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

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## Abstract

The nation of Antigua and& 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:including overexploitation and poor management of marine resources. The ~~management~~ effectiveness of management actions ~~of~~in marine protected areas have often been reduced by a lack of data to ~~efficiently~~ inform management prescriptions. This was emphasized by ~~the 2016~~ The Nature Conservancy's (TNC) 2016 Coral Reef Report Cards which highlighted not only the ~~infrequency~~lack of data collection in Antigua and Barbuda and other Caribbean nations, but also illustrated how scattered what little data available were. The government of Antigua and Barbuda recognized the need for a marine data collection program to better inform the designation and management of Marine Protected Areas (MPAs) as a tool to ~~facilitate the improvement of~~improve the health of the marine ecosystems.~~, and~~ In the past, the government has utilized the Atlantic Gulf Rapid Reef Assessment (AGRRA) protocol as ~~one~~a way ~~in which~~ to address planning and management for marine areas. There have been three AGRRA surveys carried out in the years following the ~~2016~~ TNC 2016 report, in areas of previously established managed areas: (North East Marine Management Area (NEMMA) 2017 and, Redonda 2018, Nelson Dockyard National Park (NDNP) 2019) as well as areas outlined for future management (Redonda 2018). While the results of theour surveys mirror the underlying coral reef conditions that have been shown to exist within the Caribbean region,what was published in 2016, they also highlight intra-site variation that exist within each survey location. This knowledge which can be crucial in guiding

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management decisions in~~actions which improve the management of~~ these marine areas through zoning and other management prescriptions. 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 the first of their kind, and~~ establishedd~~s~~ useful baselines ~~as the~~to aid in monitoring the island's recovery~~ is monitored~~. This paper presentsWe present an overview of data collected between the years of 2017 to 2019 using the AGRRA method in Antigua and Barbuda ~~among zones~~across marine zones which have been assigned a form of management in the past, or identified for management prescriptions in the future and discuss how this data may be used in the future~~ion of future uses of the data collected~~.

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 nation of Antigua & Barbuda 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 marine ecosystems. 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 surveys carried out in the years following the 2016 TNC report: North East Marine Management Area (NEMMA) 2017, Redonda 2018, 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 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 ReefsCoral reef ecosystems in the Caribbean have been subject to a phase-shift from coral-dominated to algal-dominated ecosystems (Hughes 1994; Mumby, Hastings, and Edwards 2007; Mumby and Steneck 2008; Mumby et al. 2012; J. B. C. Jackson et al. 2014; Robert S. Steneck et al. 2018) over the past 40 years, a shift that has been reflected in the reefs of Antigua and Barbuda (Camacho and Steneck 2016; Kramer et al. 2016). Marine Protected Areas, or MPAs, are one of the tools used to stem counter the decline of coral reef ecosystems around the world (Guarderas, Hacker, and Lubchenco 2008; Bustamante et al. 2014) by implementing regulations to reduce anthropogenic stress. However, the lack of both data-driven goals and an effective management structure can often result inn an MPAs that does not meet thewhich fail to meet the objectives for which it they wereas set up (McClanahan 1999; Kaplan et al. 2015; Camacho and Steneck 2016). The Nature Conservancy (TNC), in 2016, combined existing datasets available in the literature for the Caribbean region and published coral reef report cards in 2016 (Kramer et al. 2016) for six Caribbean participating countries (St. Kitts and Nevis, Antigua and Barbuda, Dominica, St. Lucia, St. Vincent and the Grenadines, and Grenada) (Kramer et al. 2016). These report cards provided an overview of the coral reef health parameters, baseline in coral reef health while identifying gaps in the data available to decision makers within these Small Island Developing States (SIDS) participating countries. To rate the coral reef health parameters throughout the Caribbean, TNC used a Reef Health Index (RHI) (Table 1) to conduct ratings of cCoral rReefs throughout the Caribbean. The RHI scale uses four4 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 providess 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 1Table 2). Additionally, these report cards highlighted the lack of regularity (last data collection in 2013) and evenness or /spread of data collection on coral reefs in Antigua and Barbuda. With 22 designated managed marine areas on the books (GoAB 2019), and additional areas proposed, therse is an apparent need to have relevant updated ecological information to guide the management of these marine resources. The Government of Antigua and Barbuda (GoAB) recognized the need for a regularized marinethat implementing a 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). Due to its longstanding regional network, Tthe Atlantic Gulf Rapid Reef Assessment (AGRRA) methodology (Lang et al. 2017) washas been identified as thea primary method of coral reef data collection for the island. due to its longstanding regional network, In addition, the availability of AGRRA trainers within the region and the, rapid analysis of datasets and comparability with previous data collections both locally and regionally, made it an ideal method to establish baseline coral reef data. where appropriate. Three AGRRA surveysassessments, conducted conducted over the last three yearsbetween 2017 and 2019, are reported in this paper (Figure 1). These survey sites were strategically chosen to provide information for management interventions for current and future MPAswere collected due to request of various projects/departments and the availability of relevant funding resources. They all have a common theme of being located within areas which are currently managed, or have been identified as an area of future management., and to enhance the information provided in the TNC coral reef report cards.  These surveys were not chosen to fill in all data gaps across the geographic area of Antigua and Barbuda, but as a means of enhancing the database for marine ecological conditions around Antigua and Barbuda as part of an on-going effort to collect baseline data and monitor the islands’ coral reef ecosystems. Our results highlight variation both among assessments conducted at different parts of the island, as well as within assessments, and

