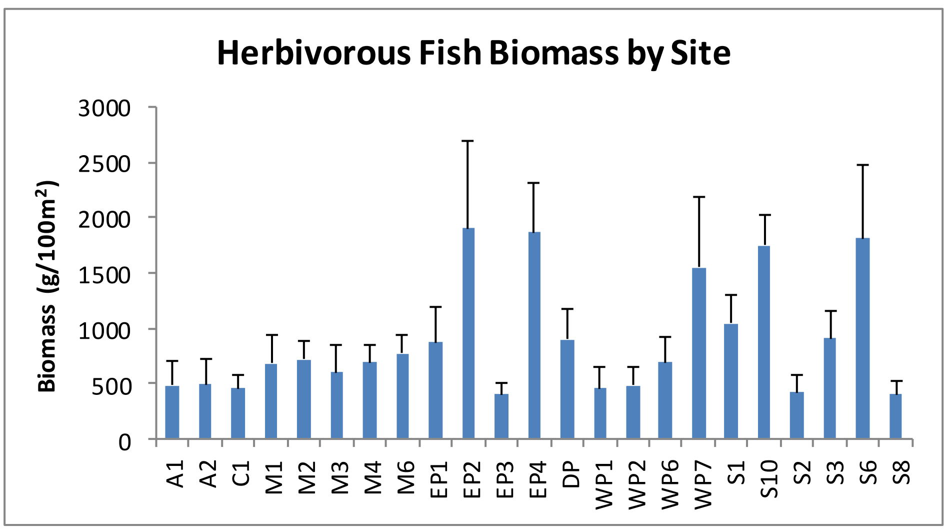
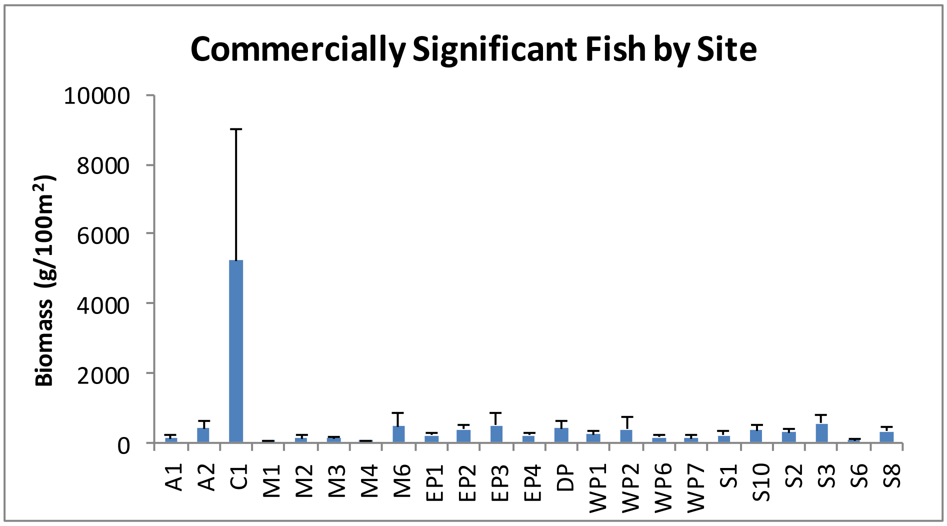


Figure 40. Mean herbivorous fish biomass (+se) by site (top) and by island (bottom).



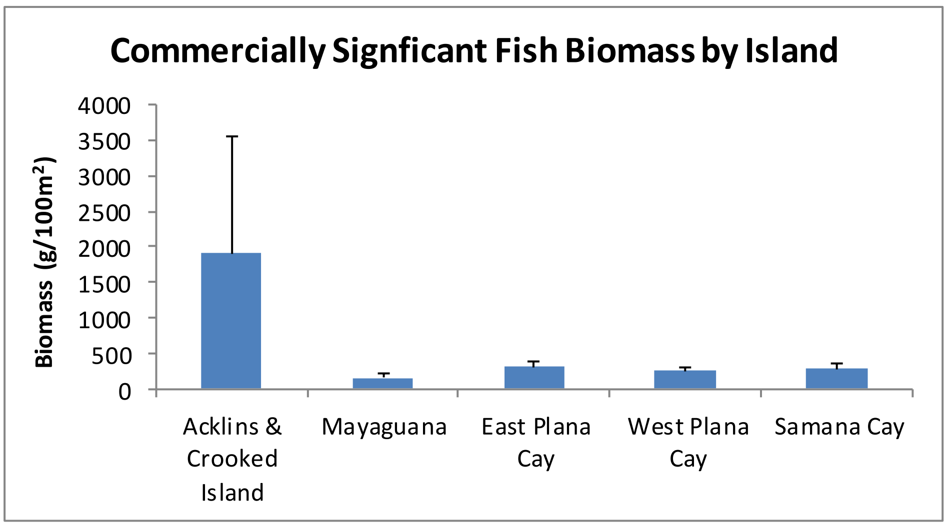
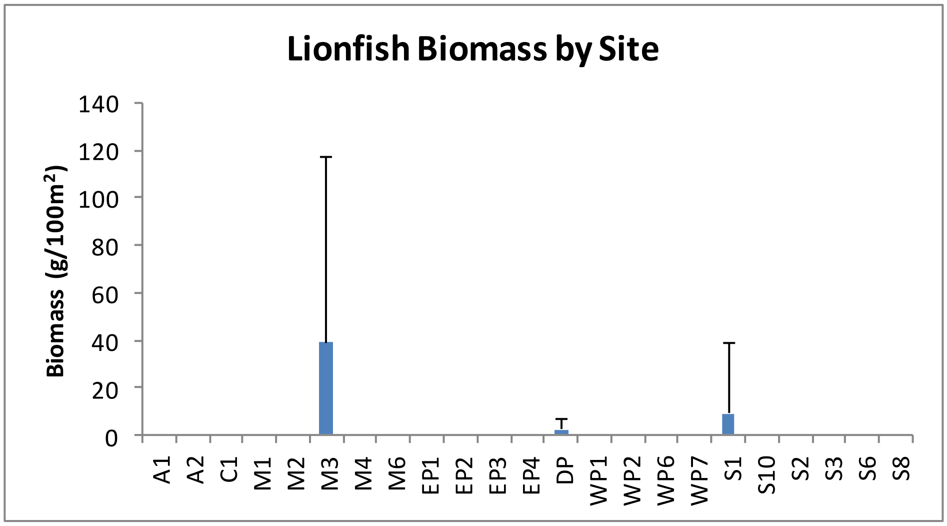


Figure 41. Mean biomass (+se) for commercially significant fish by site (top) and by island (bottom).



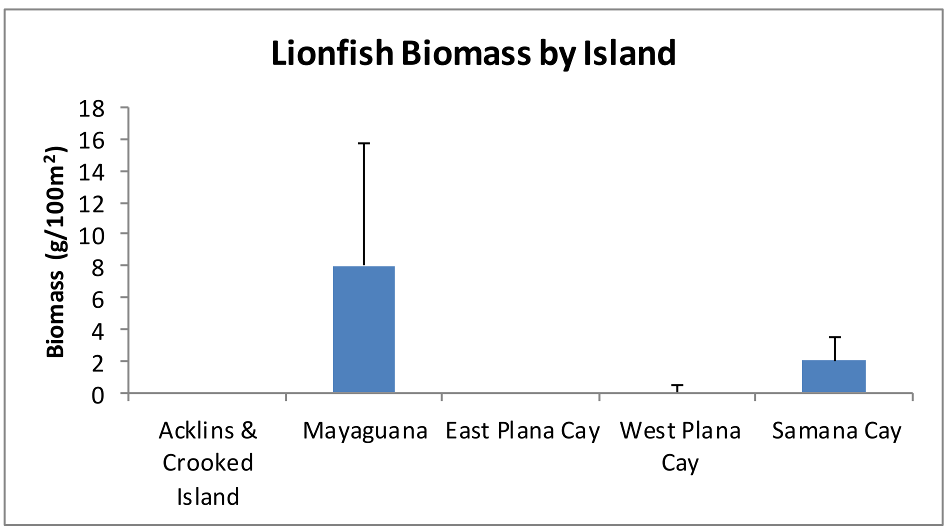


Figure 42. Mean biomass (+se) for lionfish by site (top) and by island (bottom).

Regional Comparisons

For regional comparisons, data from fore reefs in the S. Bahamas were compared (all sites pooled) to fore reef sites in the Central Bahamas and wider Caribbean (only fore reefs, all sites surveyed using same comparable method). Results are shown in the following figures. Fore reef data from other areas of the Central Bahamas included data from a) Living Oceans Foundation surveys conducted in 2012 (Cay Sal Bank, Inaguas, and Southern Andros), b) from Andros Island, Bahamas long term monitoring program conducted jointly by Perigee Environmental and AUTEC in 2011, and c) surveys conducted by Perry Institute at New Providence and Rose Island in 2011 and 2012. These data were selected because of the same methodology used and focused on comparing one habitat type - fore reefs. AGRRA-Caribbean data included data from a) LOF surveys in Colombia, Pedro Banks, Jamaica, and Navassa in 2012 and b) surveys conducted by Healthy Reefs for Healthy People in Mexico, Belize, and Honduras in 2012. Only fore reef data were analyzed. Other AGRRA data were available from numerous other sites in the Caribbean, but were not included because they were collected in earlier years (e.g., 1997 or 2009).

Live coral cover in S. Bahamas (12%) was higher than the Central Bahamian reefs (10%) and only slightly lower than AGRRA-Caribbean averages (14%) (Figure 43 top). Coral recruit abundance was lower in the S. Bahamas (2 recruits/10m2) than the Central Bahamas but similar to the AGRRA-Caribbean (Figure 43 middle). Recent mortality was low at all three regions (<1%), as expected as sea surface temperatures were not higher than normal (Figure 43 bottom). Old mortality was relatively low in all regions, and only slightly higher in S. Bahamas and Central Bahamas (19% each) compared to wider Caribbean (11%). Fleshy macroalgal abundance in S. Bahamas (27%) was similar to the AGRRA-Caribbean (26%) average and significantly lower than Central Bahamas (41%) (Figure 44 top).

Fish data comparisons included data from AGRRA surveys in Turks & Caicos (1999), Dominican Republic (2003, 2004) and Cuba (1999, 2001). S. Bahamas had significantly lower total fish biomass (1,593 g/100m^2) than Central Bahamas (12,548 g/100m2), Cuba (11,716 g/100m^2) and AGRRA-Caribbean (16,009 g/100m^2) and was more similar to total biomass of Turks & Caicos (2,661 g/100m^2) and Dominican Republic (1,496 g/100m^2) (Figure 45 top). Herbivorous fish biomass was lowest in S. Bahamas (925 g/100m^2) and Dominican Republic (1,202 g/100m^2) than the other areas (Figure 44 bottom). Herbivore biomass was greatest in Central Bahamas and AGRRA-Caribbean. Commercial fish biomass was lowest in the Dominican Republic (199 g/100m2) and S. Bahamas (463 g/100m^2) (Figure 45 middle). Cuba (7,380 g/100m^2) and Central Bahamas (5,478 g/100m^2) had the highest commercial fish biomass. Lionfish biomass was significantly lower in S. Bahamas (3 g/100m^2) compared to AGRRA-Caribbean (42 g/100m^2) and Central Bahamas (39 g/100m^2) (Figure 45 bottom). Data was not compared to Turks and Caicos, Dominican Republic and Cuba as the data available was collected before the lionfish invasion.

Spatial maps showing data for the survey area of four key indicators, including coral cover, fleshy macroalgae, herbivorous fish and commercially significant fish are shown in Figures 46-49.

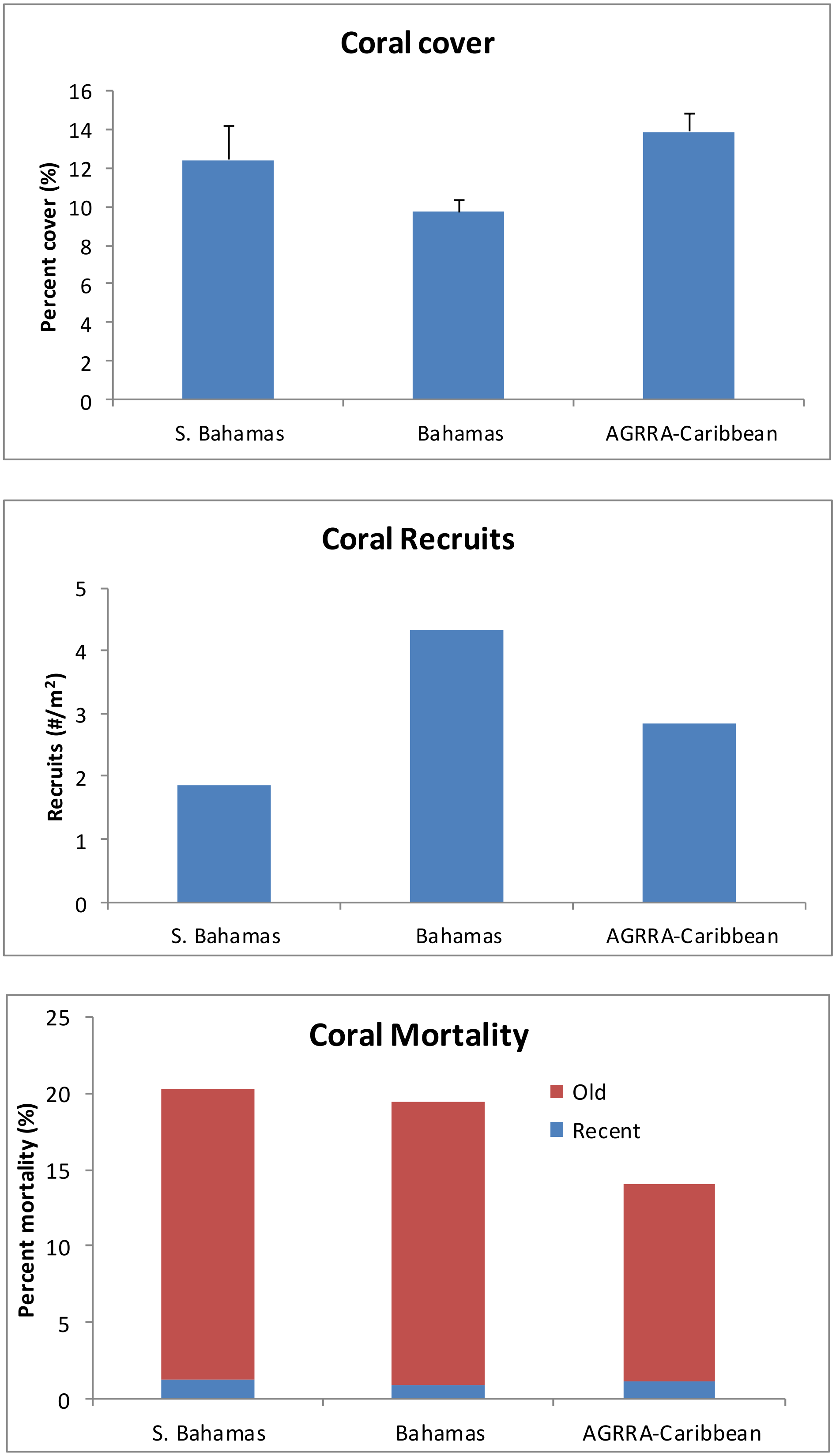
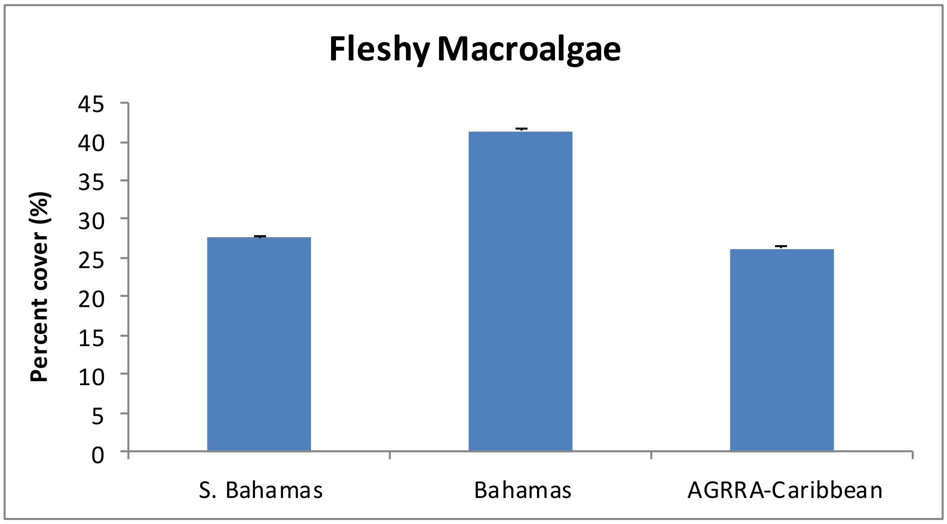


Figure 43. Regional comparison of mean living coral cover (+se) (top), coral recruits (<2cm) (middle) and amount of partial coral mortality (bottom) for fore reefs sites only.



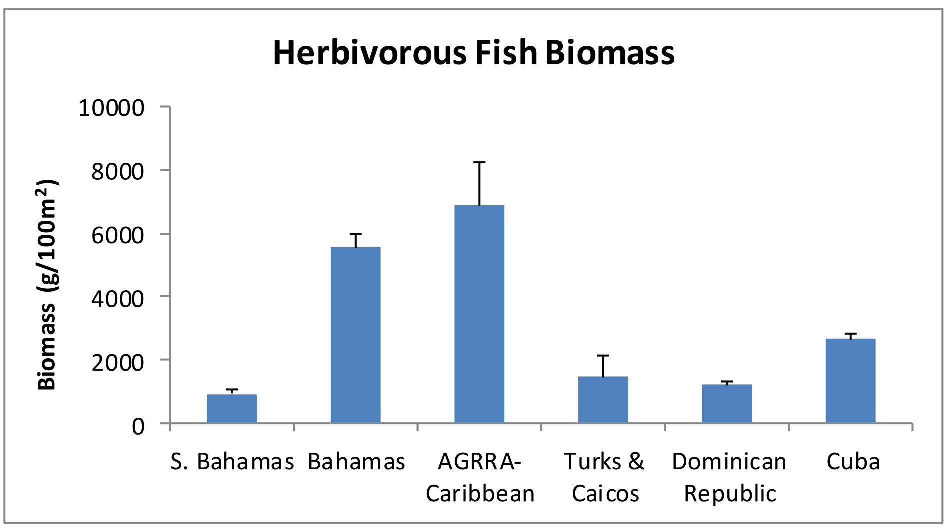


Figure 44. Regional comparison of mean (+se) fleshy macroalgae (top) and herbivorous fish biomass (bottom) for fore reefs sites only.

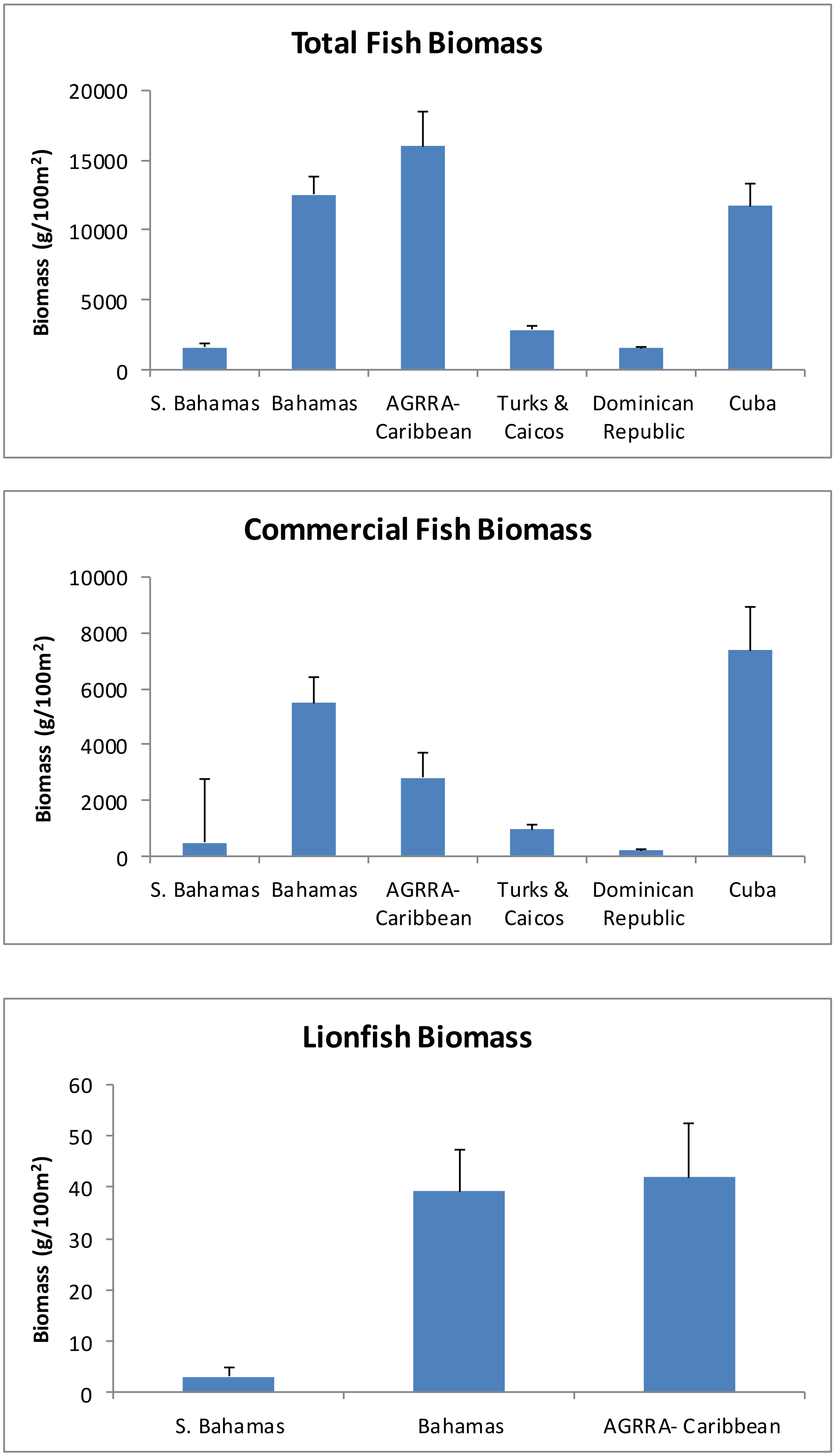


Figure 45. Regional comparison of mean (+se) total fish (top), commercial fish (middle) and lionfish biomass (bottom) for fore reefs only.

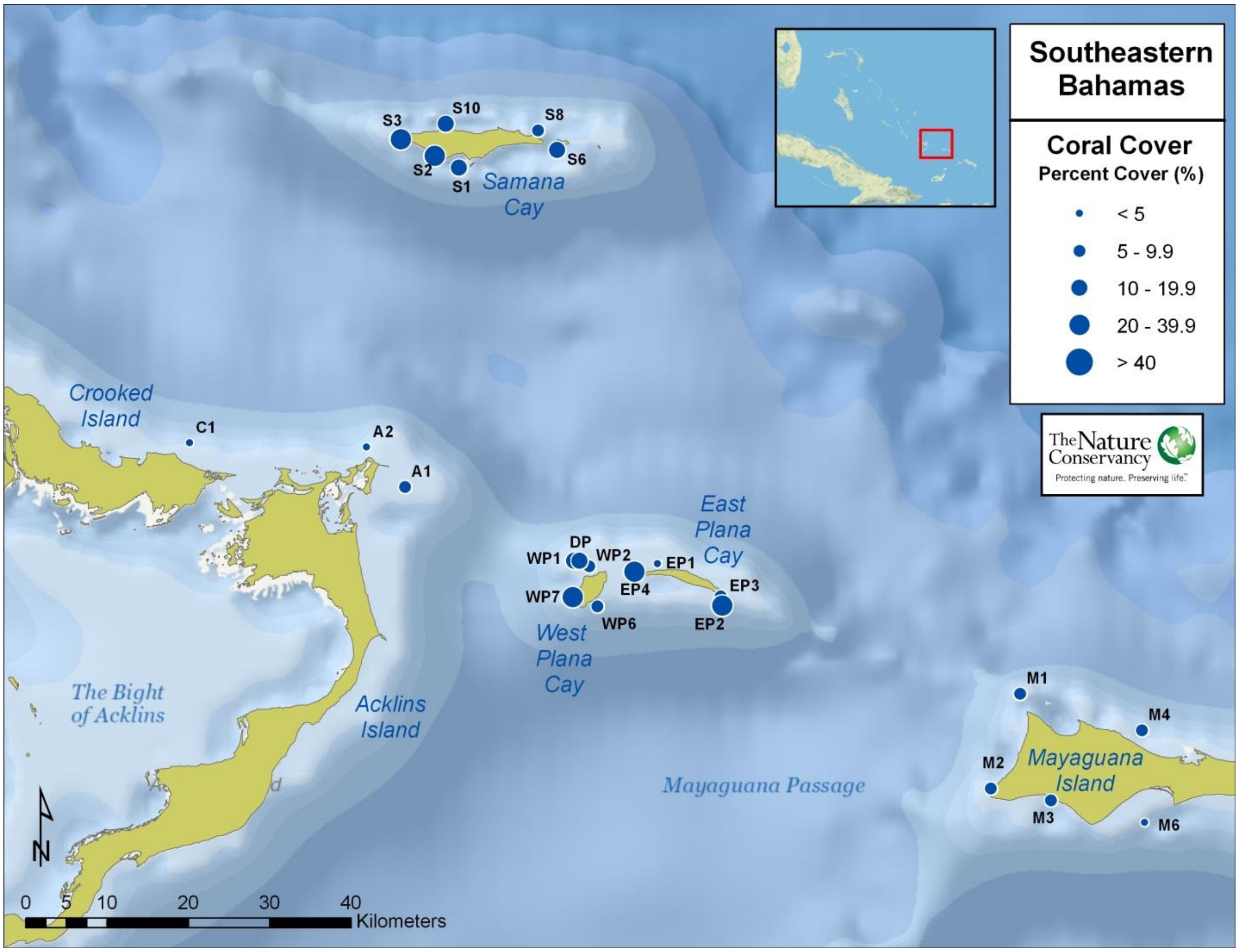


Figure 46. Map of percent living coral cover at survey sites in Southeastern Bahamas.

