Status of Coral Reefs in Antigua and Barbuda: Using data to inform management

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Abstract

The Nation of Antigua & Barbuda has experienced major degradation of their coral reef ecosystems over the past 40+ years. The primary drivers of this degradation are multiple and are highly linked to anthropogenic influences, inclusive of: overexploitation and poor management of marine resources. In an effort to provide baseline information, The Nature Conservancy (TNC) published Coral Reef report cards in 2016, which ranked Antigua and Barbuda's reef condition as poor and on the lower end of the Caribbean reef health scale. This study also inadvertently highlighted how little datum were available for the islands, and when available, were highly scattered as it relates to spatial distribution. The Government~~nation~~ of Antigua and Barbuda (GoAB) recognized the need for a marine data collection program to better inform the designation and management of Marine Protected Areas (MPAs) to improve the health of the marine ecosystem. As such, the Atlantic Gulf Rapid Reef Assessment (AGRRA) protocol has proven invaluable to the efforts of the government to collect data to help inform marine management planning, due to the comparability with previously collected data and the fast turn-over of data-analysis products. There have been three AGRRA s~~S~~urveys carried out in the years following the 2016 TNC report: North East Marine Management Area (NEMMA) 2017, Redonda 2018, and Nelson Dockyard National Park (NDNP) 2019. While the results of the surveys mirror what was published in 2016, they also highlight intra-site variation which can be crucial to identifying and designating management zones and the management of these preserves. Additionally, the marine surveys conducted around Redonda, an island that has experienced tremendous terrestrial recovery due to the removal of harmful invasive species, were

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the first of their kind. This paper presents an overview of data collected between the years of 2017 to 2019 and discussion of future uses of the data collected.

Introduction

Coral Reefs in the Caribbean have been subject to a phase-shift from coral-dominated to algal-dominated ecosystems (Hughes, 1994; Jackson, Donovan, Cramer, & Lam, 2014; Mumby, Hastings, & Edwards, 2007; Mumby & Steneck, 2008; Mumby et al., 2012; Robert S. Steneck, Mumby, MacDonald, Rasher, & Stoyle, 2018) over the past 40 years, a shift that has been reflected in the reefs of Antigua and Barbuda (Camacho & Steneck, 2016; Kramer et al., 2016). Marine Protected Areas, or MPAs, are one of the tools used to stem the decline of coral reef ecosystems around the world (Bustamante et al., 2014; Guarderas, Hacker, & Lubchenco, 2008) by implementing regulations to reduce anthropegenic stress. However, the lack of -both data-driven goals and an effective management structure can often result in an MPA that does not ~~meet t~~not meet the objectives for which it was set up (Camacho & Steneck, 2016; Kaplan et al., 2015; McClanahan, 1999).

The Nature Conservancy (TNC) published coral reef report cards in 2016 (Kramer et al., 2016) for six participating countries. These report cards provided a baseline in coral reef health while identifying gaps in the data available to decision makers within the participating countries. TNC used a Reef Health Index (RHI) to conduct ratings of c~~C~~oral r~~R~~eefs throughout the Caribbean. The RHI scale uses 4 parameters (Coral Cover, Fleshy Macroalgae, Commercial Fish Biomass, Herbivorous Fish) to enhance reef managers understanding of the conditions affecting their reef systems, recommend management prescriptions, and provides a useful comparison ranking. Within the RHI, Antigua and Barbuda ranked "poor" overall, particularly as it related to coral cover, fleshy macroalgae and commercial fish biomass, while herbivorous fish biomass ranked "fair" (Figure 1). Additionally, these report cards highlighted the lack of regularity (last data collection in 2013) and evenness/spread of data collection on coral reefs in Antigua and Barbuda. With 22 designated managed marine areas on the books (EIMAS, Government of Antigua & Barbuda), and additional areas proposed, these is a need to have updated ecological information to guide the management of these marine resources. The Government of Antigua and Barbuda (GoAB) recognized the need for a regularized marine data monitoring program which could: identify marine ecological issues, inform decision-making and MPA management planning, and assist with reporting requirements for Multilateral Environmental Agreements (MEAs) such as the Convention on Biological Diversity (CBD). The Atlantic Gulf Rapid Reef Assessment (AGRRA) methodology has been identified as a primary method of coral reef data collection for the island due to its longstanding regional network, availability of trainers within the region, rapid analysis of datasets and comparability with previous data collections both locally and regionally, where appropriate.

