

A Lesson in Conservation:
Determining how a Marine Protected Area in the Philippines has
influenced coral reef community assemblages.

by

Joseph Gosney

1817046

Under the Supervision of

Dr Jessica Savage

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Abstract

Coral reefs are immensely valuable marine habitats that provide for and protect hundreds of millions of people. However, they are under considerable threat from anthropogenic induced pressures including climate change, overfishing and pollution. To ensure the continued benefit of coral reefs for future generations, this study seeks to understand how marine conservation efforts can be improved, thereby advancing the Global Sustainable Development agenda. Utilizing data from Coral Cay Conservation to investigate the spatial-temporal impact of the Napantao Fish Sanctuary on two coral reefs in the Philippines, this study found that the marine reserve induced overly positive changes in hard coral cover and structural complexity. The impact of the Fish Sanctuary on coral diversity however was less clear, presenting an excellent opportunity for future research. Overall, this study showed that the Napantao Fish Sanctuary has been successful at protecting local coral reefs, demonstrating the efficacy of small-scale MPAs in the wider marine conservation debate. Ultimately, the findings of this investigation will help inform MPA implementation and management at both the local and global level and ultimately contribute towards healthier and more productive oceans.

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Author's Declaration

I have read and understood the rules on cheating, plagiarism, and appropriate referencing as outlined in the Undergraduate Handbook for my degree course and I declare that the work contained in this assignment is my own, unless otherwise acknowledged.

No substantial part of the work submitted here has also been submitted by me in other assessments for this or previous degree courses, and I acknowledge that if this has been done an appropriate reduction in the mark I might otherwise have received will be made.

JGosney

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Introduction

As some of the most biodiverse habitats on the planet, coral reefs have an extraordinary role to play within natural and human systems. For hundreds of millions of people all over the world, coral reefs are the lifeblood of the community, providing ecosystems services that are valued in the billions of dollars (Bruno et al., 2019). However, at the advent of the Anthropocene, coral reefs face the very real risk that they, and the communities that depend on them, will be lost forever.

To prevent this, action needs to be taken by the global community to protect these vital habitats from the various pressures that threaten them. Whilst there have been piecemeal actions that have sought to protect small pockets of coral reef since the 1970s, the scale and magnitude of action towards this goal has been, to date, ‘underwhelming’ (UN, 2020). With the threat of pollution, overfishing and human-induced climate change to coral reefs continuing to rise, it is therefore vital that more is done to protect these valuable marine ecosystems.

As an interdisciplinary issue, the degradation of coral reefs sits as an affront to the Global Sustainable Development agenda. Indeed, within the United Nations Sustainable Development Goal framework, the protection of coral reefs falls within the remit of SDG 14: Life Below Water (UN, 2020). To safeguard coral reefs for future generations, this paper seeks to further the work that has already been accomplished in advancement of this goal, choosing to address two targets within SDG 14 in particular: SDG 14.2 and SDG 14.5.

These targets state that by 2020 the global community should:

- 14.2: *Sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans.*
- 14.5: *Conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information* (UN, 2020).

Neither of these targets have been achieved by the global community and so therefore more needs to be done to help communities and governments manage and interact with the marine environment in a sustainable way.

To accomplish this, this paper will seek to add to the current discourse surrounding Marine Protected Areas (MPA), a marine conservation strategy that has proven popular, if not always successful, around the world. In particular, this paper will focus on the island nation of the Philippines, a region well known for both its high marine biodiversity and wealth of marine reserves (Carpenter and Springer, 2005; Twichell et al., 2018).

If we are to meet the goals set in SDG 14, and protect appropriate amounts of the world's marine resources, it will be important to understand the best approaches to marine conservation. However, in academic circles there is still significant deliberation around how MPAs and conservation measures can be best implemented, with debates around size, management style, community involvement, etc. relying on evidence from real-world examples. To inform this debate and eventually understand how best to approach marine conservation, it is therefore important that we first determine which MPAs have been successful and how they have affected local ecosystems and communities.

To this end, this paper, in partnership with Coral Cay Conservation (CCC), aims to determine the success of a small-scale MPA, the Napantao Fish Sanctuary, located in the Sogod Bay, Philippines. To accomplish this, this paper will seek to answer the following questions:

- 1) How has the presence of the Napantao Fish Sanctuary affected local coral reef community assemblages?
- 2) Has the presence of the Napantao Fish Sanctuary brought about the positive change it intended?