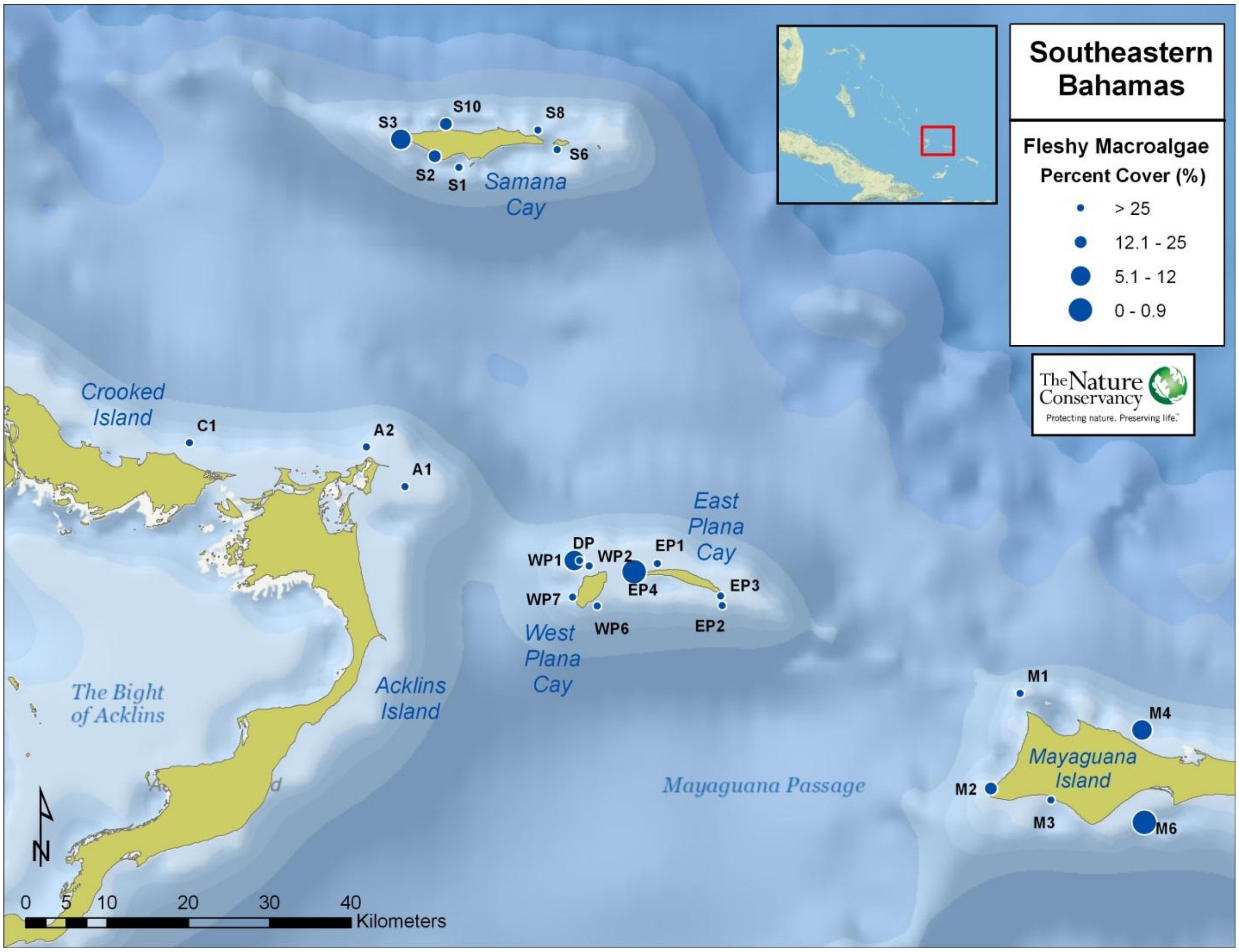


Figure 47. Map of fleshy macroalgal cover at survey sites in Southeastern Bahamas.

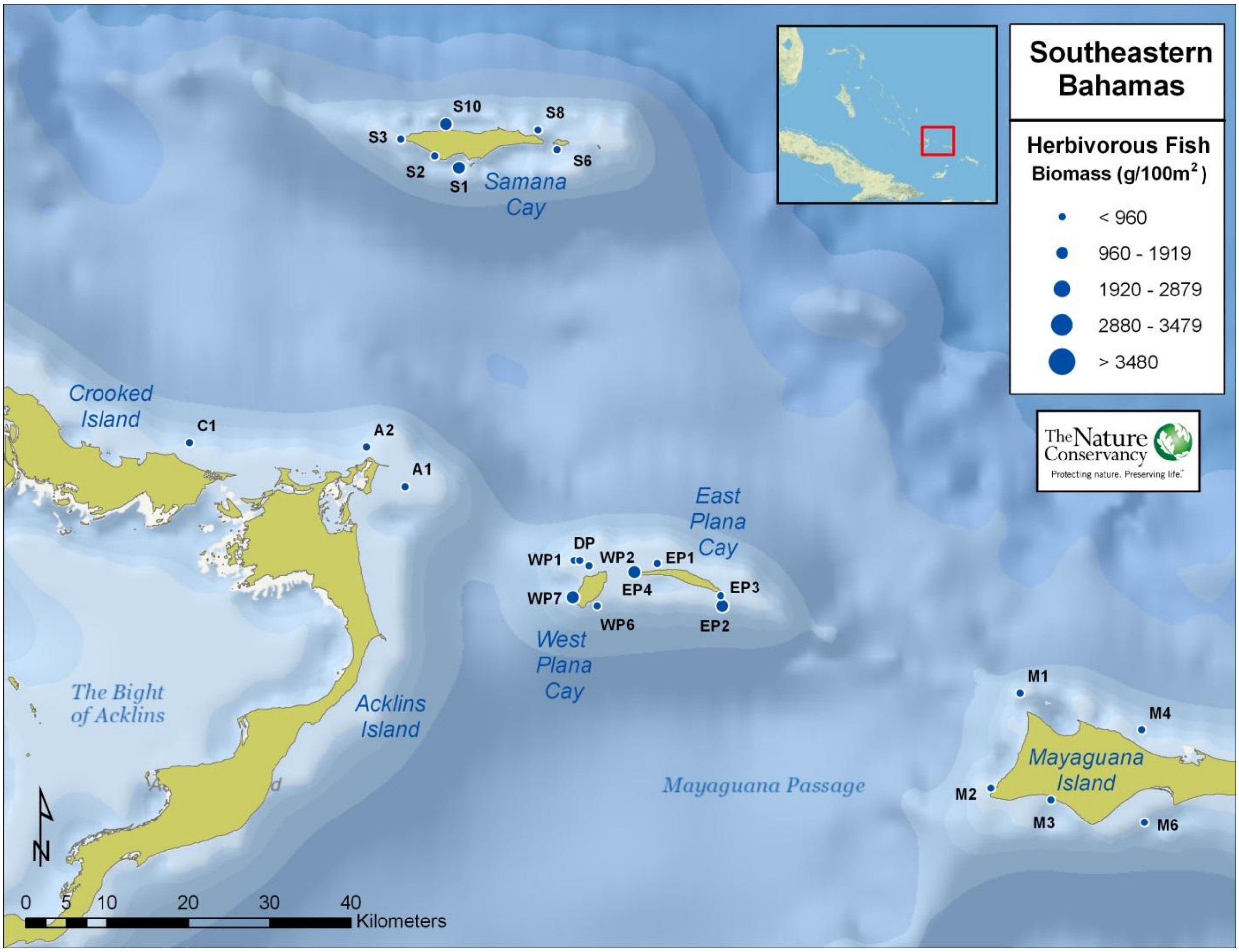


Figure 48. Map of herbivorous fish biomass at survey sites in Southeastern Bahamas.

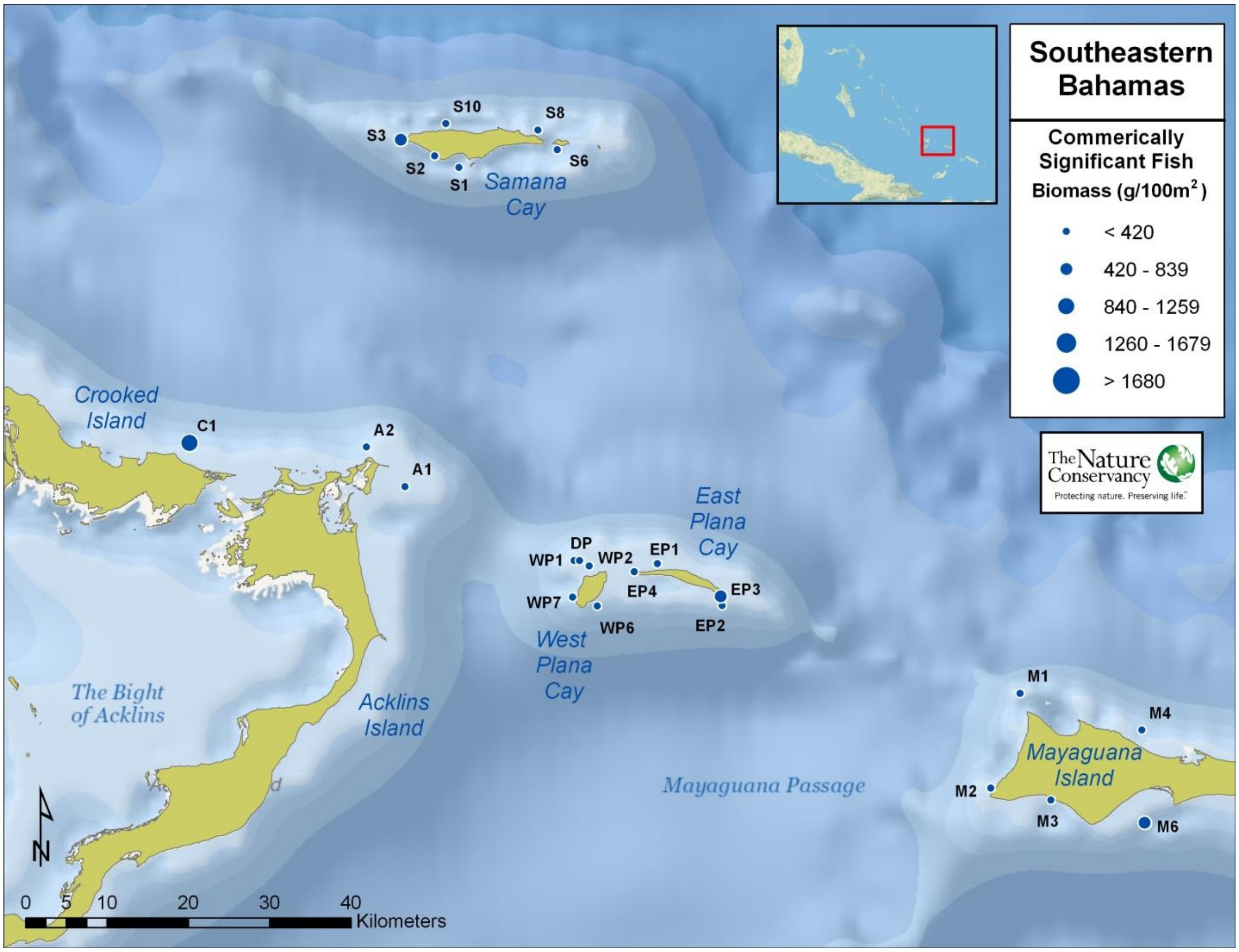


Figure 49. Map of commercially significant fish biomass at survey sites in Southeastern Bahamas.

Marine Connectivity Model

The coral connectivity work conducted in this research, takes advantage of new oceanographic data and computer simulations programs, offering new insight into how corals are connected throughout the region (Figures 50, 51, Appendix 7). Larvae movement is modeled following a spawning event in a very precise manner integrating weather and tide cycles that increases the accuracy and reliability of the model. These patterns can be analyzed to determine where settlement and recruitment are most likely to occur along with estimations on how dependent each island is on the health of corals in neighboring reefs where larvae may originate. Based on the dispersion model, it can be observed that coral larvae originating from East and West Plana Cays are mostly received and settle in Acklins Island, Samana Cay, and Cat Island. Larvae being received from East and West Plana Cays mostly originate from Mayaguana, Turks and Caicos, and Inagua islands. In Samana Cay, larvae are primarily transported to Cat Island, San Salvador, and Long Islands while larvae received mostly come from Turks and Caicos, Mayaguana, and the Plana Cays. In Mayaguana, the ocean currents transport larvae primarily to Acklins and Long Islands, as well as Samana Cay.

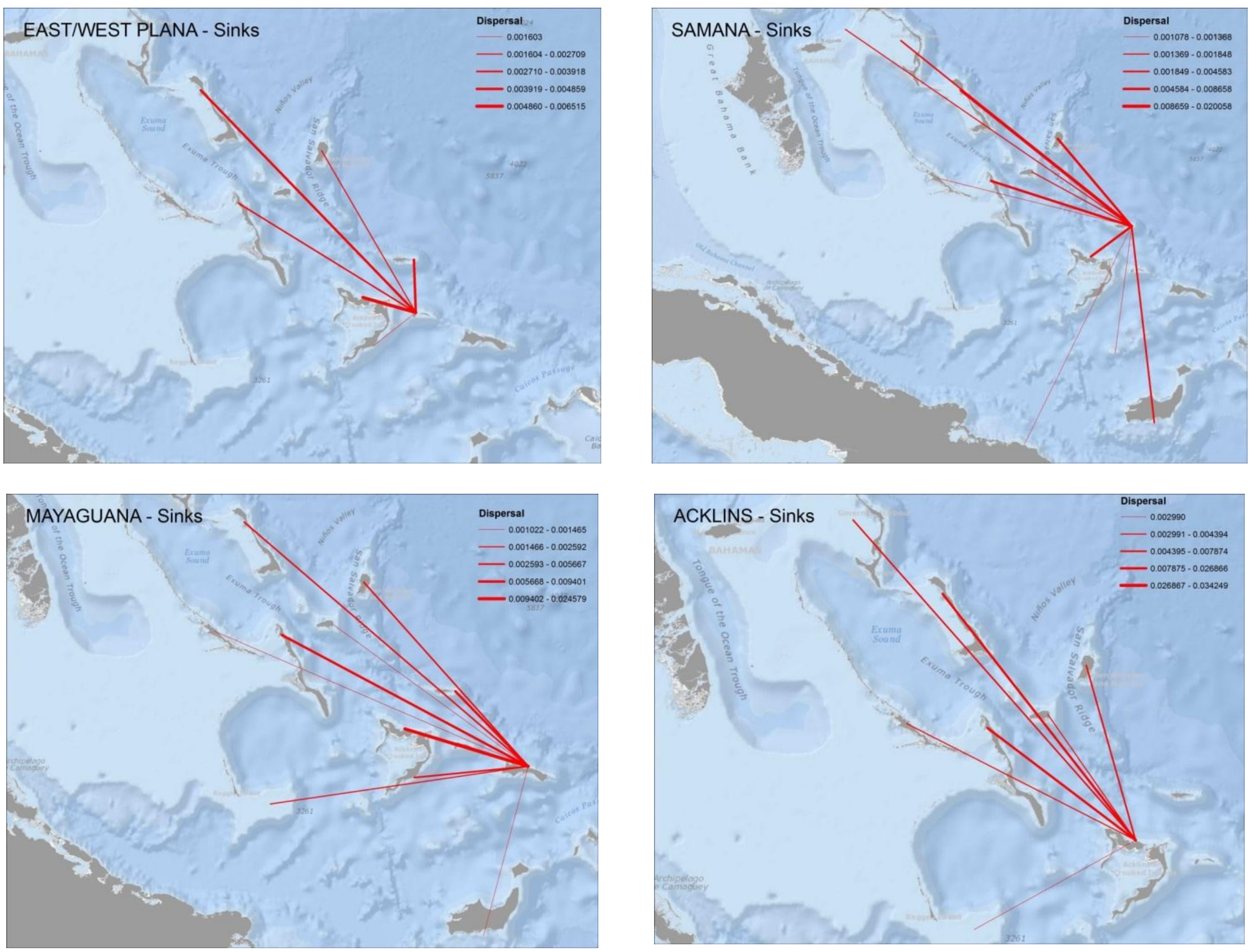


Figure 50. Modeled dispersal and probable settlement (sinks) of coral larvae originating from reefs in Southeastern Bahamas.

Larvae being received at Mayaguana come from Turks and Caicos, Inagua, and northern Cuba. Finally, when considering reefs in Acklins Island, these larvae are largely transported and received in Long, Cat, and San Salvador Islands. Larvae being received come primarily from Mayaguana, Turks and Caicos, and Samana Cay. Based on this analysis, one can see there is a strong east to west flow that dominates the system and the island of the Southeastern Bahamas are highly dependent on receiving larvae from the Turks and Caicos while the Bahamas islands of Cat, Long, and San Salvador all benefit from larvae sent from Acklins and Mayaguana Islands and the Planas and Samana Cay.

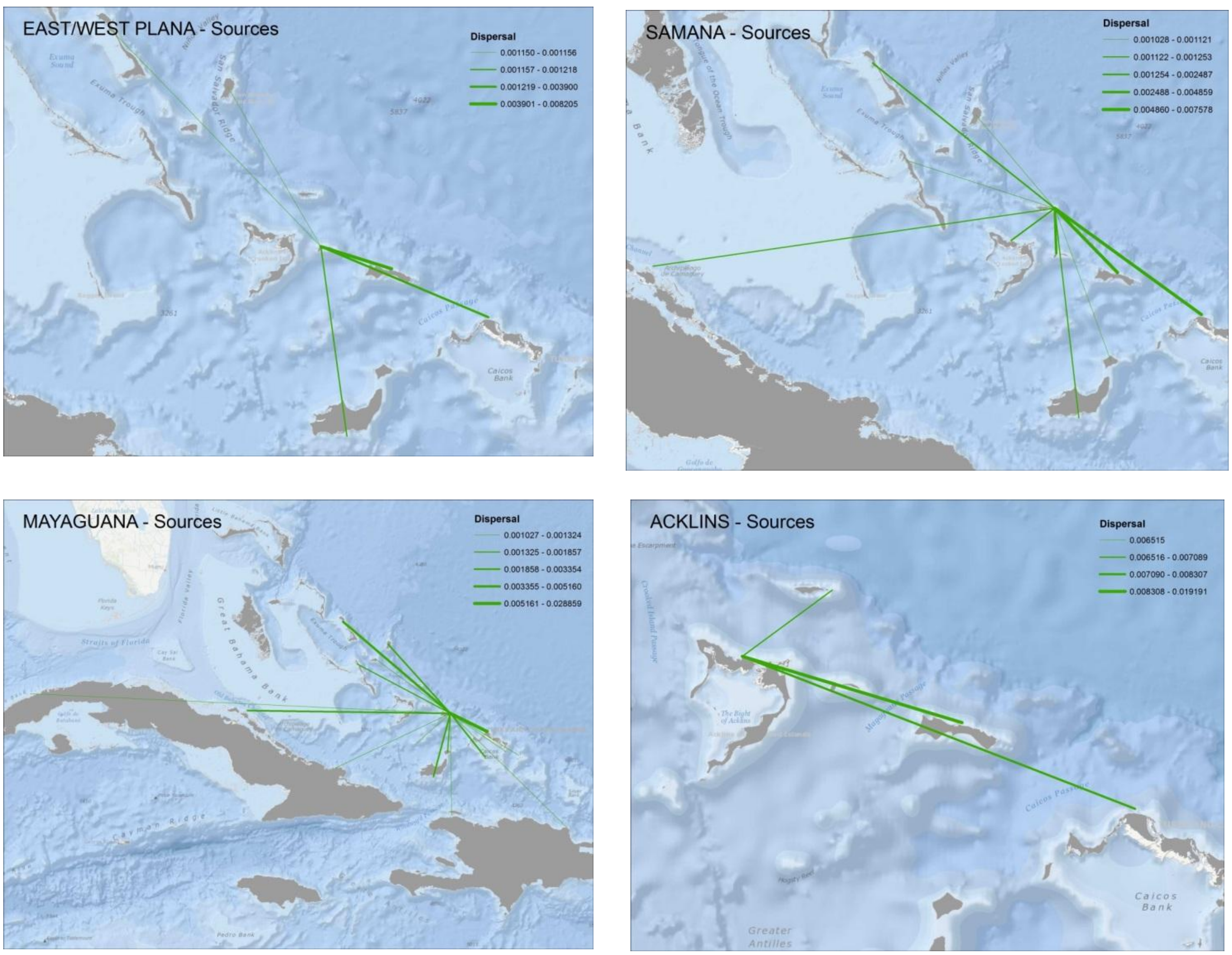


Figure 51. Modeled source areas of coral larvae that are received by reefs in Southeastern Bahamas based on NOAA's Real Time Ocean Forecast System (RTOFS) ocean current data.

Chapter 4. Discussion

The Southeastern Bahama Islands are an important link between the Bahamian island chains to the north and the Inaguas to the south, as well as further south into the Turks and Caicos and Caribbean Basin. Results from this rapid ecological assessment have provided informative and insightful findings that will benefit our understanding of this unique remote area as well as help develop measures to ensure its protection for future generations. Preliminary findings are discussed below and include:

- *Pristine islands provide critical 'land to sea' habitat for flamingos, hutia and other biota*
- *The Southeastern Bahamas support unique, extensive and healthy coral reefs*
- *These reefs are highly vulnerable to any further loss of herbivory*
- *The fish communities are threatened by overfishing and lack of nursery habitat*
- *Spawning aggregations are likely present in Southeastern Bahamas*
- *Lionfish are present even at remote reefs*
- *A new reserve in the SE Bahamas will fill a key gap in the current Bahamas network*

Pristine islands provide critical 'land to sea' habitat for flamingos, hutia and other biota
Terrestrial habitats of Samana and Plana were pristine and provide critical 'land to sea' habitat for numerous species. About 40 species of plants were counted on East Plana Cay, compared to 60-80 plant species on West Plana Cay and more than 120 plants species on Samana Cay. There was no indication of recent disturbance or invasive species. No invasive Australian pines and few other species, such as cocounut trees, that are found across many other Bahamian isalnds occurred here. A complete terrestrial survey for Mayaguana and Acklins Island was not possible given the lack of time and size of the islands, but some previous studies exist.

The hutia, the only endemic Bahamian land mammal, appear to limit the diversity of plants on East Plana Cay, but seem to have reached "equilibrium" with the remnant vegetation. Small numbers of flamingos were observed on both East and West Plana Cays, foraging in salt ponds. No other major seabird colonies (boobies, frigates, pelicans, other) were documented on the Plana or Samana cays - potentially due to the scarcity of bait fish and juvenile habitat. There was some evidence of sea turtle nesting on Samana Cay and the Plana Cays. Abundant blue holes occur on Samana and Plana Cays. At least one large cave was documented on Samana Cay with a significant resident bat population. Booby Cay, a small uninhabited island off the northeastern end of Mayaguana, has a brown booby breeding colony and a large population of an endemic Rock Iguana. Acklins and Crooked Islands have extensive tidal creeks, mangroves and seagrass beds that provide habitat for birds, conch, lobster, and bonefish.

The remote Samana and Plana Cays are government-owned Crown land and have no or very low human use. Mayaguana and Acklins/Crooked Islands have small to moderately dense human populations where mostly subsistence fishing occurs. Several fisherman/cascarilla bark harvestors camp on West Plana Cay (2-6 persons) and Samana Cay (7 persons) for periods from a few weeks to a few months. They report that large fishing vessels from the Dominican Republic illegally fish around these cays at least several times each year. Goats observed on West Plana Cay appear to be a relatively recent addition but are beginning to cause a loss of plant diversity. Significant development exists on Mayaguana, but their impacts on terrestrial habitats, tidal creeks and nearshore environments are not well known. Conservation efforts to remove exotic rat populations on Booby Cay are also being conducted (J. Wasilewski, pers. com.).

Southeastern Bahamas support unique, extensive and healthy coral reefs

The Southeastern Bahamas is home to three unique coral features including a) extensive "relict Acropora (elkhorn) forests, b) high abundance of the uncommon pillar coral Dendrogyra cylindrus and c) an unusual oasis reef 'mount'. The relict *Acropora* forests extended along Samana and East Plana cays and had thousands of massive relict coral 'trees' 2-6 m wide and 10 m high. These reefs provided important substrate for corals to flourish and habitat for numerous fish and invertebrates. In addition, individual living *Acropora palmata* colonies observed were healthy (e.g., low tissue loss, no disease, or low corallivores). Since weather conditions were rough, survey sites were limited mainly to deeper fore reefs and more extensive surveys focused specifically on *Acropora* populations should be conducted to gain a better understanding of the status of this endangered coral species. Another interesting observation from the survey was the common presence of pillar coral, *Dendrogyra cylindrus*, at the majority of survey sites. This species is often considered rare in many other parts of the Caribbean (e.g., Florida Keys, Miller et al. 2011) and is listed as 'vulnerable' on the IUCN Red List (Aronson et al. 2008). However in the Southeastern Bahamas, it was commonly observed at nearly every site in a variety of growth forms including colonies >1 m in height in low wave energy environments and short, wider flatter colonies in higher wave energy environments. The wide extent and abundance of these pillar coral populations may be due to the high wave energy environment or local recruitment/replenishment patterns. A genetic analysis of these corals would help discern if this was the case or not. The third unique feature was an unusual reef mount located on the north coast of Crooked Island. This isolated large round "'mount" was >10m high and created an oasis effect that attracted hundreds of schooling fish.

Overall, coral reefs of the Southeastern Bahamas had high diversity, a wide variety of reef types and were in very good condition. Average coral cover (12%, range 4-38%) was greater than regional averages in the Bahamas and comparable to AGRRA Caribbean values, which included several remote areas. The greatest extent of living coral cover was found along the western (or southern) island margins on deeper fore reef walls. Here, coral cover was high, although macroalgae was also abundant. Individual coral colonies were in very good condition with low recent mortality (<1%), low disease and no signs of bleaching. Ten of the 23 sites had coral cover >10% which has been theorized as the minimum coral cover threshold required to promote net positive reef accretion (Perry et al. 2013). Those reefs with <10% coral cover were more characteristic of low relief relict spurs topped with a veneer of a few small- sized corals or corals with flatter morphology. These reefs had high currents and/or wave energy and coral cover was generally lower because of the physical environment and not due to disturbance events or significant coral to macroalgal dominated phase-shifts. Coral recruitment was highly variable across the sites, but the Plana and Samana Cays had higher abundance of coral recruits than Acklins/Crooked and Mayaguana. While recruit abundance was lower compared to other Bahamian reefs, it was similar to AGRRA-Caribbean reefs.

Southeastern Bahamian reefs are highly vulnerable to any further loss of herbivory

Fleshy macroalgal abundance, mainly *Microdictyon*, on the low relief relict reef types was due in part to natural physical environment and partly to the lack of grazing herbivores like *Diadema* urchins, large-sized parrotfish, or abundant surgeonfish. *Diadema* (both adults and juveniles) urchins were observed concentrated in crevices of high relief reefs that often had high crustose coralline algae. *Diadema* densities on many reefs in the Caribbean are still so low that they are considered ecological unimportant or ineffective (e.g., Bonaire, Steneck 2011). Since herbivorous fish abundance was low, those few *Diadema* present still fulfill an important herbivory role by keeping algae cropped short thus reducing coral-algal competition and enhancing the settlement of coral larvae (Carpenter & Edmunds 2006, Arnold et al. 2010). Some areas in the Caribbean have noted a general increase in *Diadema* over the past 10 years such as Bonaire (Steneck 2011), Curacao (Debrot and Nagelkerken 2006), Florida Keys (Miller et al. 2006), Jamaica (Edmunds and Carpenter 2001), and Andros Island, Bahamas (Kramer and Kramer 2010). Low *Diadema* densities observed on the Southeastern Bahamas fore reefs suggest *Diadema* may be low because a) they have not rebounded from the 1983 die-off and lack a sufficient source of recruits to recover to former population densities or b) are not as abundant on fore reef habitats as on shallow patch and reef crests. Since rough weather prevented surveys in shallow reef crests and patch reefs, further studies of these reef types are needed.

