Ecological Assessment of Barbuda's Marine Ecosystems: Science supporting the Barbuda Blue Halo Initiative

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REPORT SUMMARY

Lobster

- There were no legal-sized lobster observed in Codrington Lagoon, nor were there 40 years ago.
- Maximum sizes of lobster are similar to 40 years ago, but average size appears to have declined.
- We recommend fully enforcing current size limits and closed seasons, and closing the lagoon to fishing to protect juvenile lobsters so they can reproduce before being caught.
- Future research and monitoring should focus on collecting fisheries data, such as size of individuals captured, total catch, fishing locations, and time spent fishing.

Conch

- The abundance of conch is lower and their size is smaller compared to many other Caribbean islands, but reproductively mature adults are still present.
- We recommend fully enforcing current size limits and closed seasons, and establishing sanctuary zones around spawning areas.
- Future research and monitoring should focus on collecting ecological data such as size structure, density, and habitat, as well as fisheries data including size of individuals captured, total catch, fishing location, and time spent fishing.

Fish

- The abundance of fish (including groupers, snappers, and parrotfish [i.e., chub]) is low compared to other Caribbean islands.
- We recommend banning the catch of parrotfish and surgeonfish (important herbivores that consume algae), banning the use of gill nets (which target herbivores, catch many juvenile fish, and damage the habitat), establishing sanctuary zones where no fishing occurs (especially around spawning areas), and enforcing the closed seasons.
- Future research and monitoring should focus on identifying spawning aggregation sites and collecting fisheries data, including catch, fishing location, and time spent fishing.

Corals

- Bottom cover of live coral is extremely low (only 2.6%) compared to other Caribbean islands. Bottom cover of algae, which competes with and kills corals, is extremely high (79% cover).
- We recommend protecting herbivores that eat algae (parrotfish, surgeonfish, and urchins), enforcing the ban on collecting or damaging coral, and establishing sanctuary zones where no fishing or anchoring occurs to help corals recover.
- We do not recommend additional research or monitoring be conducted by Barbudans at this time.

Lagoon

- The Lagoon has a high abundance of juveniles, including lobster and snapper, as well as intact mangrove forests, healthy seagrass beds, and clean water.
- We recommend reaffirming and enforcing the existing ban on harvesting or destroying mangroves, and closing the Lagoon to all fishing to protect this critical nursery habitat.
- Apart from basic water quality monitoring, we do not recommend additional research at this time.

INTRODUCTION AND CONTEXT

The Barbuda Blue Halo Initiative is a collaborative partnership between the Barbuda Council (island government), Codrington Lagoon National Park, Barbuda Fisheries Division, the Office of the Prime Minister of Antigua and Barbuda, the people of Barbuda, and the Waitt Institute. The goal is to ensure sustainable, profitable, and enjoyable use of ocean resources. To achieve this goal, the Blue Halo Initiative will develop fisheries policies, ocean zoning, and monitoring, financing, and enforcement plans for Barbuda's waters.

To enable Blue Halo ocean management decisions to be based on the best scientific data, the Waitt Institute gathered a team of marine scientists to conduct a comprehensive ecological assessment of the marine resources around Barbuda. Such an assessment had never been conducted on Barbuda, and existing ecological data was limited. In April 2013, this team conducted 12 days of surveys for lobster, conch, fish, corals, and algae at 234 sites around the island, including several sites in Codrington Lagoon (Figure 1). We also collected water samples from around the island to assess water quality.

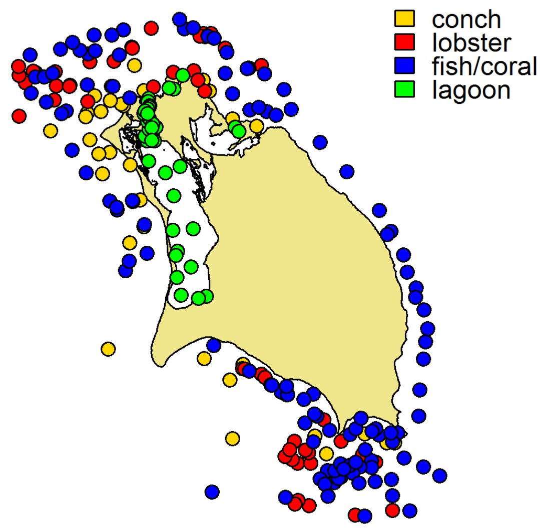

Figure 1. Map of Barbuda showing sites surveyed by scientists for the Blue Halo Initiative. Sites are color-coded by the type of survey conducted.

Many of the threats facing other Caribbean island nations are present on Barbuda. Overfishing has occurred; lobster, conch, and commercially-important fish species are less abundant in nearshore waters than they once were, such that fishers report needing to go further from shore and to fish in deeper water to make fishing trips worthwhile. The total amount of live coral has declined around the island. Many other Caribbean islands have experienced similar declines in fish stocks and coral populations but failed to act; their marine ecosystems are in poor condition, their fisheries have collapsed, and recovery will be long and difficult, if recovery is possible at all (Gardner et al. 2003, Paddack et al. 2009). Our data show that some marine resources around Barbuda may be at a tipping point. Sound, science-based management strategies have the potential to stabilize and restore marine ecosystems around Barbuda, but bold action is required soon.

This report describes the major findings from the ecological assessment of the Barbuda Blue Halo Initiative, including maps documenting the distribution of a variety of organisms. These data allow all stakeholders to learn about and visualize the current status of their marine resources, and we hope this information will be used in the help them design a Sustainable Ocean Policy for the island.

We describe the methods and results for each broad ecosystem feature that we surveyed (lobster, conch, fish, corals, and water quality), and we provide suggestions for management actions and future research that will improve the sustainability of the use of marine resources around Barbuda, enabling the ocean ecosystems to remain productive for Barbudans for years to come.

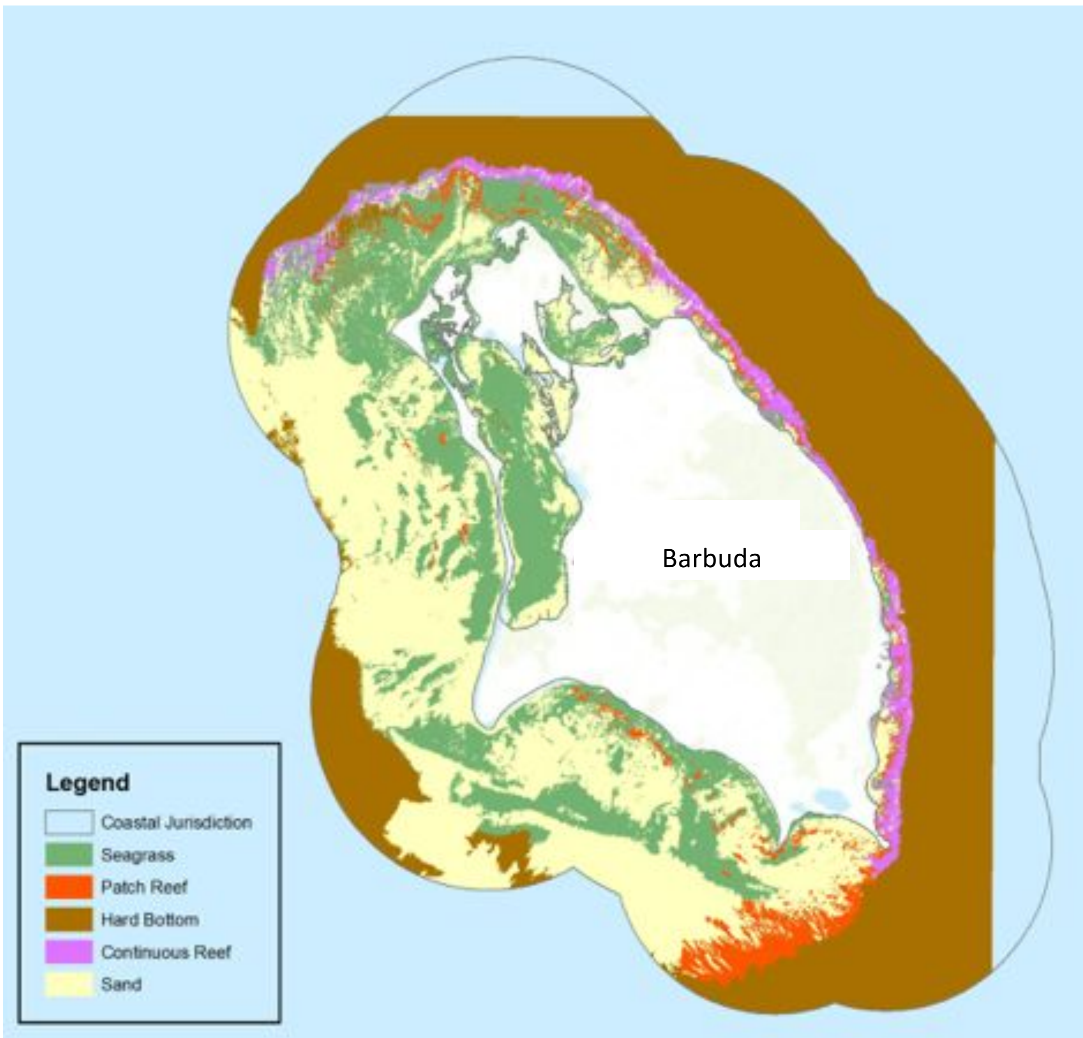

Figure 2. Map of Barbuda’s marine ecosystems, developed via analysis of high-resolution satellite imagery.

LOBSTER

Biology and Life History

Caribbean spiny lobster (*Panulirus argus*) are found in the tropical waters of the Atlantic, Caribbean Sea, and Gulf of Mexico. They can live to be 20 years old and can weigh up to 7 kg (Maxwell et al. 2007). Molting occurs several times a year (Briones-Fourzán et al. 2003). While lobster may spend a great deal of time in the same place, they are capable of long migrations up to 10s of kilometers (Herrnkind 1985). They may migrate to find spawning habitats or to seek food or shelter. Young lobster eat crabs, snails, other invertebrates, and algae (Briones-Fourzán et al. 2003). Adults feed on snails, including queen conch, crustaceans, sea urchins, worms, vegetation, and even carrion. Lobster predators include moray eels, sharks, and groupers (Briones-Fourzán et al. 2003).

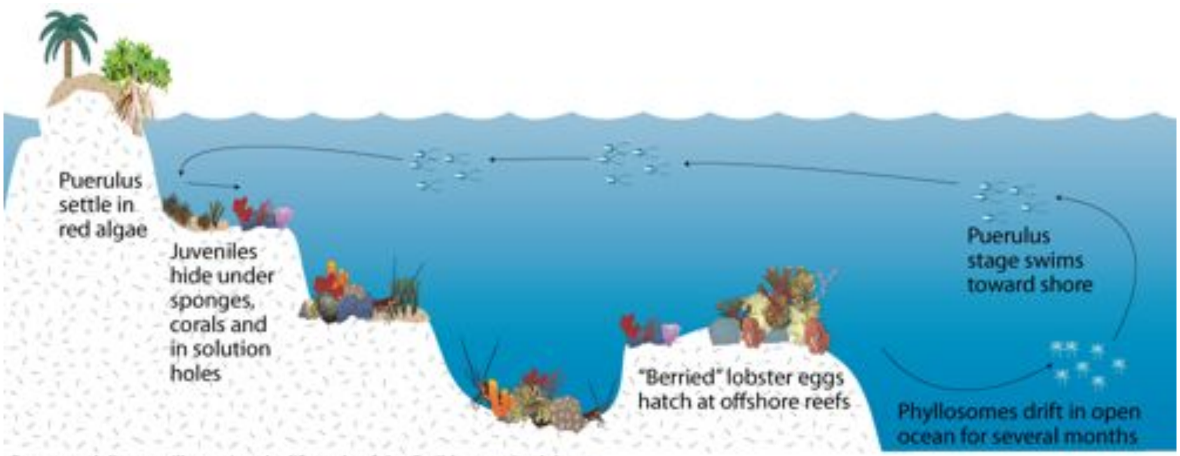

Figure 3. Life history diagram of the Caribbean spiny lobster (Kruczynski and Fletcher 2012).

Spiny lobster reach sexual maturity at 3-4 years of age and roughly 75 mm carapace length (i.e., length from the ridge between the horns near the eyes to the rear portion of the carapace, where the tail begins; Davis 1975). Spawning can occur year round, but peaks during the warmer months from May-August (Peacock 1974). Lobster generally only spawn in reef habitats (as opposed to inshore or lagoon habitats). This is because larvae (i.e., the development phase right after hatching from the eggs) are most likely to survive offshore where environmental conditions are more stable and the density of predators of lobster larvae is lower. Fecundity generally increases with size, and maximum reproductive potential may occur in females between 100 mm and 130 mm carapace length (Lyons et al 1981). Fertilization is external; males transfer a thick spermatophore called a "tarspot" to females.