Utilizing data collected and provided by CCC, this paper performed a spatial-temporal analysis on two reefs in Sogod Bay to determine how the MPA had affected the population, diversity, and spatial complexity of corals. Overall, this analysis found that the MPA has had a significant positive impact on coral cover and complexity and an inconclusive effect on coral diversity.

The findings from this inquiry reaffirm that the management techniques used at the study site are appropriate for protecting local coral reefs. The results also provide research and conservation communities with valuable new evidence supporting the use of small-scale MPAs as a conservation strategy and will likely impact future management decisions employed by local authorities in the region. Finally, lessons drawn from this investigation can help to inform academic debate concerning similar conservation efforts elsewhere in the world, ultimately contributing towards healthier and more productive oceans.

Literature Review

1. Coral Reefs

As some of the most biodiverse marine habitats on the planet (Fisher et al., 2015), tropical coral reefs support entire ecosystems and provide essential services for humanity (see Woodhead et al., 2019). The structural complexity created by coral reefs for example, offers important refugia for species across multiple life stages (Graham and Nash, 2013; Ortiz and Tissot, 2012), supporting coastal communities and providing them with vital nutrition and materials (Albert et al., 2015; Golden et al., 2016). Moreover, coral reefs also provide significant economic benefits including an estimated \$35.8 billion per annum from reef tourism (Spalding et al., 2017). Finally, their ability to dissipate wave energy protects 197 million people who live below 10m elevation and within 50 km of a reef, reducing expected damage from storms by \$4 billion each year (Beck et al., 2018; Ferrario et al., 2014).

