Coral reef health and management on the verge of a tourism boom: a case study from Miches, Dominican Republic

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Abstract

The Miches Municipality lies in the second poorest province in the Dominican Republic, and its inhabitants rely heavily on nearby coral reefs for food and livelihoods. With the sudden influx of tourism from the completion of a new highway, now is a crucial time to ensure that future tourist development in this region is locally driven and environmentally responsible. As coral reefs are a foundation of Miches' identity, economy, and natural wealth, they play an integral role in the realization of this goal. This study employed global reef monitoring protocols to conduct the first-ever quantitative health assessment of Miches' reefs in order to guide future management practices. Surveys of multi-taxa indicator species were conducted alongside assessments of coral bleaching, disease prevalence, and evidence of anthropogenic impacts. Key findings include extremely low abundances of fishery-targeted species, high prevalence of diseased coral, anchor damage at nearly every site, and high abundances of indicator species for nutrient-based pollution such as fertilizers and raw sewage. Deeper, offshore reefs exhibited better health than shallow, inshore reefs, though they were still more degraded than comparable reefs in Dominican marine protected areas. Overall, Miches reefs are highly threatened by four main factors: overfishing, land-based pollution, human-related structural damage, and coral bleaching. To improve the well-being of the region's coral reefs and the communities that depend on them, an adaptive management plan is recommended that encompasses strong fisheries regulations, basic yet consistent monitoring efforts, and the integration of land-based and marine management practices.

Highlights:

- Residents of Miches, Dominican Republic rely on coral reefs for food and income.
- The region is on the verge of a tourism boom and is already undergoing rapid change.
- This study is the first longitudinal assessment of coral reef health in the region.
- Overfishing, pollution, structural damage, and bleaching threaten Miches reefs.
- We propose management strategies that support development, culture, and reef health.

Keywords: Coral reefs; Dominican Republic; tourism; overfishing; adaptive management

1.0 Introduction

Coral reefs are some of the planet's most complex and diverse ecosystems, and are essential to the well-being of human populations worldwide. In the Caribbean region alone, coral reefs provide up to $5.8 billion annually through tourism, fisheries, and coastal protection (Burke et al. 2011). However, these ecosystems are also subject to numerous natural and anthropogenic stressors (Halpern et al. 2015), and over 75 percent of the reefs in the Caribbean are now under direct threat from human activities, with more than 30 percent classified under high threat (Burke et al. 2011).

Caribbean coral reef health has declined dramatically in the last 40 years, driven by human population growth, overfishing, coastal pollution, climate change, and invasive species (Jackson et al. 2014). Coral cover has declined by more than 80% since 1970, while macroalgae cover has almost tripled within the same time period, marking a widespread and detrimental phase shift from coral-dominated to macroalgae-dominated ecosystems (Gardner et al. 2003, Hughes et al. 2007, Jackson et al. 2014). These phase shifts may reduce a reef's ability to provide essential ecosystem services, including coastal protection and tourism, while also negatively affecting many commercially valuable fisheries (Graham et al. 2014). Decades of overfishing have also reduced the size and abundance of the majority of targeted fish in the region (Ginsburg and Lang 2003, Hodgson 1999, Jackson et al. 2014), and invasive Indo-Pacific red lionfish (*Pterois volitans* and *P. miles*), capable of reducing small native fish biomass by greater than 50% one year after colonization of a new reef, are now widely established across the Caribbean (Green et al. 2014). Introduced pathogens responsible for *Acropora* coral die-offs (White Band Disease) and the massive 1983 *Diadema antillarum* die-off have also wreaked havoc on Caribbean reef ecosystems in recent decades (Aronson and Precht 2001, Hughes et al. 1985). When compounded by the effects of climate change, all of these factors have major implications for economic and human well-being of the region (Hoegh-Guldberg et al. 2007, Hoegh-Guldberg and Bruno 2010).

However, wide variability in the health of Caribbean reefs provides reason for hope. Some locations have fared considerably better than others, such as Bermuda, Grand Cayman, southwest Curaçao, and Flower Garden Banks in the Northern Gulf of Mexico (Jackson et al. 2014). Although the severity of threats at these locations varies, the main factor contributing to their relative health is the historical implementation of coral reef management strategies that address local threats – specifically, overfishing, overdevelopment, and coastal pollution (Hughes et al. 2010, Jackson et al. 2001, Knowlton and Jackson 2008, Pandolfi et al. 2005). Strong fisheries regulations, basic yet consistent monitoring efforts, and the integration of land-based and marine management practices can have a significant effect on the well-being of coral reefs and the communities that depend on them (Jackson et al. 2014).

Located on the south side of the Samaná Bay of the Dominican Republic, the Municipality of Miches contains a population that relies heavily on nearby coral reefs for food and livelihoods (CODOPESCA 2010). The largest urban town that shares the name of the Municipality, Miches, has a population of 23,141, and is one of the poorest communities in the second poorest province in the Dominican Republic (CEES 2007). The 15 fishing communities in the Municipality employ a diversity of fishing and harvesting techniques to intensively target marine organisms for food and income, and the local reefs are under intense fishing pressure (CEES 2007, 2012). Additionally, there is no sewage treatment system, municipal water purification system, nor solid waste treatment system, and rivers and streams that flow directly onto reefs are widely used for waste disposal (Clary 2008). Concern for the region's fisheries and other nature-based economies led to the development of this study, in collaboration with local community leaders and fishers. The economic and ecological well being of this region is inextricably linked, and so efforts to improve economic growth must address ecosystem health.

In tourism booms, undeveloped and rural coastal areas are often negatively affected by stressors such as discharge of sewage directly into rivers or coastal waters, accumulation of trash and waste in natural ecosystems, increased sedimentation and nutrient enrichment of coastal waters caused by unchecked run-off, clearing or degradation of mangroves and seagrass beds for development, physical damage to coral reefs caused by snorkelers, divers, and anchors, and in the most extreme cases, filling of lagoons and extracting limestone from coral reefs for development purposes (Gormsen 1997, Cesar et al. 2003, Gil et al. 2015). Several marine management strategies have been used around the world to combat these pressures – many involve improved management of upstream and land-based practices like better wastewater treatment and agricultural methods, but commonly used marine management strategies include restrictions on anchoring and moorings, the establishment of zoned marine protected areas with designated spaces for tourism-related recreation, promotion of sustainable eco-tourism, development of education and public awareness programs, and improved fisheries management practices (Gormsen 1997, Hall 2001, Cesar et al. 2003).

The Dominican Republic is one of the most popular tourist destinations in the Caribbean, with coral reefs supporting substantial dive tourism and sport fishing industries (Weilgus et al. 2010). In December 2014, the Bavaro-Uvero Alto-Miches Highway connected Miches with the popular tourist hub of Punta Cana to the east, opening Miches itself as a tourist destination. This highway can either support further environmental and economic decline, or aid in restoration and growth. This will be determined directly by local management decisions made in the next few years. Already the region has seen a sharp increase in tourism development, which was personally observed by the authors of this study and has resulted in concern and action by local councils to address pressures such as higher levels of beach pollution after the now-heightened tourism influx on weekends. Concurrent dialogue in favor of sustainable economic growth through alternative livelihoods like ecotourism has also arisen in local communities. Now is a crucial time to put measures in place that ensure future tourist development in this region is locally driven and environmentally responsible, retaining the integrity of ecosystems, culture, and local communities in Miches. As coral reefs are a foundation of Miches' identity, economy, and natural wealth, they play an integral role in the realization of this goal.

This study arose in response to local concerns expressed by Miches' fishing communities for their fisheries and nature-based economy during a previous qualitative investigation (CEES 2016). Here, we employ global reef monitoring protocols to conduct the first quantitative health assessment of Miches-area reefs, identify specific threats, and propose feasible strategies for their future management and sustainable use by local communities.