Three AGRRA surveys, conducted over the last three years, are reported in this paper. These survey sites were strategically chosen to provide information for management interventions for current and future MPAs, and to enhance the information provided in the TNC coral reef report

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cards. The North-East Marine Management Area (NEMMA) is currently the largest managed marine area on the island (108.5km^2) and its long-outdated management plan (Jackson, 2008) needs review and renewal (Fisheries Division, *personal comm.*). The island of Redonda has been the site of tremendous terrestrial intervention (*Redonda Restoration Program - RRP*) to remove Invasive Alien Species (rats and goats), which has so far resulted in remarkable recovery of the terrestrial fauna and flora (RRP Coordinator, *personal comm.*). The island and its associated marine area is in the process of being declared as an MPA. Baseline marine data was required to advise the development of the management plan, and to help study the impacts of the terrestrial recovery on the marine ecosystem, as similar activities in other countries have demonstrated increases in reef productivity (Graham et al., 2018). The Nelson Dockyard National Park (NDNP) was traditionally managed for its historical and cultural value. However, the National Park Authority (NPA) is now driving to improve the management of the marine and terrestrial ecological aspects of the area (NPA, *personal comm.*). As such, information on the marine areas were needed to inform management prescriptions.

Materials & Methods

Site Descriptions

North-East Marine Management Area (NEMMA): This site was declared as a Marine Protected Area in 2005 under the Fisheries Act (1983) and amended Fisheries Act (2006) and has a marine area of 108.5 km^2. To the east, the NEMMA faces the full force of the Atlantic Ocean, while to the West, the coastline is a combination of mangrove wetlands, rocky shorelines and over 30 small offshore islands. NEMMA includes several industrial (inclusive of Antigua Power Company, Parham Fisheries Complex, Shell Beach Marina and Jumby-Bay Resort), recreational (Sting-Ray City and Antigua Nature Tours) and residential areas. The area has a combination of barrier, patch and fringing reefs, with the inner areas dominated by Seagrass Beds.

Redonda: The island of Redonda is located 48 km South-West of the mainland Antigua. Although geographically it is closer to the islands of St. Kitts (28 km) and Montserrat (19 km), it is politically recognized as a territory of Antigua & Barbuda. The island has been uninhabited since the 19th century, when it was used for guano mining due to the high seabird population and is recognized as an Important Bird and Biodiversity Area for its populations of nesting Boobies (Sulidae family). The island is surrounded by cliffs, with no safe coastal access. The nearshore marine areas are dominated by boulder reefs, except for a western portion which is home to "spur and groove" reef formations. Redonda and its' surrounding seas are currently under review for legal declaration as a Protected Nature Reserve under the Environmental Protection and Management Act (2019) legislation. There is no current human settlement on Redonda, or any plan for this in the future. Access to the terrestrial landscape is by helicopter due to its sheer cliffs.

Nelson Dockyard National Park (NDNP): The NDNP is a combination marine and terrestrial National Park and has a marine boundary of 41 km^2. The NDNP was declared in 1989 under the National Park Act (1984) and is a known tourism hub for the island, and is home to several major marinas, resorts and boatyards. The marine area of the NDNP is exposed to the Caribbean

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Sea on the South and is bordered in the North by coastal ecosystems (such as mangrove wetlands, rocky shores, beaches), as well as residential communities and above-mentioned commercial areas. The coral reef system are a combination of fringing and patch reefs, with few areas boulder dominated.