Egg-carrying or "berried" females (locally called "pom lobster") carry up to 1.5 million developing eggs (Fonseca-Larios and Briones-Fourzán 1998) under their tails for a month until releasing eggs on offshore reefs (Figure 3). Once released, eggs hatch into the open-ocean larval phase, where they drift and develop in open water for up to nine months (Briones-Fourzán et al. 2003). While lobster larvae have the potential to disperse great distances on ocean currents, there is evidence that they may still settle close to the location where they were released as eggs (Yeung and Lee 2002). After the larval phase, lobster settle in sheltered nursery habitats, such as mangroves, lagoons, or seagrass beds (Briones-Fourzán et al. 2003). As the lobster grow, they migrate out of juvenile habitats into creviced structures, patch reefs, and eventually onto deeper, offshore reefs (Briones-Fourzán et al. 2003).

Methods

Caribbean spiny lobster can be extremely patchy in their distribution; they are often found under very specific ledges rather than being evenly spaced across suitable habitat. This is particularly true around Barbuda, and this patchy nature makes it very difficult to assess their population density using field surveys. To address this inherent challenge, we tested several field methods during our surveys. In all methods, we paired Waitt Institute scientists with Barbudan lobster fishers, since local fishers are much more skilled at finding and catching lobster than the scientists.

Collaborative lobster surveys were conducted by Antiguan & Barbudan fishers, Codrington Lagoon National Park, Barbuda Fisheries Division, and Waitt Institute scientists.

In our first lobster survey method, we selected a random sampling of suitable hard-bottom habitats using a habitat map developed from high-resolution satellite imagery (Figure 2). Fishers searched for lobster in a fixed 15 m x 15 m area at each of these random points. However, because of the patchy distribution of lobster, searching a predefined area at randomly-selected sites resulted in zero lobster present at most sites. We modified this method and allowed fishers to search and catch lobster however they chose (i.e., they were not limited to a 15 m x 15 m area), but the general location of sites were still randomly selected. Even with this second modification, lobster were observed at few sites. Finally, we further modified the method to allow fishers to both fish however they chose and to select any sites within 3.5 miles of shore where they expected lobster would be present.

For all surveys, we determined the sex and carapace length of each lobster captured. We measured carapace length to the nearest millimeter (mm) and classified individuals as either legal size or sublegal size. The Antigua and Barbuda fisheries regulations establish 95 mm carapace length (CL) as the minimum legal size for capture. Additional regulations specify that legal lobster must also be 1.5 lb or have a tail weight of 7 ounces, but we used carapace length only to determine legal versus sublegal status. At some sites, we observed juvenile or sublegal-sized lobster but were unable to capture and measure them as they were too small to be caught by fishers' lassos. In those instances, we estimated the numbers and carapace lengths for uncaptured lobster, but we could not determine their sex.

GPS coordinates were recorded for each site. In total, we surveyed 52 sites for lobster abundance, sex ratio, and size structure in depths ranging from 1 to 18 m. Because the patchy nature of the distribution of lobster forced us to search for lobster over variable areas at each site, our abundance data cannot be converted to density (i.e., numbers per unit area). However, these data still allow us to visualize the distribution of lobster around Barbuda. Data on sex ratios and size structure provide additional information about the status of the population.

Results and Discussion

We surveyed lobster at 52 sites around Barbuda (Figure 5). For lobster abundance, combining data from all survey methods, we found an average of 0.57 legal-sized lobster and 1.54 sublegal lobster per site (excluding one outlier site with >70 sublegal lobster). However, lobster were only present at 50% of our sites, with legal-sized lobster present at 26.9% of sites, and sublegal lobster present at 38.4% of sites. At the sites chosen by fishers, we found an average of 0.8 legal-sized lobster and 4.6 sublegal-lobster per site; legal lobster were present at 36% of these sites, and sublegal lobster were present at 50% of these sites.

For lobster size, again including all survey methods, 16.7% of observed lobster (some of which were too small to catch) were legal-sized, and 32% of the lobster caught and measured were legal-sized. The sex ratio of the caught lobster was exactly 50:50 (47 males and 47 females), but males were larger than females (average size: 91 mm for males, 82 mm for females). The largest male measured 183 mm CL and the largest female 140 mm (Figure 4). The average length of legal-sized individuals was 131 mm for males and 112 mm for females. We observed 4 berried females, the smallest of which was 91 mm CL, just under the legal limit of 95 mm.

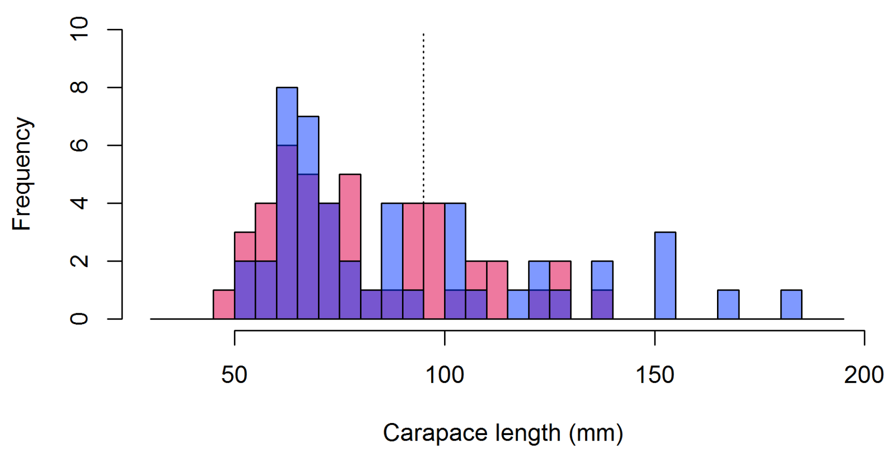

Figure 4. Size frequency histogram of lobster. Light blue bars represent males, pink bars represent females, and purple bars depict overlap of data of males and females. The vertical dashed line is at 95 mm carapace length, the minimum legal size in Antigua & Barbuda.

We surveyed lobster in Codrington Lagoon (see *Lagoon* section for description of methods), and estimated the carapace length of each lobster seen. On average, we observed 0.8 lobster per site in the lagoon, with an average carapace length of 51 mm, and a maximum of approximately 80 mm. No legal-sized lobster were observed in the lagoon, consistent with lagoon surveys conducted in 1973, indicating that for lobster the lagoon has always been primarily a nursery habitat (Peacock 1974).

Maps of the distribution of legal- and sublegal-sized lobster illustrate their patchy distribution. Legal-sized lobster were most common at mid-depths on the north and south shores, but were virtually absent from inshore patch reefs. Sublegal lobster were present in moderate densities at mid-depths, but two of the three sites with the highest density of sublegal lobster were close to shore (Figure 5).

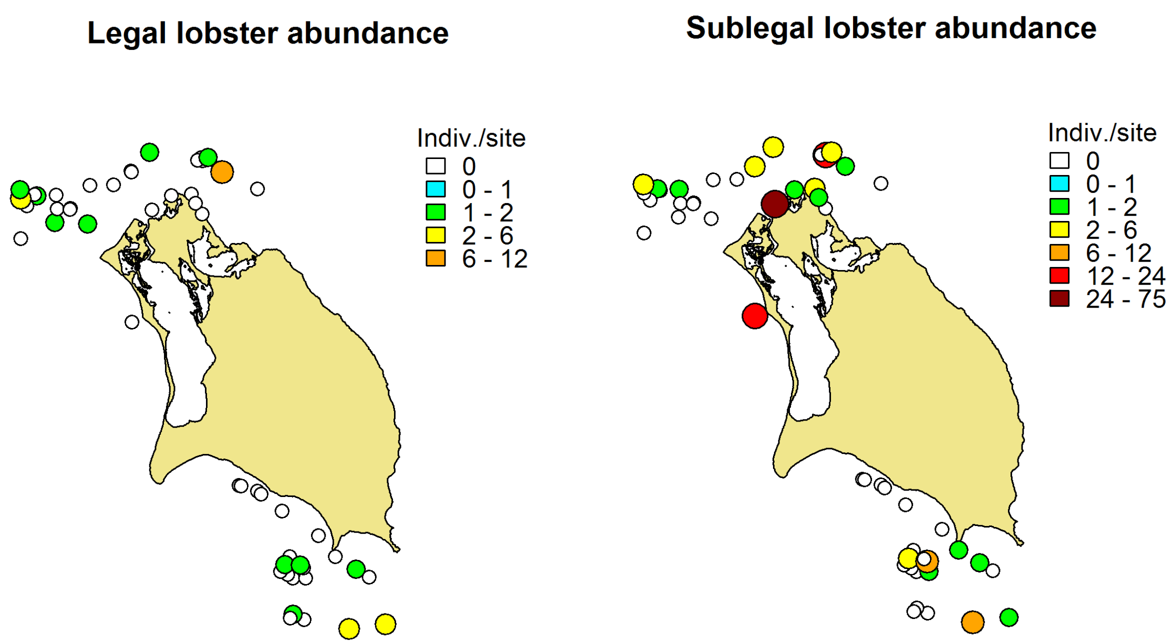

Figure 5. Abundance of legal-sized (>95mm carapace length) and sublegal-sized lobster around Barbuda. Values represent the number of lobster seen at each site.

Our surveys confirmed information obtained from local fishers, that lobster are very patchily distributed in Barbuda. This may be partly due to the patchy nature of the habitat around Barbuda, and may also be the result of heavier fishing pressure in some locations than others.

We observed some large lobster around Barbuda, and these were much larger than those found in some other areas of the Caribbean. For example, lobster in areas open to fishing in the Florida Keys, where fishing pressure is very intense, reached 90 and 100 mm CL for females and males, respectively (Maxwell et al. 2013). Sizes were larger in nearby marine reserves in the Florida Keys (110 and 135 mm CL for females and males, respectively), but still smaller than those around Barbuda.

The maximum size of lobster around Barbuda seems to have remained relatively stable over the past 40 years; Peacock (1974) found a maximum length of 170 mm in the early 1970s. Thirty-two percent of the lobster we captured were legal-sized, a much smaller fraction than the "great majority" of lobster greater than 90 mm observed in Barbuda 40 years ago (Peacock 1974). This decline in legal-sized lobster relative to sublegal lobster indicates the effects of fishing. Still, the presence of large individuals suggests that the lobster population around Barbuda has the potential to recover if changes are made to management and enforcement.

Management Recommendations

To increase the lobster population and size of lobster, we suggest the following management actions:

1. **Enforce lobster size limits** as defined in the Fisheries Act regulations. The legal size for lobster in Antigua and Barbuda is 95 mm CL, 1.5 lb total weight, and 0.7 lb tail weight. This size is large enough to allow individuals to spawn at least once (and potentially several times) before capture. However, it is clear from our discussions with local fishers, officials, and community members that undersized lobster are still captured regularly on Barbuda. Full enforcement of the Fisheries Act size restriction should greatly increase the spawning stock of lobster around Barbuda and make the fishery more sustainable.
2. **Establish and enforce sanctuary zones,** where catch of lobster is prohibited year-round, **especially in spawning and nursery habitats**. These zones would enable lobster to have a refuge within which they may grow and reproduce, and from which they can replenish fished areas outside. Codrington Lagoon and Goat Island Flash are key nursery habitats, thus good candidates for sanctuary areas.
3. **Enforce the closed season** of May 1 to June 30 as defined by the Fisheries Act regulations. This coincides with a portion of the May through August peak spawning time. Extending closed dates to encompass more of this spawning time would further enable lobster populations to rebuild.
4. **Prohibit all catch of lobster within the Lagoon**, including undersized "chicken" lobster. No legal-sized lobster were observed in the Lagoon and it is critical nursery habitat.
5. **Enforce the ban on catching berried female lobster (i.e., with eggs),** called locally called "pom lobster" in accordance with the Fisheries Act regulations. We have heard from local people that these lobster are still captured and sold (after eggs are scrapped off), although less commonly than in the past. This practice is unsustainable – if lobster are not allowed to reproduce, the fishery will collapse.
6. **Any lobster with eggs should be released where captured**, consistent with the Fisheries Act regulation on incidental catch. Fishermen have told us that when they catch females with eggs they sometimes place those lobster in traps until they release their eggs, in attempt to protect them. However, these traps are in inshore or lagoon areas, which are not the habitats where females normally release their eggs. When lobster release eggs out on the reefs (as they are adapted to do), those eggs are more likely to survive. There are many more egg predators in the lagoon than in open waters, and the eggs and larvae are adapted to conditions in the open ocean, not to those in the lagoon.
7. **Prohibit the use of fish aggregating devices (FADs)**, and remove existing FADs, consistent with the new Fisheries Act regulations The focus would instead be on conserving existing habitats. There is no scientific evidence that FADs increase the populations of fish or lobster. However, FADs do make lobster and fish easier to find and catch, even as populations dwindle, thus facilitating unsustainable fishing. Further, the materials used to create FADs can be damaging to the environment, either when FADs move around due to rough weather or when they release chemicals because of the materials of which they are composed. For example, the use of tires can be very damaging in both of these ways (Stephenson et al. 2003, Nuckols and Gray 2006).