2.0 Methods

2.1 Survey sites

Taking results from our previous study's interviews into consideration (CEES 2016), reefs with various levels of fishing activity were identified along the Miches Municipality coast using Google Earth satellite imagery (Figure 1), and visited by a dive team to determine suitability for surveys. Twelve sites were ultimately selected, and subdivided by mean transect depth into "shallower" (≤ 5m, patch reefs) and "deeper" (> 5m, fore-reef slope) reefs. The majority of sites were located within a sheltered portion of Samaná Bay, with the exception of four reefs to the east of this area. GPS points were taken and visualized on Google Earth, where distance from shore, distance from the nearest river, and distance to the nearest population source was calculated for each site. Dive teams also performed preliminary impacts assessments, with divers recording observations of anthropogenic threats such as siltation, blast fishing, poison fishing, aquarium fishing, invertebrate harvest, sewage pollution, industrial pollution, and commercial, artisanal, and recreational fishing. Input from local fishermen confirmed whether each site was used for tourism and/or natural resource extraction. All sites were likely visited throughout the study period by fishermen, one small-scale dive tourism operator, and other community members, with some inshore sites known by the study authors to be visited daily.

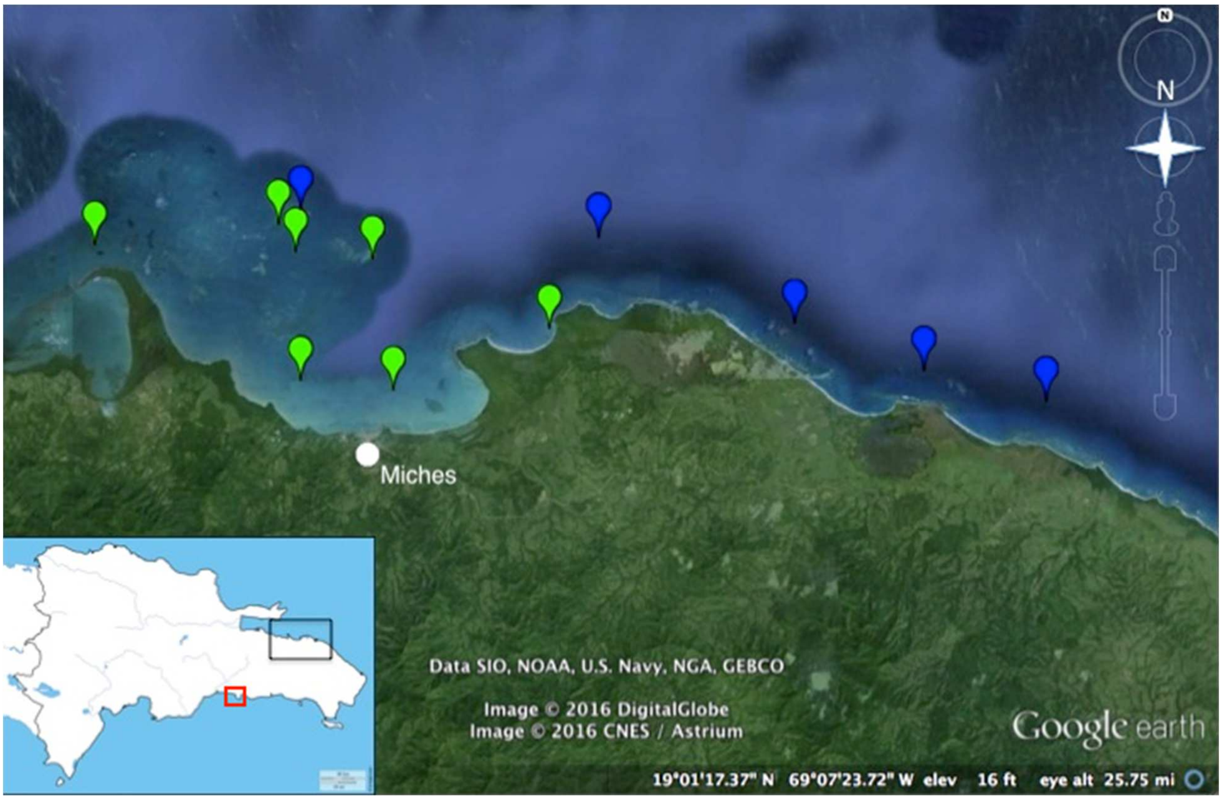

Figure 1 – Map of sites chosen in the Miches area, with shallow reefs in green and deeper reefs in blue. The location of the La Caleta protected area is indicated in red in the embedded map of the Dominican Republic. © d-maps.com, available at http://d-maps.com/carte.php?num_car=1882&lang=en.

2.2 Survey protocol

Surveys were conducted every four months over a two-year period from December 2009 to December 2011, following Reef Check protocols (see Hodgson 1999). These protocols were selected because there was an established Reef Check program in the Dominican Republic, the protocols were feasible with limited funding, they were employed globally which allows for useful cross-regional comparisons, and with the proper amount of training, they produce high-quality data while simultaneously providing educational and recreational value to volunteer divers (Lewandowski and Specht 2015). Data collectors for this study were open-water certified at minimum, and completed several pool and open-water dive skill training sessions in addition to Reef Check's standard Eco Diver training course.

Three surveys were completed during every site visit: a fish survey, invertebrate survey, and benthic survey. Indicator species recorded during fish and invertebrate surveys were selected by Reef Check according to fishery importance, sensitivity to anthropogenic threats, and ease of identification (Table 1), whereas all benthic substrate types along a transect were recorded regardless of indicator status. This was done per Reef Check protocol to enable the calculation of percent cover of indicator benthic types such as fleshy algae and hard coral. Percentage of coral bleaching and disease within each site's hard coral population were also recorded in the benthic substrate surveys, and anchor damage was recorded by divers on a scale of 0 to 3 – with 0 as no damage and 3 as high damage. Groupers (Epinepheline Serranids) were recorded by size class (30-40 cm, 40-50 cm, 50-60 cm, >60 cm) to allow for a more specific analysis of fishing pressure. Sightings of invasive lionfish (*Pterois* spp.) were recorded as well.

Table 1 – Organisms and benthic substrate recorded in surveys, and indicator type for each as designated by Reef Check. OF = overfishing, CF = cyanide fishing, DF = dynamite fishing, AF = aquarium fishing,
PL = pollution, CR = curio trade, IV = invasive species, CH = coral health.

Organism	Indicator Type							
	OF	CF	DF	AF	PL	CR	IV	CH
Groupers (*Serranidae*)	x	x	x					
Grunts/Margates (*Haemulidae*)	x							
Snappers (*Lutjanidae*)	x							
Parrotfishes (*Scarinae*)	x							
Butterflyfishes* (*Chaetodontidae*)				x				x
Moray Eels (*Muraenidae*)	x							
Banded Coral Shrimp (*Stenopus hispidus*)				x				
Black Urchin (*Diadema antillarum*)	x							
Pencil Urchin (Heterocentrotus mammilatus)						x		
Collector Urchin (*Tripneutes ventricosus*)				x				
Triton (*Chariona variegata*)						x		
Lobster	x							

(*Panulirus* spp.)								
Flamingo Tongue (*Cyphoma gibbosum*)				x		x		
Gorgonians (Sea fans, sea whips)				x		x		
Lionfish (*Pterois* spp.)							x	
Macroalgae	x				x			
Sponge					x			
Hard Coral				x		x		
Soft Coral								
Silt					x			
Recently Killed Coral		x	x					
Rubble		x	x					
Sand								
Other (tunicates, anemones, etc)								

* Designated as coral health indicators by this study's authors according to existing scientific literature (Hourigan et al. 1988, Linton and Warner 2003, Pratchett et al. 2006).

2.3 Baseline analysis

Survey data were sent to Reef Check headquarters for quality assessment, and then compiled into large datasets for analysis using a variety of packages in the statistical platform R. Mean abundances for each indicator and benthic substrate type at each site were calculated for a first-glance comparison across sites. Sizes of Nassau and other groupers were analyzed on a regional scale because of extremely low site-specific abundances. Comments recorded by divers were also compiled and searched for rare species sightings, general observations concerning the site's health, and other useful qualitative data. Lionfish counts were compiled using both transect data and off-transect sightings by the dive team, in order to assess the overall prevalence of this invasive species.

All site names were deliberately left out of reported results in this paper, to avoid the potential future exploitation of reefs that are deemed "healthier". Instead, sites are numbered and labeled according to depth.