Survey Methodology

We used the AGRRA Benthos and Fish protocols (Lang *et al.,* 2010, updated 2017) to survey: Eight sites in NEMMA in July 2017, Four sites in Redonda in July 2018, 14 sites in NDNP in January 2019 (Figure 2).

AGRRA Benthos method: Benthic cover is recorded under points at 10cm intervals alongon each of 6 10m long transect lines deployed haphazardly on the reef. Macroalgal Heights are measured in at least two transects. "Large" (>2 - <4cm) coral recruits are counted in addition to "small" (≤ 2cm) recruits. Substratum type is noted in each of five, 25cm x 25cm quadrants placed at 2m intervals along every transect line. Counts are made of all juvenile and adult *Diadema antillarum*, other urchins, Caribbean spiny lobster and queen conch, lionfish and any trash in a 1m wide belt transect centered on each transect line.

AGRRA Fish method: Visual counts and size estimates (in 10cm increments above 5cm) of the AGRRA fishes are made in 10, 30m × 2m belt transects located in the same general habitat as the benthos transects. Maximum reef relief (vertical height in cm of the tallest coral or rock above the lowest point in the underlying substratum within a 1m diameter of the transect tape) is measured at 4m intervals ~~while rewinding the tape~~.

Graphs were plotted for comparison of results, and were applicable for statistics, standard error of the means are displayed in the error bars. Analysis of Variance (ANOVA) tests were conducted to examine any differences between site averages. Where significant differences were indicated, a *Post Hoc* Tukey HSD test was used to identify which means varied significantly. All statistical analyses were carried out using KaleidaGraph Statistical Software (Figure 3).

Results

Benthic Results

NEMMA

Live Coral (LC) percentage (%) cover for the NEMMA area ranged from a low of 5% to a high of 21% with an average of 12% while Crustose Coralline Algae (CCA) ranged from 4% to 22% with an average of 10%. Coral Cover exceeded CCA for all sites with the exception of Site Codes: HG-01 and A01-01 (Figure 4A). Turf Algal Sediment (TAS) percentage (%) cover ranged from 5% to 49% with an average of 19.1%. Fleshy and Calcareous Macroalgae (MA) percentage (%) cover ranged from 18% to 43% with an average of 27.9%. MA exceeded TAS for all sites apart from Site Code: A08-01 and A03-02A (Figure 5A).

Redonda

LC percentage (%) cover for Redonda ranged from 2% to 17% with an average of 9.5%. CCA percentage (%) cover ranged from 2% to 12% with an average of 6.7%. LC exceeded CCA for all sites except for Site Code: RDAB-07 (Figure 4B). TAS percentage (%) cover ranged from 0 to 9%, with an average of 3.1%. MA percentage (%) cover ranged from6% t0 31% with an

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Commented [SJ12]: Macroalgae is known to have considerable seasonal variability. Since all sites within the NDNP region were surveyed in January, it may be worth noting in the paper to interpret the MA comparisons with caution.

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How is the reef within a survey area defined?
How is a site selected within a region?
What is the square meters surveyed?
Are the 6 belt transects replicates and will the values from each be averaged or pooled?

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Also, how is the percent cover calculated from these points?
How many data points are collected along a transect?

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Define 'substratum'. What are the categories?
Lastly, identify what data are used in the analysis included in this paper and which ones are not.

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average of 21.7%. MA exceeded TAS for all sites with the exception of Site Code: RDAB-01 (Figure 5B)

NDNP

LC percentage (%) cover ranged from 3% to 8% with an average of 5.6%. CCA percentage (%) cover ranged from 1% to 9% with an average of 3.2%. LC exceeded CCA for all sites apart from Site Codes: ABNPA 12 and ABNPA 13 (Figure 4C). TAS percentage (%) cover ranged from 14% to 66% with an average of 52%. MA percentage (%) cover ranged from 6% to 30% with an average of 17.7%. TAS exceeded MA for all sites (Figure 5C)