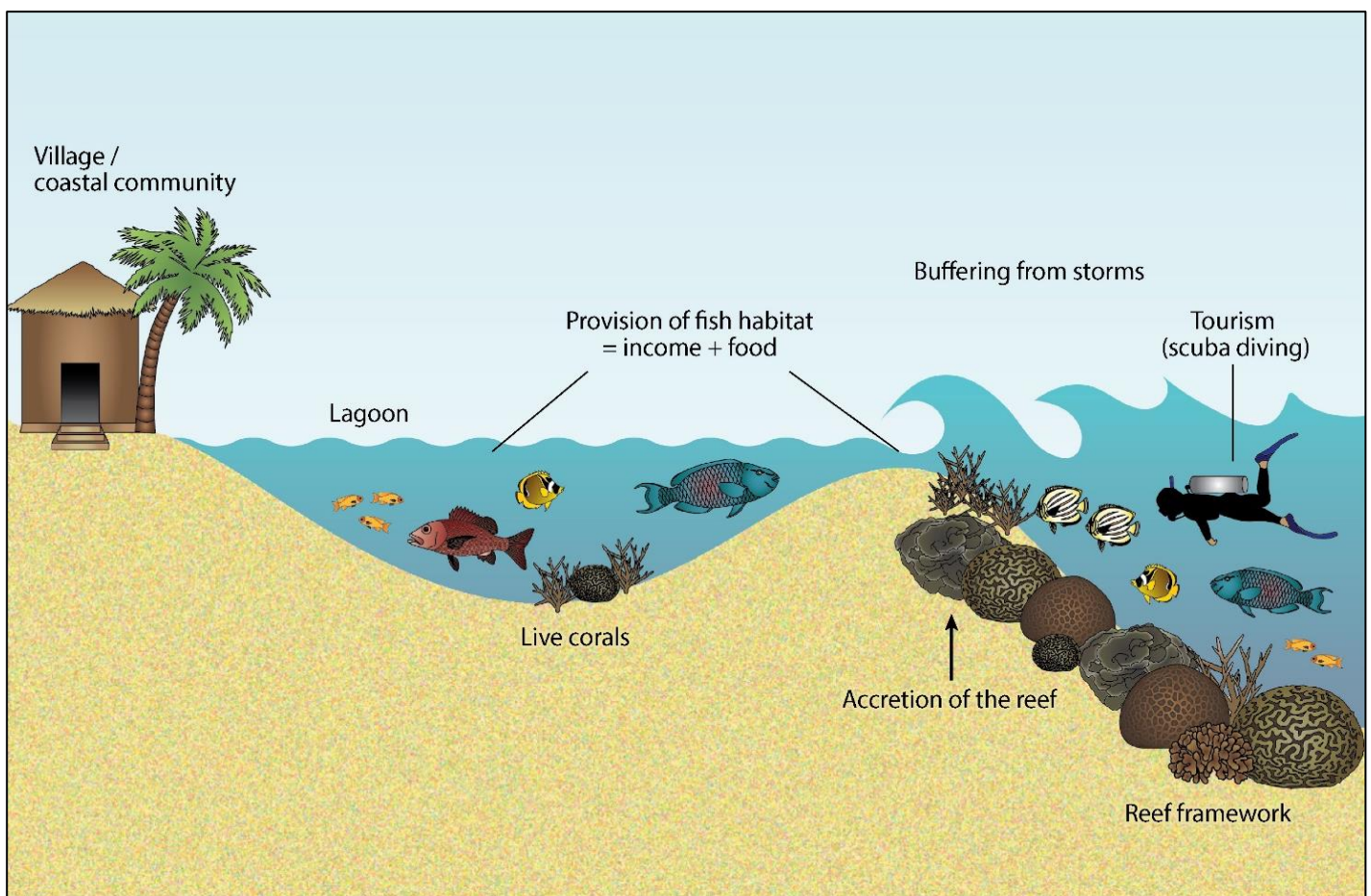


Figure 1: Ecosystem services provided by reefs and some of the geological and ecological features that support these benefits to people. Image Source: (Bruno et al., 2019).

Despite their value however, numerous studies have found that coral reefs around the world are under significant strain from anthropogenic-induced pressures (see Bruno et al., 2019). These include varying localised factors such as water column turbidity and sedimentation (Fabricius et al., 2013), eutrophication and other forms of pollution (Fabricius, 2011) as well as direct disturbances from fishing and subsequent loss of predatory and herbivorous fishes (McClanahan et al., 1999). The primary global factor of concern however is ocean warming (Hughes et al., 2018) which, along with related factors including acidification, deoxygenation, and increased storm intensity, will become increasingly problematic for coral reefs in the future (Bruno et al., 2019).

Already, average cover of living coral on tropical reefs has declined by approximately 50-75% in nearly all regions of the world (Bruno & Selig, 2007; Bruno et al., 2009; De'ath et al., 2012; Gardner et al., 2003; Hughes et al., 2018; Jackson et al., 2014; Schutte et al., 2010), driving declines in habitat complexity (Alvarez-Filip et al., 2011) and the diversity of reef inhabitants including fishes and invertebrates (Idjadi and Edmunds, 2006; Jones et al., 2004; Pratchett et al., 2008). This has led to falls in fisheries production, tourism value and coastal buffering (Moberg & Folke, 1999), endangering the livelihoods of hundreds of millions of people.

2. Marine Protected Areas

To prevent the total collapse of coral reef systems, steps need to be taken to protect these essential habitats. The implementation of Marine Protected Areas (MPAs or Marine Reserves) is one example of a solution, touted by conservationists and governments around the world, to conserve biodiversity and provide society with ecosystem services (Jones et al., 2017). The number and spatial extent of MPAs has increased severalfold since 1990 (Mascia et al., 2017) and as a result, determining how MPAs can maximise the sustainability of natural marine resources is of significant interest within the academic community (Bates et al., 2019).

An MPA, as defined by Kelleher and Kenchington (1991), is “any area of the intertidal or subtidal terrain, together with overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment”. This broad characterisation has therefore resulted in protected areas that differ greatly in not only location but also size, management style and desired outcomes, making comparisons between such areas difficult (Gill et al., 2017).

As a result of this variety, there is still significant debate around almost every aspect of MPA implementation. Taking MPA size as an example, some argue that only large MPAs (LMPAs) will be able to deliver the intended biodiversity and fisheries benefits (Gaines et al., 2010) and assert that LMPAs are administratively easier and less expensive to establish than small MPAs close to the shore (Balmford et al., 2004; McCrea-Stub et al., 2011). Others contend however that LMPAs risk becoming ‘paper parks’, a term used to describe a conservation area that lacks the capacity to take management actions, monitor changes or enforce regulation (Christie et al., 2017). They instead argue that smaller MPAs are more effective because they are better equipped to garner public interest (Singleton & Roberts, 2014) and enhance food security (Fox et al., 2012).