Fish communities on the Southeastern Bahamas reefs were dominated by parrotfish. Despite being the most abundant fish family, parrotfish biomass was alarmingly low, particularly compared to other areas in the Bahamas (this report and Kramer and Kramer 2010), AGRRA-Caribbean (this report) and Bonaire (Arnold 2011). Low biomass was more similar to the low biomass found in Turks and Caicos and Dominican Republic. The majority of the parrotfish counted during surveys were small-sized. There was a noticeable lack of those larger parrotfish species (e.g., rainbow, blue, midnight) known to be more effective at grazing (e.g., Mumby et al. 2007, Mumby and Steneck 2008). With low densities of *Diadema* on many of the Southeastern Bahamas reefs, the grazing role of parrotfish and surgeonfish is even more important to help keep fleshy macroalgae in check. The low abundance of large-sized parrotfish may be due to illegal harvesting by foreign fishermen. While harvesting of parrotfish by local Bahamians has never been common, there is also an overall growing concern that new fishermen immigrating in from other countries are targeting parrotfish and many other reef species that are easy to catch, thus region-wide populations may be at a growing risk of overharvesting as well. Given the already low overall biomass, lack of adjacent nursery habitat and absence of large parrotfish in the survey area, continual overharvesting will threaten the stability of parrotfish populations. Southeastern Bahamian reefs are highly vulnerable to any further loss of herbivory (e.g., *Diadema*, parrotfish, surgeonfish), which will result in an increase of macroalgae, higher competition for space with corals, and subsequent loss of substrate suitable for coral recruitment (Mumby 2006, Arnold et al. 2010). If the existing coral reef habitats do experience a severe disturbance event in the future (hurricane and/or thermal stress event), their subsequent ability to recover may be lower due to the lack of herbivory.

Fish communities are threatened by overfishing and lack of nursery habitat

Considering the area’s remoteness and availability of suitable coral reef habitat, we expected to find a higher diversity and abundance of fish populations. Some fish species were noticeably absent such as several grunts (no porkfish, smallmouth, Spanish), parrotfish (no blue, rainbow or redtail), and groupers (no black, yellowfin, yellowmouth). Overall fish biomass was lower than compared to other areas in the Bahamas and AGRRA-Caribbean. We also projected that more abundant, larger-bodied predatory fish would be present in the Samana and Plana Cays since uninhabited, remote islands can have 2-3 times the fish biomass as nearby populated islands (e.g., Navassa and Mona Island, Puerto Rico - Stallings 2009). Surprisingly, we found the opposite was true. In Samana and Plana Cays, the abundance of large predatory fish was low and was replaced with smaller-bodied predators (e.g., coneys and grasbys). In Mayaguana and Acklins/Crooked, large-bodied groupers, barracudas and sharks were more common, despite their being established small human populations on these islands. In the case of the Samana and Plana Cays, it is likely that despite being remote with either no people or a few fishing camps, there is a significant amount of illegal fishing from foreign fishing fleets. For Mayaguana and Acklins and Crooked Island, most fishing is localized subsistence fishing and the presence of people on these islands may deter foreign fishing fleets from fishing these waters.

While overfishing seems to play a role in fish community structure, fish populations observed in SE Bahamas may be controlled in part by habitat variables (Nagelkerken et al. 2001, Kramer et al. 2003, Dahlgren et al. 2006) such as reef type or nursery habitat availability. There was a general relationship of high herbivorous fish biomass associated with reefs with high coral cover (>10-40%) and or relief (>~75cm). Commercial fish biomass showed more variability among sites with higher biomass associated with reef type (e.g., patch reefs), orientation (e.g., northeast promontories), or proximity to other habitats (e.g., seagrass beds). The site with the highest commercial fish biomass (C1, Crooked Island) had the lowest coral cover (4%), but its unique high structure mount shape surrounded by relatively barren hardgrounds created an oasis effect with fish being attracted to the safety of its structure and availability of food. More extensive future surveys may locate additional similar reef mounts along Crooked Island's north coast. The abundance of schooling fish on Mayaguana and Acklins/Crooked may be due to the proximity of seagrass and mangrove nursery habitat found here. In comparison, the near complete lack of nursery habitats on Samana and Plana Cays may be a limiting factor affecting fish abundance.

Spawning aggregations are likely present in Southeastern Bahamas

Spawning aggregation locations have not been previously surveyed in the Southeastern Bahamas, but based on predictive models, several aggregation sites are believed to exist around Acklins/Crooked Island and Mayaguana. Although our surveys took place during daylight hours and were a week behind the February "grouper moon", we did find significant evidence of potential fish aggregation and spawning behavior near the eastern and western tips of Samana and East Plana Cays. Tiger groupers in bi-color phase were observed near East Plana Cay. It is very likely that multi-species fish aggregations occur off the eastern and western promontories of at least two of these cays. Nassau groupers, also in mating color phases, were observed around Mayaguana and Acklins/Crooked Island. Several of the reef promontories are likely candidates for potential aggregations and warrant future surveys during spawning times.

Relationships between grouper populations in the survey area and the rest of the Bahamas are not known and need further investigation. Long Island has a known spawning aggregation with Nassau grouper arriving from the Exumas to the north (Dahlgren and Hixon 2006). The strong east to west flow that dominates the Southeastern Bahamas may influence larval dispersal and connectivity of fish populations. Local fish populations may depend on receiving larvae/and or stocks from the Turks and Caicos, while Cat, Long, and San Salvador islands may benefit from larvae/and or stocks originating from Acklins and Mayaguana Islands and the Planas and Samana Cay. Even if strong connections between other areas do not exist, the importance of preserving healthy suitable coral reef habitat in the Southeastern Bahamas is important given that Nassau grouper have small home ranges and high site fidelity when not migrating during spawning season (Dahlgren and Hixon 2006).

Observations of mating and spawning behaviors were encouraging, but the overall low density and size of groupers is concerning. Only 1% of all groupers observed were larger than 40 cm in size, which is quite low compared to Andros Island, Bahamas where nearly 30% of all groupers were larger than 40 cm (Kramer et al. 2003). Groupers are highly vulnerable to fishing, especially given their higher longevity, higher age at maturity, and lower growth rate (Dulvy et al. 2003). Grouper species like Nassau and tiger have a low resilience when overfished with minimum population doubling times calculated between 4 and 14 years. Smaller bodied groupers such as red hind and coney, which were more abundant in the survey area, have a low to moderate vulnerability rate and medium resilience to overfishing with estimated population doubling times between 1 and 5 years (Pitmann et al. 2008). Eliminating illegal fishing and enforcing seasonal closures will benefit these populations, although visible increases may not be immediate.

Surprisingly, large aggregations of Bermuda chub were observed at East Plana and Mayaguana and may have been gathering for pair mating and/or mass spawning. Little is known about the reproductive behavior of Bermuda chubs, but a recent study documented the first ever report of Bermuda chub spawning aggregations in the USVI (Nemeth and Kadison 2013). Here, more than 200 chubs were observed aggregating between January and March, 1-11 days after the full moon. Peak abundances occurred 60 to 80 days after the winter solstice. They found Bermuda chub spawning coincided with spawning season of Nassau and yellowfin groupers. The Southeastern reef promontories may provide suitable aggregation habitat for Bermuda chub, but additional surveys are needed to determine if these are resident or transient aggregations and to further understand their reproductive behaviors.

Lionfish are present even at remote reefs

The invasion of the Indo-Pacific lionfish (*Pterois* sp.) in the Caribbean is having negative impacts on local fish populations, particularly juvenile fishes, because they are voracious feeders, have high reproduction rates, inhabit a variety of habitats, and have no known predators. Lionfish were first reported in the Bahamas around 2001-2002 and quickly became locally abundant in some areas (e.g., Abaco), while in other areas like Andros Island, they were not established in significant numbers until 2007 (Kramer and Kramer 2008). Lionfishes have increased significantly in size and abundance in some areas (Darling et al. 2011). Despite the area's remote location, lionfish were present but not yet widespread, with only 8 lionfish observed at only 3 of the 24 sites. These lionfish were also much smaller in size than reported in other parts of the Bahamas and Caribbean (Kramer and Kramer 2010). Several countries, including the Bahamas, have created lionfish removal efforts through licensing, derbies and commercial fisheries (Morris and Whitfield 2009). Some efforts have proven to be effective particularly smaller, localized efforts (De Leon et al. 2011), although the effectiveness of large-scale removal programs may be more challenging (Barbour et al. 2011). More effective may be a National effort to create market-based solutions that help contribute to the overall reduction of lionfish populations while also creating economic opportunities for fishermen.

A new reserve in the SE Bahamas will close a gap in the Bahamas reserve network

Numerous studies have shown the positive effects of reserve protection on fish populations with increases in species richness, fish size, density, and biomass within reserve boundaries (Poulnin and Roberts 1993, Mumby 2006, Ault et al. 2006, Lester et al. 2009). While reserve protection may benefit different fish species to different degrees, even small-sized reserves have shown positive effects for some species. Often there is a lag effect of 3-5 years from when a reserve area is established and when visible population increases occur (Roberts et al. 2001, Alacala et al. 2005). However for migrating species like Nassau groupers, marine reserves alone are not sufficient enough to protect this species during their spawning migrations (Dahlgren and Hixon 2006). More effective is establishing and enforcing consistent closed seasons during the Nassau groupers critical spawning period. Overall these islands are fairly pristine in nature and have incredible coral structures making them ideal candidates for designation as a part of a new SE Bahamas marine protected area. Such designation could restore commercially important fisheries and provide a more secure corridor for wide ranging species such as turtles, whales, sharks, and other pelagics that migrate from the eastern Caribbean up through The Bahamas. A new reserve can serve as an anchor to improve surveillance and enforcement activities in the area, thereby, reducing illegal fishing activity and ensuring national security.

Summary

- The Samana and Plana Cays are among the most isolated of the Bahamian islands. These remote cays are government-owned Crown land and have no or very low human use. Mayaguana and Acklins/Crooked Islands have small to moderate human population densities where mostly subsistence fishing occurs.

- Inclusion of this area into the Bahamas-wide marine reserve network would create an ecological corridor and fill an important gap from north to south. Located near the southeastern edge of the Bahamas territory, these islands link the northern Bahamian island chain to the Inaguas, Turks and Caicos and into the Caribbean Basin.

- Terrestrial habitats of Samana and Plana are pristine and provide critical 'land to sea' ecosystem connections for numerous species. Endemic hutia depend on undisturbed habitat on E. Plana. Flamingos were observed and other birds were found to nest, roost and feed among the various forests, lagoons and mangroves. Sea turtles rely on the sandy beaches for nesting. A large bat colony resides in one of the Samana caves.

- Outstanding and unique coral reefs in the Southeastern Bahamas provide habitat and shelter for a high diversity of marine organisms. The extent of available, quality reef habitat could support higher biomass of fish, conch and lobster if illegal fishing was eliminated and populations were allowed to rebound. However, reefs here are vulnerable to any further loss of herbivory, particularly due to illegal fishing of parrotfish.

- Southeastern Bahamas are an important source of larvae to northern Bahamian islands like Cat, Long, and San Salvador.

- Fish rely on the unique promontories for spawning. Several groupers were displaying spawning behaviors and numerous habitats were predicted to be potential spawning aggregation sites on Acklins/Crooked and Mayaguana. Large aggregations of Bermuda chub, believed to be spawning, were observed along East Plana and Mayaguana.

- Extensive mangrove, seagrass, bays and tidal creeks of Acklins/Crooked Island and Mayaguana provide important nursery habitat. Robust populations of lobster and conch and an aggregation of stingrays were found along Crooked Island. Flocks of flamingos, coots, ducks, and other birds waded among the mangrove lagoons. The pristine tidal flats of Acklins/Crooked Island are home to large numbers of bonefish and are the basis for an economically important fly fishing tourism business.

- The Southeastern Bahamas Islands are adjacent to an important humpback whale migration route and the islands act as 'stepping stones' for migratory birds.

- A new reserve in the SE Bahamas can allow for more surveillance and enforcement, which will reduce illegal fishing and increase national security.

Island	Biodiversity	Human use
Samana	Pristine terrestrial habitat, no invasive plants Unique east-west orientation New unique *Acropora palmata* 'relict' reef type discovered Sea turtle nesting habitat Large cave inhabited by significant bat colony Low fish biomass, especially commercial fish Lack of nursery habitat, but numerous land blue holes	Fishermen and cascarilla bark harvesters camps Illegal fishing by foreign vessels
East Plana	Pristine terrestrial habitat, uninhabited by people, no invasive plants Stable population of hutia, only endemic Bahamian land mammal Flamingos and an osprey nest observed. Unusual east-west island orientation New unique *Acropora palmata* 'relict' reef type discovered Aggregations of Bermuda chub, possible spawning aggregation Lack of mangrove and seagrass nursery habitat Low fish biomass, especially commercial fish	Illegal fishing by foreign vessels
West Plana	Terrestrial habitat in good condition Extensive healthy coral reef wall along western side Unusual exposed rock platform extending 2 km north More than 10 lagoons with landlocked mangrove habitat Few seagrass beds, lack of nursery habitat Flamingo population (adults and juveniles) Sandy beach habitat western side of island, possible sea turtle nesting	Fishermen and cascarilla bark harvesters camps Goats on island may alter vegetation Illegal fishing by foreign vessels
Mayaguana	Several large bays Vast nursery habitat with seagrass & mangroves High variety of healthy coral reef types Groupers displaying spawning behavior Several predicted grouper spawning aggregations Numerous conch and lobster Several predatory fish like sharks and barracudas	Moderately developed island
Acklins/ Crooked Islands	Extensive tidal creek, mangrove and seagrass nursery habitat Abundant lobster and conch Unusual high relief mount coral reef providing 'oasis' habitat Numerous sharks, large predatory fish, schooling fish Southern stingray aggregation Groupers displaying spawning behavior Several predicted spawning aggregation sites	Small human population, subsistence fishing

Table 6. Biodiversity features and human use of Southeastern Bahamian Islands.

Chapter 5. Recommendations

In recent years, coral reef ecosystems worldwide have been in great decline due to overfishing, pollution, and global climate change. Much of the world's reefs are already severely damaged, and approximately 60% of the reefs will be lost by 2030 if actions are not taken to recover and protect them. While the islands and reefs of the Southeastern Bahamas are in good condition and likely some of the best in the Bahamas, they remain particularly vulnerable to human impacts.

These risks include:

- Illegal fishing of vulnerably low fish populations may cause a collapse of fish populations if not protected quickly.
- Remote location makes it challenging to prevent illegal fishing and/or challenging to implement conservation and management efforts.
- Overharvesting of key nursery habitats of fish, conch and lobster may decimate important stocks.
- Overfishing of grouper spawning aggregations may lead to ecologically or locally extinct populations.
- Dependence on nearby reef areas for fish, coral and other biota sources (e.g., Turks and Caicos) that may not receive adequate protection may result in a depletion of larval sources and disruption of ecological connectivity.
- Unplanned infrastructure and invasive species may destroy intact terrestrial ecosystems.

The Southeastern Bahamas REA survey area has several factors that make it a good candidate for implementing effective conservation measures and establishing a protected area or reserve. The area is quite remote and the anthropogenic impacts are few. Several of the cays do not have resident human populations and the inhabited islands have populations that are quite small. The Southeastern Bahamas would also meet the criteria for setting up and maintaining MPA networks established by the international Union for the Conservation of Nature (IUCN, 2007) including:

- Adequacy - ensuring that the sites have the size, shape, and distribution to ensure the success of selected species.
- Representability - protection for all of the local environment's biological processes
- Resilience - the resistance of the system to natural disaster, such as hurricanes or flood.
- Connectivity- maintaining population links across nearby MPAs.

Thus, it is recommended that this area should be considered for inclusion into the Bahamas National Park System as a “land and sea” park. The area would protect *adequate* and *representative* habitats by including all types habitats (terrestrial habitat, sandy beaches, tidal creeks, wetlands, mangroves, seagrasses, sandy bottoms, patch reefs, spur and grooves hard bottoms, fore reefs, wall reefs, deep oceanic areas, sea mounts). Natural *resilience* would be incorporated by including appropriate niche spaces and nursery areas for all life stages of resources in the protected area. The protected area would also have positive impacts locally and Bahamas-wide if established because of the *connectivity* and linkage to the existing Inagua protected area system to the south, as well as the Exuma Cays Land and Sea Park to the north.

Conservation recommendations include:

11. Establish a land and sea reserve in the Southeastern Bahamas, particularly around the Plana and Samana Cays. Implementing protective measures will a) fill a major ecological gap in the Bahamas National Park System, b) protect nationally important biodiversity, and c) provide an ecological corridor from north to south.

12. Decrease illegal fishing from other countries in the southeastern Bahamas. Investigate the use of Unmanned Aerial Vehicles (UAVs) to monitor fishing activity and acquire ecological data in a comparatively cost effective manner.

13. Remove goats on West Plana to prevent the island from losing its largely intact and pristine forest cover. Prohibit the practice of releasing feral goats and other invasive species on small islands.

14. Protect parrotfish to maintain herbivory on reefs. Consider legislation to ban the harvesting of parrotfish as Belize and Bonaire have recently implemented.

15. Safeguard spawning aggregations of reef fish. Identify and further protect through zoning all reef fish spawning aggregations and implement consistent seasonal closures for species like Nassau grouper during their critical spawning migrations.

16. Control invasive lionfish. Consider creating incentives to promote the harvest and consumption of lionfish through sustainable market-based solutions.

17. Involve stakeholders in conservation planning to balance natural resource management with sustainable economic development. Conduct a stakeholder assessment of the SE Bahamas to better understand current usage, stakeholder conservation priorities, and economic value of the area. This should include residents, recreational fisherman, tourists, and cruisers. Consider developing microfinance stimulus programs to promote ecotourism, lionfish harvesting and conch and lobster population enhancement projects. Collaborate with stakeholders to identify appropriate measures for subsistence, sport, and commercial fishing as well as no-take areas.

18. Protect terrestrial habitats to preserve important “land to sea” habitat connections for hutia, flamingos, bats, and other biota. No substantial infrastructure developments or mining/extractive activities should be allowed on the Plana Cays or Samana Cay. Sustainable development practices should be adopted for Mayaguana and Acklins/Crooked Island.

19. Promote additional scientific investigations of the region focusing on shark and sport fish populations, grouper aggregations, nursery habitats and ecological connectivity.

20. Engage communities by creating opportunities for people to participate in environmental stewardship and encouraging environmentally friendly practices.

Marine protected areas are currently the best tool for managing the impacts to coral reefs, with "no take zones" acting as the most effective form of management to help reestablish fish populations. Though protected areas and no-take zones cannot stop the effects of global climate change, these management tools can protect islands and coral reefs from human damage and exploitation, allowing the systems and the species they support to build resilience to recover from the changes brought by global climate change more effectively and rapidly.

The area's ecological biodiversity and connectivity importance reinforce the need to provide conservation protection to the Southeastern Bahamian Islands. While this REA has provided initial insights into the extent and condition of the region's terrestrial and marine resources, additional opportunities exist to further understand and develop measures to safeguard this unique area for future generations. A map of a proposal for a MPA in the Southeastern Bahamas REA study area is given below for discussion purposes (Figure 52).

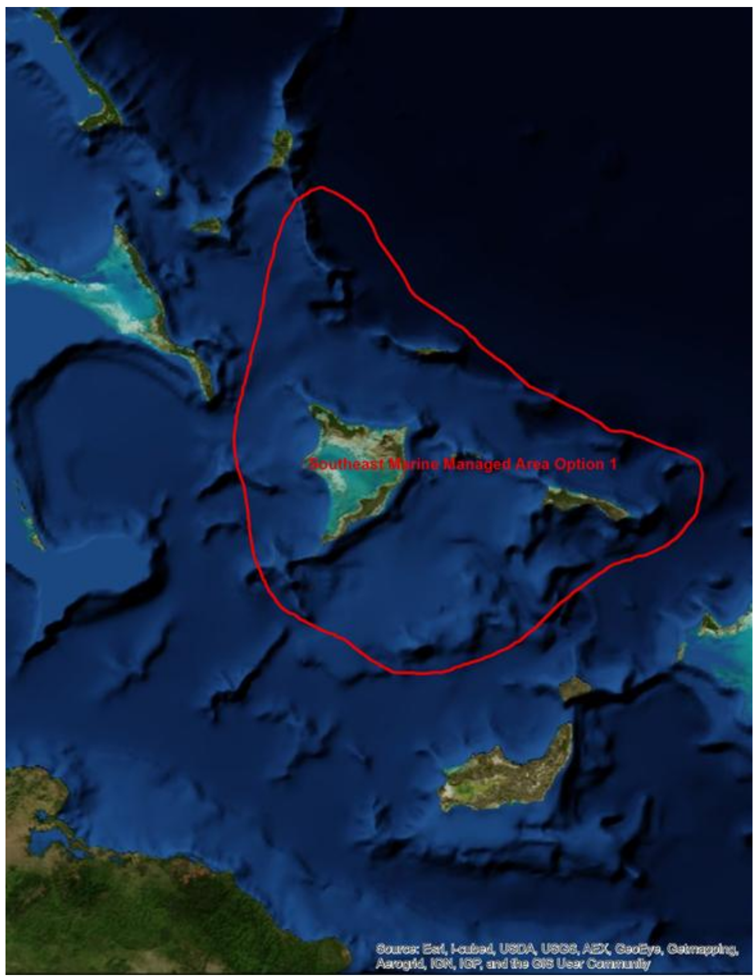


Figure 52. Proposal for the Plana Cays MPA.

Acknowledgements

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Scientific Team for the Southeastern Bahamas rapid ecological assessment

February 18 – March 1, 2013

Name	**Survey Responsibility**
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Sandy Voegeli	Benthic surveys/photography
Dr. Vallierre Deleveaux	Fish surveys
Alannah Vellacott	Fish surveys
Dr. Ethan Freid	Terrestrial surveys/photography
Dr. Steve Schill	Marine Mapping
John Knowles	Marine Mapping
Rob Gardiner	Marine Mapping

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Appendix 1.

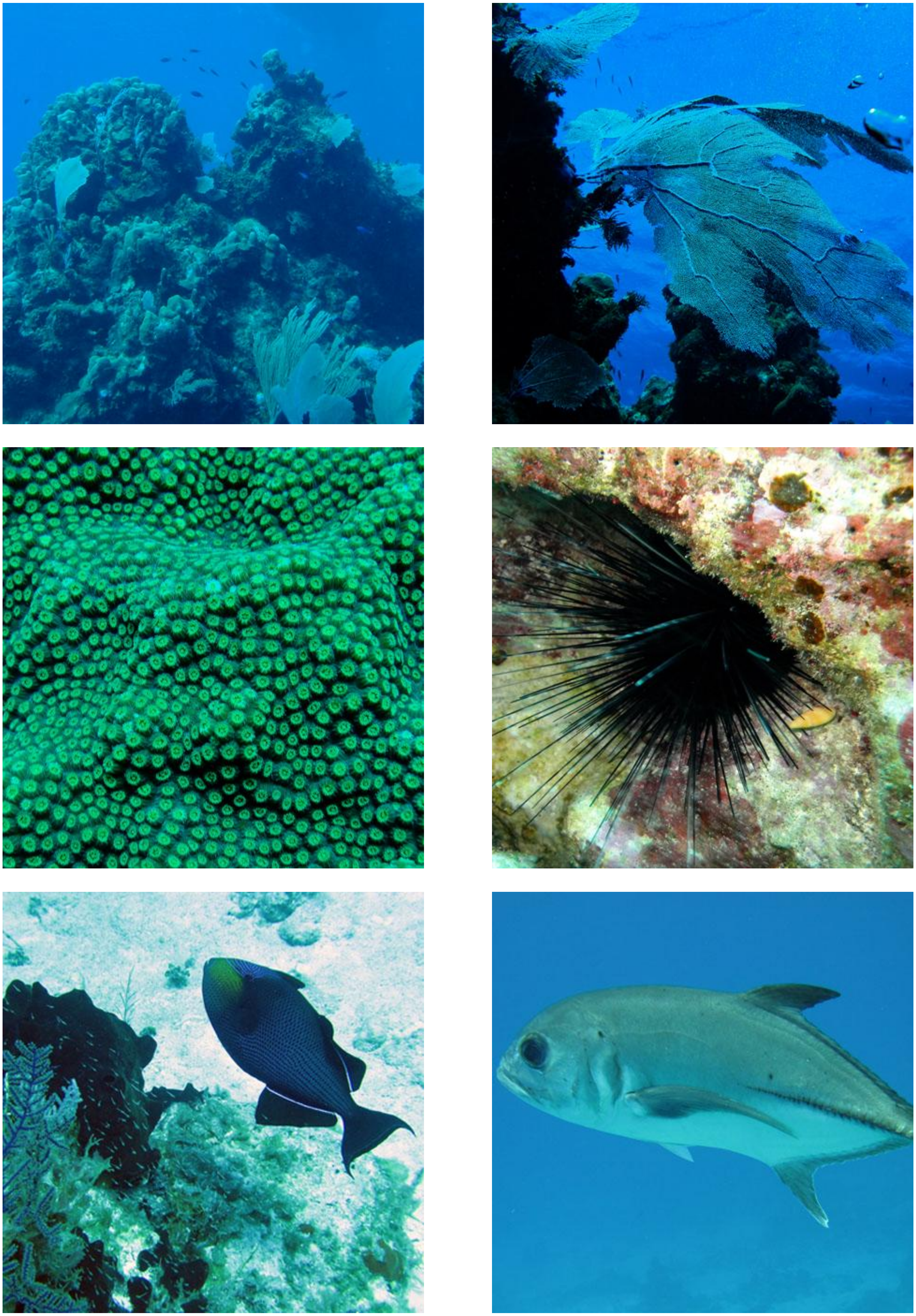
Southeastern Bahamas
Photo Journal



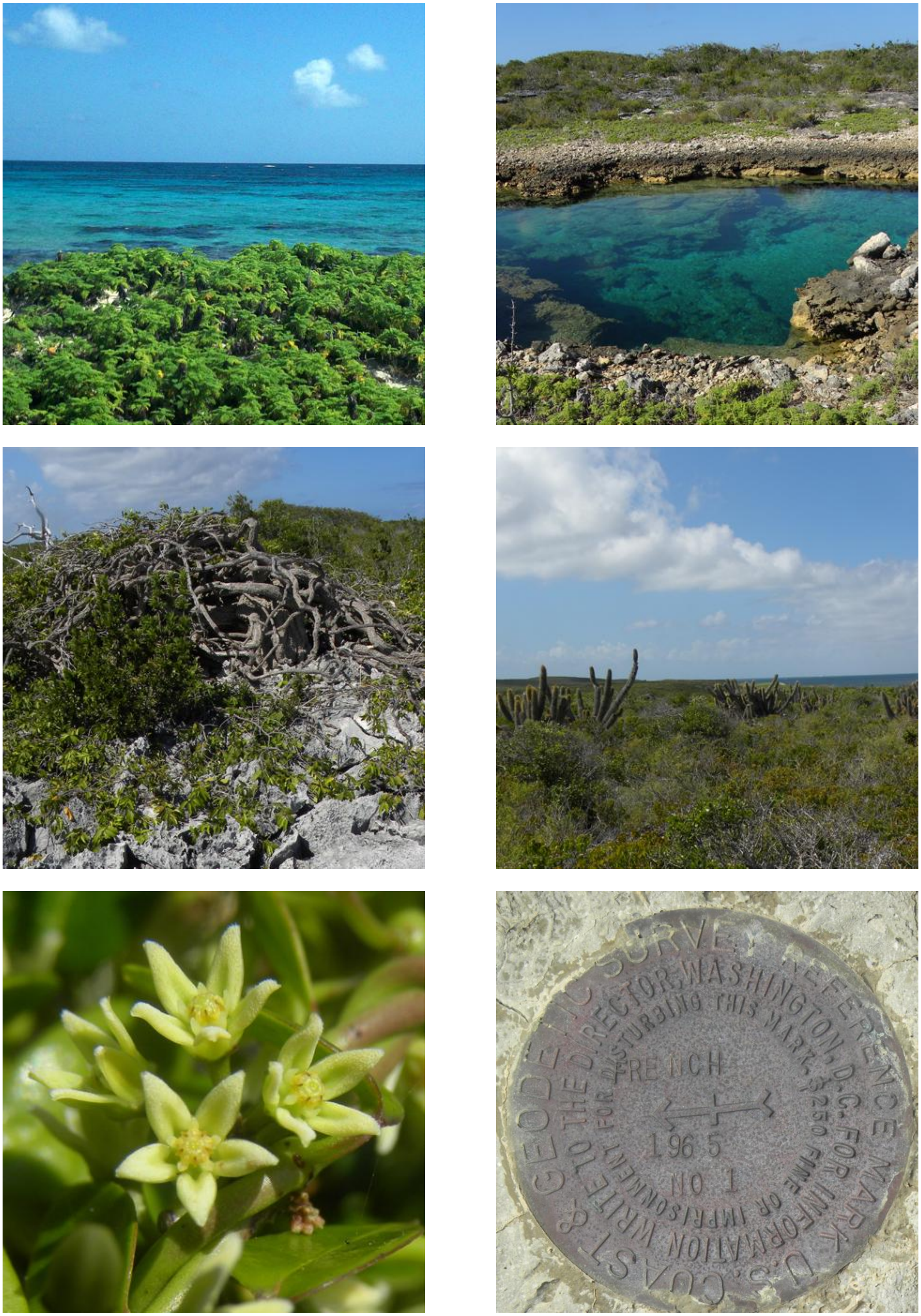



Samana Cay, Bahamas - Left column: Dry broadleaf Evergreen Formation-Forest on Samana Cay (top), *Pilocereus millspaughii* (Millspaughs Dildo Cactus) (middle); *Passiflora pectinata* (bottom). Right column: *Tillandsia circinnata* (top); *Melocactus intortus* (Turks Head Cactus) (middle); *Pedilianthus bahamensis* (bottom). Photos by E. Freid.