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these differences are crucial to better understand the marine ecology and the types of management prescriptions which should be employed at each area.

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 (I. Jackson 2008) needs review and renewal (Fisheries Division, 2018, *pers. comm.*). The island of Redonda has been the site of tremendous terrestrial intervention (*Redonda Restoration Program - RRP*) (Bell et al., n.d.) to remove Invasive Alien Species (rats and goats), which has so far resulted in remarkable recovery of the terrestrial fauna and flora (RRP Coordinator, 2019, *pers. 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, 2019, *pers. 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) (Jackson 2008) and has a marine area of 108.5 km$^2$, making it the largest within the waters of Antigua and Barbuda. Its long-outdated management plan (I. Jackson 2008) needs review and renewal (Fisheries Division, 2018, *pers. comm.*), and currently has no location specific enforcement actions other than general fishery regulations. NEMMA is located within sub-region 33, which is described as "indenting coastline with a wide shelf and greatest coral reef development" (Kramer et al. 2016). To the east, the NEMMA faces the full force of the Atlantic Ocean (Figure 1), while to the West, the coastline is a combination of mangrove wetlands, rocky shorelines and over 30 small offshore islands. On the terrestrial side of NEMMA includes, there are 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. While the ~~designation of the~~protected portion~~area~~ only ~~speaks~~encompasses~~ to~~ the marine and coastal areas, the adjacent~~se~~ developments~~ will~~ undoubtedly have direct and indirect effects on the area. The protected area has a combination of barrier, patch and fringing reefs, with the inner areas dominated by s~~S~~eagrass b~~B~~eds and sandy flats. The data was collected as an update to the benthic ecological conditions in the area (Palmer 2017) and were based off surveys conducted in 2005 by a team from the University of Miami (Brandt et al. 2005).

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Redonda: The island of Redonda is located 48 km South-Westsouthwest 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 and& Barbuda. The island has been uninhabited since the 19$^{th}$ century, when it was used for guano mining due to the high seabird population, andpopulation and is recognized as an Important Bird and Biodiversity Area (IBA – AG001) for its populations of nesting Boobies (Sulidae family). The island is surrounded by cliffs, with no safe coastal access. The marine landscape reflects a similar situation, with depths of less than 15m limited to a max distance of 150m from the island but averaging within 100m from the shore (defined as nearshore marine area hereafter) (Figure 1). The nearshore marine areas are dominated by boulder reefs, except for a western portion which is home to "spur and groove" reef formations. Outside of these reef areas are seagrass beds sloping into deeper habitat. The island of Redonda has ~~been the site of~~undergone tremendous terrestrial intervention (*Redonda Restoration Program - RRP*) (Bell et al., n.d.) to remove invasive alien species (IAS) (rats and goats), a program which has so far resulted in remarkable recovery of the terrestrial fauna and flora (RRP Coordinator, 2019, *pers. comm.*). 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. The total proposed area of this management zone is~~will be~~ 299$km^2$ with an average depth of ~60m, but the area available for survey using the AGRRA methodology is ~2$km^2$ due to depth and safe diving limitations. There is no current human settlement on Redonda, or any plan for this in the future. Access to the terrestrial landscape is by restricted to helicopter access due to its sheer cliffs and unstable terrain. Baseline marine data was required to advise the development of the management plan for Redonda and its surrounding waters. The data will also aid in helping~~, 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). Due to its small size and location away from the mainland, marine work around the island is difficult, as its total exposure, "wrap-around" currents, and the lack of a safe anchorage makes it a relatively unsafe environment for work unless in the best of weather conditions. Surveys in 2018 were limited to the relatively protected side of the island due to adverse weather. Redonda has no designated sub-region, as no previous publicly available dataset existed for it prior to the 2018 surveys, but would most resemble subregion 31, defined as "less developed fringing reefs, large areas of low relief hard bottom with numerous gorgonians" (Kramer et al. 2016).