To make the debate even more complex, the ecological and socio-economic impacts of marine reserves are also highly variable (Mascia et al., 2010; Mascia et al., 2017). Whilst there is a consensus that MPAs have the potential to enhance resilience to local and global stressors (Bates et al., 2019; Bruno et al., 2019); increase the population and diversity of fishes and invertebrates on both protected *and* adjacent reefs (Christie et al., 2017; Gill et al., 2017); improve access to nutritious food (Aswani and Furusawa, 2007) and alleviate poverty and diversify the local economy (Jones et al., 2017), the actuality of incurring any of these benefits is not assured.

Indeed, many MPAs have been deemed unsuccessful for various reasons. Some, for example neglect to reflect on the needs of local communities (Bennett and Dearden, 2014), others are not appropriately managed, monitored or funded (Claudet et al., 2008; Costello, 2014; Edgar et al., 2014) whilst more still fail to consider the range of threats they must protect against (Bruno et al., 2019). As MPAs limit or alter the ways in which communities can interact with the marine environment, unsuccessful MPAs do not only therefore fail to provide adequate protection for reefs, but also impose significant detrimental impacts on local communities (see Ban and Frid, 2018; Mascia et al., 2010). It is therefore essential that we identify successful MPAs so that we may understand the factors that result in their success.

3. Marine Conservation in the Coral Triangle

To accomplish this, many studies have focused on the Pacific Coral Triangle (see Figure 2), where approximately 25% of MPAs are located (Chaigneau and Daw, 2015) along with some of the most biodiverse coral reefs on the planet (Assad et al., 2018). The Philippines in particular is sometimes considered ‘the centre of the centre’ of global marine biodiversity (Carpenter and Springer, 2005) and boasts some of the world’s oldest marine reserves (Twichell et al., 2018). Considering that coral reefs can sometimes take a decade or more to recover from significant disturbances (Gilmour et al., 2013), the Philippines has therefore become a valuable resource when it comes to studying the long-term impacts of MPAs on coral and coral-fish assemblages.