Monitoring and Additional Data Collection

We collected as much data as possible during our 12 day survey, and adapted our methods to suit the ecological landscape of Barbuda; however, additional data would provide a better understanding of the lobster population and lobster fishery around Barbuda. Further collaborations between local fishers (drawing on their extensive local knowledge), the Fisheries Department, the Lagoon Park, and scientists will improve our understanding of the dynamics of the lobster fishery. We recommend two steps for additional data collection that together will provide a more detailed picture of the lobster fishery around Barbuda.

- Collect data on the size and sex of every lobster exported from Barbuda. This data would be relatively simple to collect during the export process, since lobster sizes already have to be verified. Ideally, associated information on catch location and fishing effort (e.g., hours at sea) would be collected as well.
- Collect information on size and sex of lobster caught for local consumption, in addition to those caught for export. Again, ideally, associated information on catch location and fishing effort would be collected as well.

Barbudan fisher Vernon Joseph with his day’s catch of lobster.

CONCH

Biology and Life History

Queen conch (*Strombus gigas*) is found throughout the Caribbean and Gulf of Mexico, from Florida to Brazil (Randall 1964). The lifespan of queen conch averages 20-30 years, though they can live up to 40 years (Stoner 2003). They inhabit warm, shallow water and are rarely found deeper than 20 m (Randall 1964, Stoner 2003). Conch are herbivores, and prefer turtle grass (*Thalassia sp.*) and manatee grass (*Cymodocea sp.*) habitats, but may also be found on sand, coral rubble, and hard rock bottom habitats (Randall 1964, Stoner 2003).

Adult conch may move 50 to 100 m per day and are capable of moving up to 2 km over 2 months (Brownell and Stevely 1981). Both juveniles and adults form aggregations, with adult densities of 2.5 individuals per m^2 and juvenile densities of up to 295 per m^2 (Stoner and Lally 1994). These aggregations are particularly vulnerable to overfishing, since thousands of individuals can be present in a single location. Predators include other species of snails, hermit crabs, spiny lobster, tiger sharks, spotted eagle rays, stingrays, loggerhead turtles, and several species of fish including triggerfish, wrasses, and porcupine fish (Randall 1964).

Queen conch generally reach maturity in 3 years, have a maximum length of over 30 cm, and weigh an average of 2.3 kg (Randall 1964, Sarkis 2009; Figure 6). Maximum shell size is reached prior to sexual maturity. Mature adults develop a flared lip at the opening of the shell. Further growth is marked by an increase in the thickness of the shell lip (Randall 1964); these sexually mature conch are referred to as "broadleaf conch" in Barbuda and much of the Caribbean.

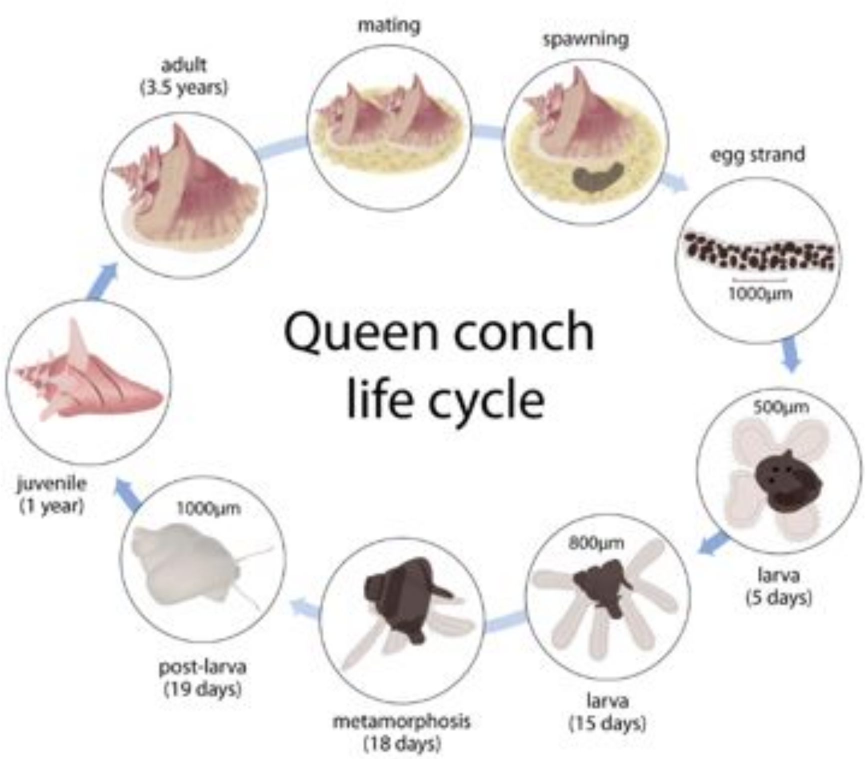

Figure 6. Life history diagram of the spiny lobster (Kruczynski and Fletcher 2012)

Spawning occurs both day and night from mid-March to November and can occur six to eight times per season (Randall 1964). After internal fertilization occurs, the female retains the sperm for several weeks before releasing it while laying her eggs in continuous strands of up to three quarters of a million eggs (Stoner et al. 1998). After hatching, larvae spend 3-5 weeks in open waters, creating the potential for long-distance transport on ocean currents (Stoner et al 1998). However, larval conch are often found close to the location where they hatched (Stoner et al. 1998). Juveniles are rarely observed until the shell exceeds 8 cm in length (Randall 1964).

Methods

Sites for conch surveys were randomly selected from sand and seagrass habitats using the habitat map (Figure 2). Conch were surveyed in teams comprised of one Waitt Institute scientist and several Barbudan divers. At each site, the team recorded GPS coordinates and evaluated depth and sea conditions to determine whether to survey via SCUBA or snorkeling. After haphazardly selecting a central point, the survey team attached a 50 m transect tape to this central point and unrolled it using a compass to maintain a constant heading.

While one team member unrolled the transect tape, other team members counted, measured, and recorded the total length of all conch within 2 m of either side of the tape. The total length of a conch is the distance from tip of the spire to the end of the siphonal canal, and was measured to the nearest centimeter. Conch more than 2 m perpendicular distance from the tape were not included in the survey. After surveying the full 50 m length, the tape was rewound to the central point. This process was repeated for a total of 4 transects per site, all originating from the same central point, but offset by 90 degrees, thus covering a total area of 800 m^2 per site (50 m long x 4 m wide x 4 transects; Figure 7). We conducted surveys at 35 sites in depths from 1 m to 15 m.

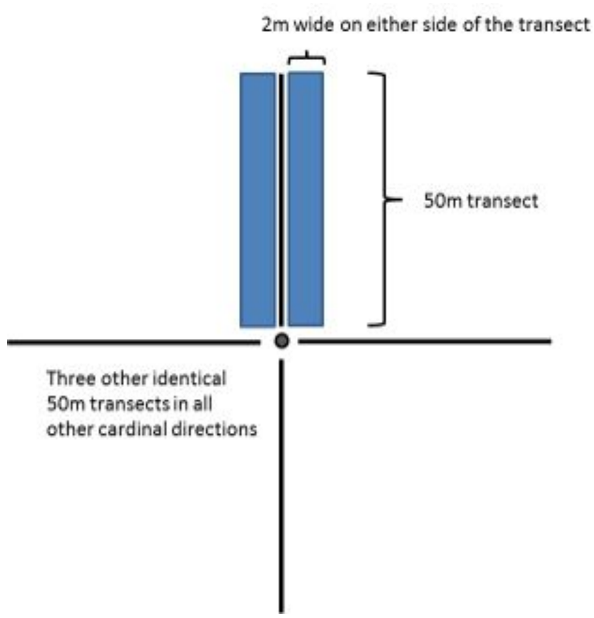

Figure 7. Diagram of sampling design for conch. Black lines represent 50 m transects. Blue bars represent a 2 m swath on either side of the transect within which all conch were counted and measured.

Results and Discussion

We surveyed conch at 35 sites around Barbuda (Figure 8). Our observations suggest that conch densities were patchy, but less so than lobster. Conch were present at 86% of randomly selected sand and seagrass sites, with adult (broadleaf) conch present at 53% of sites, and juveniles present at 71% of sites. Densities averaged 0.29 adult conch per 100 m^2 and 0.96 juvenile conch per 100 m^2 (Figure 8). One outlier site with more than 25 juvenile conch per 100 m^2 was excluded from these calculations.

These observed densities of adults around Barbuda are higher than some low-density locations, such as Barbados (less than 0.1 adults per 100 m^2, Valles and Oxenford 2012) and lower than locations such as Belize (2.4 adults per 100 m^2, Acosta 2006) or the Bahamas (0.6 to 1.3 adults per 100m^2, Stoner et al. 2012).

Similar to lobster, there was no clear pattern in the spatial distribution of juvenile or adult conch around the island. Two inshore sites along the south shore had very high juvenile abundance, and these same two sites had some of the highest adult abundance.

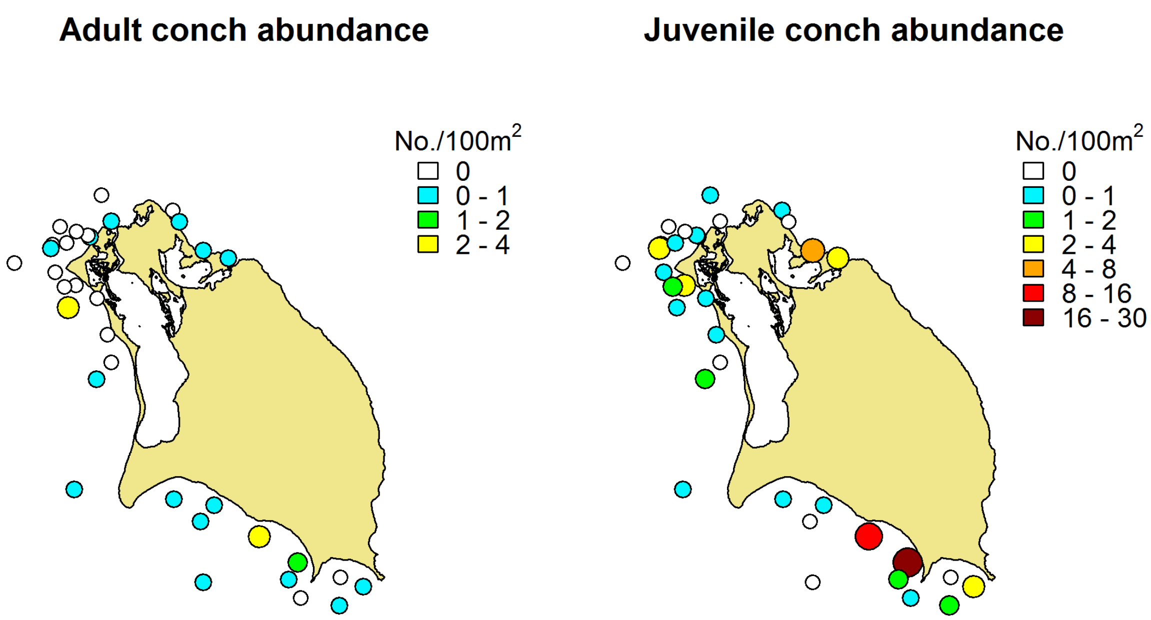

Figure 8. Abundance of conch at sites surveyed around Barbuda. Values are in numbers per 100 m^2.

The largest observed conch was 32 cm total length, and over 35 individuals (6.7% of all conch surveyed) measured over 25 cm (Figure 9). Of observed conch, 13.3% were adults, a similar proportion as found in heavily fished areas of Antigua in 1999 (Tewfik et al. 2001). We, like Tewfik et al. (2001), conclude that this proportion is an indication of consistent fishing pressure. Compared to locations with high densities and high proportions of adults (e.g., St. Lucia, 1.2 adults per 100 m^2 and 51% adults; King-Joseph et al. 2008), locations where conch are considered overfished have densities and percentages of adults similar to those we observed in Barbuda (e.g., Barbados, 0.1 adults per 100m^2 and 8% adults; Valles and Oxenford 2012).