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Nelson Dockyard National Park (NDNP): The NDNP is a combination marine and terrestrial National Park and has a marine boundary of 41 $km^2$ (Figure 1). It is designated within sub-region 31, which is defined as "less developed fringing reefs, large areas of low relief hard bottom with numerous gorgonians". 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 Sea on the ~~South~~ southern side 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 on the northern side. The coral reef system are a combination of fringing and patch reefs, with few areas ~~boulder~~ dominated by boulder reefs. The NDNP was traditionally managed for its historical and cultural value, with little focus ~~and no management prescription~~ on the marine area, but has since embarked on an effort to improve the management of the marine and terrestrial ecological aspects of the parkarea (NPA, 2019, *pers. comm.*). ~~The AGRRA data collection was a targeted project t~~To conduct marine ecological assessments within the park, the AGRRA survey method was employed to provide baseline marine ecological information to be used in future management of the park. The project ~~which allowed the survey of the reefs in the NDNP,~~ also included surveys of sSeagrass bBeds and mMangrove wWetlands which are ecologically important contributors to coral reef health.

*Survey Methodology*

We used the To assess the ecological conditions of the reefs within the subject areas, the AGRRA Benthos and Fish protocols (Lang et al. 2017) were employed.to ~~surveywas the protocol utilized to assess the ecological conditions on the reef.~~ All surveyors were trained and certified by ~~the~~ AGRRA ~~certified~~ trainers, and in some cases (NEMMA and NDNP) included AGRRA surveyors from other islands. Across the three study regions,~~In total~~ 26 sites ~~have been~~were surveyed using AGRRA protocol in~~from~~ 2017. However, for presentation within this paper, all sites 5m or less in depth were removed to allow for better analyses. Presented in this paper are:: Eight sites in NEMMA in July 2017NEMMA (four sites surveyed in 2017), Four sites in Redonda in July 2018Redonda (four sites surveyed in 2018), 14 sites in NDNP in January 2019NDNP (13 sites surveyed in 2019). (Figure Table 32).

AGRRA Benthos method: ~~B~~At each survey site, benthic cover is recorded along six transects by identifying the flora, fauna, or substrate that lies under the transect line at 10cm intervals (100 total points). Each transect is 10m in length and deployed haphazardly on the reef. ~~under points at 10cm intervals on each of six 6 10m long transect lines (10m each) deployed haphazardly on the reef.~~ Macroalgal hHeights (fFleshy and calcareous) are measured, to the nearest mm, ~~in at least~~along two transectsof the six transects conducted at~~in~~ each site. Additional data, such as cCoral rRecruits, macro-invertebrates, presence/absence of diseases and trash are also measured during these surveys, but ~~these were not reported in the paper~~are not included in the results of this study. "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 (Lang et al. 2017) are ~~made in~~recorded along 10 , 30m × 2m, belt transects (30m × 2m each) located in the same general habitat as the benthos transects. Similar to the benthos transects, the 10 fish transects are laid haphazardly on the reef in order to provide sufficient coverage across the reef at each site. ~~These 10 transects are spread across the reef site haphazardly in order to get a good coverage of the site.~~ 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

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tape) is measured at 4m intervals while rewinding the tape.~~Additional data, such as max relief, is also measured during these surveys, but these are not reported in the paper.~~ Fish length data is converted to biomass data through the use of L-W relationships sourced from FishBase primarily using the Bohnsack study (Bohnsack, J.A and Harper, D.E. 1988) with some improvements from more recent studies. Additional data, describing the topographic complexity are recorded during the surveys but are not included in the results of this study.