2.4 Protected area comparison

To compare reefs from this study with a marine protected area (MPA), Reef Check's Dominican Republic database was used to identify potential protected area sites. The search was constrained to sites with similar depth profiles and survey timeframes as Miches area reefs, and to those with at least 5 surveys between 2008 and 2012.

Two sites within La Caleta Underwater National Park – Bahamas and Paisanito – met these search criteria. This underwater park was established in 1986 at the edge of a large bay on the central southern coast of the Dominican Republic, near the capital city Santo Domingo. La Caleta is subject to similar anthropogenic threats and oceanographic conditions as the Miches area reefs – inundated by high amounts of pollution and sediment runoff from Santo Domingo via the Ozama-Haina-Nigua river complex, protected from winds and strong westward currents by the adjacent Punta Caucedo, and historically affected by high amounts of fishing pressure despite its protected status (Geraldes and Vega 2002, Torres and Ulloa 2010). It is also a popular dive site and recreational area for residents and international tourists. In 2007, Reef Check Dominican Republic began co-managing the park and a fishermen's cooperative (COOPRESCA) was formed, heightening community involvement, enforcement, and monitoring. Park boundaries are demarcated for divers via coastal landmarks such as trees or buildings, and Reef Check monitors the park's health through annual underwater surveys.

Site-based indicator species means, grouper size classes, and lionfish sightings from Bahamas and Paisanito were analyzed in the same manner as the Miches data collected in this study.

2.5 Anthropogenic impacts and coral bleaching

To assess whether harmful nutrient or sediment loads were being transported to reefs through the Miches area's river effluent, regression analyses were performed between each site's distance to the nearest river mouth and corresponding fleshy algae and silt abundances. While a more nuanced approach would include consideration of the directionality of prevailing local currents in the area, these data are not available for the region at the spatial and temporal scale needed to inform these analyses. Distance from river mouth is therefore used as a proxy for the environmental gradient we might expect to see as nutrient-rich effluent is discharged into the Miches Bay.

Coral bleaching data were also analyzed to assess the overall prevalence of bleaching in the region. Because bleaching often occurs across distinct time periods, diver-estimated percentages of bleaching during each survey period were averaged across sites, creating a temporal estimate of bleaching stress. The percentage-based method by which data were recorded prevented site-by-site comparative analyses, so the data were separated by depth to investigate differences in the prevalence of bleaching at shallow versus deeper sites. The presence of anchor damage was also assessed for each site using the diver-estimated impact levels.

2.6 Cluster analysis

To investigate whether sites can be grouped according to relative health, we conducted a hierarchical cluster analysis using abundances of key indicator species. The zero-adjusted Bray-Curtis Dissimilarity index was chosen for this analysis, as it is the most appropriate distance metric for non-binary ecological abundance data. It is widely used for quantifying differences between two or more locations, and corrects for severely low counts that may occur in ecological impact gradients – ensuring that results are not overly sensitive to 0's (no recorded sightings) in the dataset (Clarke et al. 2006).

Because Bray-Curtis dissimilarity is computed using raw counts and not relative counts, we only used surveys from periods in which every site was sampled to maintain equal numbers as well as a consistent temporal scale. The count totals were compiled in an abundance matrix, and a square root transformation was performed to down-weight the influence of dominant species (Olsgard et al. 1997). The transformed abundance matrix was then converted to a Bray-Curtis dissimilarity matrix with the R package vegan, and a cluster dendrogram was generated from the dissimilarity matrix using a group-average linkage technique, which is more robust than techniques using maximum or minimum distances between sites (Clarke and Warwick, 2001).

Sixteen of the 25 surveyed indicators and benthic types were included in this cluster analysis. Four species were excluded because they were indicators for the curio or aquarium trade, neither of which is prevalent in the Miches region. Five benthic types were excluded because they were either abiotic factors or non-indicator substrates (like sand or rock), and were not relevant for this reef health assessment. Consequently, indicator species and benthic types included in the cluster analysis are as follows – fishes: butterflyfishes, grunts, snappers, parrotfishes, groupers, Nassau grouper, moray eels, lionfish; invertebrates: *Diadema* urchin, flamingo tongue, lobster; substrate types: hard coral, soft coral, fleshy algae, sponges, recently killed coral (see Table 1).

Protected area sites were included in the cluster analysis alongside all Miches sites, to investigate whether any of the unprotected sites are comparable in relative health to protected sites, or if the two form entirely separate groups.

3.0 Results and Discussion

Investigating the condition and health of coral reef ecosystems is a complex matter, as there are often multiple stressors acting upon a system at once, and at different spatial and temporal scales. Additionally, many organisms – including a subset of those used in this study – are indicators for more than one stressor, which complicates attempts to pinpoint specific threats or causes of reef degradation. However, taking multiple observations across a wide variety of indicators can provide valuable information concerning the scope and severity of anthropogenic threats at specific reefs. After employing this approach, it is evident that Miches' reefs are largely threatened by overfishing, land-based pollution, coral bleaching, and human-related structural damage of corals.

3.1 Indicator abundances

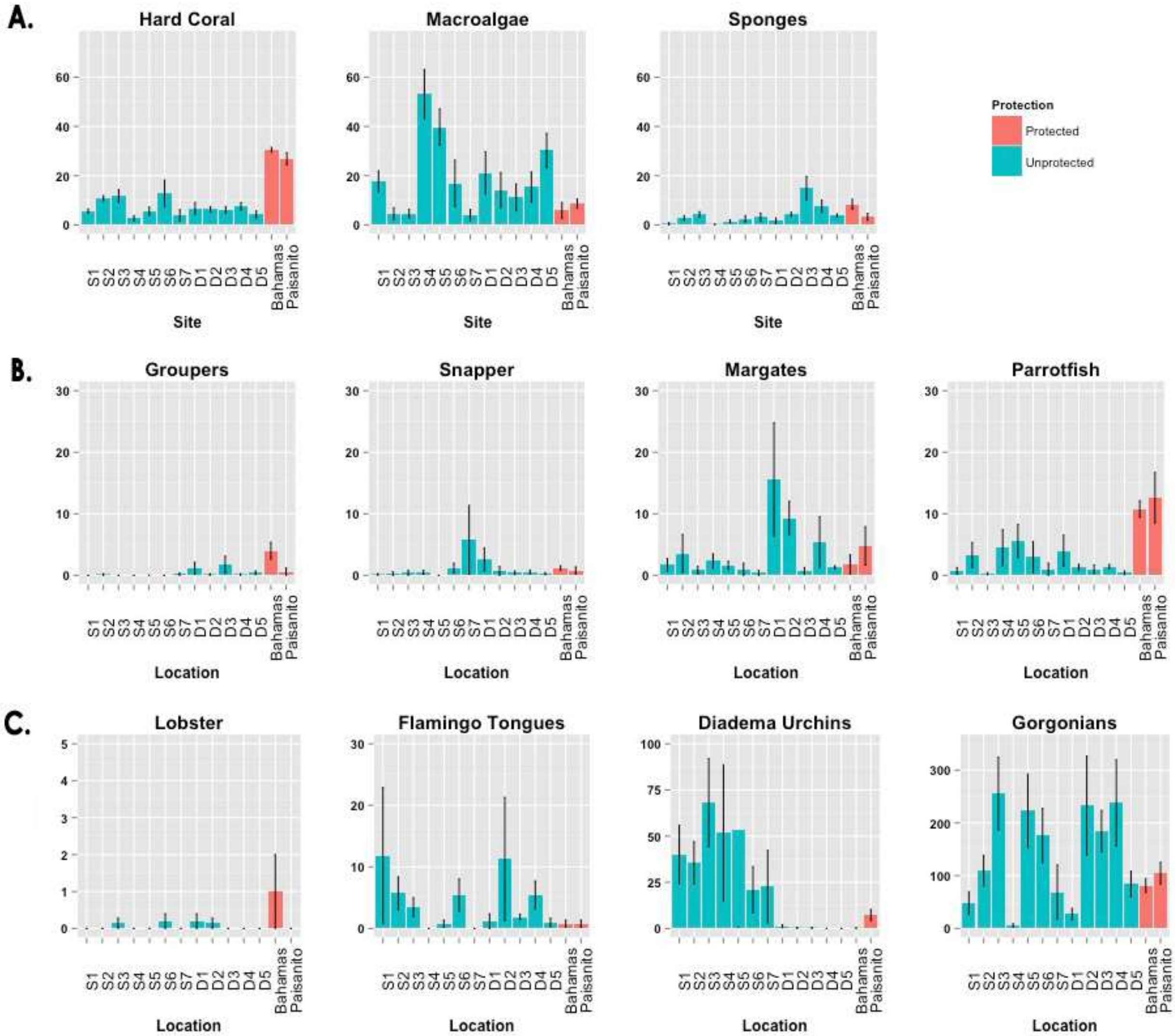

Figure 2 – Mean abundances of a) benthic indicators b) fish indicators c) invertebrate indicators. Benthic indicators are shown by mean percent cover, while fish and invertebrates are shown by mean number of individuals. "S" denotes shallow sites, "D" denotes deeper sites. Note that scales are set to the same value in a) and b), but in c) they are adjusted for better visualization of indicators with low abundances.