Fish Results

NEMMA

Total Fish (TF) biomass ranged from 695g/100m^2 to 4595g/100m^2 with an average of 2392.5g/100m^2. Commercial Species (CS) (see Appendix 1) biomass averaged 494.5g/100m^2 with a low of 72g/100m^2 to a high of 1251g/100m^2 . Herbivore (HB) Biomass averaged 1782.5g/100m^2 (Scaridae: 1183.9g/100m^2, Acanthuridae: 569g/100m^2, Figure 7A), with a high of 3613g/100m^2 and a low of 486g/100m^2. HB biomass exceeded CS biomass for all sites apart from Site Code: A05-03 (Figure 6A).

Redonda

TF biomass averaged 6521.5g/100m2, and ranged from 3659g/100m^2 to 8689g/100m^2. CS biomass averaged 1608g/100m^2 and ranged from 594g/100m^2 to 2791g/100m^2. HB biomass averaged 2466.8g/100m^2 (Scaridae: 561.8g/100m^2, Acanthuridae: 1634.3g/100m^2, Figure 7B), ranging from 1346g/100m^2 to 3779g/100m^2. HB biomass exceeded CS biomass for all sites with the exception of Site Code: RDAB-07 (Figure 6B).

NDNP

TF biomass averaged 7716.6g/100m^2, and ranged from 2524g/100m^2 to 14909.0g/100m^2. CS biomass ranged from 671g/100m^2 to 6931g/100m^2 and averaged 3193.4g/100m^2. HB biomass averaged 3406.6g/100m^2 (Scaridae:1400g/100m^2, Acanthuridae:1714.3 g/100m^2, Figure 7C), and ranged from 1698g/100m^2 to 6171g/100m^2. HB biomass exceeded CS biomass for seven of the 14 sites surveyed (Figure 6C).

Overall Results

Average live coral cover for Antigua, for the surveys carried out in 2017, 2018 and 2019, was 9%, with significant differences between the average coral cover at NEMMA vs NDNP ($p=0.0027$). CCA averaged 6.6%, with significant differences observed between NEMMA and NDNP ($p=0.0016$) (Figure 3, Figure 8A). TAS averaged 24.7%, with significant differences observed between NDNP and Redonda ($p<0.0001$), and NDNP and NEMMA ($p<0.0001$). Macroalgal cover averaged 22.5%, with significant difference seen between NDNP and NEMMA ($p=0.0148$) (Figure 3, Figure 8B).

Total fish biomass averaged 5543.5g/100m^2, with significant difference in biomass seen between NDNP and NEMMA ($p=0.0003$), as well as between Redonda and NEMMA ($p=0.0392$). Among the Commercial Species, the average biomass was 1770.5g/100m^2, with significant differences in biomass observed between NDNP and NEMMA ($p=0.0004$). Herbivorous Fish

biomass averaged 2552.0g/100m^2, with significant differences in biomass seen between NDNP and NEMMA (p=0.0121) (Figure 3, Figure 9A). Further analyzed to identify primary herbivores, Scaridae Biomass averaged 1048.4g/100m^2 while Acanthuridae biomass averaged 1305.8g/100m^2. No significant difference was observed between Scaridae biomass at the sites, but significant differences in Acanthuridae biomass was seen between NDNP and NEMMA (p=0.0015), and between Redonda and NEMMA (p=0.0327) (Figure 3, Figure 9B).

Discussion

A major issue faced by Small Island Developing States (SIDS) like Antigua & Barbuda is insufficient data availability to provide enough guidance for designation and effective management of Marine Protected Areas. The 2016 TNC Coral Reef Report Cards attempted to address this gap by summarizing regional datasets for different islands in one place, which was easily accessible to decision makers. However, it was not a targeted effort to provide the resources (financial and technical) to allow~~s~~ for local stakeholders to assess ecological conditions in current MPAs, or areas which have been identified to become MPAs in the future. AGRRA, with its regional Caribbean training program, has provided a useful platform, given the existence of existing trained personnel within the island. The AGRRA surveys conducted in the NEMMA, NDNP and Redonda were ~~as~~ a result of needs expressed by the local government to inform and/or improve management prescriptions.