All raw benthic and fish data was entered into~~submitted to~~ the AGRRA database, where basic ~~analysis to~~ descriptive/summary statistics were produced at the~~ give~~ site and transect level~~ data~~. The summary~~is~~ data was used to generate the results in this study.~~was then further analyzed for use in this paper.~~ The benthic data ~~is provided in groupings~~was separated into groups of Benthic Promoters and Benthic Detractors. Benthic Promoters are the reef organisms that facilitate reef growth and allow coral larvae to settle. These promoters include,~~, most importantly~~ live corals, crustose coralline algae and sparse turf algae. Benthic Detractors are benthic organisms like macroalgae, turf algal sediment mats and certain invertebrates (e.g. some sponges, cnidarians, tunicates) that can displace corals or prevent the settlement of coral larvae (Lang & Roth, 2018).

Fish data was ~~presented as~~summarized by total fish, commercial species and herbivores (further separated into Scaridae family, Acanthuridae family and other herbivores) biomass.

Graphs were plotted ~~for comparison of results~~to compare results, and where applicable for statistics, standard error deviation of the means are displayed ~~in the~~using error bars. Analysis of Variance (ANOVA) tests were conducted to examine any differences between site data 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 Table 43).

## Results

*Benthic Results*

NEMMA

Live Coral (LC) percent~~age~~ (%) cover for the NEMMA area ranged from a low of 5% to a high of 21% with an average of 132% while Crustose Coralline Algae (CCA) ranged from 4% to 122% with an average of 910%. Coral Cover exceeded CCA for all sites with the exception of Site Codes: HG-01 and A01-01 (Figure 24A). Turf Algal Sediment (TAS) percent~~age~~ (%) cover ranged from 5% to 1849% with an average of 139.1%. Fleshy and Calcareous Macroalgae (MA) percent~~age~~ (%) cover ranged from 2118% to 43% with an average of 27.931%. MA exceeded TAS for all sites apart from Site Code: A08-01 and A03-02A (Figure 35A).

Redonda

LC percent~~age~~ (%) cover for Redonda ranged from 2% to 17% with an average of 99.5%. CCA percentage (%) cover ranged from 2% to 12% with an average of 6.77%. LC exceeded CCA for all sites except for Site Code: RDAB-07 (Figure 24B). TAS percent~~age~~ (%) cover ranged from 0 to 9%, with an average of 33.1%. MA percent~~age~~ (%) cover ranged from 6% to0 31% with an

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average of 221.7%. MA exceeded TAS for all sites with the exception of Site Code: RDAB-01 (Figure 35B).

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 24C). 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 187.7%. TAS exceeded MA for all sites (Figure 35C).

*Fish Results*

NEMMA

Total Fish (TF) biomass ranged from 2250695g/100$m^2$ to 4595g/100$m^2$ with an average of 2392.5g3288g/100$m^2$. Commercial Species (CS) (see Figure 10Appendix 1) biomass averaged 494.5g796g/100$m^2$ with a low of 33372g/100$m^2$ to a high of 1251g/100$m^2$. Herbivore (HB) Biomass averaged 23481782.5g/100$m^2$ (Scaridae: 1530183.9g/100$m^2$, Acanthuridae: 772569g/100$m^2$, Figure 57A), with a high of 3613g/100$m^2$ and a low of 1240486g/100$m^2$. HB biomass exceeded CS biomass for all sites apart from Site Code: A05-03 (Figure 46A).

Redonda

TF biomass averaged 65221.5g/100$m^2$ and ranged from 3659g/100$m^2$ to 8689g/100$m^2$. CS biomass averaged 162108g/100$m^2$ and ranged from 645594g/100$m^2$ to 2791g/100$m^2$. HB biomass averaged 24676.8g/100$m^2$ (Scaridae: 5621.8g/100$m^2$, Acanthuridae: 1634.3g/100$m^2$, Figure 57B), ranging from 1346g/100$m^2$ to 3779g/100$m^2$. HB biomass exceeded CS biomass for all sites with the exception of Site Code: RDAB-07 (Figure 46B).

NDNP

TF biomass averaged 7953716.6g/100$m^2$ and ranged from 2524g/100$m^2$ to 14909.0g/100$m^2$. CS biomass ranged from 671g/100$m^2$ to 6931g/100$m^2$ and averaged 3193.4g/100$m^2$. HB biomass averaged 3326406.6g/100$m^2$ (Scaridae:147400g/100$m^2$, Acanthuridae:170014.3 g/100$m^2$, Figure 57C), and ranged from 1698g/100$m^2$ to 6171g/100$m^2$. HB biomass exceeded CS biomass for sixeven of the 134 sites surveyed (Figure 46C).