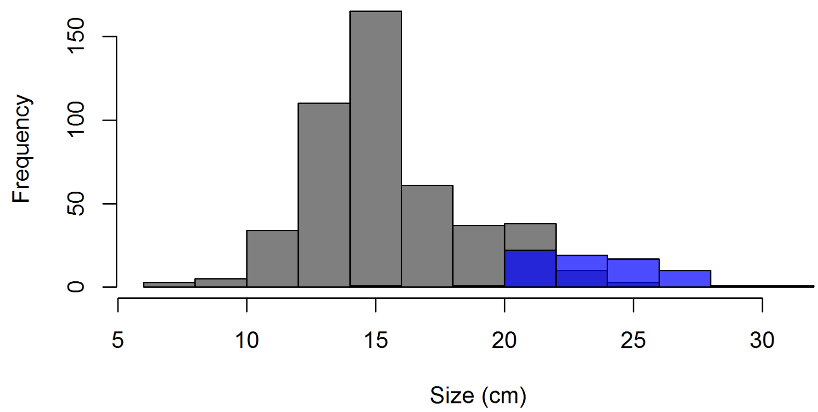

Figure 9. Size distribution of conch measured during the study.
Gray bars are juveniles, blue bars are adults, darker blue is the overlap.

There are still some larger conch around the island, but they are rare. This, combined with relatively low densities and low proportion of adults, also suggests that fishing pressure has significantly reduced the adult population. These largest individuals have the greatest reproductive potential, so increasing the adult conch population will be essential to recovering conch stocks around Barbuda.

Based on discussions with local fishers and comparison with conch populations elsewhere in the Caribbean, the abundance of conch in Barbuda appears to have been reduced significantly over the last several decades (Acosta 2006, Stoner et al. 2012). However, without information on historical densities and the fishery we cannot determine the extent to which this lower conch density is natural versus a result of fishing, but we suspect (based on the low proportion of adults and increasing fishing pressure) that fishing plays the major role. Conch are still present at most sites, and it was encouraging to observe many juvenile conch (up to 25 per 100 m^2 at the highest density sites), which suggests that the population could be rebuilt given robust management and enforcement.

Management Recommendations

Based on these data we suggest several management actions that will help increase the spawning stock of conch around Barbuda, leading to a larger, more productive and more sustainable fishery:

1. **Enforce the existing size limits** of a minimum size of 18 cm length, a flared lip greater than 5mm thick measured in the mid-lateral region, or total meat weight at least 225 g in accordance with the Fisheries Act regulations. These restrictions limit catch to adult, broadleaf conch. Though we did not collect data on abundance and sizes of cracked conch shells, we observed many that were not broadleaf individuals, indicating that sublegal conch are being harvested.
2. **Establish and enforce sanctuary zones, especially around spawning aggregations, where catch of conch is prohibited year-round**, to provide a refuge for conch to grow and reproduce, from which they can replenish fished areas outside.
3. **Enforce the closed season** of July 1 to August 31 as defined by the Fisheries Act regulations. As more is learned about spawning times for conch in Barbuda's waters, potentially adjust and extend the closed season to further enable conch to reproduce and populations to rebuild.

Monitoring and Additional Data Collection

Three research and monitoring steps would improve our understanding of conch population dynamics and the dynamics of the fishery around Barbuda:

- Continue collecting field data on the abundance and distribution of conch. This would build upon the 35 sites surveyed for this report and provide an increasingly comprehensive picture of the state of the conch fishery around Barbuda. These data could be gathered by divers from the Codrington Lagoon National Park and the Fisheries Department, several of whom have already been trained in the methodology, and with whom we are collaborating to develop a monitoring plan.
- Gather information on catch composition (number of individuals, size, weight, life stage (i.e., juvenile or adult), catch locations, and associated effort (e.g., hours at sea). This information could be collected when fishers land their catch, or (less ideal) when conch are processed for sale or export.
- Identify the locations and timing of spawning aggregations. These areas are likely to be critical to the sustainability of conch populations around Barbuda, and should be priority areas for protection.

Blue Halo scientist and Barbudan Fisheries Technician conducting a conch survey.

FISH

Biology and Life History

While there is a diversity of reef fish around Barbuda (we observed 135 species), this section focuses on the most economically important groups: groupers, snappers, and parrotfish (known locally as chub).

Groupers and snappers inhabit a wide range of hard-bottom habitats, and many species range into seagrass, sand, and mangrove habitats as well (Figure 10). Home ranges of groupers may be up to several square kilometers, while snappers may range up to 10s of square kilometers (Farmer and Ault 2011). Many groupers and snappers have long lifespans, and can live as long as 25-40 years (Choat and Robertson 2002). Maximum size varies by species; Nassau grouper can reach 120 cm and over 22 kg, red hind can reach 75 cm (but rarely more than 50 cm) and over 5 kg, and mutton snapper can reach nearly 100 cm and 15 kg (Froese and Pauly 2000). Apart from sharks, groupers and snappers are among the top predators on Caribbean coral reefs. They eat a wide range of fish and invertebrates, generally consuming more fish as they grow larger (Randall 1967). Their primary predators are sharks and other larger snappers and groupers.

Many groupers and snappers aggregate to spawn, sometimes moving 10s to 100s of kilometers to spawning grounds (Bolden 2000, Domier and Colin 1997). Groupers generally aggregate around full moons in winter (December-March) while snappers often aggregate around full moons in summer (June-September). Spawning aggregations range from a few dozen individuals to upwards of tens of thousands of individuals or more (Bolden 2000, Heyman et al. 2005). In addition, many groupers change sex, beginning life as females and changing to males as they become larger. The spawning and sex changing traits make these fish particularly vulnerable to overfishing: they can be targeted while aggregated, and targeting of large fish means targeting only males – both of which hinder reproduction.

Figure 10. Diagram of the Nassau Grouper lifecycle (BREEF). SPAG stands for “spawning aggregation.”

Parrotfish are found throughout tropical waters, generally from 1-30 m in depth. Parrotfish have much shorter lifespans than snappers and groupers, generally living no more than 6-8 years, with some species living up to 20 years (Choat and Robertson 2002). Most Caribbean parrotfish reach maximum sizes no larger than 35 cm and 2 kg, though a few of the largest species (the blue, midnight and rainbow parrotfish, known locally as "maca chub") can reach 75 cm or more (Froese and Pauly 2000).

Parrotfish are herbivores, and are critical in maintaining low levels of algae on reefs. Algae can out-compete coral for space, leading to a reduction in the coral cover, and thereby reducing structural complexity of reefs (Hughes 1994). Parrotfish graze on algae growing on dead coral, often biting off pieces of the limestone skeleton. The coral skeletons are crushed during digestion, and excreted as white coral sand. It is estimated that a single parrotfish can produce one ton of coral sand per acre of reef per year (Böhlke and Chaplin 1993). Home ranges of adult parrotfish are generally 100s to 1000s of square meters (Mumby and Wabnitz 2002). Parrotfish are preyed upon by larger predatory fish, such as snappers and groupers, as well as cryptic predators such as moray eels.

Many parrotfish species spawn year round, both in groups and in pairs. Parrotfish larvae drift in open waters for 4-5 weeks, after which time they settle to shallow reef habitats (Brothers and Thresher 1985, Lester et al. 2007). Parrotfish change sex; similar to groupers, they mature first as females and later become male as they grow larger. Unlike groupers, male parrotfish have distinct coloring from females, making it possible to visually distinguish males from females.

Methods

Sites for fish surveys were selected randomly and haphazardly using a combination of our habitat map (Figure 2) and local knowledge about the location of appropriate hard-bottom habitats that were beyond the mapped area. Coral surveys (see following section) were conducted concurrently. All data was collected by Waitt Institute scientists, but Barbudan divers accompanied and observed the research at most sites.

Fish surveys were conducted using the stationary point count method (Smith et al. 2011). A SCUBA diver descends to the bottom and haphazardly selects a point. This point becomes the center of a cylinder for which the diver estimates a radius of 7.5 m.

The fish counts proceed in 5 minute increments. During the first 5 minutes, the diver lists all of the species present inside the cylinder. As the rate of adding new species slows, the diver returns to the top of the list and estimates total numbers and sizes (recording minimum size, average size, and maximum size) one species at a time, until he/she reaches the bottom of the list. Any new species seen for the first time after 5 minutes, and again after 10 minutes, are indicated as such on the datasheet. At the end of the count, the diver records habitat information, such as habitat type, depth, and substrate height.

After completing one count, the diver swims approximately 15 m from the center of the first cylinder, and completes a second count using the same procedure (Figure 11). The two counts are averaged to obtain an estimate of the abundance of all species site. We conducted surveys at 116 sites in depths that ranged from 2 m to 25 m.

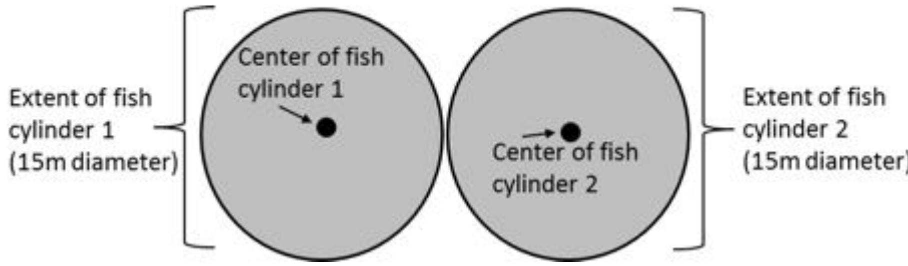

Figure 11. Diagram of fish survey design.

For each species, we calculated biomass using published length-weight relationships (Froese and Pauly 2000), and computed mean abundance and biomass per site. We computed per-site estimates of biomass for several sets of species (e.g., total fish biomass, snapper-grouper biomass, parrotfish biomass) at each site, as well as overall frequency of occurrence for several species.

Results and Discussion

We surveyed fish at 116 sites around Barbuda (Figure 12). In general, fish abundance was low around most of the island compared to other locations in the Caribbean (Jackson et al. 2013). The most common species were bluehead wrasse (present at 93% of sites), redband parrotfish (90% of sites), ocean surgeonfish (89% of sites), and blue tang (89% of sites). Larger predators were rare; Nassau grouper were present at 7% of sites, mutton snapper were present at 5% of sites, and no other large snapper or groupers species were observed. Smaller groupers, such as red hind, were more common, seen at 44% of sites. Similarly, larger parrotfish were nearly absent; rainbow parrotfish were observed at only two sites (1.7%), while midnight and blue parrotfish were not observed. Smaller parrotfish species appeared at 25-35% of sites, with the exceptions the more abundant redband parrotfish (90% of sites), and the rare redtail parrotfish (6% of sites). Zero sharks were present in our fish survey cylinders, and only two sharks were observed by divers during the entire field mission. Only one lionfish was observed during fish surveys, although lionfish were observed during lobster surveys and fishermen report that they are mostly found in deeper waters.

Calculated mean biomasses are as follows: 3300 g/100 m^2 total (range: 100-9800; Figure 12), 225 g/100 m^2 (range: 0-1700) for groupers, 121 g/100 m^2 (range: 0-2100) for snappers, and 680 g/100 m^2 (range: 0-3000) for parrotfish (Figure 13). These values are lower than much of the rest of the Caribbean, which average around 1000-1500 g/100 m^2 for parrotfish and groupers (Jackson et al. 2013). Like parrotfish, surgeonfish (locally called doctorfish and blackfish) are important grazers; their biomass averaged 640 g/100 m^2 (range: 1-3500), much lower than some sites in Caribbean, such as Bonaire and Saba, but higher than some heavily fished islands, such as Jamaica (Hawkins and Roberts 2004).

Spatial patterns of fish biomass were mixed. Total fish biomass showed no clear patterns by location, with both high and low biomass sites scattered around Barbuda. Snapper and grouper biomass was generally highest on the exposed areas on the east shore of the island (less accessible to fishing), with a few higher biomass sites inshore on the south shore. In contrast, parrotfish biomass was generally low in the exposed areas along east and north shores, and highest in the patch reefs on the south, west, and northwest shores (Figure 12).

The abundance of many species of fish appears to have been reduced in recent years, based on our conversations with locals and historical information from the Caribbean (Jackson et al 2013). Still, there are some encouraging signs. Nassau groupers, which once dominated reefs and fisheries across the wider Caribbean, have been severely depleted throughout the region, in part because of the ease of fishing their spawning aggregations. They are now virtually absent around many Caribbean islands, but they are still present (though rare) around Barbuda, with a few larger individuals observed. The same is true for mutton snappers. These observations suggest that there is more potential for recovery of these larger predatory fish around Barbuda than in many other parts of the Caribbean.