These surveys and analyses illustrated the high intra-site ecological differences, which is highlighted in Figure 4 (Benthic Promotors), Figure 5 (Benthic Detractors) and Figures 6 & 7 (Fish Biomass Comparisons). ~~Site such as~~As an example, over 20% live coral cover was recorded at site A03-02 ~~had live coral recorded at over 20%~~ (Figure 4A), which was due to a proliferation of *Acropora prolifera* stands at this site. This site proved to be the exception during these surveys, as ~~live coral cover was sparse, and~~ the total average live coral cover was measured at 9% (Figure 1). This site has been earmarked for further surveys to better understand the factors influencing the proliferation of Acroporas in this site, as well as to investigate its future use as a source site for coral restoration in other portions of the island. Crustose Coralline Algae (CCA), a known positive recruitment influencer for juvenile corals on the reef ecosystem, varied tremendously within sites. Information such as this can prove useful in the identification of potential sites for coral restoration activities and identify areas in need of greatest intervention. Macro algae, in these results a combination of fleshy and calcaerous macroalgae, was the dominant benthic detractor in NEMMA and Redonda. This however changed in NDNP where the dominant benthic detractor was Turf Algae infused with sediment to create a sediment mat (Turf Algal Sediment). The TAS mat is virtually impenetrable by herbivores, particularly small bodied parrotfish and surgeonfish (R.Camacho, *personal obs.*), and could be a factor leading to the low benthic promotors observed in the NDNP. This relationship was not explored in this paper. Sites with the lowest benthic detractors in the NDNP (Site Code: ABNPA 12) also had the highest benthic promotors, and a similar relationship was seen in several other surveys at the NDNP site, as well as the NEMMA and Redonda site. This information will be valuable when prescribing zoning and other management prescriptions.

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Commented [SJ29]: This is the first we have heard of turf algae in this paper. I feel that the reef benthic types that identify as benthic promotors or benthic detractors should be described in the methods.

Commented [SJ30]: Why would the inability of herbivores to penetrate the TAS be a leading factor to low benthic promotors? Explain your reasoning.

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Further unevenness was also illustrated in the fish biomass comparisons, with total fish (TF) biomass ranging from as low as 695g/100m^2 to 14909g/100m^2 in NDNP (Figure 6). When considering the group dynamics of this biomass, with the focus on herbivorous (HB) and commercial fish (CS) species (Figure 10), HB exceeded CS in most sites, with few exceptions in each survey area. The greatest of these was at NDNP (Site Code:ABNPA11). Further analysis of the HB biomass illustrated that the Scaridae family was the dominant herbivore group in NEMMA, while the NDNP surveys illustrated mixed variation among all sites. Redonda proved unique as it illustrated a higher proportion of Acanthuridae family to Scaridae family at all sites. A partial explanation for this is the large schools of surgeonfish observed during the surveys, but concern has been registered regarding the lack of large bodied Scaridae observed in the marine habitat, particularly considering the important role these species are known to play in algal regulation (source).