*Overall Results*

Average live coral percent~~age~~ (%) 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=0.0108027). CCA averaged 6.6%, with significant differences observed between NEMMA and NDNP (p=0.006016) (Figure Table 3, Figure 68A). TAS averaged 234.7%, with significant differences observed between NDNP and Redonda (p<0.0001), and along with NDNP and NEMMA (p<0.0001). Macroalgal cover averaged 2322.5%, with significant difference seen between NDNP and NEMMA (p=0.03440148) (TableFigure 3, Figure 68B).

Total fish biomass averaged 59215543.5g/100$m^2$, with significant difference in biomass seen between NDNP and NEMMA (p=0.00030205). , as well as between Redonda and NEMMA (p=0.0392). Among the Commercial Species (CS), the average biomass was 1914770.5g/100$m^2$, with significant differences in biomass observed between NDNP and NEMMA (p=0.00040171)

(Table 3,Figure 7A). Herbivorous Fish biomass averaged 2765552.0g/100$m^2$, with no significant differences in biomass seen between NDNP and NEMMA (p=0.0121) (Figure 3, Figure 9Athe assessments). Further analyzed to identify primary herbivores, Scaridae Biomass averaged 1048.4g1189g/100$m^2$ while Acanthuridae biomass averaged 1305.8g1369g/100$m^2$. No significant difference was observed between Scaridae biomass or Acanthuridae 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) at any of the assessment locations (Figure Table 3, Figure 79B).

## Discussion

A major issue faced by Small Island Developing States (SIDS) like Antigua and & 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 issue by summarizing regional pre-existing datasets for different Leeward islands in the Caribbeanislands into one report~~place~~, which was easily accessible to decision makers.. The goal of the TNC study was~~is was in order~~ to create an ecological report of comparable coral reef conditions across islands with similar locations and pressures, which was ~~comparable and~~ easily digestible for decision makers. However, it was not a targeted effort to, provide the resources (financial and technical) to conduct additional surveys within the existing or proposed MPAs. ~~which allows for local stakeholders to assess ecological conditions in current MPAs, or assess areas which have been identified to become MPAs in the future.~~
AGRRA, with its regional Caribbean training program, has provided a useful platform for allowing Caribbean SIDS to assess and better understand the condition of their marine ~~ecological conditions of the marine~~ ecosystems. AGRRA provides training for personnel for the use of the AGRRA protocol and has an online database which allows for ~~the comparability of assessments~~data comparison not only within a territories waters', but also throughout the region.~~,~~ To aid in the data investigation and comparisons, the AGRRA site provides ~~along with~~ assistance in basic data analyses methods and provides~~ision of~~ data-related GIS products. Currently, several trained~~qualified~~ AGRRA surveyors exist within the island of Antigua and Barbuda, ~~having been~~who are skilled ~~trained~~ in various protocols ~~via several group training initiatives hosted by AGRRA~~. Despite the presence of trained surveyors within the island, , given the existence of existing trained personnel within the island. ecological surveys are normally dependent on available~~the~~ funding resources ~~becoming available~~ (normally through the use of project grants), and trained personal being available to conduct surveys at the indicated time. The 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 prescriptionsprescriptions and funded through various grants.
These surveys and analyses illustrated the high intra-site ecological differences within each assessment, which is highlighted in Figure 24 (Benthic Promotors), Figure 35 (Benthic Detractors) and Figures 46 & 57 (Fish Biomass Comparisons). Sites such as A03-02 had live

**Commented [SJ33]:** This is the first we have heard of the islands as Leeward. Is there any significance for these islands being leeward?