Benthic survey means indicate that the abundances of hard corals, which make up the structural foundations of every reef, are low across all Miches sites (Figure 2a). The most recent estimate of average coral cover in the Caribbean is 14.3% (Jackson et al. 2014), and when average coral abundances for each Miches site were divided by the total 160 observation points on the transect, only three of the twelve Miches sites have over 10% hard coral cover (10.8%, 11.7%, and 12.9%). All sites are dominated by rock and fleshy macroalgae, with many sites exhibiting higher abundances of algae than rock, and one site displaying over 50% algal cover. Two of the deeper reefs also have relatively high abundance of sponges compared to the rest of the sites, averaging 14.8% and 7.5% cover.

The Miches reefs are also marked by very low overall abundances of fishery-targeted species, particularly lobster, large-bodied groupers, eels, and snappers. Some variation was observed in fish abundances across sites, with deeper and more inaccessible reefs exhibiting slightly higher averages of fish indicators (Figure 2b). One shallow reef had higher mean snapper abundances than deeper reefs (5.8 individuals/100 m^2), but this particular site also had near-zero abundances of all other fish indicators recorded. Similarly, two of the shallow, algae-dominated sites had the highest mean parrotfish abundances observed (5.6 and 4.5 individuals/100 m^2), but all other fish indicator means were near zero at these sites.

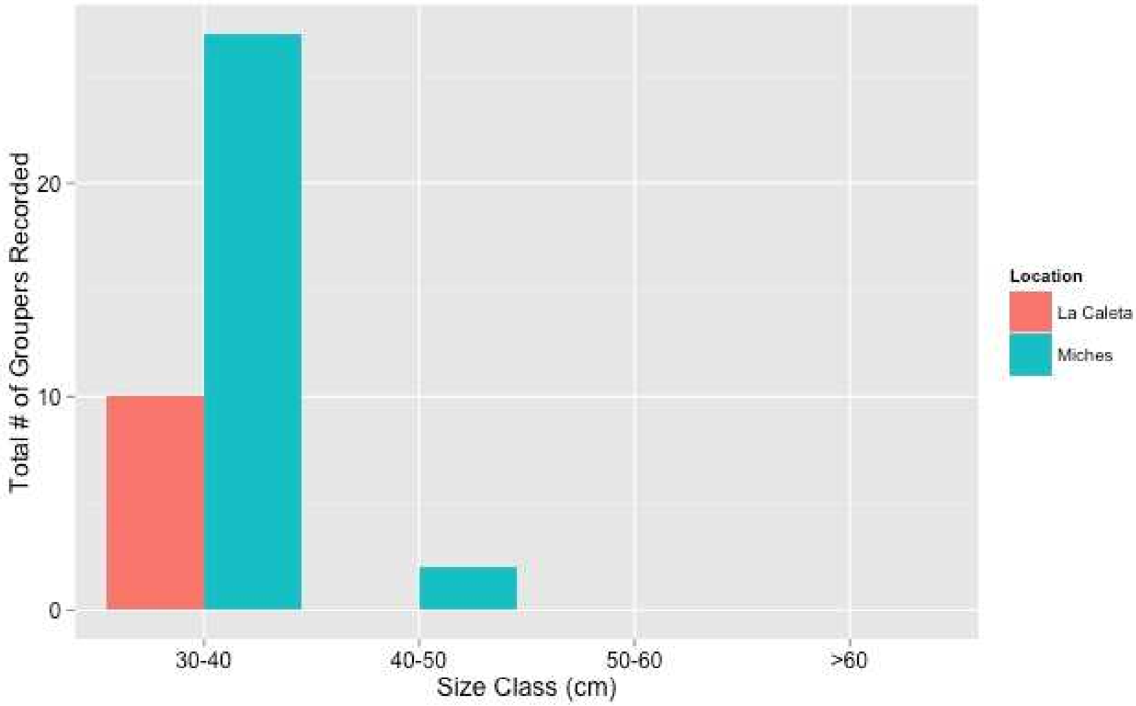

Figure 3 – Grouper sizes observed on Miches reefs (blue) and La Caleta protected reefs (orange).

A total of 25 groupers were recorded throughout the entire survey period, with 10 of those observed at one site during the April 2010 survey. These groupers could indicate the occurrence of a spawning event at that time – however, species identification was not recorded for this indicator group so definitive conclusions cannot be made. Further, all but two groupers observed fell into the smallest size class, 30-40 cm (Figure 3), indicating that larger individuals of these species are subject to high fishing pressure in the region. This is a common observation in overfished waters globally, and can be particularly detrimental for populations of slow-growing, long-lived organisms like groupers (Berkeley et al. 2004).

Despite low abundances of indicator fish, there were several instances where divers' comments noted that general fish diversity was high, and abundances of non-indicator fish species were higher than that of recorded groups. This may be an further indication of overfishing in Miches, as non-indicator fish species tended not to be targeted by fishermen. Many uncommon or cryptic species of marine organisms were also observed across sites throughout the study, including nurse sharks, rays, octopus, hawksbill turtles, and conch. There were seven sightings of invasive lionfish in the area, three of which were at one survey site.

The dominant invertebrates surveyed on Miches' reefs were gorgonians (Figure 2c). These are some of the most abundant benthic taxa in the Caribbean, and they are also more resilient to detrimental effects of climate change (Lasker 2003, Ruzicka et al. 2013). Flamingo Tongue snails, which commonly feed on gorgonian corals and are eaten by many carnivorous fish (Chiappone et al. 2003, Burkepile & Hay 2007), were also found in high numbers across many sites, with the exception of two sites – one of which had the lowest numbers of gorgonian colonies recorded.

According to the preliminary site assessments based on local knowledge, lobster fishing is one of the most prevalent uses of the reefs around Miches, yet only four individuals of this important target species were recorded during the study (Figure 2c). Fishermen interviews conducted concurrently with this study indicate that lobster numbers have declined substantially in recent years, with 90% of survey participants reporting that they had noticed a decrease in this species' population over the last 10 years (CEES 2016). However, low abundances of these and other indicators in this study could be due to sampling difficulties, since lobsters and other indicators like moray eels are nocturnal and tend to wedge themselves into cracks and under overhangs. While divers in this study were trained to search these areas carefully, surveys were conducted during the day when these invertebrates tend to be inactive, and thus more difficult to spot. This is a problematic yet unavoidable shortcoming of surveys relying on volunteers to monitor abundances of biotic assemblages that include nocturnal species. A meta-analysis of this study's nocturnal species recordings (grouper, moray eel, lobster) was conducted to determine whether differences existed between surveys conducted at midday and those conducted closer to dawn and dusk (8am-10am, 4-6pm), and no difference was found. This is probably due to the fact that very few surveys were conducted within the dawn and dusk time frames (n=3), as well as the fact that these time frames are still somewhat outside the time of day when nocturnal species are most active (Helfman 1986). For studies using Reef Check methods to survey nocturnal species, additional and complementary methods to estimate target species abundances (e.g. fishermen interviews mentioned above) should always be employed when possible.