A high inter-site variability between results highlighted the differences between sites throughout the island. ANOVA analysis (Figure 3) showed that there were significant differences between sites for each category (promotor and detractors) of the benthic characteristics (Figure 8). This was also seen in fish biomass, particularly when considering the economically important category of commercial species, or the ecologically important category of herbivores (Figure 9). Using the Reef Health Index as a tool to compare ecological assessments, there are some changes between the 2016 TNC Report Card for Antigua and Barbuda and the AGRRA surveys described above (Figure 1). On a nation-wide level, coral cover has remained virtually the same, indicating no major loss since the 2016 report cards, which may be attributed to the slow growth rates of the brain corals which dominate the landscape around the island (R. Camacho, *personal obs.*). However, it also indicates the low impact that bleaching events and coral diseases such as the Stony Coral Tissue Loss Disease (SCTLD), which has not yet been observed in Antigua and Barbuda (AGRRA, 2019), is currently having on the coral reef ecosystems of the island. Additionally, sites of higher than expected coral cover, such as seen in the NEMMA (Site Code:A3-02), will provide useful natural experiments to observe factors which are promoting coral growth, and provide source areas for coral restoration activities. Fleshy Macroalgae percentage cover, on average, was higher than was seen from the TNC analysis, which is shadowed by a decrease in Herbivorous Fish Biomass. There have been several studies looking at the relationship between herbivorous fish biomass and fleshy macroalgae coverage (Mumby & Steneck, 2008; Mumby et al., 2012), and the subsequent negative cascading effect that proliferation of fleshy macroalgae can have on the recruitment of juvenile corals (Arnold, Steneck, & Mumby, 2010) and the ability of adult corals to grow (Rasher & Hay, 2010). Additionally, as Valles and Oxford (2014) have demonstrated that analysis of parrotfish body size could be utilized as an indicator of fishing pressure, the data collected here will be useful in assessing management effectiveness of these areas in the future. Commercial Species biomass displayed a positive trend with an increase in biomass observed across sites surveyed, which can be attributed to the closed seasons implemented by the Fisheries Division (FD) in 2013 (Division, n.d.), as a nation-wide management measures being initiated by the FD.

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Commented [SJ34]: Is this an extrapolation of the TNC and AGRAA surveys? If so, it may be more appropriate to state your overall results as such since these results are not entirely comprehensive for Antigua and Barbuda.

Commented [SJ35]: I don't think either one of these assumptions can be made without including other demographic and condition data in your analysis. Is coral bleaching and coral disease information collected during AGRRA surveys? How do you know there is low impact from bleaching and disease? Also, if SCTLD has not been documented in the area, then it cannot have a 'low' impact.

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The information collected during these three reported AGRRA surveys will be directly utilized in the creation of management prescriptions, by incorporating assessment of changes and potential damages to the ecosystem over time by serving as baseline ecological condition indicators. The NEMMA information will be incorporated into the update of the Management Plan for the area, and information has been used to identify hotspots (areas of unusually high coral cover) for further research. The marine surveys conducted around Redonda have been fed directly into the rationale for the creation of the Redonda Ecosystem Reserve management plan which will encompass one of the largest MPAs in the Eastern Caribbean. Moreover, the marine data will provide a useful baseline for future studies of the impact that terrestrial recovery following the removal of Invasive Alien Species has on the marine ecosystem, particularly considering the results of similar scenarios in the Indian Ocean (Graham et al., 2018) and the unique situation created by the low anthropogenic pressure on Redonda. In the NDNP, an area traditionally managed from a cultural and historical perspective, this data collection represents the first extensive marine data collection at the site and was part of a project that collected data on seagrass beds and mangrove wetlands. These data sets will be used to implement management of the marine resources using an Ecosystem Based Management approach, which incorporates the connectivity of coral reefs and associated ecosystems (R. S. Steneck et al., 2009).

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Conclusions

The overall picture gained from these surveys is that the current status of coral reefs in Antigua and Barbuda are reflective of what is seen throughout the wider Caribbean region, and greater management efforts are needed to improve the overall health of these ecosystems. The high inter- and intra-variability between coral reefs sites highlight the importance of site level data ~~to guide~~to guide the management prescriptions for these ecosystems. With increasing pressures from anthropogenic and natural influences, it is important to fully understand the variability between sites, the impact of stressors and how the management prescriptions will differ appropriately.

Future work will focus on increasing the spread of assessed coral reef sites around the islands, with emphasis on those areas within designated or proposed MPAs, in order to create a network of effectively functioning MPAs. Additionally, there are plans to establish permanent monitoring sites within the MPAs ~~so as to~~to increase the understanding of the coral reef ecosystem and its reaction to external pressure and management interventions, with the aim to improve the health of coral reef ecosystems around the island.

Acknowledgements

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