coral recorded at over 20% (Figure 24A), which was due to acould be attributed to a proliferation of *Acropora prolifera* stands at this site, something which has been seen in the neighboring island of Guadeloupe (Japaud, Fauvelot, and Bouchon 2014). Despite few isolated high coral cover sites, the total average live coral cover was measured at 9% ~~This proved to be the exception during these surveys, as live coral cover was sparse, and the total average was measured at 9%~~ when calculated across all study regions (Figure Table 1). This siteA03-02 has been earmarked for further surveys to better understand the factors influencing the proliferation of Acroporidsas 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 between assessmentssites, but had an average percentage cover of 6%. 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) (Figure 3). The TAS mat can reduce herbivory processesis virtually impenetrable by herbivores, particularly small bodied parrotfish and surgeonfishby restricting the feeding of parrotfish species, and affect the processes of coral recovery by locking the reefs in an alternative state that does not promote coral growth (Bellwood and Fulton, 2008R. Camacho, 2018, *pers comm.*), and could be a factor leading to the low benthic promotors observed in the NDNP. This The extent of this relationship was not explored in this paper but has been identified as an area for future studies. 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 NDNPsite results from the NDNP surveys (ABNPA05, ABNPA11, ABNPA13)site, as well as the NEMMA (A03-02 and A04-02) and Redonda (RDAB-01 and RDAB-02) site surveys (Figure 2 & Figure 3). The site level information of the Benthic Promoters and Benthic Detractors will be utilized in the planning, revision and zoning of these managed areas. Identification of the areas with the greatest reef promotors can help to identify suitable areas to conduct coral restoration experiments and establish conservation zones with the goal of promoting the positive drivers to result in a healthier reef ecosystem. 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. This information will be valuable when prescribing zoning and other management prescriptions. Further unevenness was also illustrated in the fish biomass comparisons, with total fish (TF) biomass ranging from as low as 695g2250g/100m$^2$ in the NEMMA region to a high of 14909g/100m$^2$ in NDNP region (Figure 46). When considering the group dynamics of fish~~this~~ biomass, with the focus on herbivorous (HB) and commercial fish (CS) species (Figure Appendix 10), HB exceeded CS in most sites, with few exceptions in each survey assessment area. The, g greatest of these was atwhich was seen at NDNP (Site Code:ABNPA11). Further analysis of the HB biomass illustrated that the Scaridae family was the dominant herbivore group

**Commented [SJ35]:** Why was this switched to "could be"? Does the AGRRA data not tell you what species were at a site?

**Commented [SJ36]:** Is the 9% across all study regions?

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 due in part to the~~. A partial explanation for this is the~~ large schools of surgeonfish observed during the surveys.~~, but c~~Concern has been registered however, regarding the lack of larger bodied Scaridae (vs smaller bodied Acanthuridae) observed in the marine habitat, particularly considering the important role these species ~~are known to play~~ in ~~algal~~ regulating algal growth~~ion~~ (Lokrantz et al. 2008) (Table 5). Understanding these ecological differences within ~~management zones~~these protected areas can play an important role in ensuring ~~the~~ effective~~icient~~ management decisions~~of the area~~. The data collected from this study can aid reef managers in establishing~~Establishment of~~ fish conservation zones and provide evidence for developing fishing regulations and restrictions within the protected areas.~~, restriction of gear types and activities will be informed from the survey data collected.~~ Additionally, all information collected will be utilized as a baseline from which to understand future replication studies, establish monitoring protocols, and assist with development decisions.

A high inter-site variability between survey results for each area highlighted the differences between sites throughout the islandassessments. ANOVA analysis (Figure Table 3) showed that there were significant differences between sites assessments for each category (promotor and detractors) of the benthic characteristics (Figure 68). This was also seen in fishSignificant differences were also seen in fish biomass of the assessments, particularly when considering the economically important category of commercial species, or the ecologically important category of herbivores when looking at total fish biomass, as well as isolating commercial species biomass group. However, no significant differences were seen between biomass of herbivore groups (Figure 79).
Using the Reef Health Index (Figure 1) 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 (TableFigure 1). Although the TNC and AGRRA datasets cannot be directly compared due to differing data collection methods and sampling design, ~~We do recognize that this is not a direct comparison, as a variety of data collection methods were utilized in the data-sets compiled by TNC, and the reef locations and the environmental and socio-economic factors affecting each of our three assessments differ, it is still a useful tool as~~ the ecological characteristics are ~~presented are~~ quantified in the same way providing a useful comparison. 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, despite season limits being placed on parrotfish in 2013 after an ~~observation of the decline of the parrotfish catch numbers~~observed decline in catch numbers in Antigua and Barbuda (Horsford 2014) . There have been several studies looking at the relationship between herbivorous fish biomass and fleshy macroalgae coverage (Mumby and 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, and Mumby 2010) and the ability of adult corals to grow (Rasher and Hay 2010). Additionally, as ~~(~~Vallès and Oxenford (2014) have demonstrated, the~~at~~ analysis of parrotfish body size can~~ould~~ be utilized as an indicator of fishing pressure, ~~the data collected here~~which will be useful in assessing management effectiveness of these protected areas in the future (Table 5). Commercial s~~S~~pecies (Appendix 1) biomass, a collation of species with~~of~~ commercial value across the region, displayed a positive trend with an increase in biomass from 2015 to 2019 ~~observed~~ across sites surveyed~~from the assessments~~. One factor leading to this could be the establishment, of which can be attributed to the closed seasons implemented by the Fisheries Division (FD) in 2013 (Division 2013) as a nation-wide management measures being initiated by the FD. Further management prescriptions; such as limitation of gear types, greater enforcement of closed seasons, or even lengthening of closed seasons; may be needed to enhance the recovery of these species, particularly when considering the importance of key herbivore species (parrotfish) to the coral reef ecosystem.