The invertebrate survey also revealed high variation in *Diadema antillarum* abundances – a widespread and ecologically important reef grazer that feeds on macroalgae (Edmunds and Carpenter 2001). These herbivorous urchins were nearly absent in deeper sites, while shallower sites showed much higher mean abundances, with one shallow reef hosting over 50 individuals/100 m^2 (Figure 2c). These urchins are eaten by large predatory reef fish and compete for food with parrotfish, both of which are typically targeted by fishermen (Hay and Taylor 1985, Robertson 1987). Removal of this invertebrate's predators and competitors has been shown to cause population booms throughout the Caribbean (Hay 1984, Hughes 1994), so their high prevalence within the shallower Miches sites may be another indicator of overfishing on these reefs. However, densities of this invertebrate are also influenced by patterns of larval connectivity and the physical structure of the reef, with more urchins being found in places where circulation eddies facilitate recruitment and where the reefs provide refuges for urchins to hide from predators (Carpenter 1984, Clemente and Hernandez 2008). While the lack of predatory fish on shallower reefs may indeed play a role in *Diadema* urchins' high abundances in these areas, it is more likely that the geophysical characteristics of these reefs are more amenable to the species.

Given the very low abundances and small size classes of important fishery-targeted species observed in this study, overfishing is clearly a pressing issue in the Miches region, and a difficult problem to tackle. Improvements must be made in order to ensure the continued ability of these reefs to provide for the local human populations, especially as their role expands to include ecotourism in the future. Possible strategies for more sustainable fishing practices and resource management are discussed in Section 3.5.

3.2 Land-based pollution

Miches waterways carry agricultural run-off, eroded sediments from deforested areas, and untreated human waste directly into coastal marine waters (CEES 2007). This high influx of sediments and organic pollution has detrimental effects on the Miches reefs, demonstrated most clearly by high amounts of macroalgae cover and the presence of the gorgonian disease, *Aspergillosis*, at the majority of sites, particularly those closest to river mouths.

The investigation of effects of Miches-area river effluent on coral reef health revealed a clear negative correlation between each reef's distance from the nearest river and macroalgae abundance (Figure 4). One of the deeper reefs (> 5 m) presents an exception, as it is the farthest reef from any river (~ 7.6 km) and still hosts a relatively high amount of macroalgae cover (roughly 20%).

Macroalgae compete with reef-building corals through chemical defenses and competition for space and light, and have a competitive edge over corals in nutrient-rich waters (Larsen and Webb 2009, McCook et al. 2001, Rasher & Hay 2010, Rasher et al. 2011). The top-down process of herbivory by fish and urchins is a crucial factor in keeping fleshy algae at bay (Hughes et al. 2007, Mumby et al. 2006, Mumby et al. 2007a), but overfishing degrades this protective process, and has likely played a role in the overabundance of macroalgae in this region. At two inshore reefs in Miches, however, relatively high abundances of parrotfish and urchins are associated with surprisingly elevated macroalgae cover (53% and 39%, respectively). These are the closest sites to river mouths, so nutrient levels at these inshore sites may be overwhelming the herbivores' ability to keep macroalgae in check.

Further, coral diseases such as *Aspergillosis* are also indicators of land-based pollution (Bruno et al. 2003, Kaczmarsky et al. 2005, Stabili et al. 2006). This gorgonian-affecting disease was widely present in the Miches region, at times affecting up to 60% of gorgonian colonies in a survey.

Siltation is also a direct result of land-based erosion and can lead to lowered growth rates and species diversity of hard corals (Larsen and Webb 2009, McCook et al. 2001), and many sites surveyed here did exhibit high amounts of silt cover. However, this study did not find any correlation between siltation and a site's distance from the nearest river mouth (Figure 5). This could be due to differences in the extent of vegetation around each river since mangroves and grasses filter sediments out of river water, differences in the slope of riverbeds, speed at which water flows out, and grain size and structure of the sediment itself. Oceanographic currents may also play a role in moving silt and sediments around, especially during storms when sediment loads are at their highest (Larsen and Webb 2009).

Taken together, information from nutrient-indicator algae and coral disease analyses point to land-based nutrient pollution as a major factor in the degradation of Miches reefs, and mitigation strategies like those discussed in section 3.5 should be pursued.

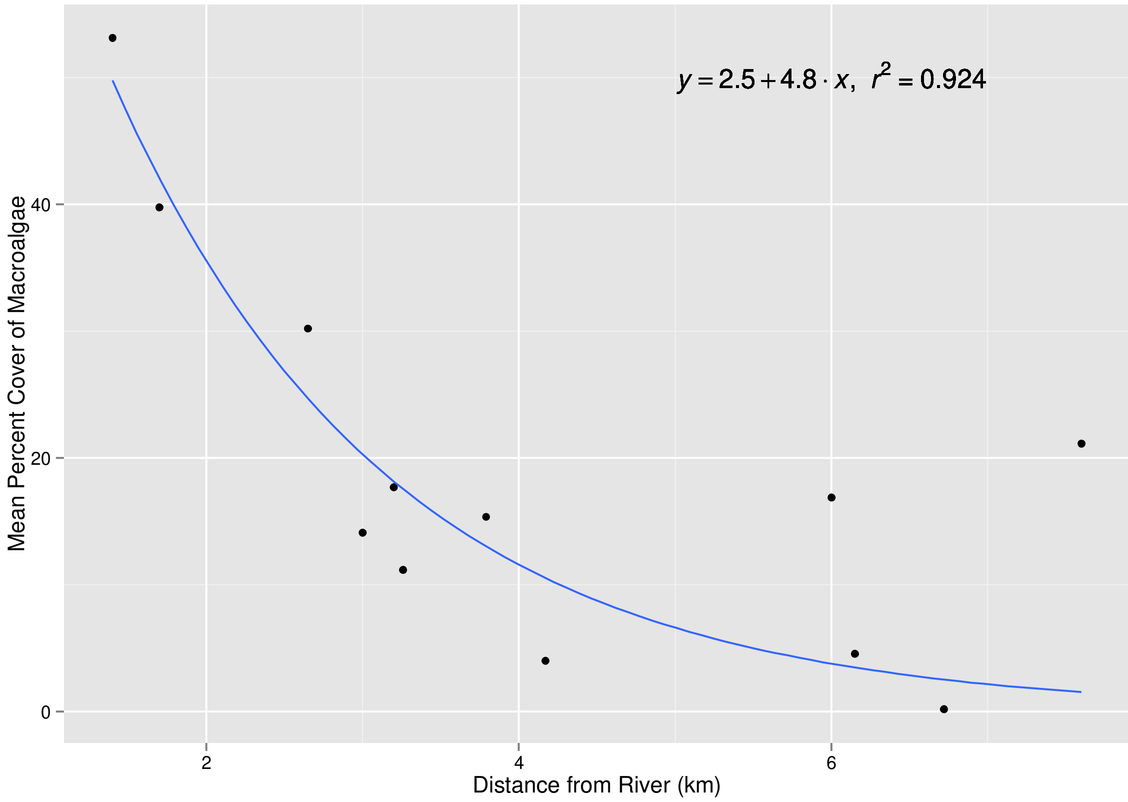

Figure 4 – Effect of river effluent on macroalgae cover in Miches area reefs, with logarithmic decay function regression line in blue.