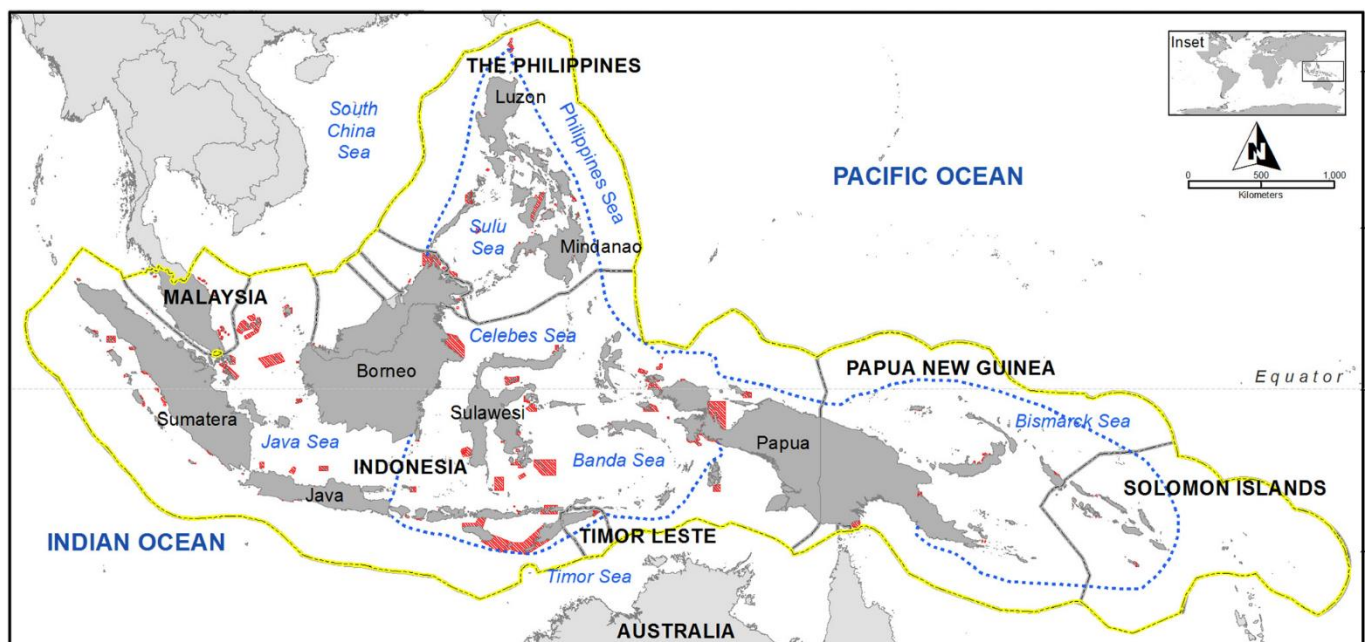


Figure 2: Map of the Coral Triangle. The Coral Triangle countries EEZ outer (yellow-dashed line) (representing the Coral Triangle Initiatives implementation area) and internal boundaries (grey-dashed line), and the Coral Triangle scientific boundary (proposed by Vernon et al., 2009) (blue dashed line) are indicated. Nearly 2000 MPAs occur in the area (red). Image Source: (Assad et al., 2018, p. 199).

As an island nation, fisheries are essential to the Philippines’ economy, providing substantial employment and income for much of the population (Tupper et al., 2015). Coral reefs support many of these fisheries, with an estimated 10-15% of marine fish production and over 70% of total fish catch on smaller islands attributed to these habitats (Tupper et al., 2015), highlighting their importance to the country. However, like many other nations globally, fisheries in the Philippines have been depleted by overfishing (Muallil et al., 2019) and as such the Philippines government has introduced over 1,100 MPAs since 1974 to preserve and replenish its fish stocks (Tupper et al., 2015).

The success of the Philippines' MPAs has however been underwhelming, with less than 25% deemed to have met their management objectives (White et al., 2006). When implemented correctly, MPAs in the Philippines have been demonstrated to improve coral cover (Magdoang et al., 2014). Nevertheless, in the last decade, overall coral cover has continued to fall, declining by over a third (Licuanan et al., 2019). Populations and distribution of the majority of coral-fish species have also declined and many are now at the point of being classified as 'under threat of local extinction' (Go et al., 2015).

4. Southern Leyte Coral Reef Conservation Project

One site that has seen substantial success however is the Southern Leyte Coral Reef Conservation Project (LRCP), a collection of MPAs located in the Sogod Bay, Southern Leyte. A joint venture between Coral Cay Conservation, the Philippines Reef and Rainforest Conservation Foundation Inc. and the provincial Government of Southern Leyte, the LRCP is monitored by CCC, who have been active in the bay since the project was established in 2002 (Dallison and Tyley, 2021).

An ongoing project, the LRCP has been split into three distinct phases (see Dallison and Tyley, 2021). Phase I, conducted between 2002 and 2012, undertook a comprehensive assessment of coastal marine resources in Sogod Bay, whilst Phase II, beginning in 2013, saw higher resolution studies across multiple sites in the bay. Finally Phase III, initiated in 2019, has involved working to determine how MPAs in the bay have influenced coral reef assemblages using a Before-After-Control-Impact (BACI) methodology.

Throughout the project CCC have used their findings to inform improvements to the site, the majority of which have been adopted by the provincial government (Dallison and Tyley, 2021). During Phase I for example, CCC recorded high levels of coral cover and coral diversity as well as high diversity and abundance of reef-associated fishes throughout the bay, motivating the creation of six new MPAs (Dallison and Tyley, 2021).

The implementation of these MPAs has, at least in part, been informed by findings from one MPA in particular, the Napantao Fish Sanctuary, which was established in 1997. As one of the oldest MPAs in the bay, the Napantao Fish Sanctuary was the subject of a long-term monitoring project by CCC, conducted between 2013 and 2019 (Dallison and Tyley, 2021). Whilst CCC has released annual reports pertaining to the data they collected at the Napantao Fish Sanctuary (see Broadribb et al., 2019a; Broadribb et al., 2019b; Dallison and

Ferguson, 2018; Knowles and Dallison, 2020; Longhurst et al., 2013; Lancaster et al., 2016; Parker et al., 2017) as of yet there has been no analysis of the data to either measure the overall health of the reefs surveyed or determine how coral and coral-fish assemblages have changed over time and space.