The largest Nassau grouper and mutton snappers observed were 70-75 cm long. Lengths of the more common red hind ranged from 10-40 cm, averaging 24 cm, far shorter than observed in some other Caribbean locations (e.g., US Virgin Islands: 35-40 cm; Nemeth 2005). Parrotfish size distributions were skewed toward smaller individuals, but initial phase (juvenile and female) generally ranged to 25-35 cm, with terminal (male) phase individuals ranging from 15-40 cm (Figure 14). Sex-specific size-frequency plots for parrotfish revealed that a relatively small proportion of parrotfish (10-18%) are males (Figure 9) but because these males are larger, they comprised around 41% of the parrotfish biomass. In other locations, such as the Central Pacific, males can make up 30% or more of the individuals (DeMartini et al. 2005)

Parrotfish abundance was also relatively low compared with the rest of the Caribbean (Jackson et al. 2013). Based on our conversations with local community members, our understanding is that parrotfish were much more abundant even as little as five years ago, but that targeting parrotfish with gill nets and spearguns has increased in recent years, particularly in the patch reef habitats where parrotfish are most abundant. It is these habitats where the positive effects of parrotfish grazing are likely to have the greatest benefits to corals, by reducing their competitor algae. In addition, larger parrotfish have much higher grazing abilities than smaller individuals, but the size structure of parrotfish in Barbuda is skewed, with few large individuals above 25 or 30 cm remaining.

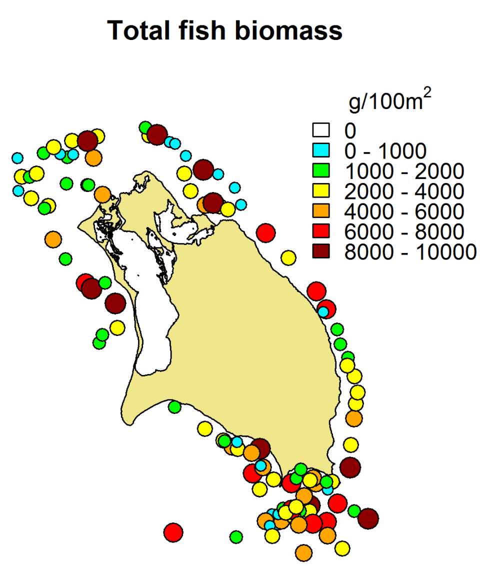

Figure 12. Total biomass of the fish communities at sites surveyed around Barbuda. Values are in g/100 m^2.

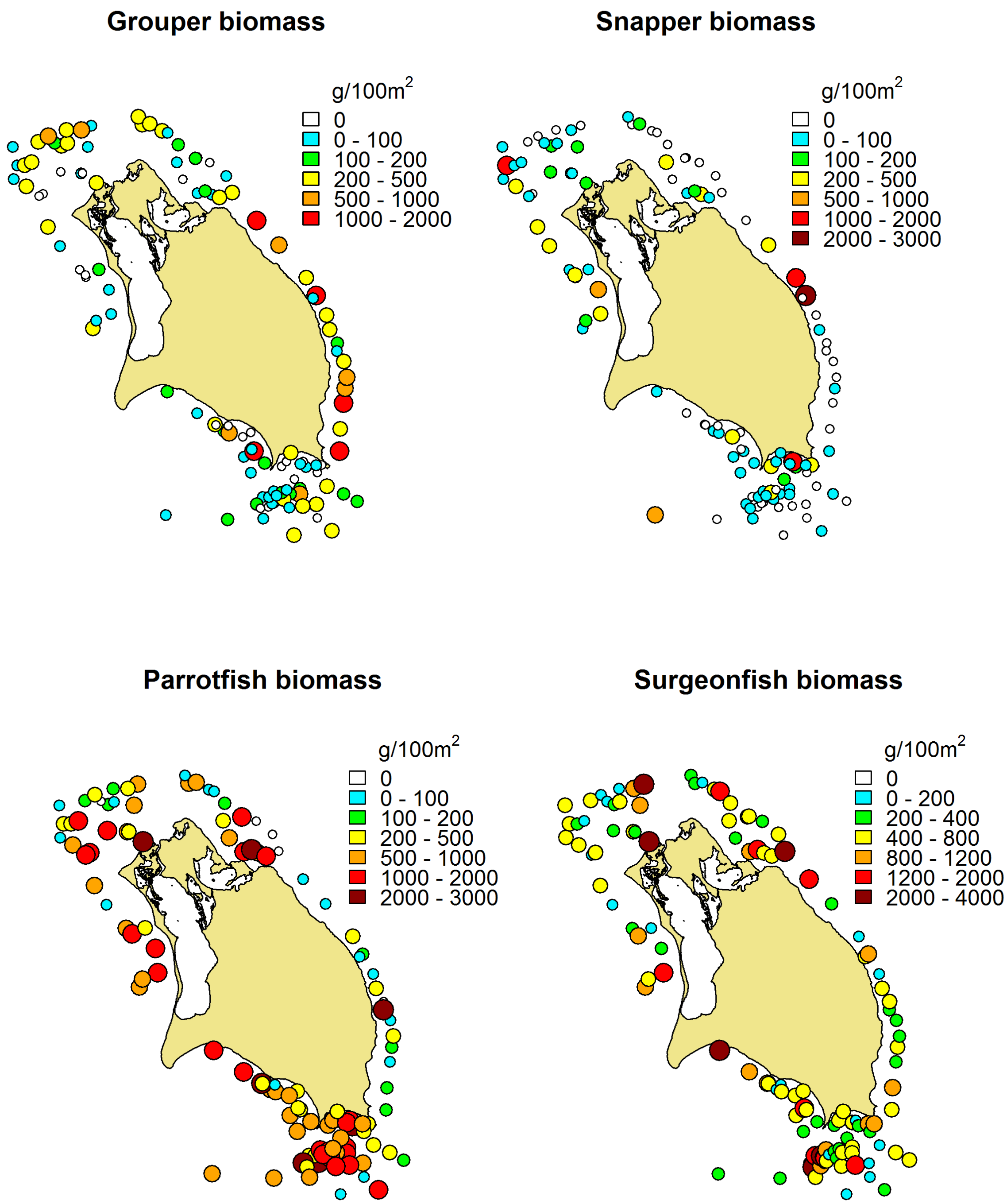

Figure 13. Total biomass of groupers, of snappers, of parrotfish, and of surgeonfish around Barbuda. Values are in g/100 m^2.

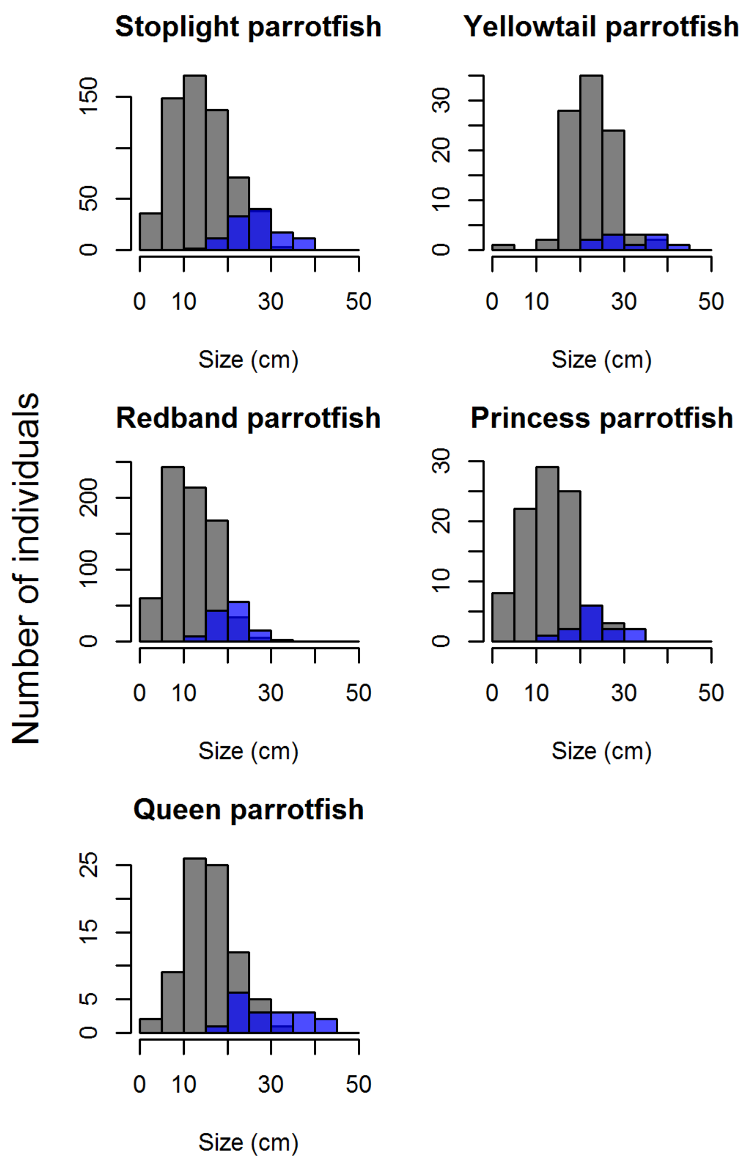

Figure 14. Size frequency plots for the 5 most common larger species of parrotfish around Barbuda. Gray bars represent juvenile and female fish, blue bars represent terminal phase males.

Management Recommendations

Based on these data, we recommend the following to restore fish populations and increase the sustainability of the fishery:

1. **Prohibit the catch of parrotfish and surgeonfish** because their populations have recently been reduced by increased fishing pressure and their consumption of algae and production of sand are critical to ecosystem health. The Fisheries Act regulations establish a closed season for parrotfish from May 1 to July 31 each year. However, given the increasing pressures on parrotfish and surgeonfish, and the high levels of algae found across Barbuda's reefs, we identify a complete prohibition on catch of parrotfish and surgeonfish as the single most important step to take in order to promote overall reef health.
2. **Establish and enforce fish sanctuary zones where fishing is prohibited year-round**. This will give fish a refuge where they may safely grow to reproductive size while creating a source population of larger fish that will help replenish fished areas outside of the sanctuary zones.
3. **Prohibit catch of groupers and snappers while they are gathered in spawning aggregations**. If these critically important spawning aggregations continue to be fished, populations of these large and important predators are likely to collapse. To start, the closed season must be enforced (January 1st – March 31st) and the season length should be adjusted or particular areas closed as more data on spawning times and locations are collected.
4. **Prohibit the use of gill nets around Barbuda.** At present, gill nets are being used to target parrotfish and surgeonfish, key herbivores critical to keeping algae levels low. Based on our conversations with locals, little of the parrotfish catch from gill nets is landed on Barbuda or fished by Barbudans, so this harvest has minimal benefit to the local island population while hurting the island's ecosystem health. Protecting parrotfish will help reduce algal cover on reefs, which will help increase coral growth and recruitment, with subsequent benefits around the island for fisheries, tourism, and the enjoyment of reefs.
5. **Require the inclusion of escape gaps in fish and lobster traps** (i.e., pots) to allow juvenile and ornamental fish to escape before traps are hauled. Fish hauled from significant depths are unlikely to survive, even if they are released. Enabling juvenile and slender-bodied fish to escape while traps are at depth will reduce the catch and death of un-targeted, un-marketable, and un-consumable fish.

Monitoring and Additional Data Collection

Improving data collection for Barbuda's fisheries is a challenge. It is more complicated to implement data collection for fish than for lobster or conch because there are many fish species in Barbuda. Therefore, we recommend prioritizing data collection efforts on lobster and conch over the next several years. However, based on available local capacity, we recommend the following actions be taken to improve our understanding of fish population and fishery dynamics around Barbuda:

- Identify and map spawning aggregations of snappers and groupers. Although the remaining aggregations may be small, it may be possible to identify locations by interviewing local fishers and to verify these locations by visiting sites during spawning.
- Begin collecting data on fish catches around Barbuda (fish species, size, catch location, and fishing effort) by surveying fishers as they land their catch.

CORAL AND ALGAE

Biology and Life History

Corals create habitat for many of the ecologically and economically important reef species around Barbuda. Corals are colonial animals in which each colony is comprised of thousands of individual coral polyps. All polyps in a colony are genetically-identical clones of a single individual larva which settled to a reef and began to grow. Corals obtain some of their energy by filtering microscopic food particles from the water column, but they derive the majority of the energy from microscopic algae that live in their tissues. These algae use photosynthesis to produce energy for themselves and for the coral polyp, and in return, the coral provides nutrients and protection for the algae (Veron 2000; Figure 15).