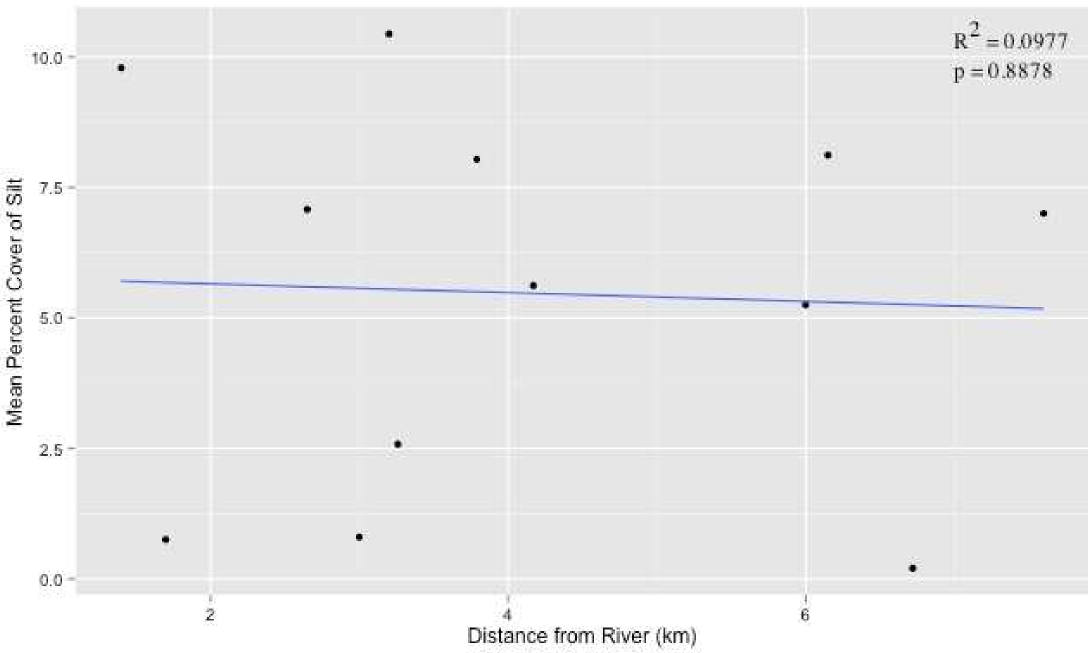

Figure 5 – Effect of river effluent on siltation in Miches area reefs, with linear regression line in blue.

3.3 Coral damage

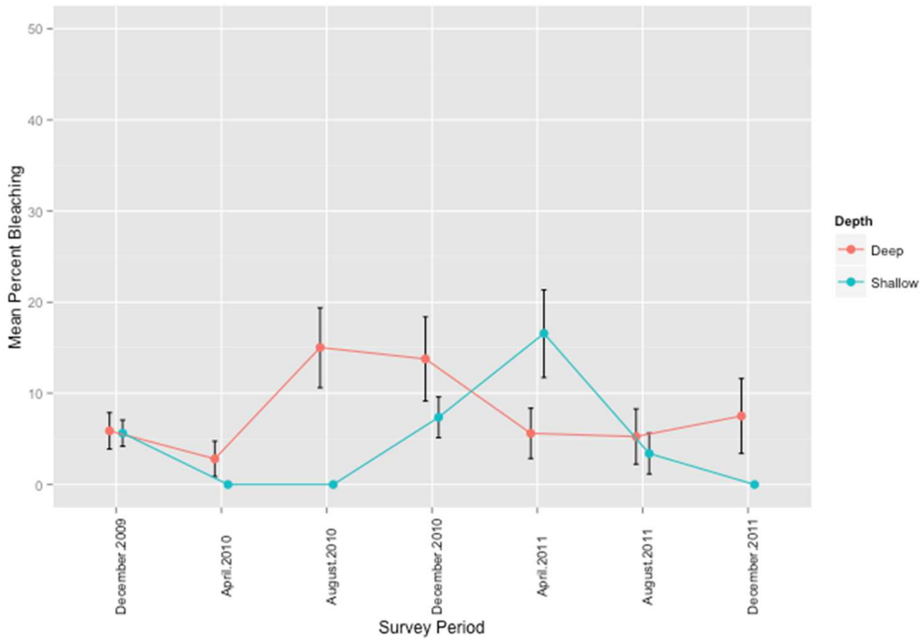

Figure 6 – Severity of coral bleaching in the Miches area over time.

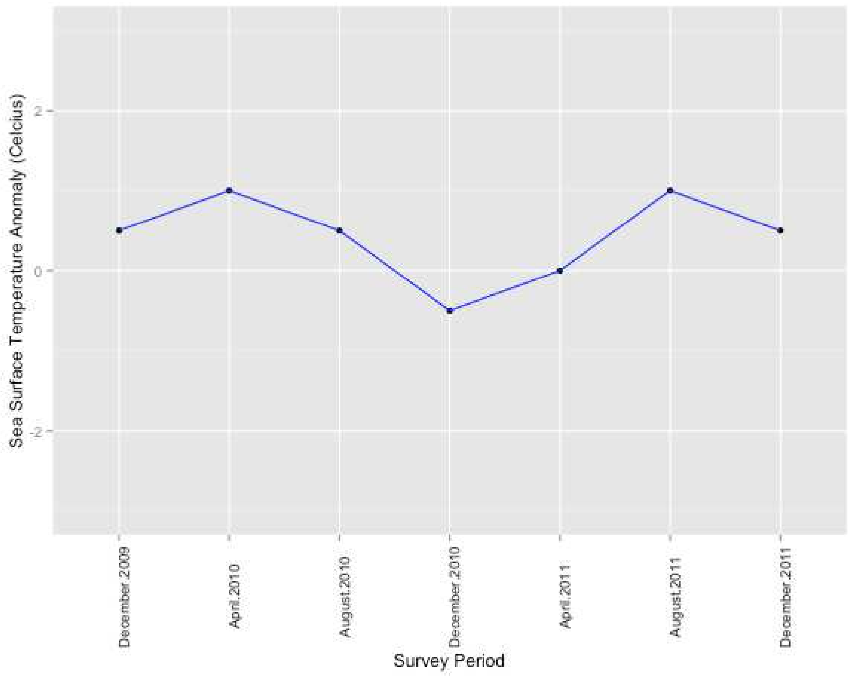

Figure 7: Sea surface temperature (SST) anomalies recorded in the northeast region of the Dominican Republic during the study period (NOAA Coral Reef Watch).

The Miches reefs are widely affected by natural and anthropogenic coral damage. All but two of the sites surveyed showed evidence of blunt-force injuries to corals typical of anchor damage. By reducing this type of damage to reefs, Miches communities can help maintain the structural integrity of these complex yet fragile ecosystems.

Additionally, surveys indicated that coral bleaching occurred at low levels in the Miches region throughout the entire duration of the study (Figure 6). NOAA's Coral Reef Watch issued Bleaching Warnings for the area in August 2010 and August 2011, but locally observed high sea surface temperature (SST) anomalies generally did not coincide with this study's observations of bleaching (Figure 7). This may be due to the relatively large resolution of NOAA's operational SST anomaly (50km), which may not pick up local-scale surface warming to which Miches reefs are subject.

Further, surveys showed that deeper reefs (> 5 m deep) experienced maximum bleaching earlier in the survey period than the shallow sites (< 5 m deep) (Figure 6). This could be due to differences in temperature and water clarity at different depths, or differences in coral communities, as some coral species are resistant to bleaching while others (e.g. Agaricia, Orbicella) bleach readily. Genus- or species-level identification of coral would enhance the utility of these analyses greatly, but is often outside the scope of studies like this one.

Some variation also existed within each depth class. Of the deeper sites, two reefs consistently experienced higher amounts of bleaching than the others – these sites exhibited 44% and 38% of corals bleached over two consecutive surveys, while all other deep reefs displayed less than 10% bleaching during the same period. Of the shallow sites, the majority of bleaching in December 2010 occurred within only three sites, whereas the majority of bleaching in April 2011 occurred in a completely different set of sites. At one shallow site in particular, there was zero bleaching in December 2010 but over 50% of observed coral was bleached by the next survey period, highlighting the temporal variability of bleaching within these reefs.

The nature of these data does not permit a direct comparison of site-by-site severity of bleaching, but does lead to the general conclusion that each region is indeed affected by bleaching, and some sites are perhaps more vulnerable than others. However, quantitative site-by-site comparisons would be useful in determining which sites may be more resilient to future bleaching events. In order to enable such comparisons, the Reef Check survey protocol should also incorporate the total number of hard corals at each site to provide context for bleaching percentage estimates. Currently, the only individual coral count is conducted as part of the line transect survey, in which only corals lying directly under the transect tape are counted. Coral bleaching, on the other hand, is quantified by the diver estimating the percentage of corals bleached within a 5m "belt" centered along the transect tape. If coral counts were conducted within this belt transect as well, bleaching estimate percentages could be more accurately compared across sites and provide more useful information for marine managers. However, we recognize this would involve more time and effort on behalf of survey divers, which is sometimes not possible in difficult conditions.