5. *Hard Coral*

As part of their ongoing monitoring of the Napantao Fish Sanctuary, CCC has collected data on the composition of the benthic substrate (seafloor), including the population sizes and distribution of hard coral growth forms. Hard corals (or scleractinian corals) are keystone species and form the foundation of coral reef ecosystems, providing numerous functions on which other marine species rely (Darling et al., 2017; Hall-Spencer and Moore, 2000). However, many are also particularly susceptible to environmental stressors (Day, 2011). Significant increases in ocean temperatures for example, can trigger the ejection of a coral's symbiotic algae (zooxanthellae), causing wide-scale coral bleaching and mass die-off of coral (Lough, 2011). Ascertaining how corals' population size, diversity and composition change in the presence of an MPA is therefore an important step in both understanding how coral reefs are affected by local environmental conditions as well as determining the ability of an MPA to maintain the overall health of a coral reef ecosystem.

6. *Research Gap*

As a well-monitored, long-term study, the Napantao Fish Sanctuary therefore presents an excellent opportunity to inform not only management strategies within the LRCP, but also to contribute to wider academic debate surrounding MPA implementation and their subsequent impacts on coral and coral-fish assemblages.

Considering that most studies investigating coral reef health choose to concentrate on the abundance and diversity of fishes because of their direct value to local economies (Di Lorenzo et al., 2020), this paper instead chooses to focus on the less studied area of corals themselves, looking at hard coral cover, hard coral diversity, and hard coral composition to inform the study's objectives.

Methodology

1. Study Site

The Napantao Fish Sanctuary (or Barangay Napantao MPA) is a 5-hectare MPA located on the west coast of Panoan Island, Southern Leyte in the Sogod Bay (see Figure 3). The MPA is usually marked with demarcation buoys, however these are regularly displaced by storms and result in a boundary which is semi-fluid in nature (Knowles and Dallison, 2020). The MPA is comprised of a no-take zone (NTZ) in which all fishing and boat anchoring is banned, as well as a 50m buffer zone where hook and line fishing are permitted (Knowles and Dallison, 2020). The MPA is accessible to SCUBA divers, however they must pay a fee before entering (Knowles and Dallison, 2020).