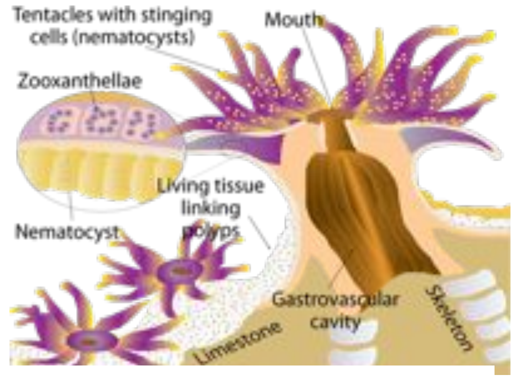

Figure 15. Diagram of a coral polyp.
(Source: Kruczynski and Fletcher 2012)

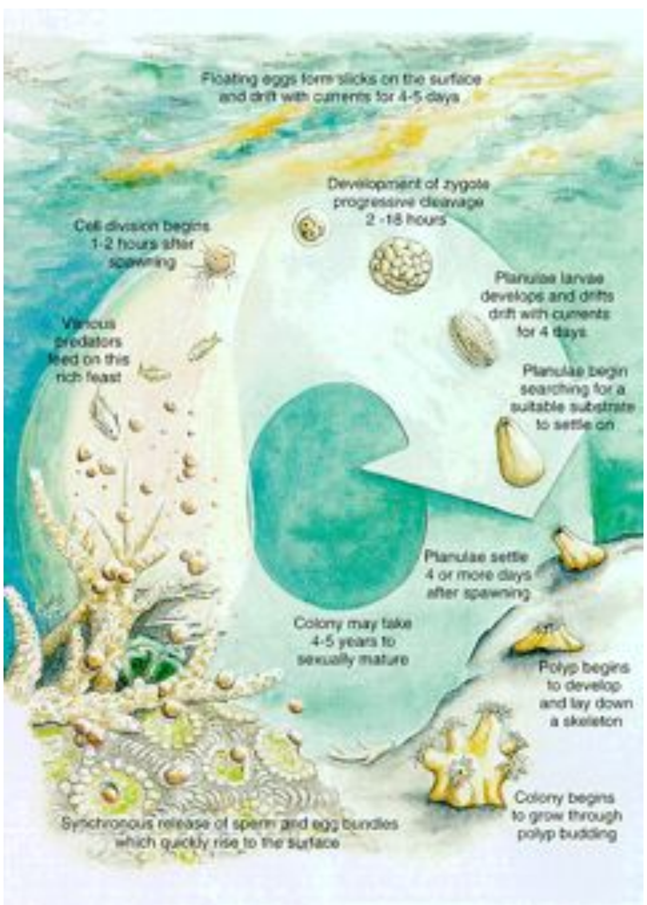

Figure 16. Life cycle of a spawning coral.
(Source: Australian Institute of Marine Science)

Different species of corals grow at different speeds, form different colony shapes, reach different maximum sizes, and can have different lifespans. Large colonies can be several meters across and live for hundreds of years. Corals reproduce sexually by one of two modes: broadcasting or brooding. In broadcast spawning species, many colonies release eggs and sperm together in a mass spawning event. These broadcast spawning events often happen around new or full moons on only a few days during the year. Other species reproduce by brooding, a process in which eggs are fertilized while still inside the coral polyp. Brooded larvae are released already swimming and usually settle closer to the parent colony than larvae from spawning coral species. Although the larval phase may last from a few hours to several days to a few weeks, some larvae are trapped in eddies and currents during this time, eventually settling relatively close to their home reef (Veron 2000; Figure 16).

Corals grow slowly. Even the fastest branching corals only grow a few to 10 cm per year, but most species grow ~1cm per year (Veron 2000). They compete for space with many other sessile (i.e., fixed-place) organisms, such as sponges, soft corals, and a variety of different types of algae.

On healthy reefs, fleshy algae are normally kept in check by abundant herbivores including parrotfish, surgeonfish and sea urchins. When these herbivores are overfished, fleshy algae can overgrow, out-compete, and even kill corals. The health of reef bottom communities is often assessed by determining the abundance of different reef building organisms (corals and encrusting coralline algae) versus fleshy non-reef building organisms (including turf algae, fleshy macroalgae, sponges, etc.).

Methods

The standard technique for determining benthic (i.e., ocean bottom) composition is by estimating the percent of the bottom occupied by different organisms, such as corals, sponges, and various types of algae. In our ecological assessment, we conducted surveys to determine the percent cover of corals and other benthic groups at each site where fish community surveys were conducted. All coral and algae data was collected by Waitt Institute scientists, but Barbudan divers accompanied and observed the research at most sites.

On each dive, one diver surveyed fish while another diver surveyed coral and algae (see methods for Fish, above), and laid out a 25 m transect (Figure 17). The coral surveyor then swam back towards the start of the transect, taking a photograph of the bottom every 2 m using a camera mounted on a pole (80 cm long). The pole ensured that the camera captured the same total surface area in each photograph. After completing the first transect, the diver returned to the starting point and laid a second 25 m transect in the opposite direction and repeated the process of taking photos as described above. This process yielded 24 photographs per site.

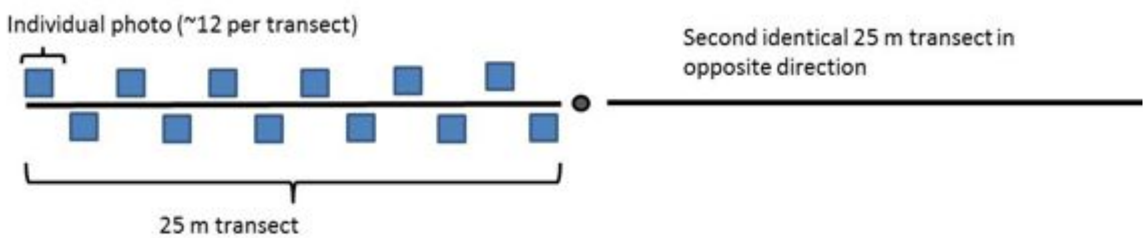

Figure 17. Diagram of benthic survey methodology.

To analyze the photos, we used computer software designed to analyze ocean bottom photographs (PhotoGrid). This software marks 25 random locations on each photograph with a marker dot. Coral and algae identification experts from the ecological assessment team then identified the organism or object under each dot, using the finest scale taxonomic discrimination possible. All hard corals were identified to the species level. Distinct types of algae, soft corals, and sponges were identified to the level of genus, and all other organisms were identified according to their functional group (e.g., red fleshy calcified algae, whip gorgonian, etc.). When the total data are compiled from this method, the percentage of dots associated with each species, genus, or functional group at each site directly corresponds to the percentage of the reef bottom covered by members of that group. This allows us to make calculations about coral and algae coverage at the dive-site level and for Barbuda as a whole. In total, we analyzed 71,979 dots in 2,854 benthic photos.

In addition, divers also measured urchin abundance during the fish and benthic community surveys. The black, long-spined sea urchin (*Diadema antillarum*, or sea egg) is an important grazer of algae, and its presence can often help facilitate the recruitment and growth of corals by scraping algae completely offof limestone surfaces. The ecological assessment team counted the number of these urchins present in each of the fish cylinders while fish divers were collecting habitat information and in the benthic transects (in a 1 m wide band) while divers were setting up transects for photography. Because our main focus was on the fish and coral/algae communities, our searches for urchins were not exhaustive. Further, urchins can be hidden in rocks and crevices, especially during the day. Therefore our estimates of urchin density are conservative.

Results and Discussion

We conducted benthic surveys at 116 sites around Barbuda. We observed 27 species of hard coral. Island-wide, live coral cover averaged 2.6%. Of all sites surveyed, the maximum coral cover observed was 16%; only three sites had more than 10% live coral cover. Overall, even the three most common coral species in terms of total area covered, *Porites astreoides* (the mustard hill coral), *Porites porites* (finger coral), and *Siderastrea siderea* (massive starlet coral) each averaged less than 1% live cover. Two formerly dominant coral species in the Caribbean, staghorn and elkhorn coral (*Acropora cervicornis* and *Acropora palmata*, respectively), were extremely rare. Staghorn coral was present in only two photographs and elkhorn coral was not observed in any photographs. However, dead but still relatively intact skeletons of these species were observed on multiple reefs, indicating that the loss of these species was recent and significant. Another group of important reef-building corals in the Caribbean (massive star corals in the *Montastraea annularis* complex) together averaged just under 0.6% live cover.

Calcified crustose coralline algae (CCA), which is important in helping to cement the reef together and serves as settlement substrata for larval corals, was uncommon. Overall, the average cover of CCA was only 2.0%, with a maximum cover of 13%. In contrast, fleshy/soft algae were much more abundant on Barbuda's reefs. Turf algae, a group of short, fast-growing algae, had a mean cover of 66% and a maximum of 92%. Macroalgae, a group of larger fleshy algae that are generally able to out compete corals for space, averaged 13% cover with a maximum of 50% cover. The frequency distributions for these four groups of algae are shown in Figure 18. Overall, the average percent cover of turf algae and macroalgae combined was 79% island-wide.

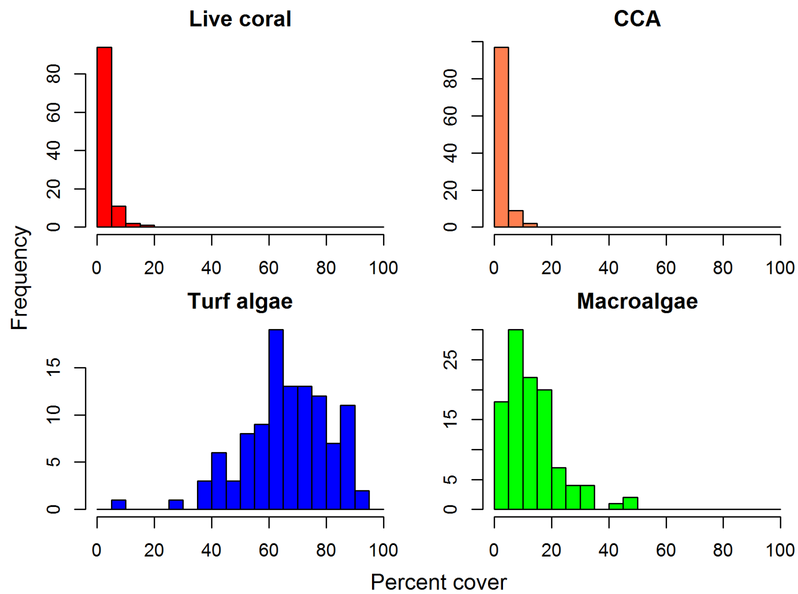

Figure 18. Frequency distribution for percent cover of four main coral and algae groups.

Spatially, the sites with the highest coral cover were clustered in the patch reefs along the south shore of Barbuda, and, to a lesser extent, along the west shore (Figure 19). The inshore patch reefs along the north shore had low cover in general. The lowest cover overall was generally in the deeper areas outside the forereef, especially in exposed areas of the north and east shores. At all of the shallow patch reef and back reef habitats there was clear evidence of recently living coral as all of the skeletons were still standing and intact. However, these dead skeletons were now largely covered in fleshy algae.

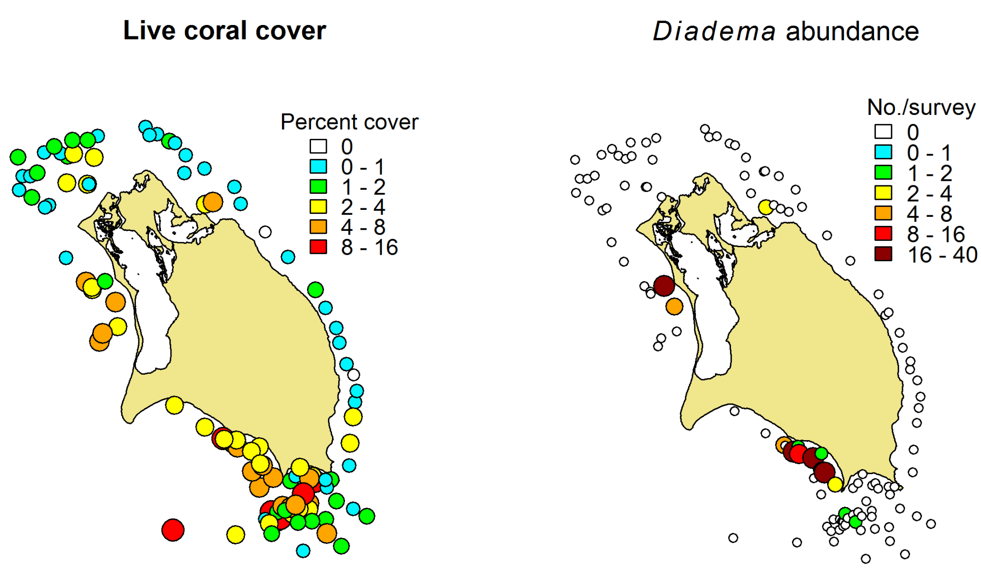

Figure 19. Left: Coral abundance at sites surveyed around Barbuda. Values are percent bottom cover of live coral. Right: Occurrence of long-spined sea urchins (*Diadema antillarum*) at sites around Barbuda where fish and coral surveys were conducted. Values are total number of urchins observed per survey.