Finally, while the overall severity of bleaching was low throughout this study's duration, the Dominican Republic has experienced at least one major bleaching event in the last decade, and rising sea surface temperatures are likely to bring more frequent and severe events to this region (Hoegh-Guldberg et al. 2007, Wilkinson and Souter 2008). Coral reefs' resilience to bleaching events is improved by several factors, including high water quality and strong presence of herbivores (Hughes et al. 2007). By addressing overfishing and land-based pollution, Miches marine managers will also be able to improve the ability of their reefs to recover from future bleaching-induced coral mortality.

3.4 Comparative health

The anthropogenic threats of overfishing, land-based pollution and siltation, and coral bleaching or structural damage are some of the most common problems facing coral reefs worldwide. Putting the severity of these threats at each site within Miches into local and regional contexts can provide valuable information for local management efforts.

For instance, it is readily apparent that the La Caleta Underwater National Park sites of Bahamas and Paisanito fare better than Miches area reefs overall. Both protected sites displayed substantially higher hard coral coverage than any of the Miches sites, with an average of 30.5% and 24.1% cover, respectively (Figure 2a). Macroalgae cover was similar to that of the lower values observed in the Miches area. When comparing fish survey data, the main differences were higher mean butterflyfish abundances than in the Miches, as well as slightly higher grouper means than all but two Miches sites (Figure 2b). There were no differences observed in grouper size classes, as all protected area groupers were between 30-40 cm (Figure 2). The relatively recent implementation of effective protection strategies within La Caleta Underwater Park may explain this, since positive effects of protected areas are closely linked to the amount of time spent under effective protection, especially with long-lived and slow-growing species like groupers (Claudet et al. 2008, Edgar et al. 2014). However, the low total number of groupers observed ultimately lends little statistical power for a comparison of size structure between protected and unprotected sites.

Parrotfish abundances were also much higher in protected areas (Figure 2b). Numbers of parrotfish found at La Caleta averaged 10.8 individuals/100 m^2 at Bahamas and 13.75 individuals/100 m^2 at Paisanito, as opposed to a maximum of 5.6 individuals/100 m^2 in unprotected Miches sites. Parrotfishes play an essential role in promoting coral health through the herbivory of macroalgae, and recent assessments of Caribbean reefs emphasize the importance of protecting reef grazers like parrotfish in enhancing the resilience of coral reefs to climate change (Burkepile and Hay 2010, Jackson et al. 2014, Mumby et al. 2007b). Figure 8 indicates a positive correlation between parrotfish abundances and hard coral cover in the sites investigated.

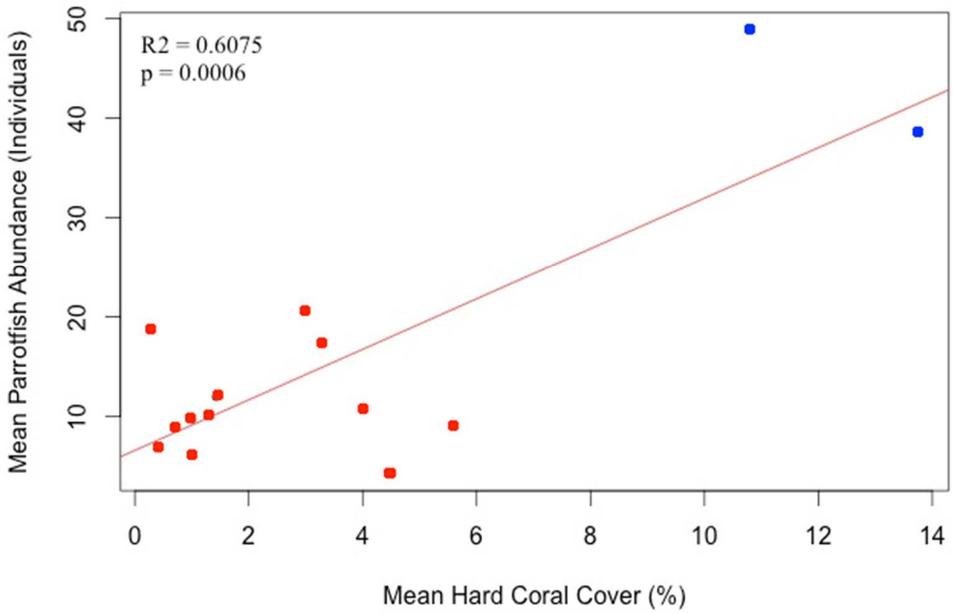

Figure 8 – Relationship between parrotfish abundances and hard coral cover in protected (blue) vs unprotected sites (red), with the line of best fit in red.

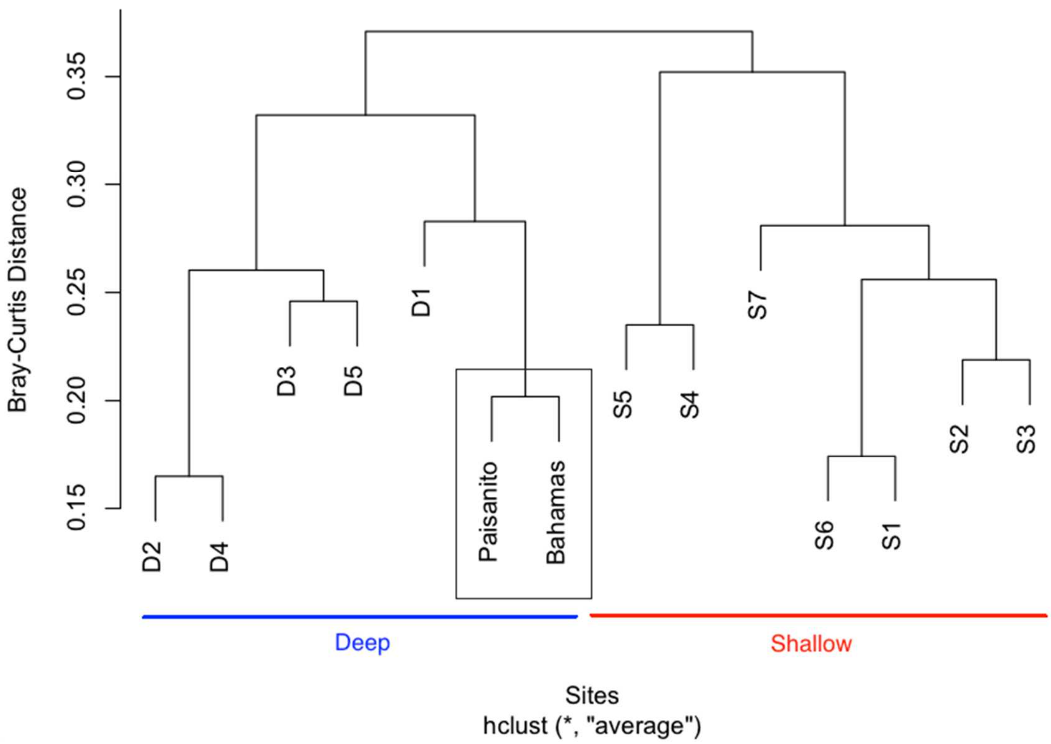

Figure 9 – Bray-Curtis dendrogram showing similarities in indicator abundances across sites, with higher levels of similarity indicated by lower values on the y-axis. Protected areas are indicated by black box.

Results of the cluster analysis are a synthetic representation of the relative health of each site's reefs compared to others, and are useful in comparing sites from this study with those in the protected area (Bahamas and Paisanito). The dendrogram reveals four general groups at the 30% mark, from left to right: (1) D2 - D5; (2) protected reefs of Paisanito and Bahamas along with D1; (3) S4 and S5; and (4) S1, S2, S3, and S6 (Figure 9). When "cut" at the 35% mark, these four groups can be further consolidated into two larger groups, which correspond with depth assignments – reefs in the left portion of the dendrogram are all deeper reefs, while those to the right are all shallow.

These results reflect patterns displayed by indicator abundance analyses as well, with sites in the branch to the left (deeper reefs) generally showing higher abundances of healthy indicator species and fishery-targeted species than those in the branch to the right (shallow reefs). This demonstrates the possibility that deeper, offshore sites receive de-facto protection in Miches, likely due to the increased effort needed to reach them. However, as tourism establishes itself further in Miches and economic barriers dissolve, these sites risk becoming more exposed to harmful exploitation and degradation. The implementation of smart, feasible management strategies in the area is paramount to the promotion of sustainable practices and the protection of these fragile ecosystems.