Samana Cay, Bahamas - Cave on Samana Cay (top); Dune system on Samana Cay (middle), Ethan and Eugene (bottom). Right column: Blow hole (top), Coastal arch (middle), *Croton eluteria* (Cascarilla Bark) (bottom). Photos by E. Freid.



Samana Cay, Bahamas -Left Column: Fore reef (top); Mountainous star coral, *Montastraea favelota* (middle) (photos by S. Voegeli); Black durgon, *Melichthys niger* (bottom) (photo by L. Knowles). Right Column: Sea fan, *Gorgonia ventalina* (top); Long-spined sea urchin, *Diadema antillarum* (middle); Bar jack, *Caranx ruber* (bottom). Photos by S. Voegeli.

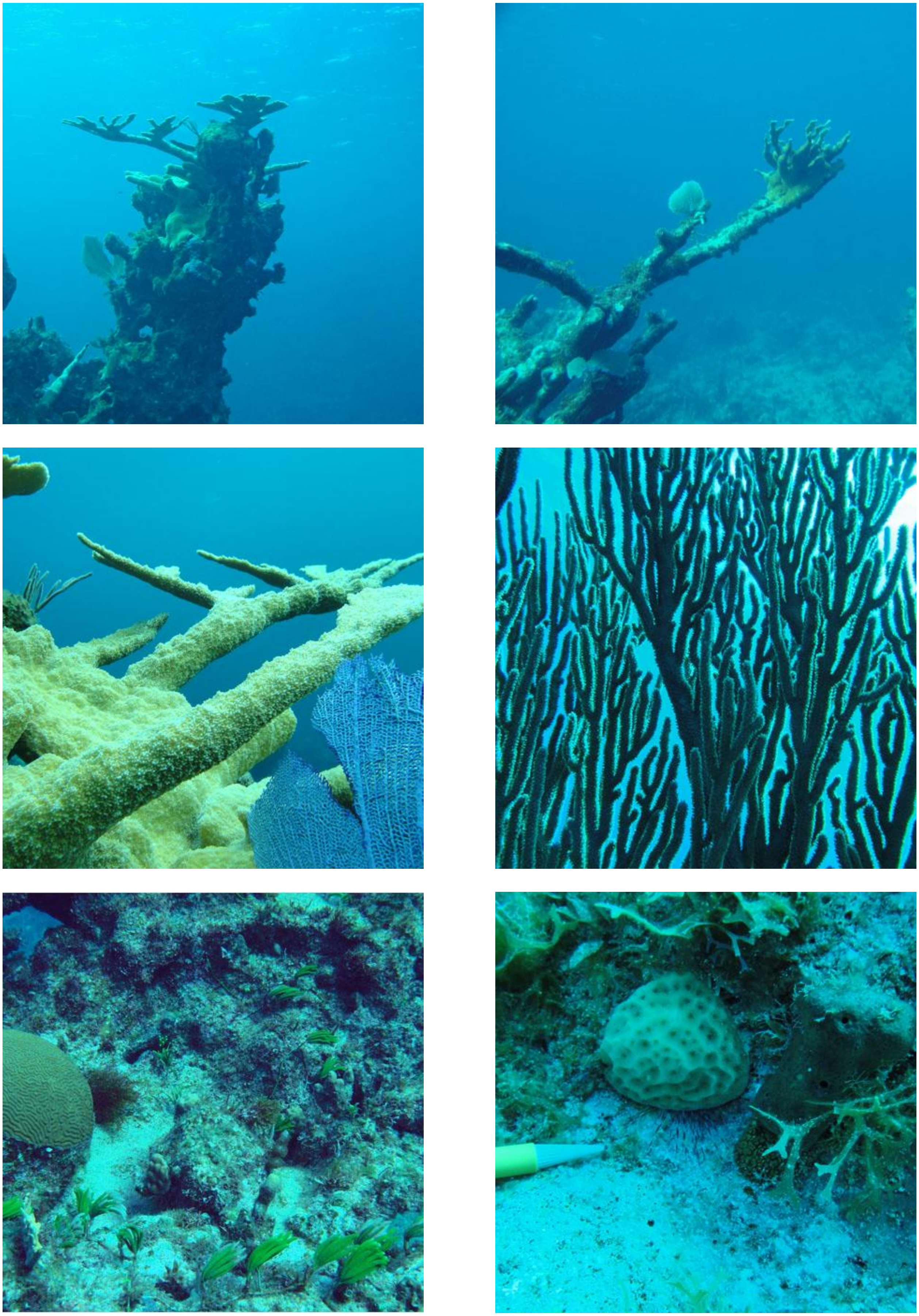


East Plana Cay, Bahamas - Left column: View from a ridge (top); *Capparis flexuosa* (middle), *Metastelma* sp. (bottom). Right column: Blue Hole (top); Dry Broadleaf Evergreen Formation - Shrubland (middle); Survey Marker (bottom). Photos by E. Freid.






East Plana Cay, Bahamas - Left column: Hutia tracks, *Geocapromys ingrahami* (top); Osprey nest (middle); Kestrel, *Falco sparverius* (bottom). Right column: Flamingo chick, *Phoenicopterus ruber* (top); Osprey chick, *Pandion haliaetus* (middle); Sea turtle bones (bottom). Photos by E. Freid.

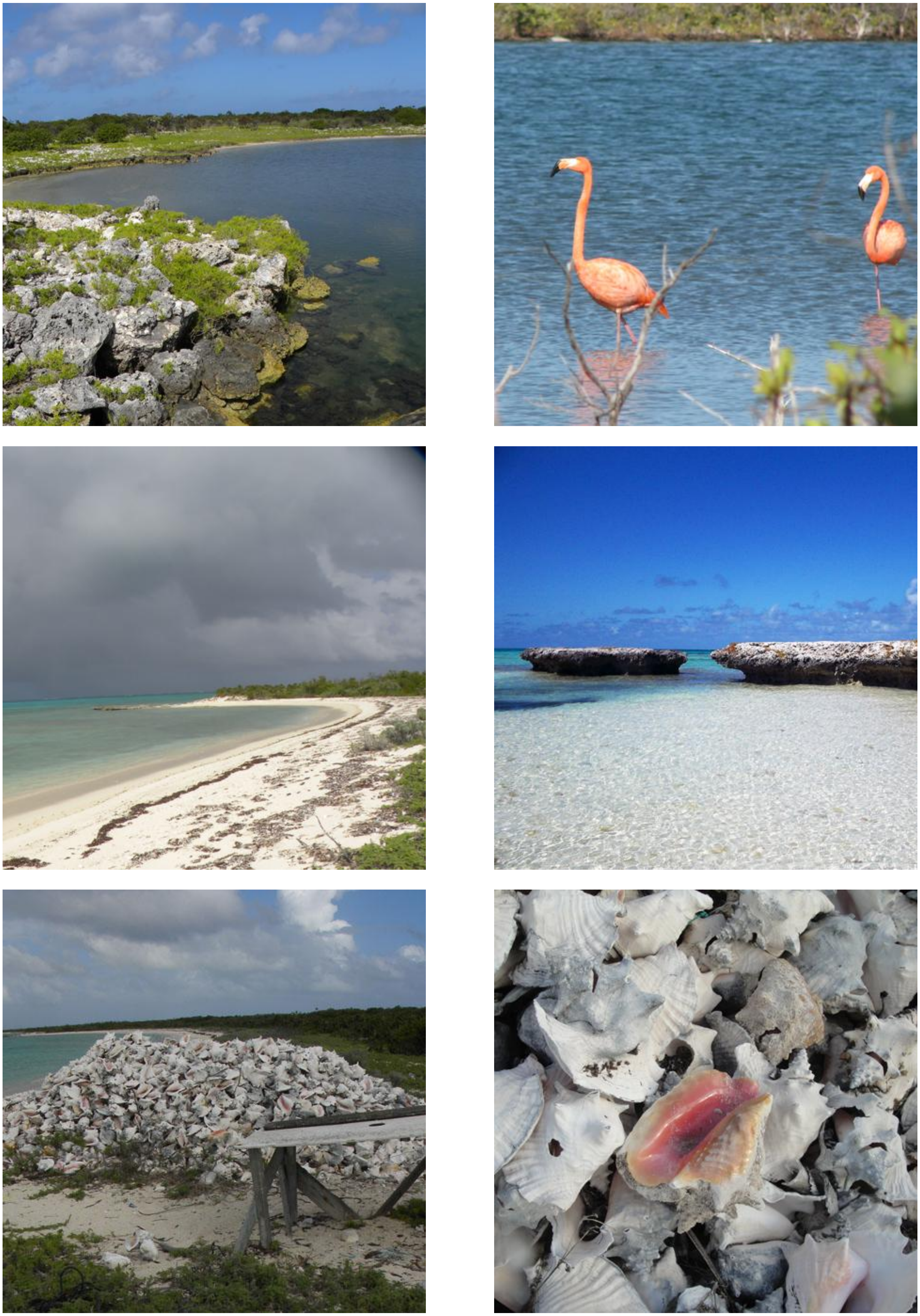


East Plana Cay, Bahamas - Left column: Elkhorn coral, *Acropora palmata* (top); Elkhorn coral (middle); Green algae, *Caulerpa sp.* and brain coral, *Diploria strigosa* (bottom). Right column: Young elkhorn coral on old dead colony (top); Soft coral sea rod (middle); Juvenile long-spined urchin, *Diadema antillarum* (bottom). Photos by S. Voegeli.

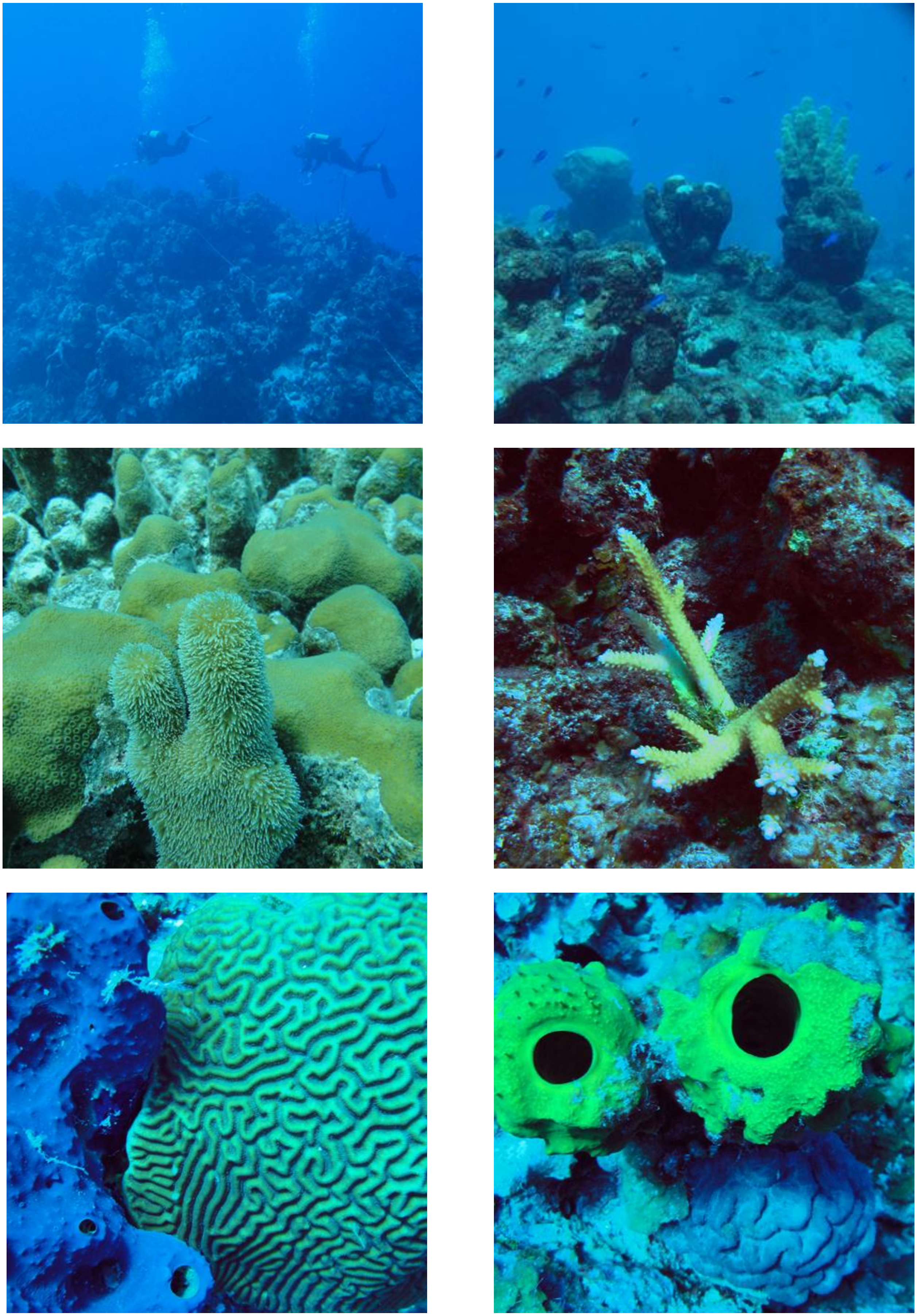





West Plana Cay, Bahamas - Left column: *Sweientia mahagoni* (Mahogony) tree (top); Fishermen's temporary shelter (middle); Goat (bottom). Right column: *Tillandsia utriculata* (top); Trash (middle); Migratory bird (bottom). Photos by E. Freid.

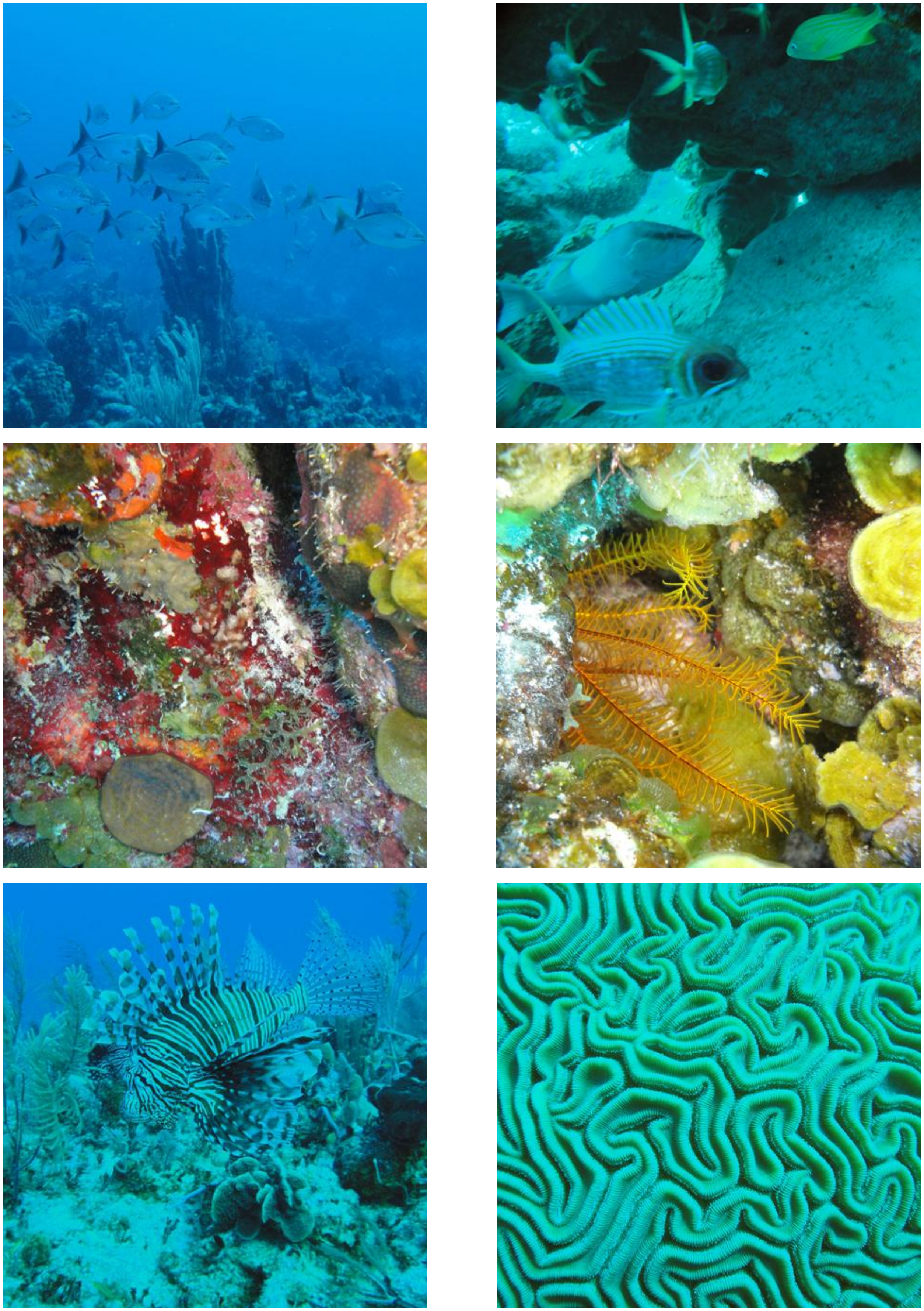


West Plana Cay, Bahamas - Left column: Blue hole (top); Dune system (middle); Conch midden (bottom). Right column: Flamingos (top); Exposed eroded coastal limestone (middle) Photo by A. Vellacott; Conch (bottom). Photos by E. Freid.



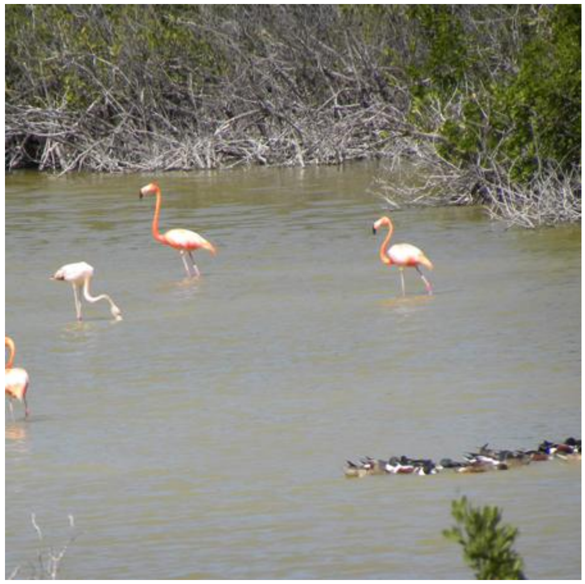
West Plana Cay, Bahamas - Left Column: Survey team (top); Pillar coral, *Dendrogyra* cylindrus (middle); brain coral, *Diploria strigosa* (*bottom).* Right column: Pillar coral, *Dendrogyra cylindrus* (top); Fused staghorn coral, *Acropora prolifera* (middle); *S*ponge (bottom). Photos by S. Voegeli.

Mayaguana, Bahamas - Left column: Southern rocky shoreline (top); Rocky shore (middle); Dry Broadleaf Evergreen Formation – Forest (bottom). Right column: Interior mangrove lake (top); Mangrove shrubland (middle); *Lysiloma latisiliquum* (Wild Tamarind) (bottom). Photos by E. Freid.



Mayaguana, Bahamas - Left Column: Bermuda chub aggregation (top); Benthic algae (middle); Invasive lionfish, *Pterois volitans (bottom).* Right Column: Nassau grouper (back) and squirrelfish (fore) (top); Golden crinoid, *Davidaster rubiginosa* (middle); Grooved brain coral, *Diploria labyrinthiformis* (bottom). Photos by S. Voegeli.



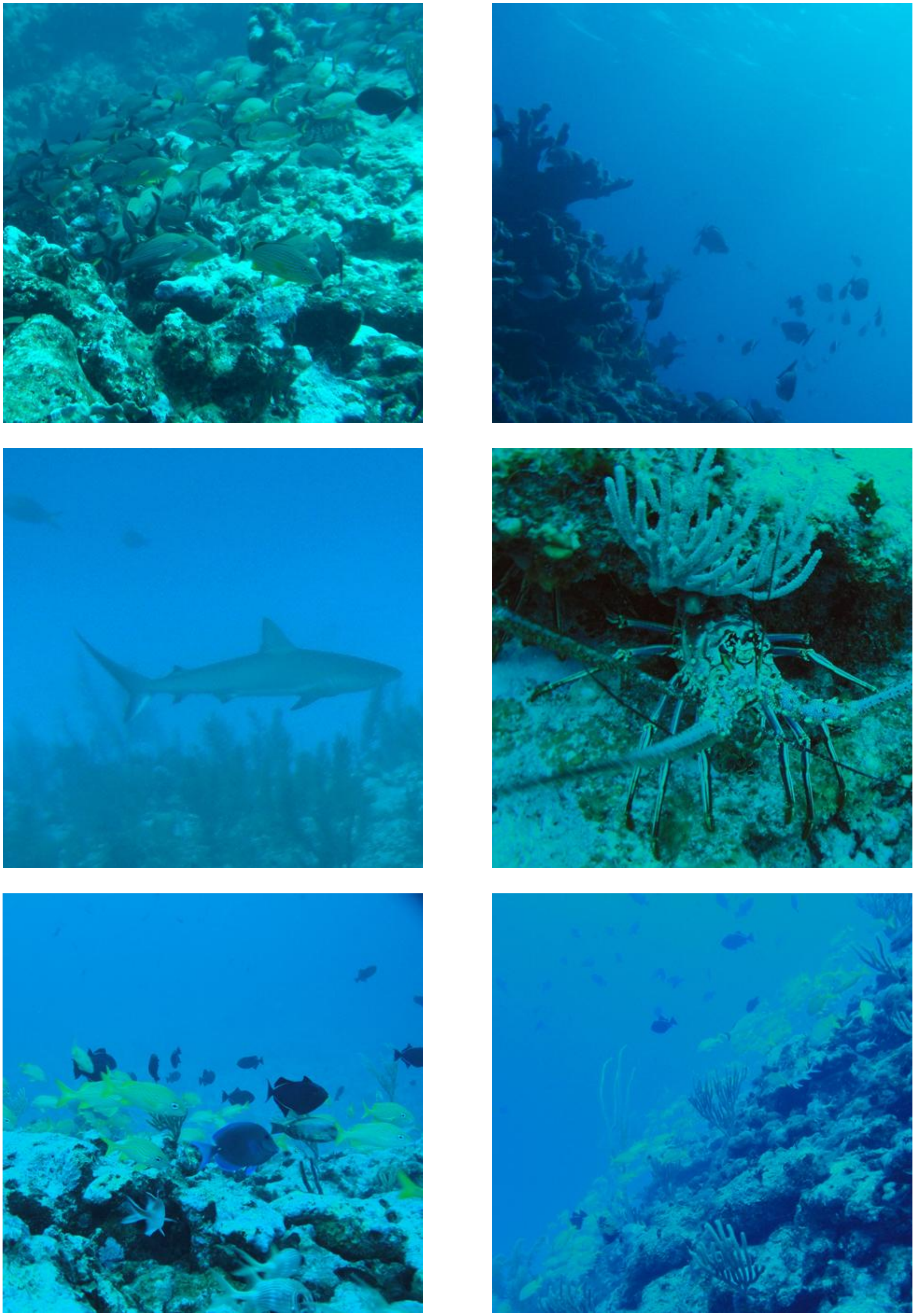
Acklins, Bahamas - Left column: Creek system (top); American coots (middle); Abandoned church (bottom). Right column: Elkhorn coral (top) Photo by J. Knowles; Flamingos (middle); *Coco nucifera* (Coconut) (bottom). Photos by E. Freid.

Acklins, Bahamas - Left column: *Oplonia spinosa* (top); *Consolea millspaughii* fruit (middle); *Pithecellobium keyense* (Rams Horn) (bottom). Right column: *Euphorbia gymnonota* (top); *Lantana involucrata* (middle); *Pithecellobium keyense* (Rams Horn) (bottom). Photos by E. Freid.