Island-wide coral cover (2.6%) is much lower than the Caribbean average (17%; Jackson et al. 2013). Barbuda sits in the extreme northeast corner of the Caribbean, and is therefore exposed to all of the swells from Atlantic storms to the north, east, and to a lesser extent, to the south. Many of the forereef survey sites in the most exposed areas of Barbuda had coral habitat that was low in relief, with little three-dimensional structure, and with evidence of frequent scouring by waves. Therefore, it is possible that the most exposed areas of Barbuda have never had high coral cover.

However, this is not likely the explanation for the low levels of coral cover seen in the more protected inshore areas of Barbuda. Many of the patch reefs, especially those by Palastar reef and along the south shore, have remnant structures built by elkhorn corals and massive star corals, which appear to have died in the last decade or so. It is unlikely that storms are the cause of coral death in this part of the island because of the presence of dead coral that is still standing (i.e., was not knocked over by waves) (Goreau and Goreau 1996).

From our ecological assessment, we cannot determine exactly what caused this coral die-off, but it appears to have occurred much more recently than the Caribbean-wide die-off of elkhorn coral in the early 1980s (Aronson and Precht 2001). As of 1996, scientists reported that the reef off of North Beach had 50% live coral cover (35%+ of which was staghorn and elkhorn coral), abundant fish, and virtually no algae (Goreau and Goreau 1996). We suspect that fishing pressure may have played a significant role in the reefs decline because (1) the decline is recent, (2) dead coral skeletons remain standing, (3) there are no anecdotes of major pollution, and (4) there is currently low abundance of fish in this area. We cannot conclusively determine whether higher levels of macroalgae at many of the patch reefs were an additional cause of this coral mortality, but it is possible that algae played a role both in initial coral die-offs and in the prevention of subsequent recruitment of juvenile corals.

Live coral cover of 50% as recent as 1996 near North Beach is in line with the historical Caribbean standard. Regional analyses have shown that healthy Caribbean reefs typically had greater than 50% live coral cover (Gardner et al. 2003, Goreau and Goreau 1996). Due to the abundance of dead coral skeletons that we observed in Barbuda sites, many of which appear to have died the last 10 to 20 years, we are certain that Barbuda's overall coral cover in the past was much higher than current 2.6%.

Long-spined sea urchins were present primarily on the inshore patch reefs, with the highest abundance on the inshore patch reefs along the south shore. These urchins are often most abundant in similar habitats in other inshore areas in the Caribbean, where they may help lead to recovery of corals (Edmunds and Carpenter 2001). Note that our data underestimate the actual abundance of urchins because counts were conducted concurrently with fish and coral surveys and likely missed the most hidden individuals.

Management Recommendations

As in much of the Caribbean, the decline in coral cover on Barbuda is likely the result of many factors, some of which are local (e.g., fishing and pollution), some of which are regional (e.g. urchin and coral diseases; Roff and Mumby 2012), and some of which are global (e.g., climate change; Gardner et al. 2003, Jackson et al. 2013), and some of which are natural (e.g., hurricanes). Therefore, rebuilding coral will be a slow and uncertain process. However, we have several management recommendations that could contribute to restoring coral populations in suitable habitats around Barbuda:

1. **Protect herbivore populations around Barbuda**. Herbivores will help reduce the cover of turf algae and macroalgae, thereby reducing the amount of competition corals face from these algae. This will enable corals to grow more quickly and in more locations. This will help reduce damage from disease pathogens and predatory invertebrates that hide in algae. This will also help clear space for increased coral recruitment. This is particularly relevant for sites with high habitat complexity (three-dimensionality) in the shallow nearshore and patch reef locations.
2. **Prohibit removing, damaging, touching, or anchoring on coral**, as consistent with the Fisheries Act regulation stating coral may only be taken for scientific research with a permit.
3. **Establish sanctuary zones where no fishing occurs year-round**, so that in these places corals are not threatened by damage from spearguns, nets, traps/pots, fisher's anchors, etc. When corals have a refuge where they can more quickly grow and reproduce, they can also produce more juveniles to help replenish areas outside the sanctuaries.
4. **Establish specifically-designated anchoring zones** in areas of sand, and potentially install boat moorings as well. Prohibit anchoring in coral habitats to reduce anchor damage to corals. Anchoring should especially be prohibited in sanctuary zones.

Monitoring and Additional Data Collection

As with fish surveys, a great deal of experience and training are required to successfully implement a benthic monitoring program, and changes in coral communities generally occur very slowly. Therefore, we do not recommend Barbudans establish a coral monitoring program at this time.

Photo of a young Elkhorn coral (*Acropora palmata*) in Barbuda's waters, surrounded mostly by algae.

CODRINGTON LAGOON

Biology and Ecology

Codrington Lagoon is the gem of Barbuda's marine systems. It is large (35 km^2) with generally clear water throughout the lagoon. In many tropical systems, lagoons serve as important nursery areas for a wide range of species, including fish and lobster. These species use the mangrove prop root structure and seagrass as shelter from larger predators and as foraging areas (Figure 20). Many species subsequently move out onto reefs as adults (Acosta and Butler 1997, Jones et al. 2010). Because of their importance as nursery habitats, lagoons can be critically important in maintaining healthy populations of adults, since adult populations depend on large numbers of surviving juveniles.

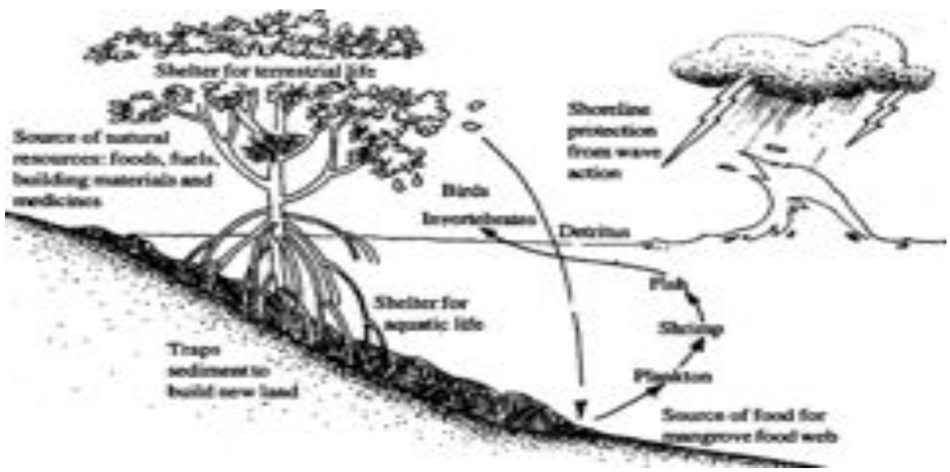

Figure 20. Diagram of the functions mangroves serve in coastal ecosystems (IIRR).

In many other parts of the Caribbean, lagoons have been heavily impacted by coastal development (including destruction of mangroves), pollution, and runoff, with detrimental effects on water quality, mangroves and seagrasses, and subsequent impacts on their ability to serve as effective nursery areas for key species. Our initial assessment suggests that the Codrington Lagoon has been minimally impacted to-date, and appears very healthy.

Methods

We surveyed 37 sites in the lagoon. We selected sites within the lagoon and the channel haphazardly, with an emphasis on the mangrove channel. At each site, we deployed four 15 m transects. In areas with mangroves (e.g., the channel), transects followed the mangrove edge. In areas in the middle of the lagoon, transects were deployed in a straight line from a haphazardly selected starting point. Transects were surveyed by a pair of snorkelers. Along each transect, one Blue Halo scientist identified, counted and estimated sizes for each fish and lobster in a 2 m wide belt (1 m on either side of the tape). The second scientist took downward-facing photos of the bottom every meter, using a similar approach as that for corals. The data for all four transects were averaged to generate one estimate of the community per site. All data was collected by Waitt Institute scientists.

Benthic photos from the lagoon sampling have not yet been analyzed, due to time constraints. We hope to complete this project in the coming months, and we will provide these data when they are available.

Results and Discussion

Overall, the lagoon is in excellent condition, appears to be critical juvenile habitat for a range of marine species, and as such is key to recovery of fishery species around Barbuda.

We observed 44 different species of fish in the lagoon; the most common were yellowfin mojarra (80% of sites; average of 20 per 100 m^2), gray snapper (68% of sites; average of 5.8 per 100 m^2) and schoolmaster snapper (64% of sites; average of 17 per 100 m^2; Figure 21). Schoolmaster were only observed in the channel, and gray snapper were the most abundant species in the channel. Of the sites where lobster were found, they were most common in the channel, but were also present at high numbers at one middle lagoon site that had a number of ledges and overhangs. Not surprisingly, the vast majority of individuals were juveniles; only 1 schoolmaster was >20 cm (~0.1% of all individuals), while 19 gray snapper were >20 cm (8% of all individuals). No legal sized lobster (i.e., >95 mm CL) were seen in the lagoon.

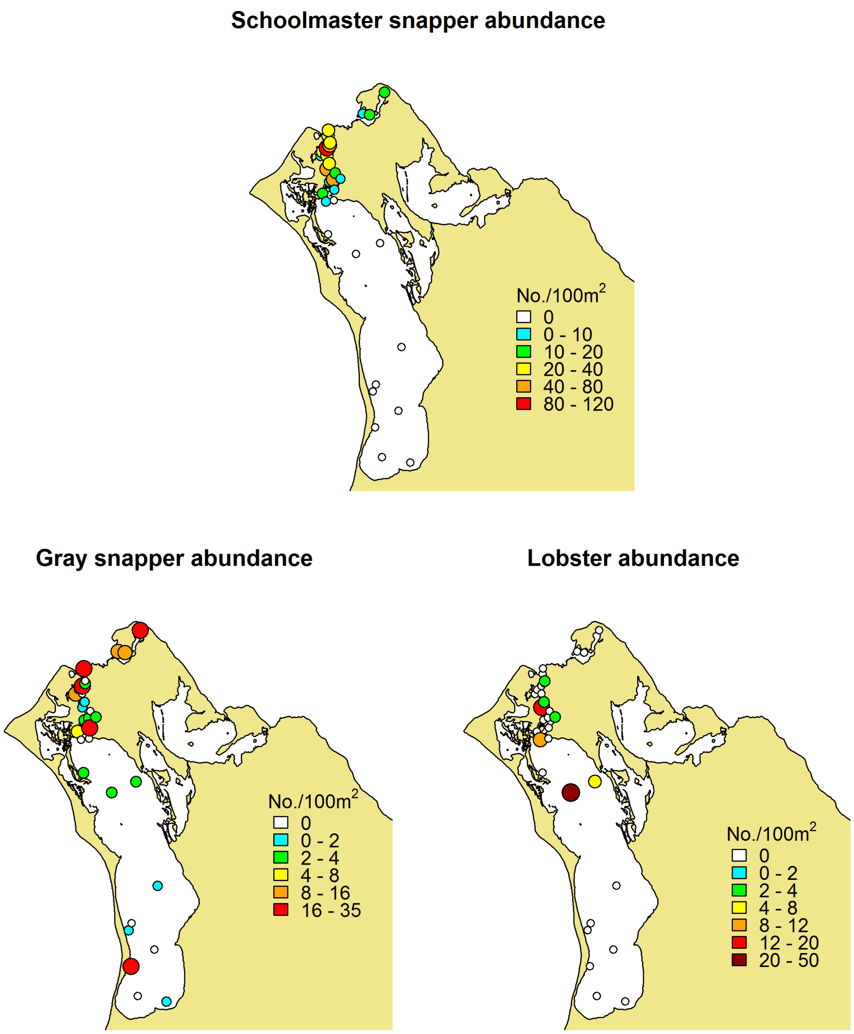

Figure 21. Abundance of schoolmaster snapper, gray snapper, and lobster at sites surveyed in Codrington Lagoon. Values are number of individuals per 100 m^2.