3.5 Management considerations

The threats facing the Miches reefs are large in scope, but can be addressed in part through the use of robust and comprehensive marine and land-based management strategies. Strong fisheries regulations, basic yet consistent monitoring efforts, and the integration of land-based and marine management practices must be employed to improve the well-being of Miches' coral reefs and the human communities that depend on them.

Because successful marine management plans are characterized by the incorporation of stakeholders at every stage of the development process (Lundquist and Granek 2005), an important first step towards sustainable marine management in Miches would be the organization of a council. Representation from local fisher associations, CODPOESCA, Ministry of Environment, the tourism sector, local and national government representatives, conservation groups, and other relevant stakeholders would enable the community to more equitably address future tourism-related growth, and put policies in place to ensure the area's environmental, economic, and cultural sustainability.

Further, some specific changes to fishing gear used in the region could provide simple avenues for combating Miches' overfishing problem. For instance, minimally selective fish traps are widely used in artisanal fisheries across the Caribbean and are known for trapping high amounts of bycatch and juvenile members of target species (Stewart 2007). Incorporating two short (20 x 2.5 cm) escape gaps into traps can significantly reduce bycatch while maintaining overall catch value, substantially improving the sustainability of trap fisheries (Johnson 2010). The nearby Sabana de Nisibon community already uses bamboo fish traps with escape gaps built in them ("nasas de bambu"), providing the Miches region with a local model to follow. These bamboo traps could easily be employed across the rest of the region, with Sabana de Nisibon fishermen educating other communities in their construction and use.

Additionally, fishers in Miches often use gill nets with mesh sizes as small as one inch (*trasmallos acidos*), indiscriminately capturing fish of all sizes and life stages (CEES 2012). These nets – in fact, gill nets of *all* sizes – are banned nationwide by CODOPESCA law 307-2004, but this law is rarely if ever enforced. The widespread and systemic lack of enforcement in Miches contributes significantly to the degradation of Miches' reefs, and must be addressed if the above gear modification suggestions – and sustainable fisheries in general – are to be achieved in the future.

Gear modifications like these are often supplemented with comprehensive and scientifically informed minimum size restrictions for targeted species (or groups of species). This is intended to further enable juveniles to mature and contribute to the recovery of standing spawning stock. Currently, CODOPESCA laws delineate minimum size restrictions and seasonal closures for lobsters and marine crabs, (Decree 316/86 in Law 301-2004), but no such restrictions exist for groupers or other economically critical fish species.

Where a comprehensive ban on multiple species at different life stages is not feasible, a species-specific ban of herbivorous parrotfishes may be an effective alternative. Parrotfishes play an essential role in promoting coral health through the herbivory of macroalgae, and recent assessments of Caribbean reefs emphasize the importance of protecting reef grazers like parrotfish in enhancing the resilience of coral reefs to climate change (Mumby et al. 2007b, Burkepile and Hay 2010, Jackson et al. 2014). Protecting these critical species would strengthen reefs' resilience in the face of threats like bleaching-related coral mortality and overfishing of other herbivorous species like surgeonfish, helping to prevent detrimental phase shifts from coral- to algal-dominated ecosystems (Mumby et al. 2006, Hughes et al. 2007). Belize has recently enacted the first nation-wide parrotfish ban, the results of which are forthcoming (Cox et al. 2013, Cox and Bruno *in prep*), and Reef Check DR has developed a seafood certification scheme called AquaCheck which calls for the non-commercialization of parrotfish. This environmental certification program also calls for respecting seasonal bans on certain seafood and increased marketing of invasive lionfish, which were present on Miches reefs during surveys.

A parrotfish ban is likely to be a controversial management strategy, since parrotfishes now make up the majority of landed catch instead of the previously abundant predatory species. In order to alleviate the economic stress introduced by this and other previously mentioned strategies, the goal of diversifying fishermen's income should be integrated into a sustainable fisheries management plan. The increased access to tourism brought by the opening of the Bavaro-Uvero Alto-Miches Highway presents the opportunity to diversify income by building upon the skills and expertise that `already exist within the fishing communities. This could include ecotourism opportunities for sport fishing, dive tourism, creating a market for invasive lionfish (e.g. the previously mentioned AquaCheck program), or wildlife guiding and adventure sports as demonstrated in the recently established local community-based Kayak Limon excursions (kayaklimon.wordpress.com) (Heyman et al. 2010). Further, interest in many of these specific alternative livelihoods has already been indicated by local community members, as shown by surveys conducted by this study's authors in 2009 about willingness to participate in potential future ecotourism endeavors (CEES 2016).

Additionally, consideration should be given to upland watershed protection to prevent agricultural runoff, erosion, organic pollution, and soil waste from reaching the reefs. Even reefs with inherent resilience have been shown to be unable to withstand repeated exposure to reduced water quality, siltation, and nutrient pollution (Larsen and Webb 2009, Wenger et al. 2015).

Finally, the implementation of a well-managed, well-planned, no-take marine protected area (MPA) in Miches could significantly improve the state of marine resources in the region. MPAs can increase spawning stock biomass, maintain species diversity, preserve habitat, and sustain ecosystem function of the area directly protected, as well as allowing for larval dispersal and the movement of adults into non-protected areas, boosting adjacent fisheries' productivity (Allison et al. 1998, Roberts et al. 2001, Gell and Roberts 2003, Gaines et al. 2010, Selig and Bruno 2010, Rassweiler et al. 2012). The success of any protected area in this region will be dependent upon the integration of scientific and socioeconomic information into planning and design, extensive government and community input and support, and rigorous monitoring and enforcement efforts (Roberts et al. 2001, Bergen and Carr 2003, Almany et al. 2009).

While this is the most intensive option for sustainable management of Miches reefs, the La Caleta Underwater Park provides a direct model for the Miches communities to follow – including full legal protected status, engagement with communities in the form of a fishermen collective (e.g. COOPRESCA) and educational outreach, clear demarcation of protected area boundaries, and regular monitoring combined with enforcement (Torres and Ulloa 2010). The management criteria and enforcement scenarios present in nearby MPAs such as Manglares de la Gina and Los Haitises should also be considered in the planning process. Results from this study's protected area comparison do indicate that protection, while generally positive, has not yet resulted in higher grouper sizes than unprotected sites, which may imply that some positive effects of protection may take several years if not decades to realize. This is likely due to increases in poaching in these areas as general fish populations rebound (Ruben Torres, personal communication, July 12, 2015), as well as the slow growth rate of some important fish species (Russ and Alcala 2003). For instance, sexual maturity of the Nassau grouper (*Epinephelus striatus*) – one of the most important grouper species for commercial fisheries in the Caribbean – is reached after 7 years at the earliest (Sadovy de Mitcheson and Eklund 1999).

Integrating a legally recognized, enforced, and permanent no-take protected area in combination with the many management strategies discussed above would be an intensive yet extremely effective method of sustainably managing marine resources for the future. Additionally, as this option is highly reliant on the presence of effective legal enforcement and strong community buy-in, it is strongly advised that it be linked with improved community relations and enforcement efforts in the region. In fact, none of the fisheries strategies listed above have any hope of being effective if this is not addressed. For example, the *trasmallos acidos* nets are in fact already outlawed in CODOPESCA law 307-2004, but because community involvement is limited and law enforcement capacity is low and at times nonexistent, these harmful nets are still widely used (CEES 2012). The widespread and systemic lack of community support and law enforcement in Miches contributes significantly to the degradation of Miches' reefs, and must be addressed if sustainable fisheries are to be achieved moving forward.

4.0 Conclusion

Establishing a baseline for local coral reef health is an essential step towards successful and sustainable management of these crucial ecosystems. This study demonstrates that by combining basic survey protocols like those developed by Reef Check with regional policy, socioeconomic, and land management information, the identification of feasible, locally-appropriate marine management strategies is possible. In the Miches Municipality, where tourism growth and future infrastructure development is imminent, the time is now to implement strategies that conserve the coastal and marine environments, while allowing for the growth of economic leadership from within the local communities.

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