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, which although designated in 2005, the management plan was not created until 2007 (Jackson 2008), and did not utilize the data assessed in Brandt et al. 2005, but used a series of rapid ecological studies which predominantly provided presence/absence data of species (Jackson 2008). Additionally, information collected will be used to identify areas of greatest conservation needs, such as , and information has been used to identify hotspots (areas of unusually high coral cover) for further research. In the The NDNP is a national park which has, an area traditionally been managed from a cultural and historical perspective. A recognition of the various threats being faced as a result of a growing economy and an increasingly volatile climate, has led to a greater emphasis on the management of the environmental (marine and terrestrial) resources within the park., this data collectionThe execution of AGRRA surveys represents the first extensive marine data collection at the siteNDNP and was part of a project that designed to collect baseline ecological information for the boundaries of the park, and included the collection ofed 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). Promotor and Detractor information along with fish abundance and other ecological parameters will be used to help to aid the process of zoning, identify suitable areas for coral restoration and restricted use.

The story of Redonda is a unique one, as the island had been abandoned for many years after previously being a mining area for guano. Invasive alien species (IAS) such as rats and goats were introduced as a result and wreaked havoc on the terrestrial fauna and flora. The island, being recognized an important biodiversity hotspot in the Eastern Caribbean for its importance to nesting sea-birds (e.g. Brown Boobies), as well as its endemic species. The Redonda Restoration Program was created as a way to remove the IAS and restore the island to its former glory, in a bid to designate it as a protected area (Redonda Ecosystem Reserve). During this process, there was a recognized need to better understand the ecology of the surrounding marine environment, which included not only the nearshore areas which were surveyed using the AGRRA protocol, but also the deeper coral bank which surrounds the island primarily using drop-camera technology. The rationale here is that the information collected would help to inform the management and zonation of the marine area, an area which when approved will encompass 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).

This paper draws three non-related data collection missions to establish a useful baseline for the island of Antigua and Barbuda. We recognize that the data presented has several limitations which are primarily driven by the lack of funding and resources to implement a larger marine data collection program. As such, some ecological differences (such as exposure, depth, time of surveys, number of sites surveyed per assessment) as well as anthropogenic factors (proximity of commercial institutions, pollution and water quality, fishing pressure, presence/absence of enforcement, etc.) are lacking as crucial factors which could help to explain some of the variation seen both among and within assessments. Other limitations to the establishment of this dataset as a true baseline for Antigua and Barbuda is the lack of Barbuda data present in the survey. This gap has been identified as an area that needs to be surveyed for addition to this dataset, and to help inform management plans. Additionally, while AGRRA has been identified as the principal coral reef assessment methodology for Antigua and Barbuda going forward, there is still a need for a greater understanding of additional ecosystems characteristics; such as those of seagrass beds and mangrove wetlands; to be fed into the conversation in conjunction with socio-economics to have an EBM approach to the management of these marine areas. What this paper represents is an initial effort of the GoAB to not only attempt to better understand the marine ecological conditions affecting the nation coral reefs through standardized marine data collection, but also an effort to use an holistic approach in the management of marine ecosystem through the incorporation of site level information.

## 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-assessment variability between coral reefs sites locations surveyed highlight the importance of site level data 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 sitesstudy areas, 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 areas~~coral reef survey efforts around the islandsnation, 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 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.

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