From our observations, the mangroves appear to be healthy and to have recovered from the damage observed by scientists after Hurricane Luis (Goreau and Goreau 1996). The seagrass is also generally in good condition. Many places had abundant calcified green algae. These algae are slow-growing and generally thrive in clear, lower nutrient waters, and are often indicators of good conditions in a lagoon. Fast growing fleshy algae, indicators of higher nutrients, were rare, a positive sign. In some areas, particularly mangrove areas in the channel, juvenile fish are abundant and juvenile lobster are common.

However, we observed a two negative signs in the lagoon. First, scars made by boat propellers are common; these scars can require many years to heal fully, and continued scarring can begin to degrade a seagrass bed. Second, from our conversations with locals, the present abundance of *Cassiopeia* jellyfish is much higher that in the recent past. It is unknown what causes these population increases, nor how they may change local systems.

Management Recommendations

Maintaining the Codrington Lagoon in excellent condition is critically important to the productivity of Barbuda's fisheries. Therefore, we recommend:

1. **Re-affirm and enforce the existing ban on clearing or harvesting mangroves,** including for costal development or use of wood. These mangroves create critical juvenile habitats.
2. **Close the lagoon to all fishing**. Allowing juveniles to grow and mature will allow the lagoon to fulfill its role as a protective nursery, and should ultimately lead to an increase of populations of larger adult animals in the reefs around Barbuda.

Monitoring and Additional Data Collection

As with fish and benthic surveys on the reefs, conducting similar surveys inside the lagoon require a great deal of training, making it challenging to implement a monitoring program. Therefore, we do not recommend a biological monitoring program within the lagoon until conch and lobster monitoring are up and running. However, as additional capacity and training are available, a developing a monitoring program would be useful for tracking changes to the lagoon and enabling management decisions to be made accordingly.

Juvenile fish and lobster under mangrove roots in Codgrinton Lagoon.

WATER QUALITY

Context

Nutrient levels are typically very low in pristine coral reef environments, and corals are adapted to grow well in low-nutrient waters. Nutrients (which include nitrogen and phosphorus) can fuel algal growth, which means algae (which grows quickly) can outcompete coral (which grows slowly) for space. Thus, nutrient pollution is a factor in the balance between coral and algae on reefs. Waters with high levels of nutrients are often associated with areas negatively impacted by humans.

Methods

We collected water samples to analyze nutrient concentration and bacterial population densities. All samples were collected by Waitt Institute scientists. Water quality sampling locations included sites along the forereef, the backreef, and in the lagoon. Water samples for nutrient analyses were frozen after collection, and processed at the Analytical Laboratory facility in the Marine Science Institute at the University of California Santa Barbara. We analyzed samples for 5 parameters that are standard in water quality sampling programs: phosphate, silicate, nitrite, nitrite + nitrate, and ammonia.

Water samples taken to measure bacterial abundance were processed and analyzed in the field, using techniques designed to rapidly quantify culturable *Vibrionaceae* bacteria. After seawater was collected in clean polycarbonate bottles, a 0.1 ml sample of the raw seawater was plated onto each of two replicate agar plates (i.e., plastic laboratory dishes containing a solid growth substrate suitable for culturing bacteria) using the spread plate method. A 10x dilution was also prepared from this raw seawater using freshly-sterilized seawater. A 0.1 ml sample of this diluted seawater was then plated onto each of two replicate agar plates. In total, four agar plates were prepared for each of the microbial testing sites. Agar plates were incubated overnight at ambient seawater temperature (27°C). Standard microbiological scoring methods were followed to quantify colony-forming units (CFU) of bacteria (as in Dinsdale et al. 2008).

A subset of culturable *Vibrionaceae* bacteria are pathogenic and the overall abundance of culturable *Vibrionaceae* is considered to be a rough indicator of overall water quality on coral reefs (Dinsdale et al. 2008). However, there are limitations to the interpretation of culturable *Vibrionaceae* data because not all *Vibrio* species present in seawater will grow in overnight cultures. Therefore, these data should be interpreted with caution as they represent only a preliminary assessment of reef water quality in Barbuda. Additional laboratory analyses are currently underway to further quantify the abundance and types of bacteria in Barbuda's waters.

Photo of mangroves, seagrass, and clear water in Codrington Lagoon.

Results

Nutrient parameters were generally within acceptable levels. Offshore, ammonia was within normal levels from other marine systems (0.25-1 µmolar; Boyer and Briceño 2008), but lagoon levels were somewhat elevated (Figure 22). Nitrite was well within normal levels (0.025-0.15 µmolar), as were nitrate + nitrite (0.15-0.75 µmolar), and silicate (1-10 µmolar; Boyer and Briceño 2008). Phosphate levels were low, even relative to nutrient poor open ocean systems (average of 0.14 µmolar in the tropical Atlantic; Conkright et al. 2000).

In general, nutrients that were higher outside the lagoon (forereef and backreef sites) were lower inside the lagoon (middle lagoon and dock), and vice versa. Within the lagoon, ammonia and nitrate levels showed a trend of being higher at the sites closer to town (i.e., dock and mid-lagoon sites).

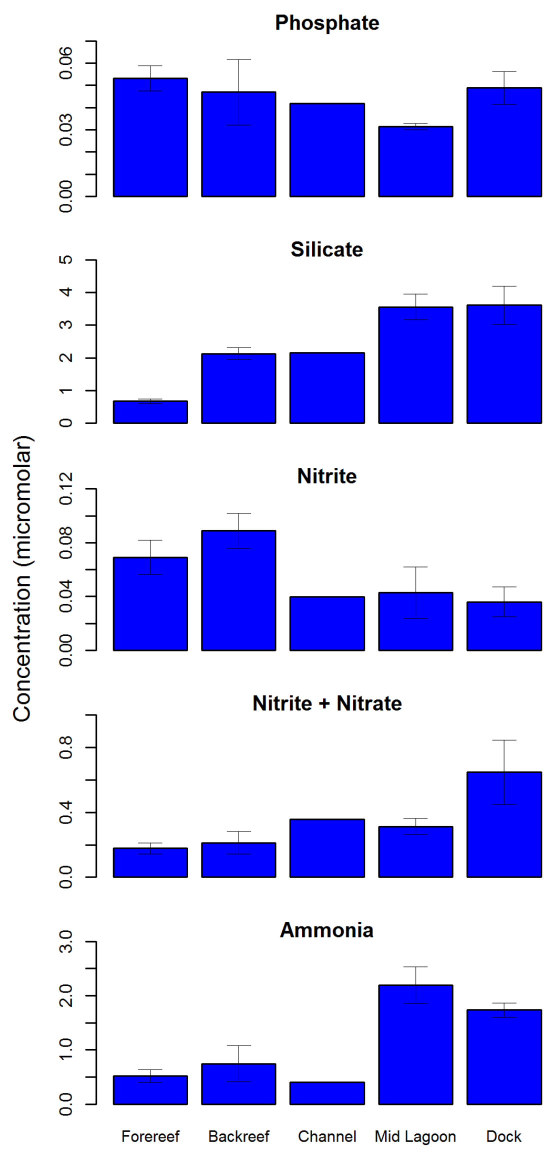

Figure 22. Water quality parameters grouped by habitat for 5 water quality parameters.
All values are in micromolar (micromoles per liter).

The number of culturable *Vibrionaceae* bacteria in Barbuda's waters was overall low, even in lagoon waters and near-shore sites. At many sites there was zero culturable *Vibrionaceae* detected (Figure 23). Among coral reef surveys, bacterial levels this low are typically seen only in the most remote uninhabited Pacific islands (Dinsdale et al. 2008). These results suggest that the input of sewage and agricultural runoff into Barbuda's reef and lagoon waters are low compared to most sites in the Caribbean.

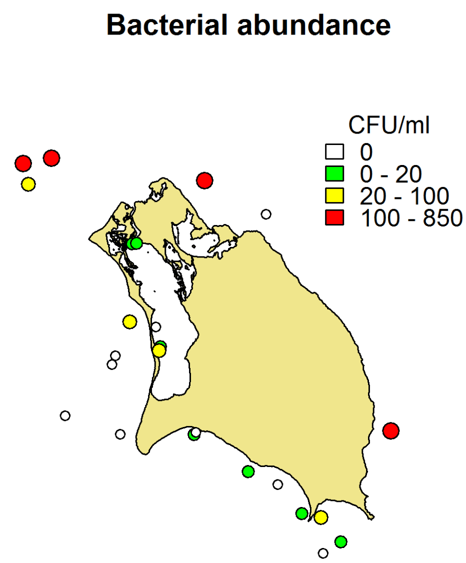

Figure 23. Abundance of culturable *Vibrionaceae* at sites around Barbuda where microbial abundance was sampled. Values are presented as colony-forming units (CFUs) per ml of seawater.

Management Recommendations

The goal of management should be to maintain the currently good water quality around Barbuda. Water quality can deteriorate quickly with even small changes in land use, sewage and fertilizer inputs, coastal development, and population growth. If changes occur in any of these factors, possible effects on water quality should be carefully considered and then mitigated. It is important to avoid land use practices that result in erosion, and to ensure that untreated sewage and waste do not end up in the water. Proper maintenance of septic tanks can reduce the amount of seepage of waste into the water.

Monitoring and Additional Data Collection

Water quality monitoring can be expensive and equipment intensive. However, we encourage the Codrington Lagoon National Park to continue the monitoring of water quality in the lagoon they are currently conducting using existing equipment. Over time, daily monitoring of temperature, salinity, and dissolved oxygen in the lagoon could provide some useful information. This could be implemented by simply recording those measurements from the main Lagoon dock on a daily basis.

CONCLUSIONS

Barbuda's marine ecosystems are unique and productive, and have the potential to support sustainable fisheries over the long term. However, these ecosystems appear to have declined dramatically in recent years and may be at a tipping point. Based on our observations, conversations with many Barbudans, and comparison with research conducted elsewhere in the Caribbean, a number of species are overfished and nearshore ecosystems have declined. Population sizes of lobster, conch, fish, and corals are much lower than they used to be. Fishers report having to go further from port and into deeper waters in order to make fishing trips worthwhile. Many other Caribbean islands have experienced similar declines but have failed to act, with the result that their ecosystems and fisheries have collapsed.

At the same time, there are reasons to be optimistic. There are still many juvenile lobster in the reefs and lagoon, and large lobster are still present around the island. These large lobster have the greatest reproductive potential; combined with extensive intact juvenile habitats in the lagoons, they might provide an ample supply of juveniles. Closing the lagoon to fishing, closing fishing during the reproductive season, and implementing sanctuary zones (where no fishing occurs) is likely to greatly increase the size and number of fishable lobster around Barbuda. Increasing data collection on lobster caught should help the Fisheries Department evaluate the impact of these measures.

Conch are not abundant around Barbuda, but juveniles are still common in some locations. Creating sanctuaries, especially around spawning areas, may help increase the reproductive potential around Barbuda, the number of fishable adults, and the sustainability of this fishery. Increasing monitoring of fishery catches and *in situ* populations will provide information to further improve management.

The populations of many species of fish have declined around Barbuda, and the top predator snappers and groupers are rare. Parrotfish are still common on patch reefs, but they appear to be less abundant than in the past. Identifying and creating sanctuaries around spawning aggregations of snappers and groupers can begin to rebuild their population numbers. Banning the catch of parrotfish and surgeonfish, the key herbivores that keep algae levels controlled, will help these species recover.

Coral cover is very low around Barbuda, and there is evidence of severe recent declines in coral cover. The causes of these declines are unknown, although algal growth from the loss of herbivorous fishes, storms, coral disease, and the use of gill nets around coral patch reefs are all likely contributors. Reducing fishing of herbivores will help reduce algae on Barbuda's reefs, which in turn may help corals increase growth and recruitment rates. Creating sanctuaries will also help improve conditions for corals.

In Codrington Lagoon, mangroves and seagrasses, which provide critical juvenile habitat for many species, are extensive and healthy. Water quality also appears to be good. Juvenile fish and corals are locally abundant, especially in the channel. Protecting the seagrasses will help ensure these habitats remain healthy. Closing the Lagoon to fishing will most likely help increase population sizes of many of these species by allowing juveniles to reach maturity and reproduce before being captured, thereby contributing to the next generation, and increasing the size of fishable adult populations.

These recommended management actions, based on the scientific data in this report, are expected to improve the condition of Barbuda's marine ecosystems, increase the value and sustainability of fisheries, and increase tourism value. Barbuda can be an example to the rest of the Caribbean, providing a model for how to effectively manage ocean resources and foster ecosystem recovery, but it will require bold action now. We strongly encourage the people of Barbuda to seize this opportunity.

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