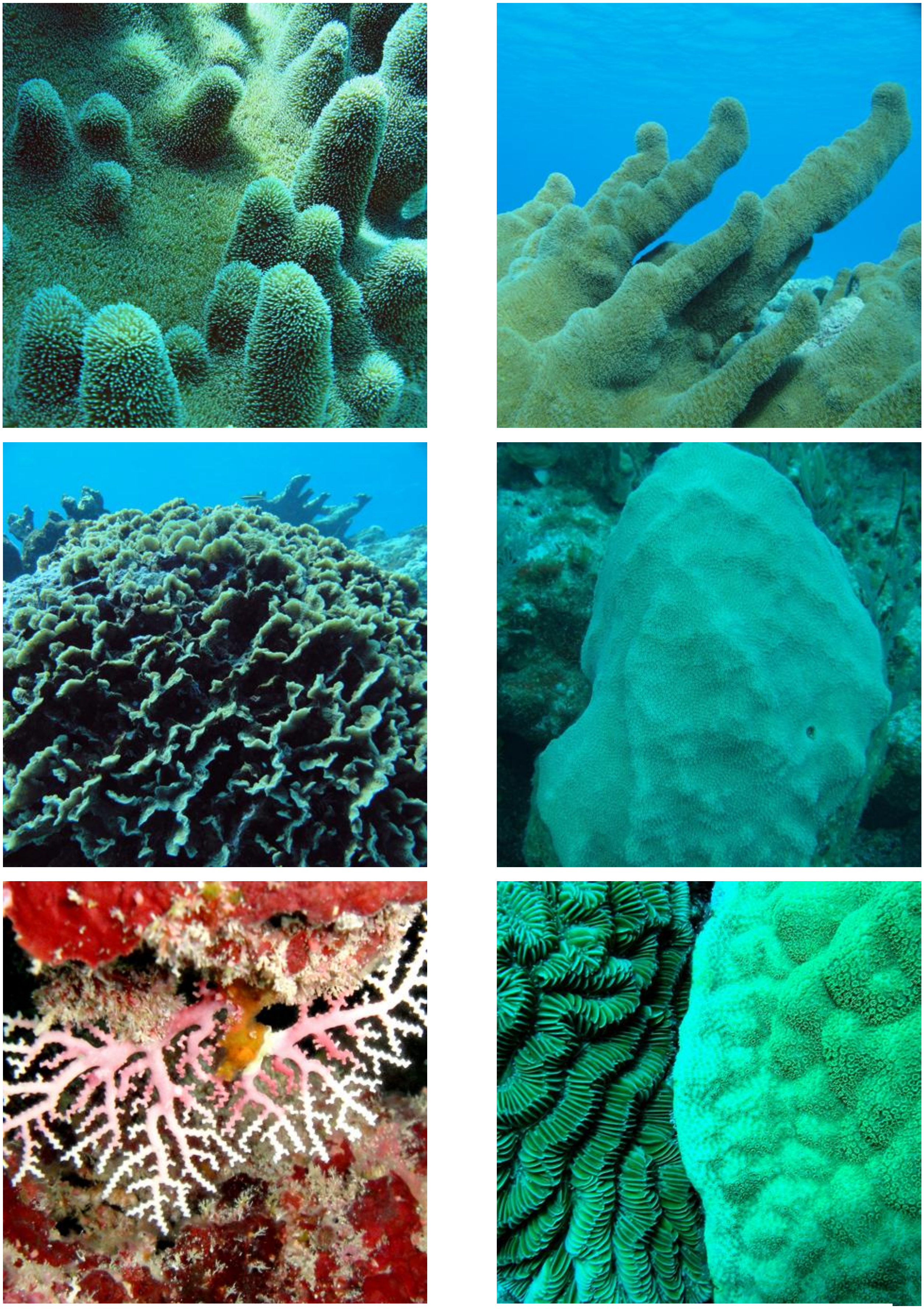





Crooked Island, Bahamas - Left column: Limestone rock outcrop (top); Sea star, *Oreaster reticulatus* (middle); Soft corals (bottom). Right column: Southern sting ray, *Dasyatis Americana* (top); Queen conch, *Lobatus gigas* (middle); Flamingo tongue, *Cyphoma gibbosum*, on sea fan (bottom). Photos by S. Voegeli.



Acklins/Crooked Island, Bahamas - Left column: School of grunts (top); Reef shark (middle); Schools of grunts, black durgons, blue tangs (bottom). Right column: Reef mount with elkhorn coral (top); Lobster (middle); Steep slope of reef mount with large schools of fish (bottom). Photos by S. Voegeli.



Corals of Southeastern Bahamas - Left column: Pillar coral, *Dendrogyra cylindrus* (top); Lettuce coral, *Undaria tenuifolia* (middle); Rose lace coral, *Stylaster roseus* (bottom). Right column: Pillar coral, *Dendrogyra cylindrus* (top); Mountainous star coral, *Montastraea faveolota* (middle); Maze coral, *Meandrina meandrites and* mustard hill coral, *Porites astreoides* (bottom). Photos by S. Voegeli.

Appendix 2.

Bahamian Marine Resources and Sea level model

The Bahamas is rich in natural resources. Maps (by J. Knowles, TNC) indicating the distribution of important marine environments and resources are given below:

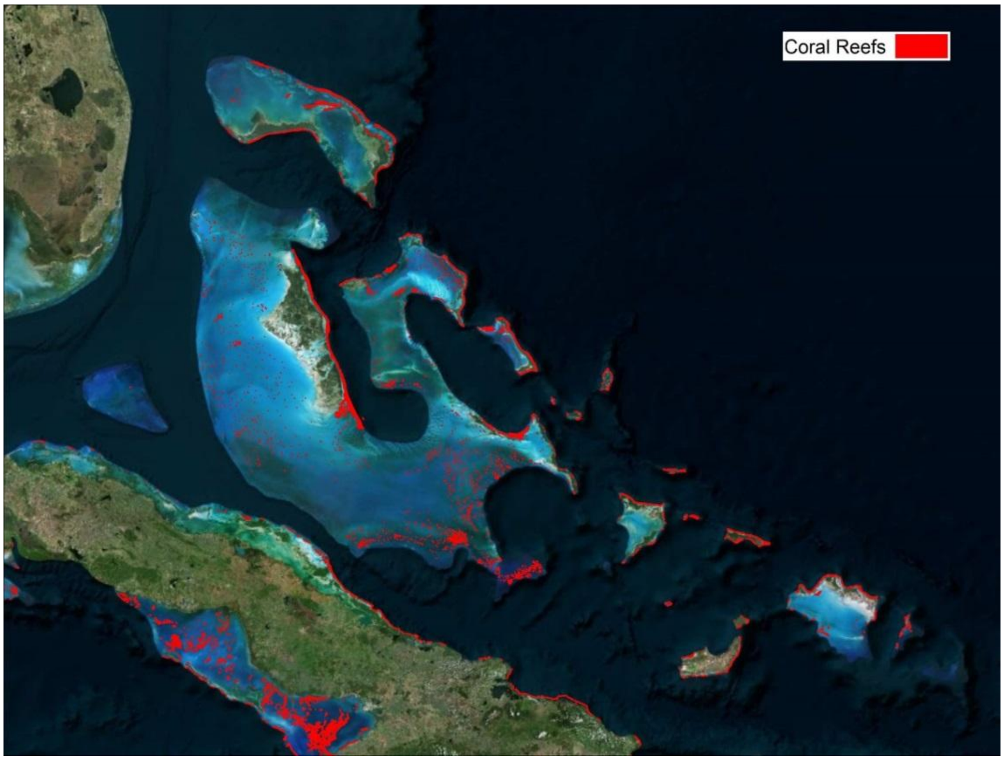


Figure 2.1. Distribution of coral reefs.

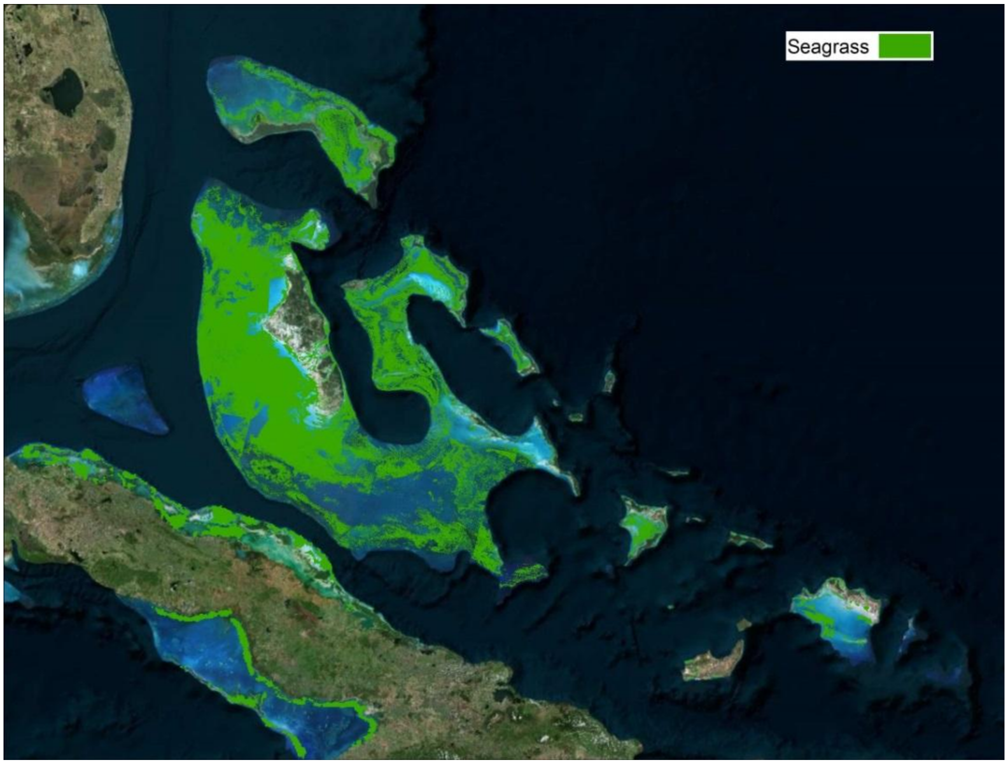


Figure 2.2. Distribution of seagrass.

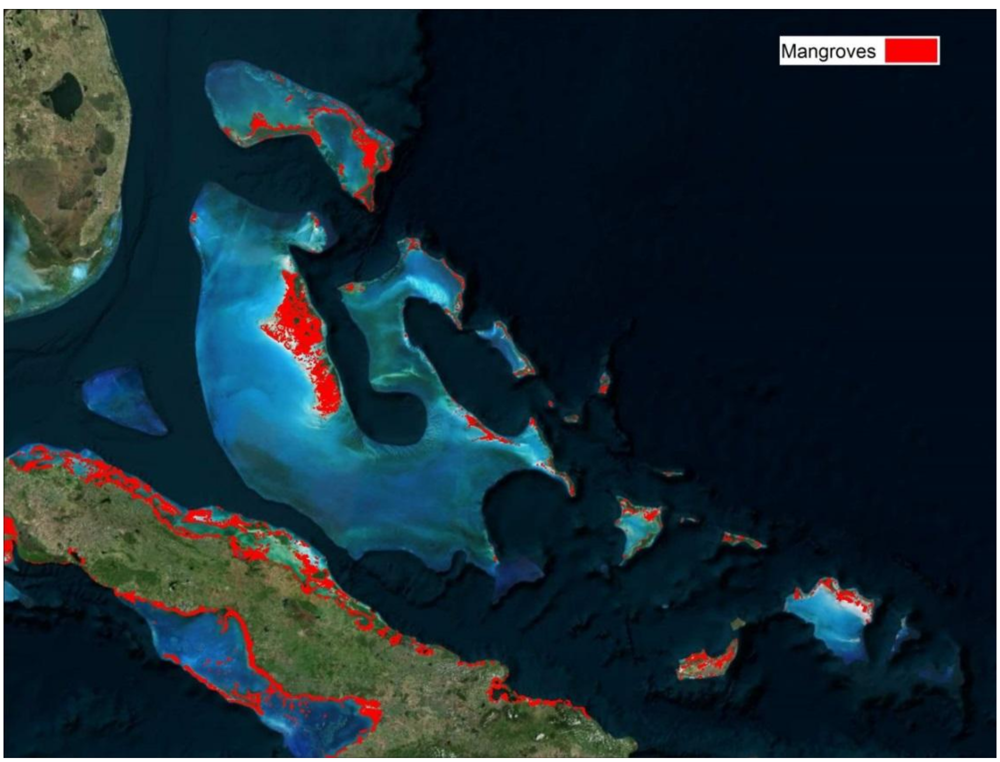


Figure 2.3. Distribution of mangroves.

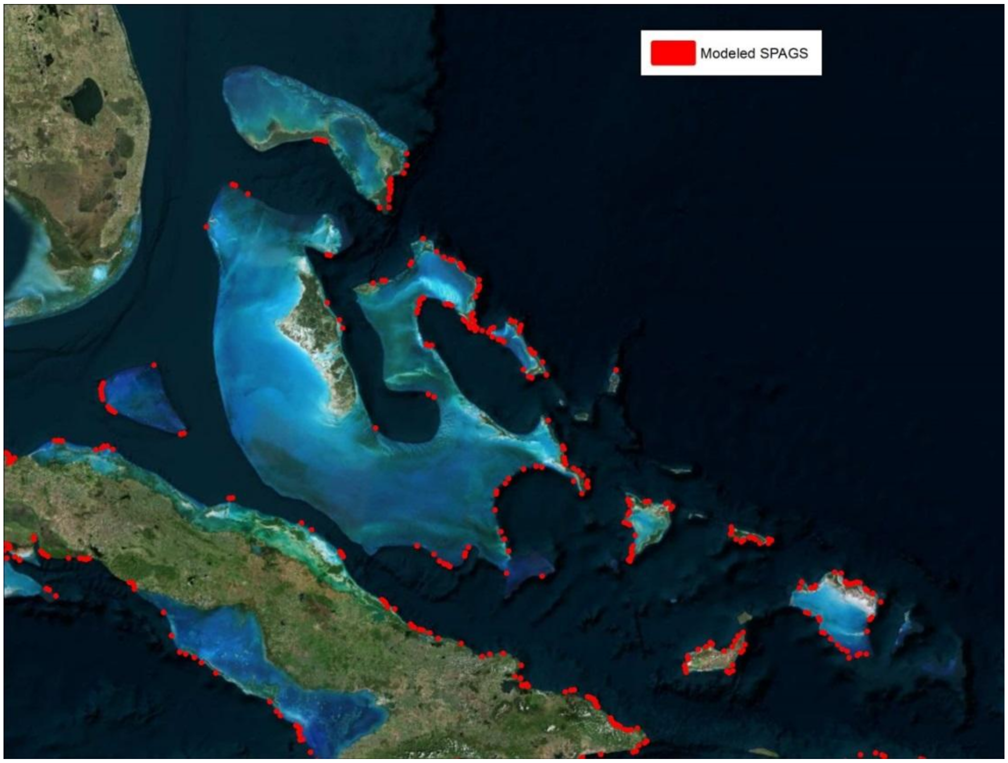


Figure 2.4. Distribution of modeled Spawning Aggregation.

Figure 2.5. Distribution of humpback whale areas.

Figure 2.6. Distribution of seabird nesting areas..

Climate Change and Sea-level rise

An estimated 1-meter sea-level rise in the Bahamas would impact approximately 5% of the land area (613 sq km). If you consider only the land that lies 1 kilometer from the ocean where most people live, the percentage goes up to 10%.

The Bahamas has an estimated 1,051 sq km of mangroves (44% would be impacted by 1-meter sea-level rise); 113 sq km of beach (16% would be impacted by 1-meter sea-level rise); and 997 sq km of coral reef.

These estimates have been calculated using the ASTER 30-meter digital elevation model and marine features mapped from satellite imagery.

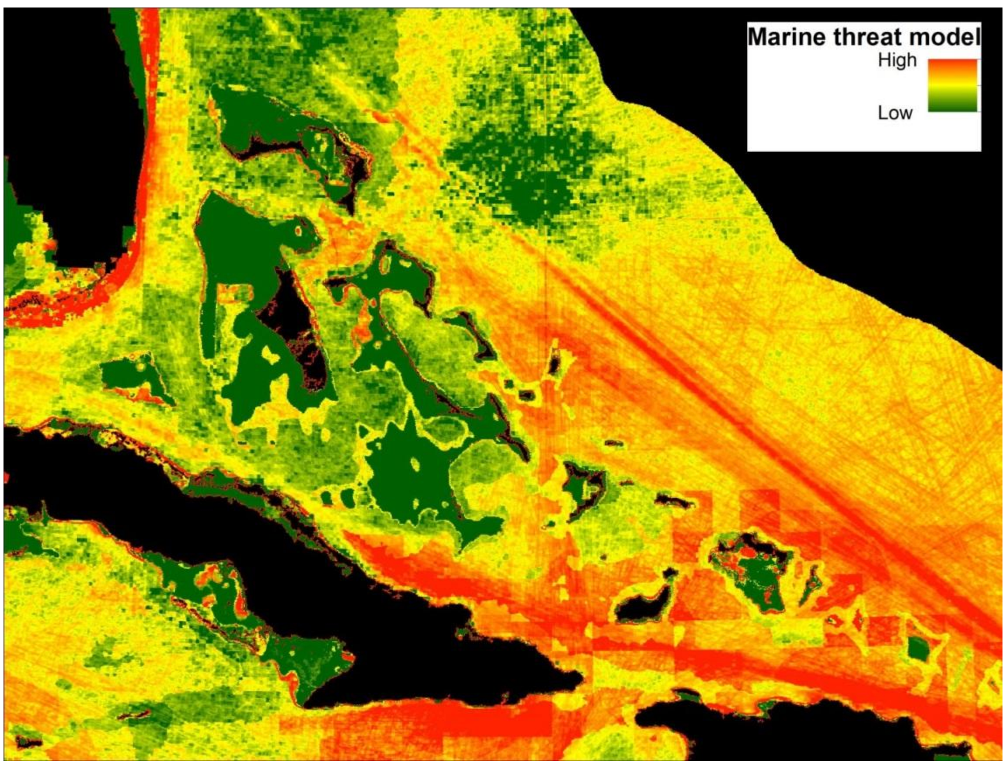


Figure 2.7. Sea level threat model.

The marine threat model in figure 2.7 represents a cumulative impact surface that was created by aggregating a variety of threat layers, using vulnerability scores to translate the threats into a metric of ecological impact. Areas of red indicate high threat, yellow indicates medium threat, and blue represents lower threat levels- or areas where the accumulation of the input threat layers was minimal. The initial baseline threat layers contained within TNC's Caribbean Conservation Information System were developed for the TNC's Caribbean Ecoregional Assessment (Huggins et al., 2007) and represent a consistent region-wide mosaic of relative human impacts on marine resources and consider coastal development, tourism expansion, sediment and pollution from inland sources, marine based pollution, and pressure on fisheries. Additional baseline threat layers came from Burke and Maiden's Reefs at Risk work in 2004. All threat layers were integrated with the 1 km cell global marine threat model developed by Halpern et al. (2008). This threat model represents the cumulative impact and corresponding marine ecosystem vulnerability scores of 17 categories of anthropogenic drivers of change developed through expert workshops and include the following:

Artisanal Fishing	Demersal Destructive Fishing	Demersal Non-Destructive, High-By catch Fishing	Demersal Non-Destructive, Low-By catch Fishing
Inorganic Pollution	Invasive Species	Nutrient Input	Ocean Acidification
Benthic Structures (Oil Rigs)	Organic Pollution	Pelagic High-By catch Fishing	Pelagic Low-By catch Fishing
Ocean-Based Pollution	Population Pressure	Commercial Activity (Shipping)	Climate Change (SST)

Literature Cited

Burke, L. and Maidens J. (2004) Reefs at Risk in the Caribbean. Washington, DC: World Resources Institute.

Halpern, BS, S Walbridge, KA Selkoe, CV Kappel, F Micheli, C D'Agrosa, et al. 2008, A global map of human impact on marine ecosystems, Science 319:948-952.

Huggins, A.E., Keel, S., Kramer, P., Núñez, K., Schill, S., Jeo, R., Chatwin, A., Thurlow, K., McPherson, M., Libby, M., Tingey, R. Palmer, M. and Seybert, R. (2007) Biodiversity Conservation Assessment of the Insular Caribbean Using the Caribbean Decision Support System, Technical Report, The Nature Conservancy.

Appendix 3.

Bathymetric and Benthic Habitat Mapping Daily Log

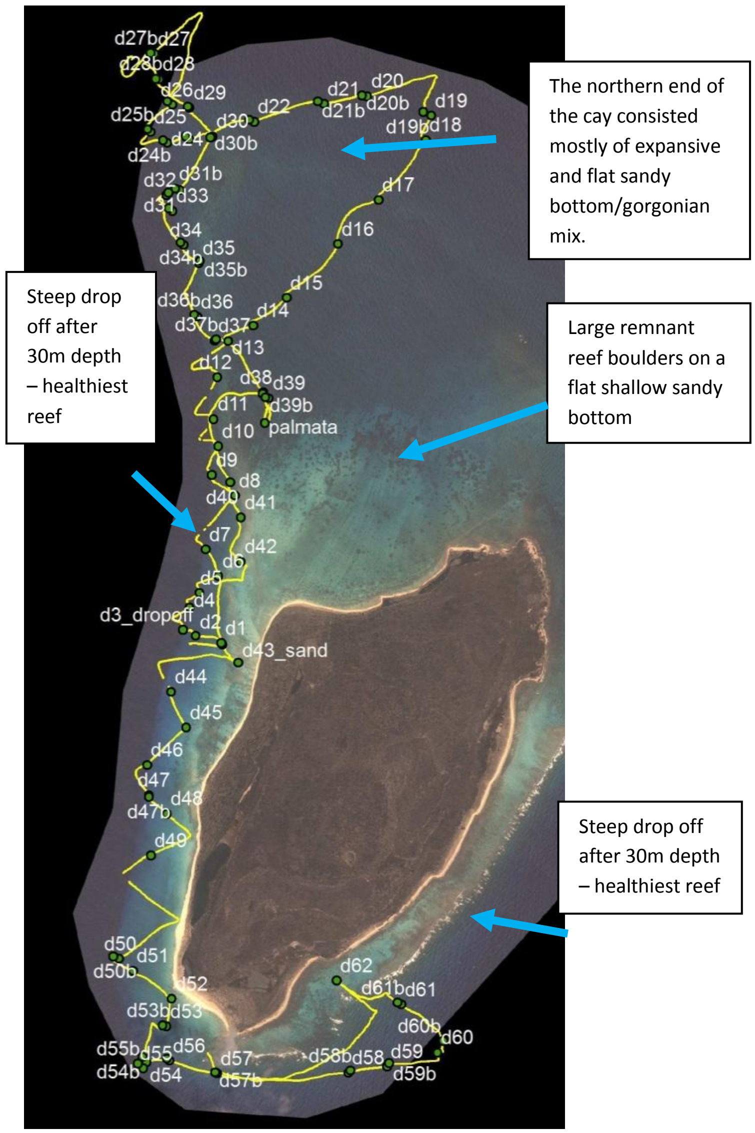
Number of Underwater video transects and Distance covered

Date	Underwater Camera Points	Km of bathymetric tracks	Area
20-Feb	62	35	West Side of West Plana
21-Feb	60	40.4	West side of Samana
22-Feb	47	52.5	East side of Samana
23-Feb	41	41.8	East Plana
24-Feb	33	28.2	East Side of West Plana
25-Feb	32	20.3	Mayaguana South
26-Feb	43	26.7	Mayaguana North
27-Feb	45	27.2	Acklins
Total	362	272.1	

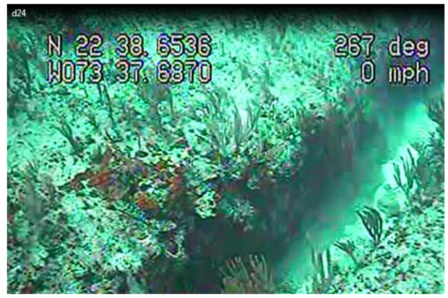
Appendix 3. continued

Bathymetric and Benthic Habitat Mapping Daily Log

Feb 20, Wednesday- The first day of surveying we started on the western side of West Plana Cay completing a total of 95 samples. We mapped a very steep sheer coral face drop off after passing the 30m depth- went down to >100+m. The healthiest coral and fish abundance occurred near the 20-30m depth range near the drop off areas. Many of these areas had deep and straight trenches where sand would accumulate and drain to deeper areas. No seagrass was observed. At the end of the day we were hit by a rogue wave from the back which drenched the equipment and shut down the laptop. Fortunately the data was rescued from the hard drive after the survey trip.



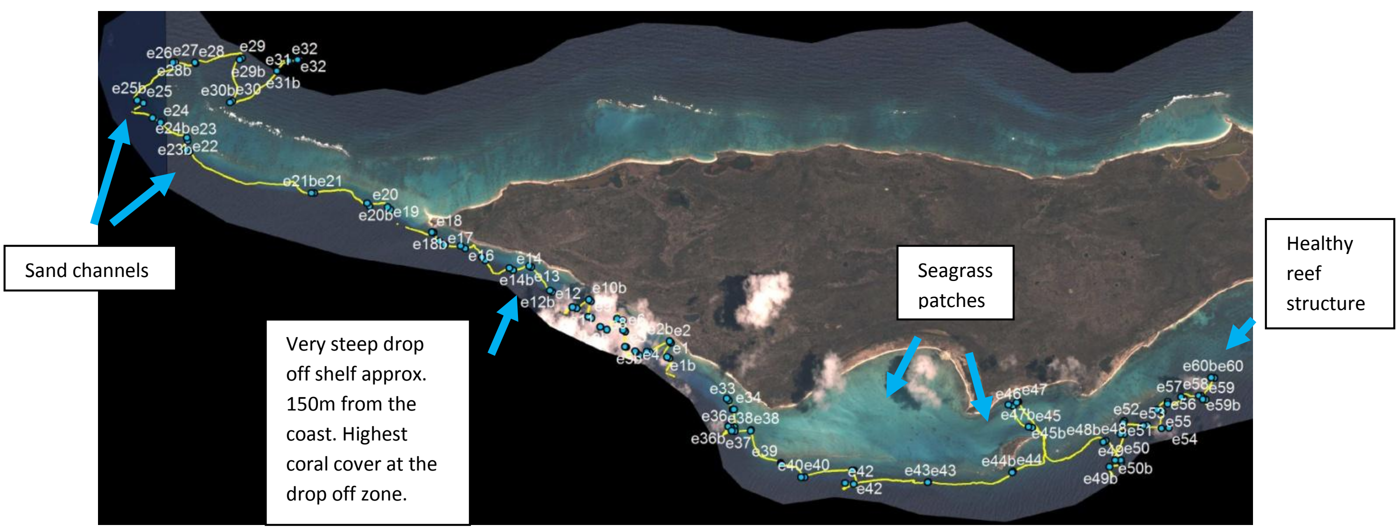
D3 – Higher coral cover at the dropoff areas



D24 – Example of a sand trench near the drop off zone

Feb 21, Thursday- Samana Cay (South and West)

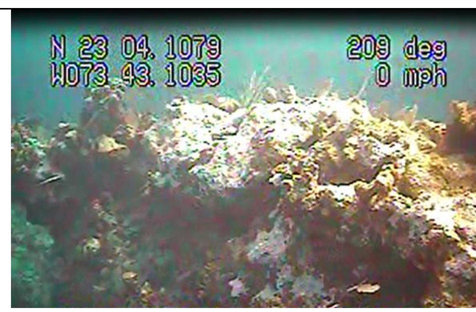
Our goal for the day was to survey the southern and western sides of Samana Cay. We started on the southwestern side of the cay where the shelf drop off was very close to the shore, occurring at approximately 150-500m away from the coast – resulting in very little shelf in this area of the cay. Similar to Plana West, coral cover and fish abundance appeared highest near the drop off zone. The submerged platform extended far out to the west where the surf and current over this submerged peninsula was very strong. We conducted surveys west along the long linear reef feature that appears to be a relic coastline of the cay. These reefs were very shallow, preventing us from being able to navigate through them due to risk of damaging the boat. The south side of this linear reef had extensive sand drainage channels leading to the drop off zone. In the afternoon, we headed back east and surveyed the southeastern side of the cay. The shallow reef crest in this area prevented us from conducting a good zig zag survey pattern, so we concentrated on the drop off areas. We discovered a few patches of seagrass in the sheltered bays on the southern side. We also snorkeled on the south side of the small island and found large relic palmata stands although they were not as extensive as those that were found on the north side of the cay. On the outer edges of the southern bay we observed mostly coral rubble and gorgonians.



E7 – Patch reef

E24 – Sand channels near drop zone

E42 – Rubble and gorgonians

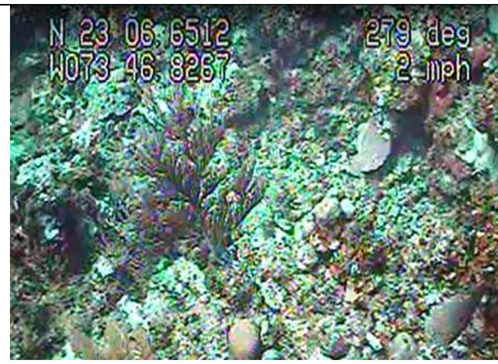


E58 –Reef structure

Feb 22, Friday- <u>Samana Cay (North and East)</u>

We started the day surveying on the west end of Samana Cay on the north side of the shallow reef crest that extends from the western point of the cay. Here we observed in the deeper areas, large areas of hard ground with abundant gorgonians. Much like East Plana Cay, the entire north side of the cay has extensive relic palmata stands. This may be due to the east-west configuration of these islands where constant ocean currents provide abundant nourishment. In the afternoon we broke the transducer arm while traveling too fast in the boat but where able to repair it with spare parts. On the eastern side of the cay we surveyed large areas of sandy bottom with occasional reef patches. We discovered a chub aggregation site near the farthest northeastern tip of the cay. The large fringing reef crest to the south preventing the boat from entering and surveying the inside of the reef. We suspected seagrass in these sheltered areas and later learned that seagrass was found in this area by the dive team.

F10 – Barjack and barracuda



F15 –Patch reef and gorgonians

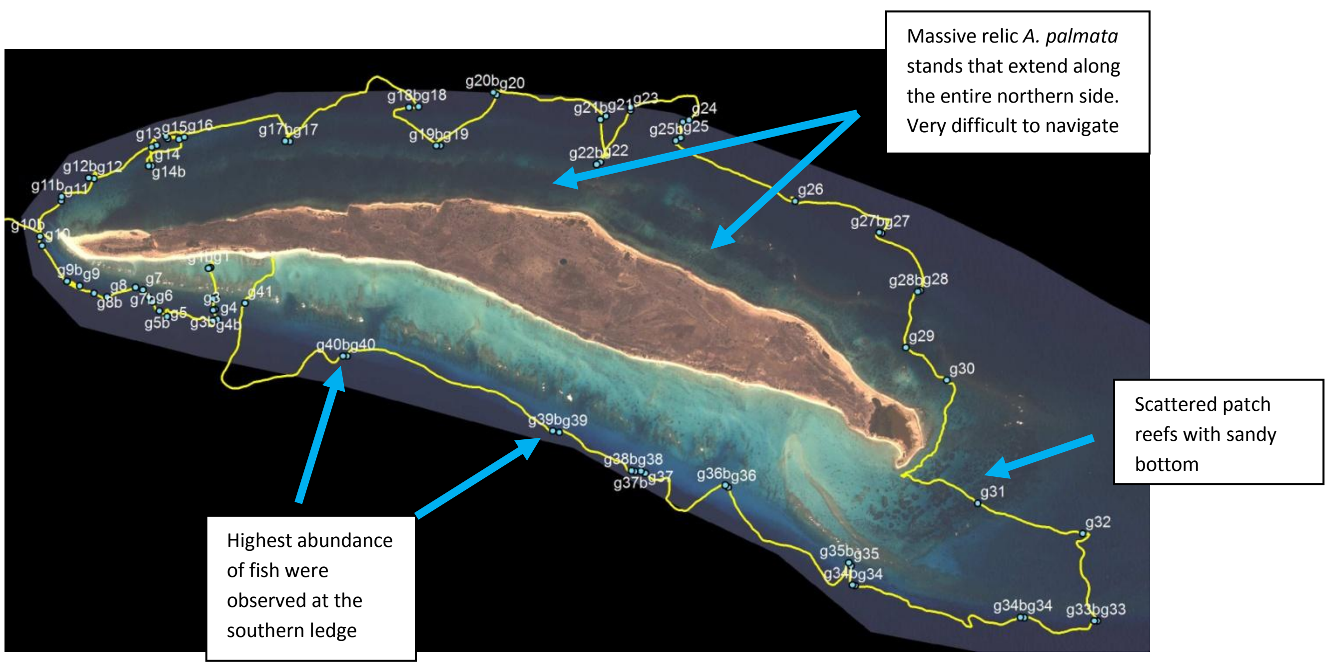
F22 – Extensive structure and channels

E38 – Chub aggregation

Shallow patch reef on the east end of Samana Cay near point f36.

Feb 23, Saturday- <u>East Plana Cay (entire island)</u>

We began the survey of East Plana Cay on the western tip on the south side. The drop off is much more distinct on the southern side of the cay. Similar to Samana Cay, we found the highest coral cover and fish abundance near the 20-30m depth just before the drop off. In the inside of the reef we observed scattered patch reef and sandy bottom with depths less than 10m. At the most western point, there was a strong north current and we observed worn coral structure with gorgonians/sponges. The north side of the island is very different, having a large swath (approximately 1km) of massive relic palmata stands that extends nearly the entire length of the cay. These dense reef structures almost look like old growth forests and extend vertical from 10-15m depths, with some reefs reaching out of the water at lower tides. The reefs are largely dead with sporadic resheeting and outgrowths but the structure is impressive. The dense and shallow nature of these reefs prevented the boat from entering this area. Near point G15 we saw a tiger shark swim past our camera (estimated to be 6-7 ft). Compared to the sharp drop off on the south side of the cay, the northern side has a gradual drop off. On the eastern side we maneuvered through a mine field of patch reefs where occasional coral was exposed above the water. We anchored the boat on the eastern tip and snorkeled to shore – there we observed evidence of abundant hutias in and around the mangroves surrounding the salt pond.



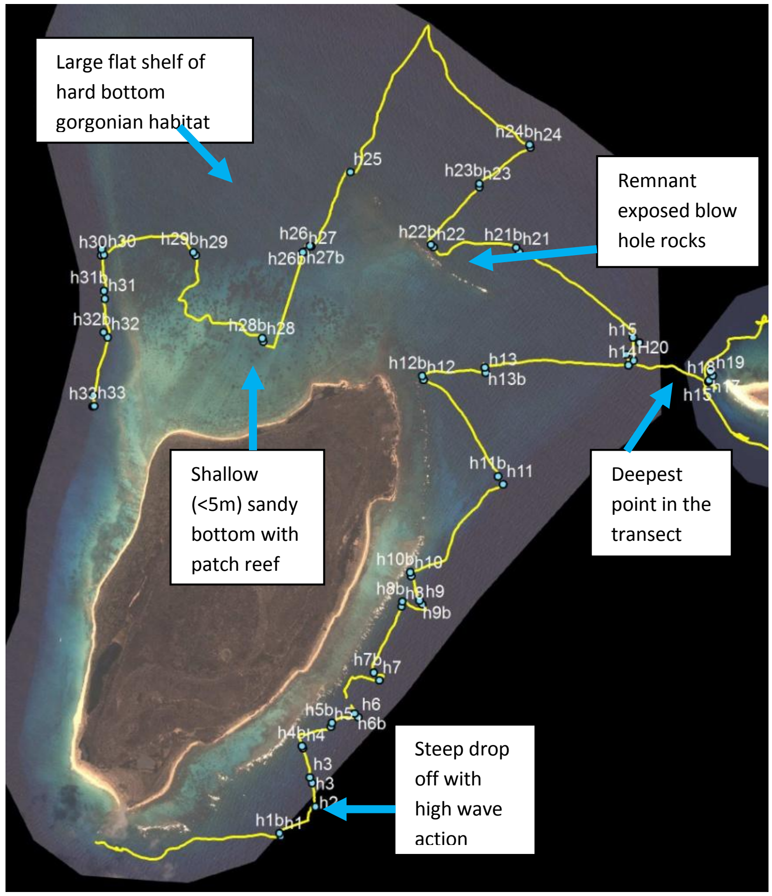
G12 – Worn reef structure and gorgonians

G15 – Tiger shark

G31 – Patch reef with gorgonians on east end

G39 – Reefs near the southern drop off

Feb 24, Sunday- Eastern side and northern end of West Plana



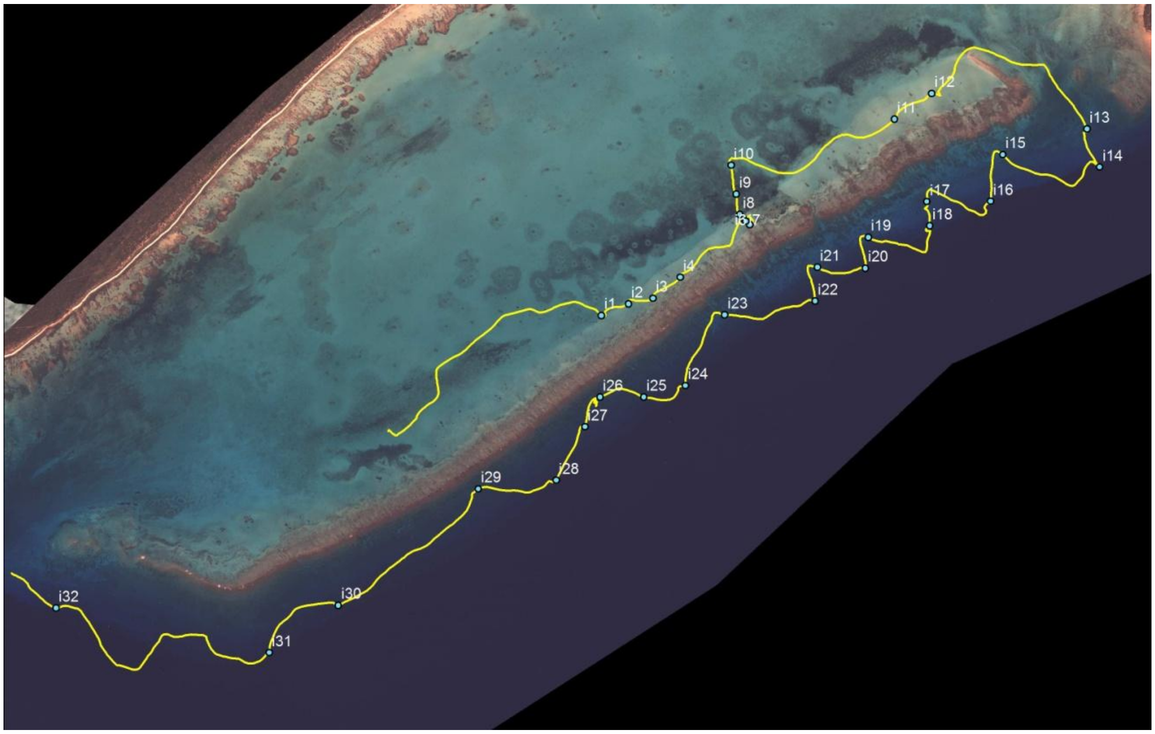
Our objective this day was to finish surveying the eastern side and northern end of West Plana. We also surveyed the trench between the West and East Plana Cays in order to obtain a good bathy profile. We tried to enter inside the reef crest on the western side of West Plana for a survey closer to the shore, but there were too many shallow reefs and our captain did not want to attempt it due to the rough surf. The bathy transect we delineated between the two cays showed a gradual drop off heading east from West Plana with depths of >100m only 500m from the western tip of East Plana. Around noon we realized that the transducer had stopped recording to the hard drive for the past two hours so we resurveyed the bathy transect between the islands and collected more video samples along the drop off points where we were looking specifically for evidence of any spawning aggregation sites. We saw several bar jacks and barracuda in this area. The benthic habitat in these areas was mostly hard bottom with algae and reef rubble along the ridge. Just northeast of West Plana there is very interesting rocky outcrop island remnant that has been eroded away by the pounding waves that cause regular blow hole eruptions. We ended the day surveying the northeastern side of West Plana Cay in the lagoon where there was a large sandy shelf with scattered patch reef and boulders. Afterwards, we maneuvered out of the lagoon, and skirted along the ledge, collecting samples as we headed back along the Eastern coast of West Plana and towards the ship.

H2 – Reef structure near the drop off on east side of West Plana	H14 – Reef and soft corals near western tip of East Plana
 H18 - Reef near the western tip of East Plana	 H33 – Reef near the drop off on west side of West Plana

Narrow exposed rock with blow hole on northeastern side of West Plana Cay.

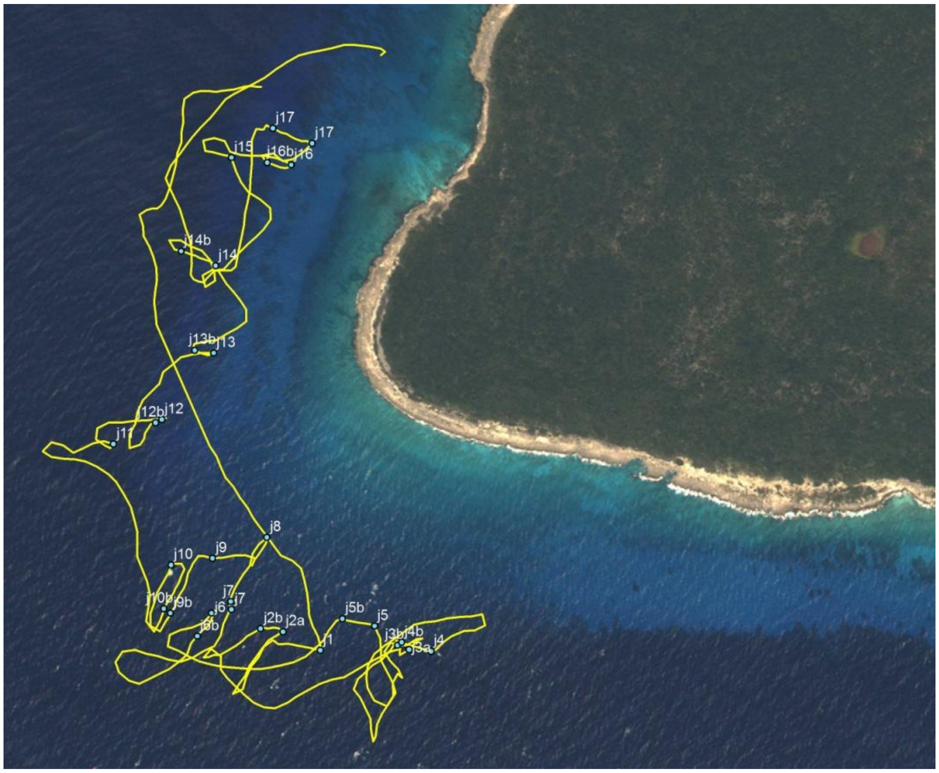
Feb 25, Monday- Mayaguana – Abraham's Bay

We spent the afternoon surveying at Abraham's Bay. We were only able to work a half day since John arrived at 12:30pm. Upon studying the imagery, we saw what appeared to be seagrass in the imagery and verified its existence after we surveyed the eastern side of the lagoon, close to the reef crest. The water is very calm in this area as the large reef crest protects the bay from the waves. After collecting a few samples in the shallow lagoon we headed out of the channel at the eastern edge of the lagoon and sampled the ledge profile, right along the reef crest and along the shelf drop off.

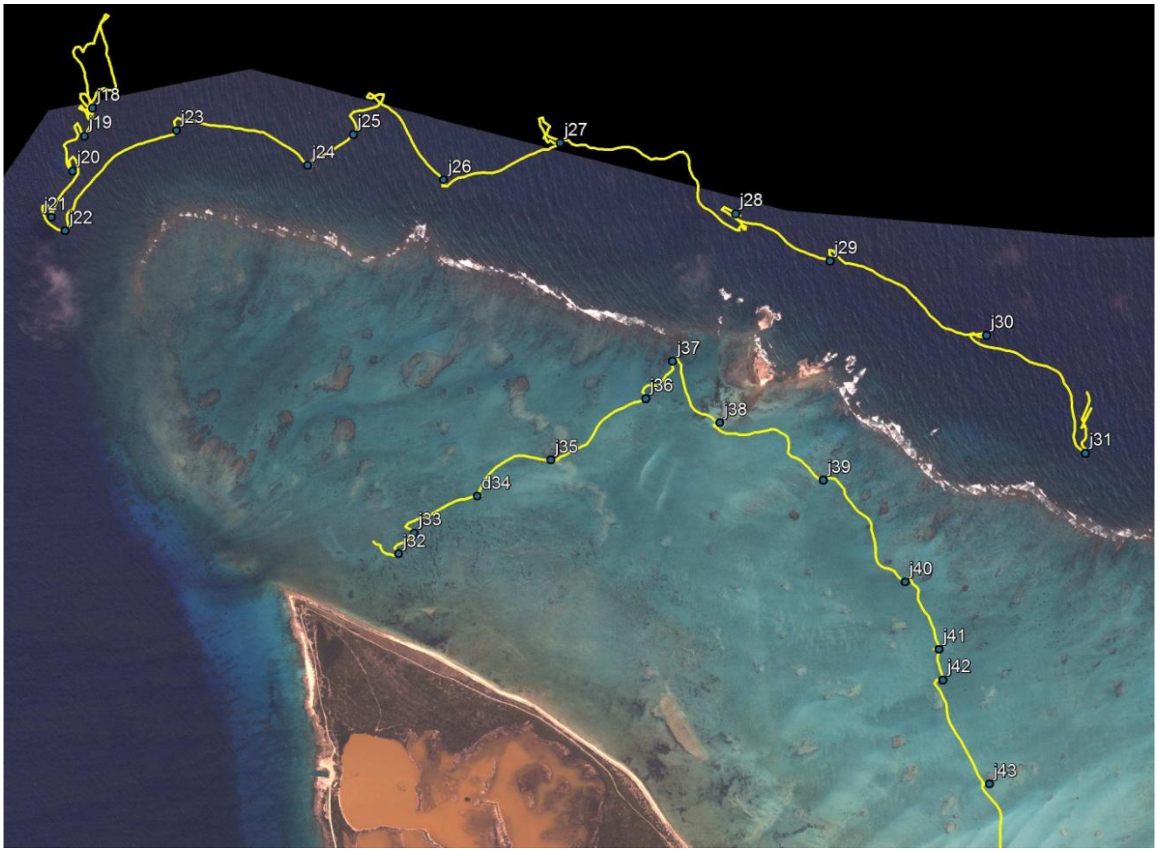


Feb 26,Tuesday- Mayaguana (West coast)

We started the day surveying at the southern tip of the West coast of Mayaguana because the day before the dive team had observed grouper spawning behavior in this area. We surveyed the ledge and saw several fish, but the cable for the underwater video camera was only 30 meters long so we were unable to tell what type of fish we were seeing. The seas here were extremely rough and once we were satisfied with our efforts we headed up north to survey the northern tip of the west coast. Here, we sampled a vertical profile of the ledge that sticks out to the northwest, then we headed east and surveyed inside the lagoon. Once in the lagoon, we identified some sea grass and algae as well as some patch reef coral.



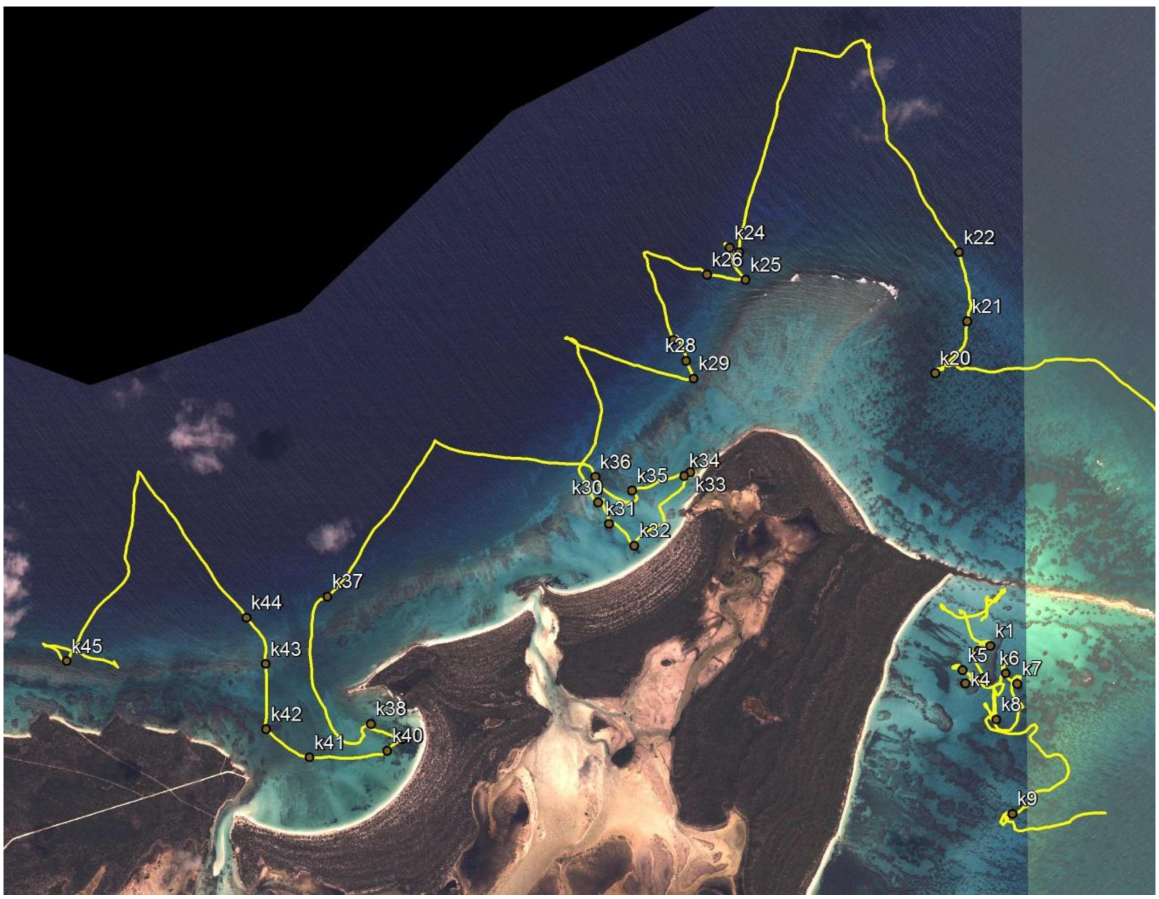
Surveys collected for the southwest corner of <u>Mayaguana</u>



Surveys conducted for the northwest corner of <u>Mayaguana</u>

Feb 27, Wednesday- Acklins East Coast

We started the survey on the east coast of Acklins, sampling in shallow areas where we expected to find seagrass. In this lagoon we found seagrass, algae, and both hard and soft corals. We then surveyed a profile of the ledge, going beyond the 30m drop off, then headed back around to the northern side of the island. We surveyed in a large V-transect pattern until we arrived at the first shallow bay where we collected more seagrass and algae points. We then surveyed away from the shore, collecting points until it became too deep for the underwater camera. At Acklins, we observed overall higher fish abundance and the dive team later verified that this island had the most fish and diversity seen at all sites during this trip. This is most likely attributed to the fact that there are so many tidal streams/nursery areas and interconnectivity from one side of the island to the other.



Appendix 4.

Southern Bahamas Rapid Ecological Assessment: Terrestrial

Ethan H. Freid Ph.D.
Botanist, Bahamas National Trust

The terrestrial survey of the Southern Bahamas REA was conducted to assess general plant diversity, habitat type and structure, coastal quality assessment, invasive plant status as well as any general information that may be of future use (hutia, birds, blueholes). The surveys and this report focused on East and West Plana Cay and Samana Cay.

METHODOLOGY

To record the vascular plant diversity walking transects were conducted. Along the transect line as new species were encountered and identified they were recorded. Additionally, as the transect line crossed through different habitat types they were documented and digital images taken. For future land cover mapping projects Waypoints were taken (Garmin 60 CSX in UTM coordinates) in different habitat types, the type recorded and digital images taken. Vegetation nomenclature is based on Areces et al. 1999. Vascular plant taxonomy is based on Correll and Correll 1982. Along the shoreline as dune systems were observed a qualitative assessment of sea turtle nesting habitat was noted.

Literature Cited

Areces-Mallea, A. E., A. E. Weakley, X. Li, R.G. Sayre, J. D. Parrish, C. V. Tipton, and T. Boucher. 1999. *A guide to Caribbean vegetation types: Preliminary classification systems and descriptions*. The Nature Conservancy, Arlington, VA.

Clough, G. C. and G. Fulk. 1971. The vertebrate fauna and the vegetation of East Plana Cay, Bahama Islands. Atoll Research Bulletin. No, 138. The Smithsonian Institution.

Correll, D.S. and H. B. Correll. 1982. *The Flora of the Bahama Archipelago*, Strauss and Cramer, Germany.

West Plana Cay

Total transect time: 8.5 hours

Species

58 vascular plant species were observed (See Table 1)

Habitats

Coastal

Coccothrinax argentata woodlands

Uniola paniculata herbland

DBEF-S/DS

Mixed species Shrubland

Erithalis fruticosa shrubland

Strumpfia maritima dwarf shrubland

Wetlands

Laguncularia racemosa Shrubland

Rhizophora mangle Shrubland

Batis/Sporobolus/Salicornia herbland

Discussion

There are no invasive plants on the island but there are goats, chickens, and at least one dog

The vegetation is in good condition despite the presence of the goats. Based on the vegetation the goats are a relatively recent introduction

The coastline vegetation and structure is intact but not great for sea turtles except for a few locations on the western and eastern sides of the island. IN other areas there are good dunes but they are very steep.

Over all diversity is good but only one day of surveying so likely higher than what was observed.

There are blueholes that show connection to the sea.

The island is frequented by fishermen and cascarilla barkers.

A wetland on the southern side had a group of 7 Flamingos (4 adults and 3 juveniles)

EAST PLANA CAY

Total transect time: 18 hours

Species

44 vascular plant species were observed (Table 1)

Habitats

Coastal

Ambrosia hispida herbland

Rocky shore

Coccothrinax argentata woodlands

DBEF

Shrubland (mixed species)

Dwarf Shrubland (*Strumpfia maritima* or *Croton/Foresteria* or *Phyllanthus epiphyllanthus* dominated)

Wetland

Avicennia germinans Shrubland

Batis maritima herbland

Discussion

The Hutia are alive and well.

There are no invasive plants

No other non-native animals

The vegetation is intact but diversity is lower than comparable islands. Habitats are homogenous. Habitats the same as Clough and Fulk 1971 but I observed 18 species they did not (Table 2). This is likely due to the surveyors in the late 1960's notbeing trained botanists or widely familiar with the species of the Bahamas rather than changes in the flora of the island.

No dune with low slope toward ocean and all have exposed rock along waters edge

Blueholes: lots of blue holes many connected to the ocean. One had shrimp in it.

A wetland on the northern edge had a single flamingo in it.

SAMANA CAY

Total transect time: 17 hours

Species

116 vascular plant species were observed (Table 1)

Habitats

Coastal

Uniola paniculata herbland

Rocky Shore

DBEF

Open pavement: exposed flat limestone. Typically high in cacti.

Forest/Shrubland (mixed species)

Wetlands

Conocarpus erectus Shrubland/Woodland

Laguncularia racemosa shrublands

Discussion

Vegetation is in great condition

No invasive plants

Shoreline has great beaches for sea turtle nesting. Eugene said no turtles come up on the beach but another person Leonard says that yes they do come up in the spring and they collect the eggs from them

Continuous humans on island collecting cascarilla bark

Caves at least one (Figure 4.13), with a story about a possible second cave site.

Figure 4.1: *Coccothrinax argentata* woodland on West Plana Cay

Figure 4.2: *Uniola paniculata* herbland (Dune) on West Plana Cay

Figure 4.3: Dry Broadleaf Evergreen Formation – Shrubland (mixed species) on West Plana Cay.

Figure 4.4*: Laguncularia racemosa* Shrubland surrounding wetland on West Plana Cay

Figure 4.5: wetland with *Batis maritima, Sporobolus virginicus* on West Plana Cay

Figure 4.6: *Ambrosia hispida* herbland on East Plana Cay

Figure 4.7: *Avicennia germinans* Shrubland at edge of over wash pond on East Plana Cay

Figure 4.8: Rocky shore with *Strumpfia maritima* shrubs on East Plana Cay

Figure 4.9: Dry Broadleaf Evergreen Formation – Shrubland with sparse *Coccothrinax argentata* woodland in background on East Plana Cay

Figure 4.10: Dry Broadleaf Evergreen Formation Shrubland/Dwarf Shrubland on East Plana Cay.

Figure 4.11: *Uniola paniculata* herbland on Samana Cay

Figure 4.12: Dry Broadleaf Evergreen Formation – Forest/Shrubland (Coppice) on Samana Cay.

Figure 4.13: Cave on Samana Cay

Family	Genus	Specific Epithet	E. PLANA	W. PLANA	SAMANA
Aizoaceae	*Sesuvium*	*portulacastrum*			X
Amaryllidaceae	*Hymenocallis*	*arenicola*	X		X
Anacardiaceae	*Metopium*	*toxiferum*	X		X
Apocynaceae	*Angadenia*	*sagraei*		X	X
Apocynaceae	*Urechites*	*lutea*			X
Arecaceae	*Coccothrinax*	*argentata*	X	X	X
Arecaceae	*Cocos*	*nucifera*		X	X
Arecaceae	*Leucothrinax*	*morrisii*			X
Aristolochiaceae	*Aristolochia*	*pentandra*	X		
Asclepiadaceae	*Metastelma*	*sp.*	X		X
Asphodelaceae	*Aloe*	*vera*			X
Asparagaceae	*Agave*	*sisilana*			X
Asteraceae	*Ambrosia*	*hipida*	X	X	X
Asteraceae	*Bidens*	*alba*			X
Asteraceae	*Borrichia*	*arborescens*	X		X
Asteraceae	*Conzya*	*canadensis*			X
Asteraceae	*Eupatorium*	*villosum*			X
Asteraceae	*Gundlachia*	*corymbosa*		X	X
Asteraceae	*Iva*	*imbricata*			X
Asteraceae	*Pluchea*	*symphytifolia*			X
Asteracaee	*Wedelia*	*bahamensis*	X		
Avicenniaceae	*Aviceniia*	*germinans*	X		X
Bataceae	*Batis*	*maritima*	X	X	
Bignoniaceae	*Tabebuia*	*bahamensis*			X
Boraginaceae	*Argusia*	*gnaphlodes*		X	X
Boraginaceae	*Bourreria*	*succulenta*			X
Boraginaceae	*Cordia*	*bahamensis*			X
Boraginaceae	*Cordia*	*brittonii*			X
Boraginaceae	*Heliotropium*	*nanum*		X	
Boraginaceae	*Tournefortia*	*volubilis*	X		X
Brassicaceae	*Capparis*	*cynophallophora*		X	X
Brassicaceae	*Capparis*	*flexuosa*	X		
Brassicaceae	*Cakile*	*lanceolata*	X		X
Bromeliaceae	*Tillandsia*	*circinnata*			X
Bromeliaceae	*Tillandsia*	*flexuosa*			X
Bromeliaceae	*Tillandsia*	*utriculata*		X	X
Burseraceae	*Bursera*	*simaruba*			X
Buxaceae	*Buxus*	*bahamensis*	X	X	
Cactaceae	*Cephalocereus*	*millspaughii*	X	X	X
Cactaceae	*Consolea*	*nashii*			X
Cactaceae	*Melocactus*	*intortus*	X		X
Cactaceae	*Opuntia*	*stricta*	X	X	X
Canellaceae	*Canella*	*winterana*			X
Celestaceae	*Crossopetalum*	*rhacoma*		X	X
Chenopdiaceae	*Salicornia*	*virginica*	X	X	
Combretaceae	*Conocarpus*	*erectus*	X	X	X
Combretaceae	*Laguncularia*	*racemosa*	X	X	
Combretaceae	*Terminalia*	*catapa*			X

Table 4.1: Vascular plants observed on East and West Plana Cays and Samana Cay

Family	**Genus**	**Specific Epithet**	**E. PLANA**	**W. PLANA**	**SAMANA**
Convolvulaceae	*Cuscuta*	*sp.*		X	
Convolvulaceae	*Evolvulus*	*squamosus*	X	X	X
Convolvulaceae	*Ipomoea*	*alba*			X
Convolvulaceae	*Ipomoea*	*pes-capre*		X	
Convolvulaceae	*Ipomoea*	*sp.*	X		
Convolvulaceae	*Jacquemontia*	*cayensis*			X
Convolvulaceae	*Jacquemontia*	*havanensis*		X	X
Cyperaceae	*??*	*sp.*		X	X
Cyperaceae	*??*	*sp.*		X	X
Cyperaceae	*Abildgaardia*	*ovata*	X		X
Cyperaceae	*Fimbrystylis*	*spathacea*			X
Ebenaceae	*Diospyrus*	*crassinervis*			X
Erythroxylaceae	*Erythroxylum*	*rotundifolium*	X	X	X
Euphorbiaceae	*Argythamnia*	*candicans*			X
Euphorbiaceae	*Chaemacyse*	*mesembrianthemifolia*	X		X
Euphorbiaceae	*Croton*	*eleuteria*		X	X
Euphorbiaceae	*Croton*	*linearis*	X	X	X
Euphorbiaceae	*Croton*	*lucidus*	X	X	X
Euphorbiaceae	*Euphorbia*	*sp.*			X
Euphorbiaceae	*Gymnanthes*	*lucida*			X
Euphorbiaceae	*Hippomane*	*mancinella*	X	X	
Euphorbiaceae	*Pedilianthus*	*tithymaloides ssp. bahamensis*			X
Euphorbiaceae	*Phyllanthus*	*epiphyllanthus*	X	X	X
Fabaceae	*Acacia*	*choriophylla*		X	X
Fabaceae	*Caesalpinia*	*bonduc*		X	X
Fabaceae	*Caesalpinia*	*bahamensis*		X	X
Fabaceae	*Canavalia*	*rosea*			X
Fabaceae	*Cassia*	*lineata*	X		X
Fabaceae	*Cassia*	*sp.*			X
Fabaceae	*Crotalaria*	*retusa*	X		
Fabaceae	*Lysiloma*	*latissiliquum*			X
Fabaceae	*Pithecellobium*	*keyense*		X	X
Fabaceae	*Rhynchosia*	*minima*			X
Fabaceae	*Sophora*	*tomentosa*	X		
Fabaceae	*Stylosanthes*	*hamata*			X
Goodeniaceae	*Scaevola*	*plumieri*			X
Lauraceae	*Cassytha*	*filiformis*		X	X
Lamiaceae	*Salvia*	*serotina*	X		
Malvaceae	*Gossypium*	*hirsutum*			X
Meliaceae	*Sweitenia*	*mahagonii*		X	
Moraceae	*Ficus*	*citrifolia*	X	X	X
Myrtaceae	*Eugenia*	*axillaris*			X
Myrtaceae	*Eugenia*	*foetida*	X	X	X
Myrtaceae	*Psidium*	*longipes*		X	X
Nyctaginaceae	*Guapira*	*discolor*		X	X
Oleaceae	*Forestieria*	*segregata*	X	X	X
Orchidaceae	*Encyclia*	*altissima*			X

Table 4.1 continued: Vascular plants observed on East and West Plana Cays and Samana Cay

Family	Genus	Specific Epithet	E. PLANA	W. PLANA	SAMANA
Passifloraceae	*Passiflora*	*cuprea*			X
Passifloraceae	*Passiflora*	*pectinata*			X
Passifloraceae	*Passiflora*	*subera*			X
Poaceae	*??*	*sp.*		X	X
Poaceae	*Cenchrus*	*incertus*			X
Poaceae	*Dactyloctenium*	*aegyptium*			X
Poaceae	*Eleusine*	*indica*			X
Poaceae	*Lpetochloopsis*	*virgtata*			X
Poaceae	*Spartina*	*patens*		X	
Poaceae	*Sporobolus*	*domingensis*			X
Poaceae	*Sporobolus*	*virginicus*		X	X
Poaceae	*Uniola*	*paniculata*		X	X
Polygonaceae	*Coccoloba*	*diversifolia*			X
Polygonaceae	*Coccoloba*	*uvifera*			X
Polypodiaceae	*Cheilanthes*	*microphylla*			X
Polypodiaceae	*Nephrolepsis*	*sp.*			X
Portulacaceae	*Portulaca*	*sp.*			X
Rhamnaceae	*Ziziphus*	*taylorii*		X	
Rhizophoraceae	*Rhizophora*	*mangle*		X	
Rubiaceae	*Antirhea*	*myrtifolia*	X	X	
Rubiaceae	*Catesbaea*	*parviflora*			X
Rubiaceae	*Erithalis*	*fruticosa*		X	X
Rubiaceae	*Erithalis*	*salmeoides*		X	
Rubiaceae	*Rachicallis*	*americana*			X
Rubiaceae	*Strumpfia*	*maritima*	X	X	X
Rutaceae	*Amyris*	*elemifera*			X
Rutaceae	*Zanthoxylon*	*corciaceum*			X
Rutaceae	*Zanthoxylon*	*flavum*			X
Sapindaceae	*Dodonaea*	*ehrenbergii*		X	X
Sapindaceae	*Hypelate*	*trifoliata*		X	X
Sapindaceae	*Thounia*	*discolor*			X
Sapotaceae	*Sideroxylon*	*americana*		X	X
Scrophulariaceae	*Capraria*	*biflora*	X		
Scrophulariaceae	*Stemodia*	*maritima*	X		
Simaroubaceae	*Picramnia*	*pentandra*		X	
Smillaceae	*Smilax*	*havanensis*			X
Sterculiaceae	*Helicteres*	*jamaicensis*		X	X
Sterculiaceae	*Melochia*	*tomentosa*			X
Sterculiaceae	*Waltheria*	*indica*			X
Surianiaceae	*Suriana*	*maritima*	X	X	X
Theophrastaceae	*Jacquinia*	*keyensis*			X
Tiliaceae	*Corchorus*	*hirsutus*		X	X
Turneraceae	*Turnera*	*diffusa*			X
Turneraceae	*Turnera*	*ulmifolia*			X
Ulmaceae	*Trema*	*lamarckianum*	X		
Verbenaceae	*Lantana*	*involucrata*	X	X	X
Vitaceae	*Cissus*	*trifoliata*	X		

Table 4.1 continued: Vascular plants observed on East and West Plana Cays and Samana Cay

Family	**Genus**	**Specific Epithet**	**Clough/Fulk 1971**	**Freid 2013**
Amaryllidaceae	*Hymenocallis*	*arenicola*	X	X
Anacardiaceae	*Metopium*	*toxiferum*		X
Arecaceae	*Coccothrinax*	*argentata*	X	X
Aristolochiaceae	*Aristolochia*	*pentandra*		X
Asclepiadaceae	*Metastelma*	*sp.*	X	X
Asteraceae	*Ambrosia*	*hipida*	X	X
Asteraceae	*Borrichia*	*arborescens*		X
Asteraceae	*Wedelia*	*bahamensis*		X
Avicenniaceae	*Aviceniia*	*germinans*		X
Bataceae	*Batis*	*maritima*	X	X
Boraginaceae	*Tournefortia*	*volubilis*		X
Brassicaceae	*Cakile*	*lanceolata*	X	X
Brassicaceae	*Capparis*	*flexuosa*		X
Buxaceae	*Buxus*	*bahamensis*		X
Cactaceae	*Cephalocereus*	*millspaughii*	X	X
Cactaceae	*Melocactus*	*intortus*	X	X
Cactaceae	*Opuntia*	*stricta*	X	X
Chenopdiaceae	*Salicornia*	*virginica*		X
Combretaceae	*Conocarpus*	*erectus*	X	X
Combretaceae	*Laguncularia*	*racemosa*		X
Convolvulaceae	*Evolvulus*	*squamosus*	X	X
Convolvulaceae	*Ipomoea*	*sp.*	X	X
Cyperaceae	*Abildgaardia*	*ovata*		X
Erythroxylaceae	*Erythroxylum*	*rotundifolium*		X
Euphorbiaceae	*Chaemacyse*	*mesembrianthemifolia*	X	X
Euphorbiaceae	*Croton*	*linearis*	X	X
Euphorbiaceae	*Croton*	*lucidus*	X	X
Euphorbiaceae	*Hippomane*	*mancinella*		X
Euphorbiaceae	*Phyllanthus*	*epiphyllanthus*	X	X
Fabaceae	*Cassia*	*lineata*		X
Fabaceae	*Crotalaria*	*retusa*		X
Fabaceae	*Sophora*	*tomentosa*	X	X
Lamiaceae	*Salvia*	*serotina*	X	X
Moraceae	*Ficus*	*citrifolia*	X	X
Myrtaceae	*Eugenia*	*foetida*		X
Oleaceae	*Forestieria*	*segregata*	X	X
Rubiaceae	*Antirhea*	*myrtifolia*	X	X
Rubiaceae	*Strumpfia*	*maritima*	X	X
Scrophulariaceae	*Capraria*	*biflora*	X	X
Scrophulariaceae	*Stemodia*	*maritima*		X
Surianiaceae	*Suriana*	*maritima*	X	X
Ulmaceae	*Trema*	*lamarckianum*	X	X
Verbenaceae	*Lantana*	*involucrata*	X	X
Vitaceae	*Cissus*	*trifoliata*		X

Table 4.2: List of species observed on East Plana Cay by Clough and Fulk 1971 in comparison to current survey.

Appendix 5.

Overview of the Geology of the Southeastern Bahamas, with particular focus on the Plana and Samana Cays

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While considerable investigations have been carried out to understand the geology of the Bahamas, most of that effort has been concentrated on the northern Bahamas. The northern Bahamas region contains massive large banks with elongated and high islands typically occurring along their eastern margins. These large banks act as carbonate factories shedding sediments and building out large islands like Andros and Abaco to the west. In contrast, the southern Bahamas contains small carbonate banks that are narrow and more scalloped shaped with multiple reentrants. The islands are smaller and typically occupy a much larger portion of the banks that most typically form just a narrow fringe around the islands themselves.

One reason for the difference between the geology of northern and southern Bahamas is thought to be from the influence of tectonics. Although the entire southern Bahamas sits on the passive margin of the North American plate, the boundary with the Caribbean plate is within two hundred km of the southern Bahamas. Investigations by Mullins et al. 1992 around the submerged banks - Mouchoir and Navidad, which are within 50 km of the plate boundary has revealed major tectonic influences resulting in erosion and collapse over time. However, until recently, these plate boundary influences were thought to be fairly localized to the southern Turks and Caicos and not of great importance to the southern Bahamas.

In 2011, Kindler et al. found that the northern edge of the island of Mayaguana contains the oldest exposed surface rocks ever found in the entire Bahamas archipelago dating to the Miocene - over 17 million years ago. In contrast, most other islands of the Bahamas only contain Holocene and Pleistocene rocks dating to less than 1 million years old and Miocene aged rocks are often buried dozens to hundreds of meters below sea level. They concluded that that Mayaguana has undergone differential subsidence and tilting to the south leading to these older rocks being exposed. A large fault was found parallels the northern edge of Mayaguana along with noticeable reentrants. Bathymetric data from this region shows a shallow linear ridge marking the fault line extending from the northern edge of Mayaguana to the northwest to the northern edge of west Plana up to the northern tip of Acklins Island. A line of exposed rocks on West Plana several km from the present day islands appears to mark this fault line. These offshore rocks are hypothesized to be the remnants of a once larger island that has since been eroded back to the present day position. While the more recent island material has been eroded around them, these rocks remain because they are probably more weather resistant, being composed of well cemented Miocene dolomites similar to those found on Mayaguana. Over the course of our stay, we observed that the exposed rocks on West Plana were pounded by direct Atlantic swells and featured distinct blowholes that launched geysers of water up to 15m into the air visible for many km.

Another surprising feature on all three of the smaller islands- Samana, East Plana, West Plana- was the prodigious amount of sand. All three islands were generally ringed by wide sandy beaches with well-developed sand dunes broken only occasional outcrops of rocky shoreline and beach rock. Exotic *Casurina* trees, so ubiquitous on other Bahamian islands, were virtually absent. This is partly thought to occur because of the unstable shifting beaches and steep slopes. On the southern sides of all three islands, a sandy bottom type predominated with only a thin marginal wall reef occurring at 20-25 m depth. The source of sand for islands with such narrow platforms is puzzling. No recent evidence of recently active ooid shoals were found on any of the islands. Patch reefs did occur on portions of the narrow platform- particular towards the exposed eastern sides - but generally these occupied only 15-30% of the coastal waters. Thus there is not thought to be sufficient and extensive live coral reef to generate enough skeletal material to account for the sand. Similarly, calcifying macroalgae were not very abundant and only found in and around coral reefs.

One possible source for the sand is from erosion of a larger island/bank complex during the Holocene transgression. Reworking of the shelf sediments and possible the entire island edge over time as sea level rose in the last 10,000 ybp is suspected. The original island shoreline on all three islands could have extended several hundred meters from the present day shoreline. On West Plana there is a line of rocks nearly 1 km from the present day shoreline that were probably once part of the northeastern shoreline of a larger or more northern island. Differential cementing of different aged aoleonitic sediments allowed softer (more recent) material to be eroded leaving behind only more resistant (older) well cemented outcrops. It is also possible that the original platform size on all three islands was once considerably larger and has since been eroded back. Recent erosion and redistribution of sediment is evident on all three islands- northern and eastern sides of the islands show the greatest erosion evident by exposed limestone cliffs some 10 m tall that are falling into the ocean. In contrast, the southern and western shorelines of the islands appear to be prograding in places by 10's of meters.

Characterization of present day habitats of Samana and Plana Cays

The east-west orientation of both east Plana and Samana Cay are distinctly different than other islands of the Bahamas which typically are orientated north-south. The small size of the islands coupled with their orientation allows Atlantic swells to pass across the islands with only a minimal barrier.

Blue holes:

- West Plana: Only 1 of moderate size visible in southern center of island on what appears to be a core of island. No open blue holes around shelf observed.
- East Plana: Only 1 of moderate size visible on the central eastern side of the island.
- Samana: Over 24 observed. Most small, several quite large. Distributed across a fairly large area.

Inland lagoons:

- West Plana: 10 lagoons visible on satellite imagery. All appear trapped between original shoreline and prograding sand – most common on west and southern and northwestern sides of island. Mangroves, flushing evident.
- East Plana: Only one large lagoon on the far eastern side of the island evident. Smaller seasonal salt ponds evident in isolated places of the northern shoreline.
- Samana: At least 14 observed on both north and southern shore - several quite large. Color is brackish on many of them and suspect minimal tidal influence.

Mangroves:

- West Plana: Mangroves restricted to salt lagoons. No visible surface connection to sea but underground tidal connections are suspected. Waters in many of the lagoons appear clear and well flushed.
- East Plana: Very few observed. Restricted to large lagoon on the western tip of the island.

Caves:

- West Plana: None observed
- East Plana: None observed
- Samana: One very large cave observed in central portion of island. Others expected particularly at base of high bluffs/cliffs.

Seagrasses:

- West Plana: No dense beds observed. Occur in very sparse form along protected western edge of island at depths greater than 8 m.
- East Plana: No dense beds observed. No sparse grass observed. Only semi-protected (from waves) was south eastern tip of island where a sand spit provides some protection for a rocky tidal flat - some macroalgae were observed along with *Amphiroa*.
- Samana: dense grasses occur around a gap between the main island and a smaller island further east - dense lines both sides of the opening on the southern sides of both islands. Predominantly *Thalassia* with *Syringodium* - some of the densest observed. Very few conchs.

Coral reefs:

- West Plana: The entire island is surrounded by a narrow shelf with a well-developed fringing reef crest restricted to the eastern side of the island. Patch reefs are found mainly north of the island across the center of a submerged platform that extends to a small line of rocks about 2 km north.
- Samana: Patch reefs well developed along southern shore - particularly inside of well-developed crests around the eastern sides of the island.

Coral reef walls:

- West Plana: Well-developed along western edge of the island. Less developed on eastern side of island.
- East Plana: Well-developed along the southern edge of island. Less developed on northern side of island.
- Samana: Well-developed along southern side of island. Less developed on northern edge.

Literature Cited

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Appendix 6. List of observed fish species.

Common Name	Scientific Name	East Plana Cay	West Plana Cay	Samana Cay	Mayaguana	Acklins	Crooked Island	All Observed
Angelfish								
French	*Pomacanthus paru*					X		X
Gray	*Pomacanthus arcuatus*			X			X	X
Queen	*Holacanthus ciliaris*				X			X
Rock Beauty	*Holacanthus tricolor*	X	X	X	X	X		X
Boxfish								
Honeycomb Cowfish	*Acanthostracion polygonia*		X		X			X
Scrawled Cowfish	*Acanthostracion quadricornis*		X					X
Spotted Trunkfish	*Lactophrys bicaudalis*	X						X
Butterflyfish								
Banded	*Chaetodon striatus*	X	X	X	X	X	X	X
Foureye	*Chaetodon capistratus*		X	X	X	X		X
Longsnout	*Chaetodon aculeatus*		X					X
Reef	*Chaetodon sedentarius*							
Spotfin	*Chaetodon ocellatus*	X	X	X				X
Damselfish								
Beaugregory	*Stegastes leucostictus*	X	X	X	X		X	X
Bicolor Damselfish	*Stegastes partitus*	X	X	X	X	X	X	X
Cocoa damselfish	*Stegastes variabilis*							
Dusky Damselfish	*Stegastes adustus*		X			X	X	X
Longfin Damselfish	*Stegastes diencaeus*	X			X			X
Threespot Damselfish	*Stegastes planifrons*	X	X	X		X		X
Yellowtail Damselfish	*Microspathodon chrysurus*	X	X	X	X	X	X	X
Sergeant Major	*Abudefduf saxatilis*							
Blue Chromis	*Chromis cyanea*	X	X	X	X	X	X	X
Brown Chromis	*Chromis multilineata*		X	X				X
Grunt								
Black Margate	*Anisotremus surinamensis*							
Bluestriped	*Haemulon sciurus*					X		X
Caesar	*Haemulon carbonarium*	X		X	X	X	X	X
Cottonwick	*Haemulon melanurum*							
French	*Haemulon flavolineatum*	X	X	X	X	X	X	X
Porkfish	*Anisotremus virginicus*							

Sailors Choice	*Haemulon parra*							
Smallmouth	*Haemulon chrysargyreum*							
Spanish	*Haemulon macrostomum*							
Tomtate	*Haemulon aurolineatum*							
White Grunt	*Haemulon plumieri*			X			X	X
White Margate	*Haemulon album*			X	X			X
Juvenile Grunts	*Haemulon / Anisotremus*							
Parrotfish								
Blue	*Scarus coeruleus*							
Greenblotch	*Sparisoma atomarium*	X	X	X	X	X		X
Midnight	*Scarus coelestinus*	X	X		X	X		X
Princess	*Scarus taeniopterus*	X	X	X	X	X	X	X
Queen	*Scarus vetula*	X	X	X	X	X	X	X
Rainbow	*Scarus guacamaia*							
Redband	*Sparisoma aurofrenatum*	X	X	X	X	X	X	X
Redfin (Yellowtail)	*Sparisoma rubripinne*	X		X	X	X		X
Redtail	*Sparisoma chrysopterum*							
Stoplight	*Sparisoma viride*	X	X	X	X	X	X	X
Striped	*Scarus croicensis*	X	X	X	X	X	X	X
Grouper								
Black	*Mycteroperca bonaci*							
Coney	*Epinephelus fulvus*	X	X	X	X	X	X	X
Graysby	*Epinephelus cruentatus*			X	X			X
Nassau Grouper	*Epinephelus striatus*		X	X	X	X	X	X
Red Grouper	*Epinephelus morio*		X					X
Red Hind	*Epinephelus guttatus*	X	X	X	X	X	X	X
Rock Hind	*Epinephelus adscensionis*	X	X	X		X		X
Tiger	*Mycteroperca tigris*	X	X	X	X		X	X
Yellowfin	*Mycteroperca venenosa*							
Yellowmouth	*Mycteroperca interstitialis*							
Barred Hamlet	*Hypoplectrus puella*		X		X	X		X
Butter Hamlet	*Hypoplectrus unicolor*				X			X
Indigo Hamlet	*Hypoplectrus indigo*				X			X
Harlequin Bass	*Serranus tigrinus*	X		X	X			X
Tobaccofish	*Serranus tabacarius*	X		X	X			X
Snapper								
Gray	*Lutjanus griseus*							
Lane	*Lutjanus synagris*		X					X
Mahogany	*Lutjanus mahogoni*		X	X	X			X

Mutton	*Lutjanus analis*			X				X
Schoolmaster	*Lutjanus apodus*	X	X	X	X	X		X
Yellowtail	*Ocyurus chrysurus*		X			X		X
Squirrelfish								
Blackbar Soldierfish	*Myripristis jacobus*				X	X	X	X
Longjaw Squirrelfish	*Neoniphon marianus*				X	X	X	X
Longspine Squirrelfish	*Holocentrus rufus*	X	X	X	X	X	X	X
Squirrelfish	*Holocentrus adscencionis*			X	X	X		X
Reef Squirrelfish	*Sargocentron coruscum*					X		X
Surgeonfish								
Blue Tang	*Acanthurus coeruleus*	X	X	X	X	X	X	X
Doctorfish	*Acanthurus chirurgus*	X	X	X	X	X	X	X
Ocean	*Acanthurus bahianus*	X	X	X	X	X		X
Triggerfish								
Black Durgon	*Melichthys niger*	X	X	X	X	X		X
Ocean Triggerfish	*Canthidermis sufflamen*	X	X	X	X			X
Queen Triggerfish	*Balistes vetula*		X	X	X			X
Wrasse								
Bluehead	*Thalassoma bifasciatum*	X	X	X	X	X	X	X
Clown Wrasse	*Halichoeres maculipinna*	X				X		X
Creole Wrasse	*Clepticus parrae*	X	X	X	X			X
Rainbow Wrasse	*Haliochoeres pictus*				X			X
Puddingwife	*Halichoeres radiatus*	X	X	X	X	X		X
Slippery Dick	*Halichoeres bivitattus*	X	X	X		X		X
Spanish Hogfish	*Bodianus rufus*	X	X	X	X	X	X	X
Yellowhead Wrasse	*Halichoeres garnoti*	X	X	X	X	X	X	X
Filefish								
Orangespotted Filefish	*Cantherhines pullus*						X	X
Scrawled Filefish	*Aluterus scriptus*							
Whitespotted Filefish	*Cantherhines macroceros*		X	X	X	X	X	X
Porgy								
Jolthead Porgy	*Calamus bajonado*							
Pluma	*Calamus pennulata*							
Saucereye Porgy	*Calamus calamus*			X				X
Sheepshead Porgy	*Calamus penna*							
Porcupinefish								
Ballonfish	*Diodon holocanthus*		X					X
Porcupinefish	*Diodon hystrix*							
Others								

Sharpnose Puffer	*Canthigaster rostrata*	X			X	X		X
Rosy Razorfish	*Xyrichtys martinicensis*	X						X
Peacock Flounder	*Bothus lunatus*						X	X
Bar Jack	*Caranx ruber*	X	X	X	X	X	X	X
Black Jack	*Caranx lugubris*			X				X
Horse-Eye Jack	*Caranx latus*		X	X	X	X		X
Bermuda or Yellow Chub	*Kyphosus* sp.	X	X	X	X	X		X
Great Barracuda	*Sphyraena barracuda*	X	X	X	X	X	X	X
Permit	*Trichonotus falcatus*							
Lionfish	*Pterois* sp.	X	X	X	X	X	X	X
Blackcap Basslet	*Gramma melacara*							
Fairy Basslet	*Gramma loreto*	X	X	X	X	X		X
Spotted Goatfish	*Pseudupeneus maculatus*				X	X		X
Yellow Goatfish	*Mulloidichthys martinicus*	X	X	X	X	X		X
Yellowfin Mojarra	*Gerres cinereus*						X	X
Cero	*Scomberomorus regalis*	X	X		X	X		X
Pallid Goby	*Coryphopterus eidolon*				X			X
Yellow Stingray	*Urolophus jamaicensis*			X			X	X
Nurse Shark	*Ginglymostoma cirratum*				X		X	X
Reef Shark	*Carcharinus perezii*	X	X	X	X	X	X	X
Sand Tilefish	*Malacanthus plumieri*		X	X		X		X
Greater Soapfish	*Rypticus saponaceus*				X			X
Trumpetfish	*Aulostomus maculatus*			X	X			X
Redspotted Hawkfish	*Amblycirrhitus pinos*					X		X
Shark Sucker	*Echeneis naucrates*				X			X
Hawksbill Turtle	*Eretmochelys imbricata*				X		X	X

Appendix 7.

Analysis of coral connectivity in SE Bahamas

Steve Schill

The Nature Conservancy

A marine connectivity and coral larvae transport model was completed by Schill et al, (2012) for the Caribbean Basin and Gulf of Mexico. As part of the REA for the South-eastern Bahamas, we present the results of the connectivity model for East and West Plana Cays, Samana Cay, Mayaguana, and Acklins Islands. The marine connectivity and larval transport models produced explore where do coral larvae go following a spawning event and where settlement and recruitment is most likely to occur. This research is important in determining how reefs and islands depend on one another for their long-term survival and reproduction.

For this investigation, we developed a regional ocean connectivity model (8x8km) for the Caribbean Basin and Gulf of Mexico, integrating the ocean current information in NOAA's Real-Time Ocean Forecast System (RTOFS) [http://polar.ncep.noaa.gov/ofs/]. The RTOFS-Atlantic system has been operational since December 2005 and is the first real-time ocean forecast system based on the Hybrid Coordinate Ocean Model (HYCOM) ocean model (http://hycom.org) (Bleck, 2002). It runs daily and provides one-day and six-day forecasts of the Atlantic basin which extends from 25°S to 72°N and from 98°W to 16°E. Preliminary evaluations of model performance indicate that predictions compare well to historical observations but are only partly able to capture the daily variability of mesoscale features, fronts and associated transports (Mehra and Rivin 2010). Improvements to RTOFS relative to HYCOM include a finer spatial sensitivity to currents - enough resolution to resolve the oceanic response to large severe storms such as hurricanes or large wind events. This behaviour is attributed to a superior spatiotemporal resolution of the underlying forcing data (3hr and 25km cell). ROTFS also incorporates the tide cycle which improves reliability of current direction and velocity.

Prior to setting up and running the larval dispersion models, several biological parameters that define the larvae biological characteristics and behaviour had to be considered. These parameters influence the dispersion, settlement, and recruitment rates calculated in the mode and are further explained in Schill et al (2012). Using the two-dimensional hydrodynamic larval dispersal framework described by Treml et al. (in review) and applied by Mora et al. (2012), we simulated the movement and settlement of coral larvae for the years 2008-2011 throughout the Caribbean Basin, Gulf of Mexico, and southwest Sargasso Sea (8-35 N, 56-98 W). These dates represent the total time period available for the RTOFS dataset. Our first step was to assemble a comprehensive map of the locations of coral reefs throughout the study area using data from the Millennium Reef maps (Andréfouët et al., 2005).

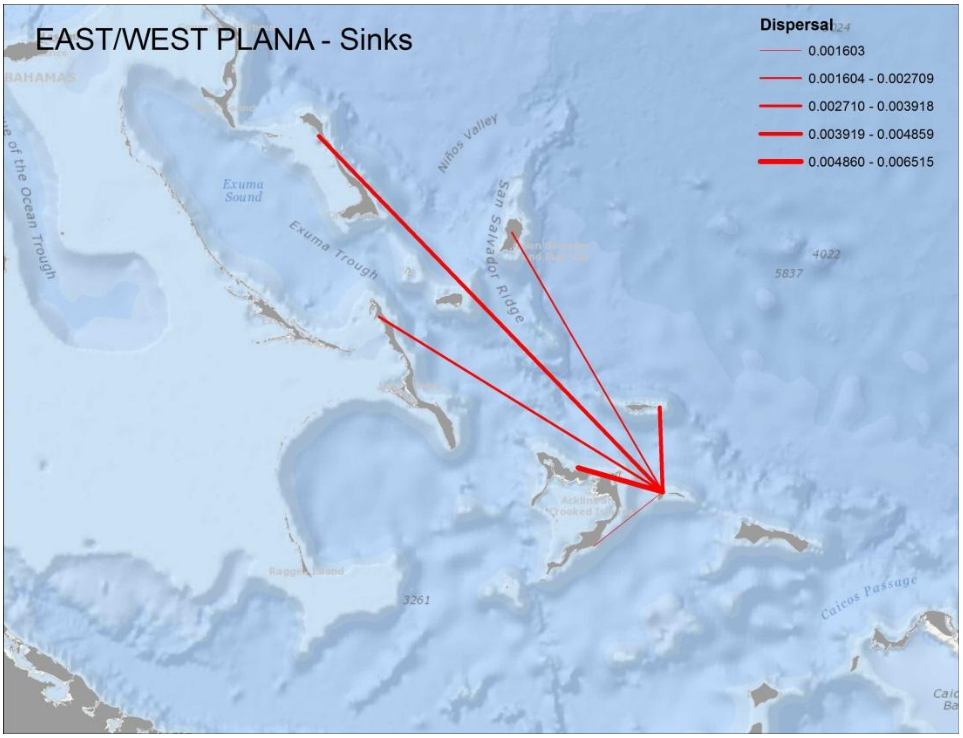
We then performed eight dispersal simulations--two per year--that started on the dates of the last quarter moon in August and September (23 August 2008,22 September 2008, 13 August 2009, 12 September 2009, 1 September 2010, 1 October 2010, 21 August 2011, 20 September 2011). We selected these dates based on observations of coral mass spawning events in the Caribbean reported by van Woesik et al. (2006, Supplemental Information), Bastidas et al. (2005), and Medes and Woodley (2002).

At the start of each simulation, the hydrodynamic model released larvae at the ocean surface above each of the 423 reef units and allowed them to drift with the ocean surface currents. The quantity of larvae released was proportional to the abundance of coral habitat at each 8km grid cell. For ocean currents, we used hourly estimates from the Real Time Ocean Forecast System (RTOFS) (Mehra and Rivin, 2010), which integrates a number of physical processes including geostrophic currents, Ekman (wind-driven) transport, and tides. Larvae were allowed to drift for 30 days (i.e. the pelagic larval duration (PLD) was 30 days). Following Treml et al. (in review), larval competency was modeled using a gamma cumulative distribution function that allowed all of the larvae to reach full competency in 3 days.

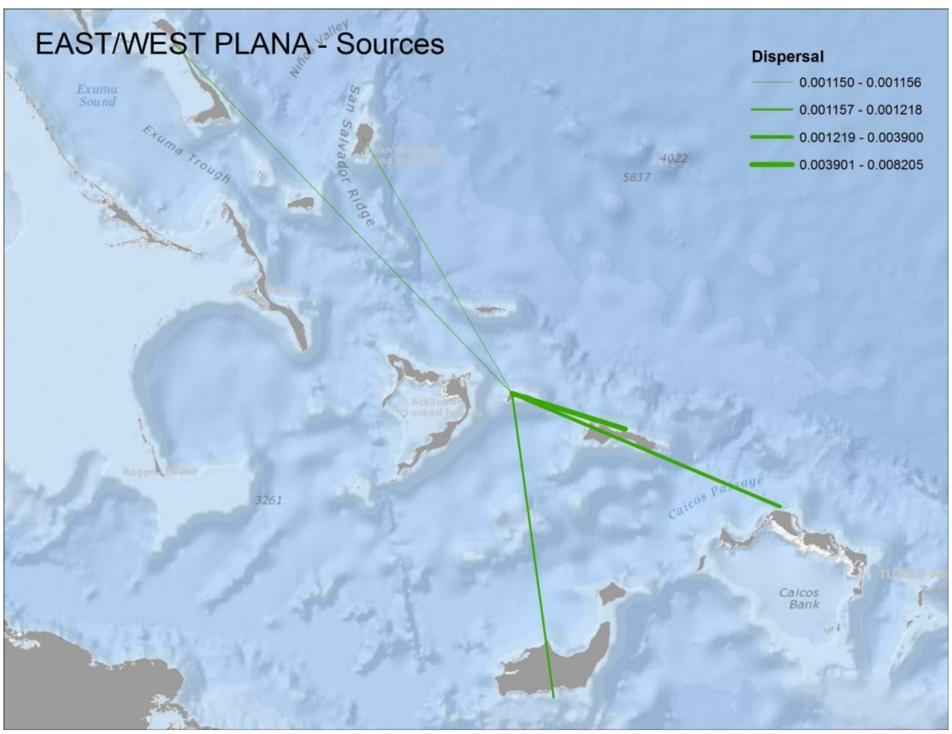
After reaching competency, when larvae drifted over coral habitat they settled at a rate of 75% per day (i.e. if 100 larvae were suspended over habitat for 1 day, 75 of them would settle there). Larval mortality was not considered; all larvae were permitted to drift until they settled or until 30 days elapsed, at which point they were assumed to be lost. Mortality is an important factor that will make short connections much stronger relative to long connections. At the end of each simulation, we tallied the quantity of larvae transported between each of the 423 reef units, including larvae that settled on their natal patch (so-called self-recruitment), for a total of 178,929 possible connections. Using the centroid of each reef unit, we drew a connection between each connected from-to reef pair. The output values that are shown in the figures below represent the estimated quantity of transported larva that was calculated in cell units.

The coral connectivity work conducted in this research, takes advantage of new oceanographic data and computer simulations programs, offering new insight into how corals are connected throughout the region. These models permit the tracking of larvae following a spawning event in a very precise manner integrating weather and tide cycles that increases the accuracy and reliability of the model. These patterns can be analyzed to determine where settlement and recruitment are most likely to occur along with estimations on how dependent each island is on the health of corals in neighboring reefs where larvae may originate.

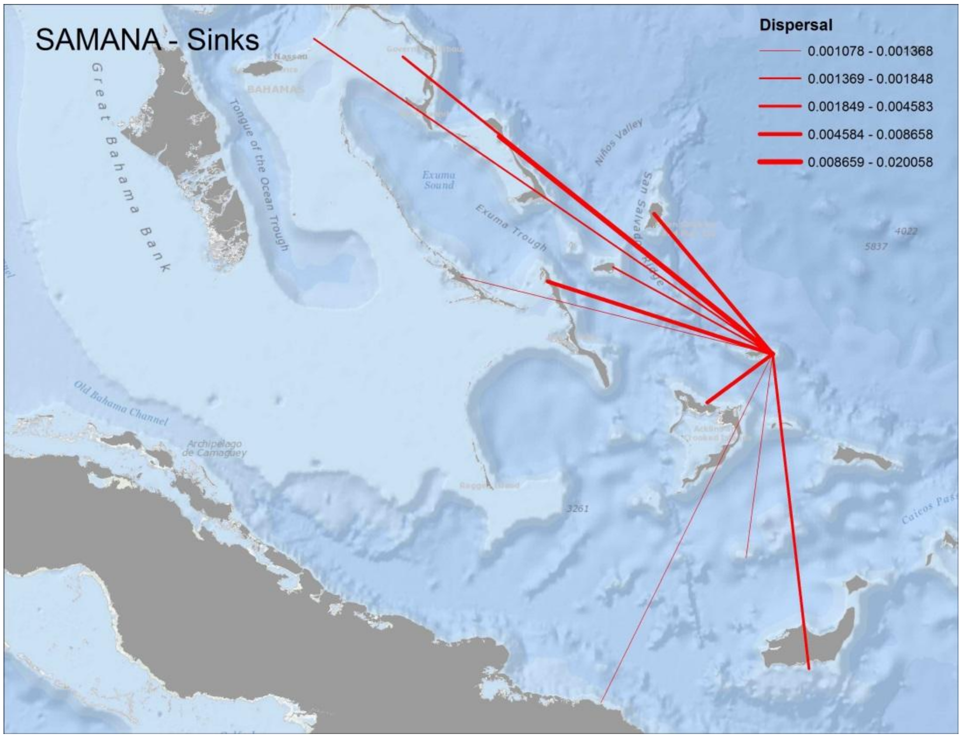
Based on the dispersion model, it can be observed that coral larvae originating from East and West Plana Cays are mostly received and settle in Acklins Island, Samana Cay, and Cat Island. Larvae being received from East and West Plana Cays mostly originate from Mayaguana, Turks and Caicos, and Inagua islands. In Samana Cay, larvae are primarily transported to Cat Island, San Salvador, and Long Islands while larvae received mostly come from Turks and Caicos, Mayaguana, and the Plana Cays. In Mayaguana, the ocean currents transport larvae primarily to Acklins and Long Islands, as well as Samana Cay. Larvae being received at Mayaguana come from Turks and Caicos, Inagua, and northern Cuba. Finally, when considering reefs in Acklins Island, these larvae are largely transported and received in Long, Cat, and San Salvador Islands. Larvae being received come primarily from Mayaguana, Turks and Caicos, and Samana Cay. Based on this analysis, one can see there is a strong east to west flow that dominates the system and the island of the Southeastern Bahamas are highly dependent on receiving larvae from the Turks and Caicos while the Bahamas islands of Cat, Long, and San Salvador all benefit from larvae sent from Acklins and Mayaguana Islands and the Planas and Samana Cay.



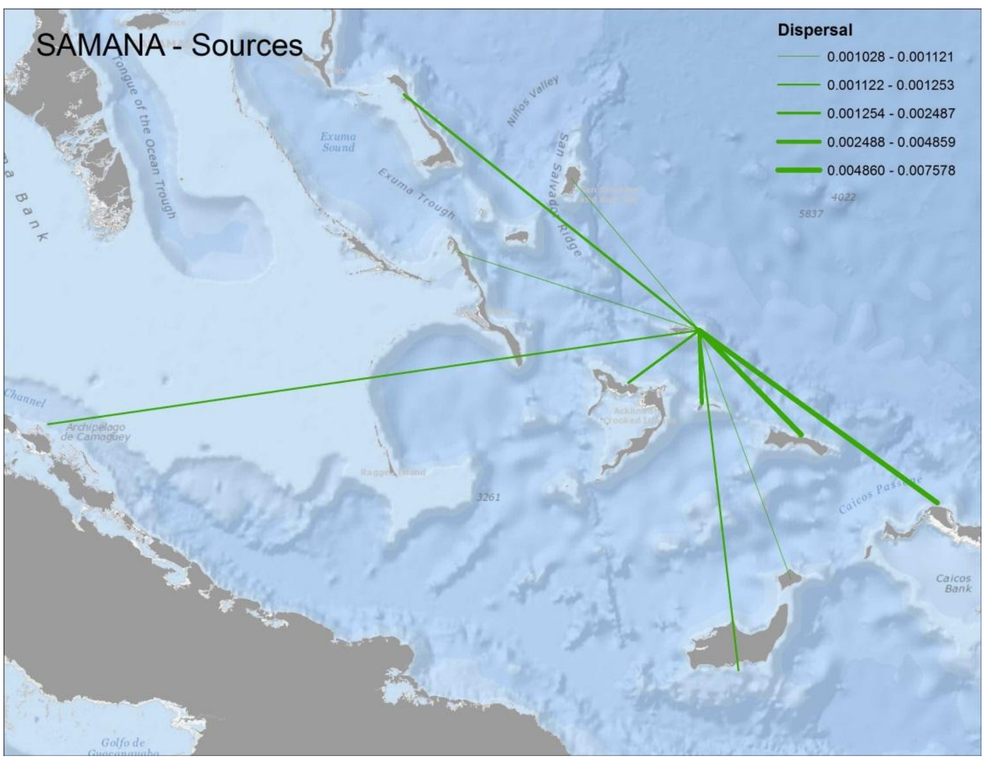
Modeled dispersal and probable settlement (sinks) of coral larvae originating from reefs in East and West Plana Cays based on NOAA's Real Time Ocean Forecast System (RTOFS) ocean current data.



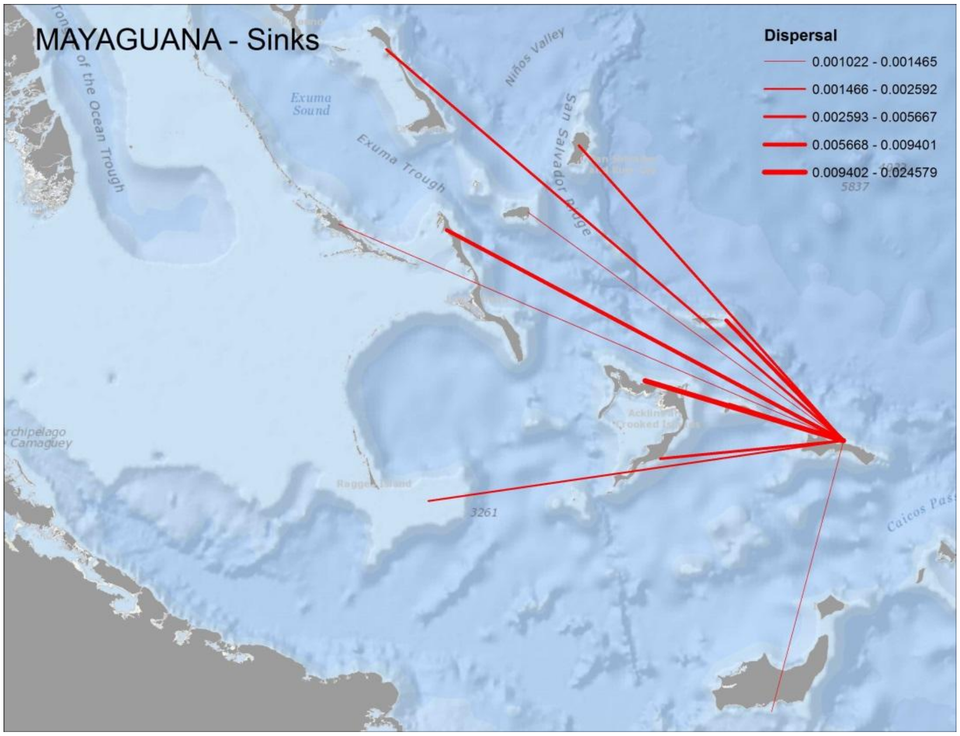
Modeled source areas of coral larvae that are received by reefs in East and West Plana Cays based on NOAA's Real Time Ocean Forecast System (RTOFS) ocean current data.



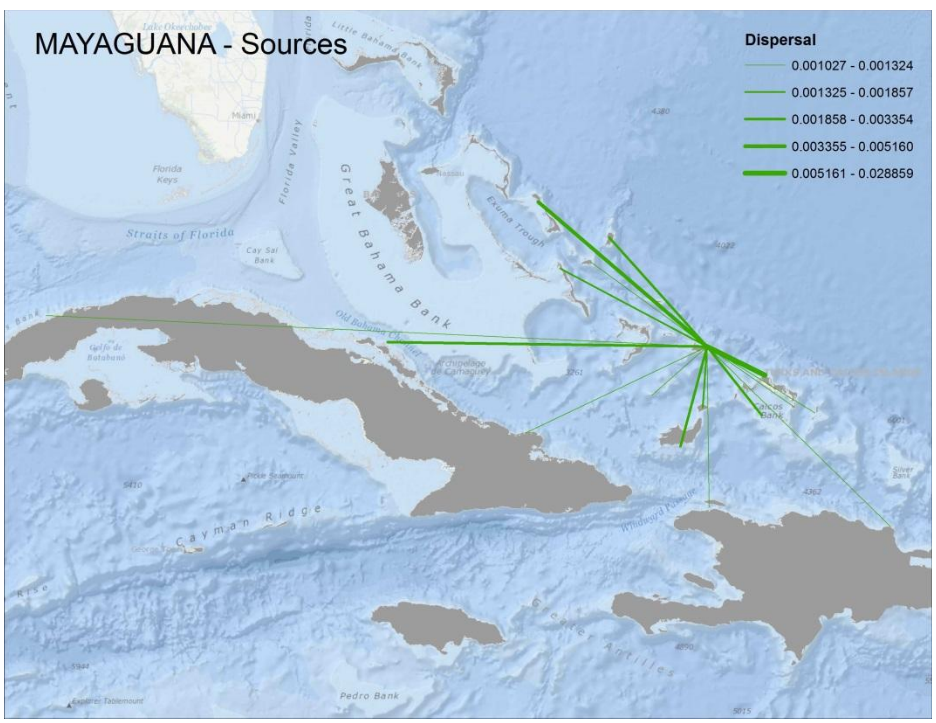
Modeled dispersal and probable settlement (sinks) of coral larvae originating from reefs in Samana Cay based on NOAA's Real Time Ocean Forecast System (RTOFS) ocean current data.



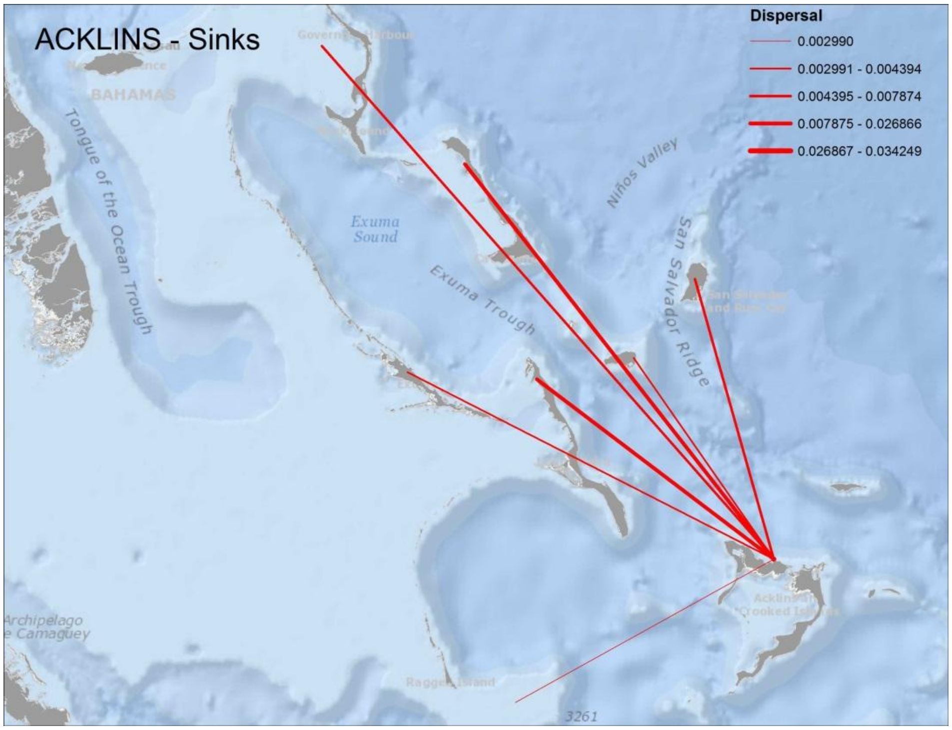
Modeled source areas of coral larvae that are received by reefs in Samana Cay based on NOAA's Real Time Ocean Forecast System (RTOFS) ocean current data.



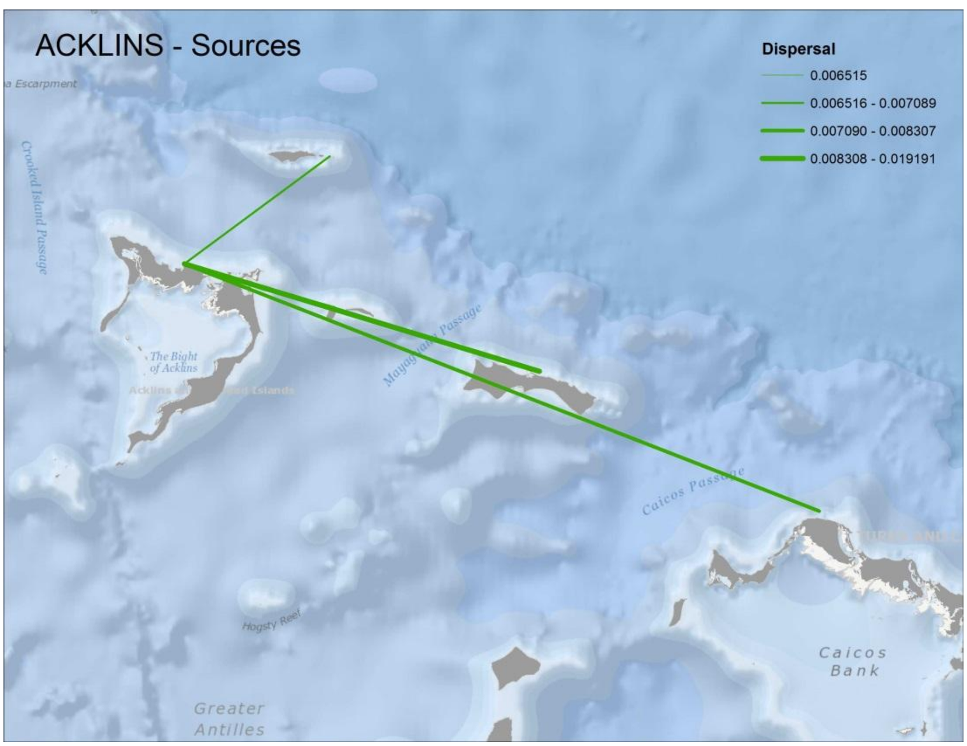
Modeled dispersal and probable settlement (sinks) of coral larvae originating from reefs in Mayaguana Island based on NOAA's Real Time Ocean Forecast System (RTOFS) ocean current data.



Modeled source areas of coral larvae that are received by reefs in Mayaguana Island based on NOAA's Real Time Ocean Forecast System (RTOFS) ocean current data.



Modeled dispersal and probable settlement (sinks) of coral larvae originating from reefs in Acklins Island based on NOAA's Real Time Ocean Forecast System (RTOFS) ocean current data.



Modeled source areas of coral larvae that are received by reefs in Acklins Island based on NOAA's Real Time Ocean Forecast System (RTOFS) ocean current data.

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