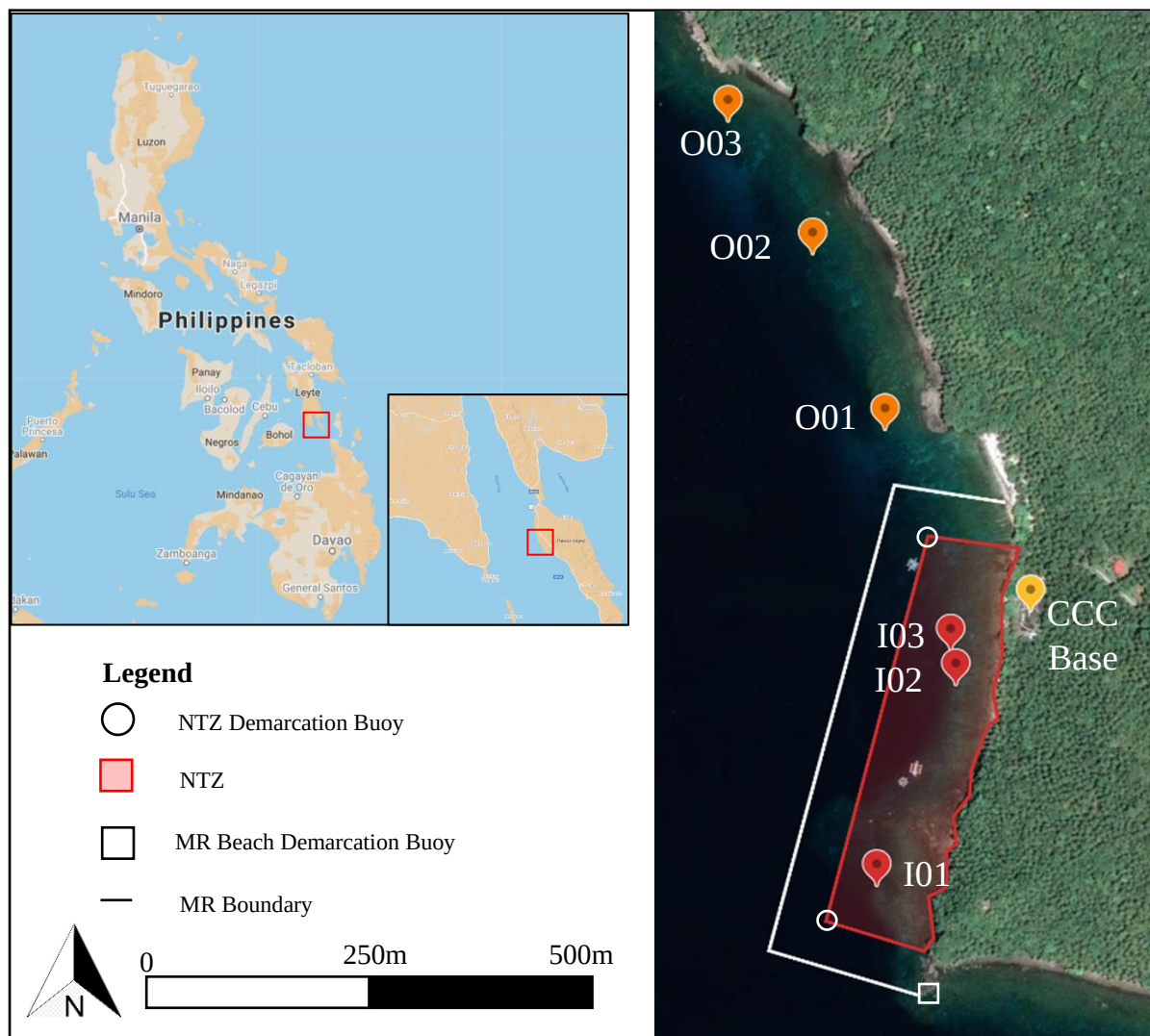


Figure 3: Barangay Napantao Marine Protected Area (MPA) with sampled transect locations in relation to Coral Cay Conservation's project base ($10^{\circ} 3' 57.06''$ N, $125^{\circ} 8' 8.86''$ E). The MPA is zoned with a No-Take Zone (NTZ) (red) and a Marine Reserve (MR) (white) with trans-boundary transect placements (Inside (I0X) and Outside (O0X)). Map Source: (Google Maps, 2021).

Benthic topography of the site creates two distinct environments; in the north, there are gradually sloping reefs whilst in the south, a vertical wall that experiences strong currents is present (Knowles and Dallison, 2020). The depth of coral reef found at the site ranges from <1m at low tide on the fore reef and >30m.

The mouth of a small river can be found 1.3km south along the coast, which is around 80m wide and provides occasional siltation to the reef (Knowles and Dallison, 2020). There are no direct sources of sewage or industrial effluent to the reef, however ocean currents do sometimes transport plastic pollution to the area (Knowles and Dallison, 2020).

Sogod Bay is the subject of a natural phenomenon that causes a reversal of the trade wind direction, resulting in two distinct seasons, Habagat and Amihan (Knowles and Dallison, 2020). During Habagat (July - October), winds blow from the south west into Sogod Bay, causing high frequency wave action. Amihan (November – June) is characterised by a north-easterly wind direction, with the east of Sogod Bay (including Barangay Napantao) being shielded, resulting in calm flat waters and little to no wave action. Sea surface temperatures are usually highest in June, and lowest in January, generally ranging between 27-29°C (Knowles and Dallison, 2020).

The study site consists of six transects, three inside and three outside the MPA. The start and end of all transects, both inside and outside, are permanently marked with rebar (Knowles and Dallison, 2020). Each transect was surveyed parallel to the shore in a north-south direction at a depth of 12m. Transects were 100m in length and split in four 20m replicates separated by 5m gaps in which no data was collected (See Figure 4). Underwater visibility ranged from 8-35m throughout the survey period. The weather varied but was predominantly sunny (58%), sometimes cloudy (32%) and occasionally raining (10%). Over the survey period, there was a mean average air temperature of 28.6°C during March and 29.4°C during October. There was a 0.2°C drop in water temperature between the surface and 10m in March and a 0.4°C drop in October, with a mean average water temperature over the survey period of 27.1°C and 28.9°C, respectively.

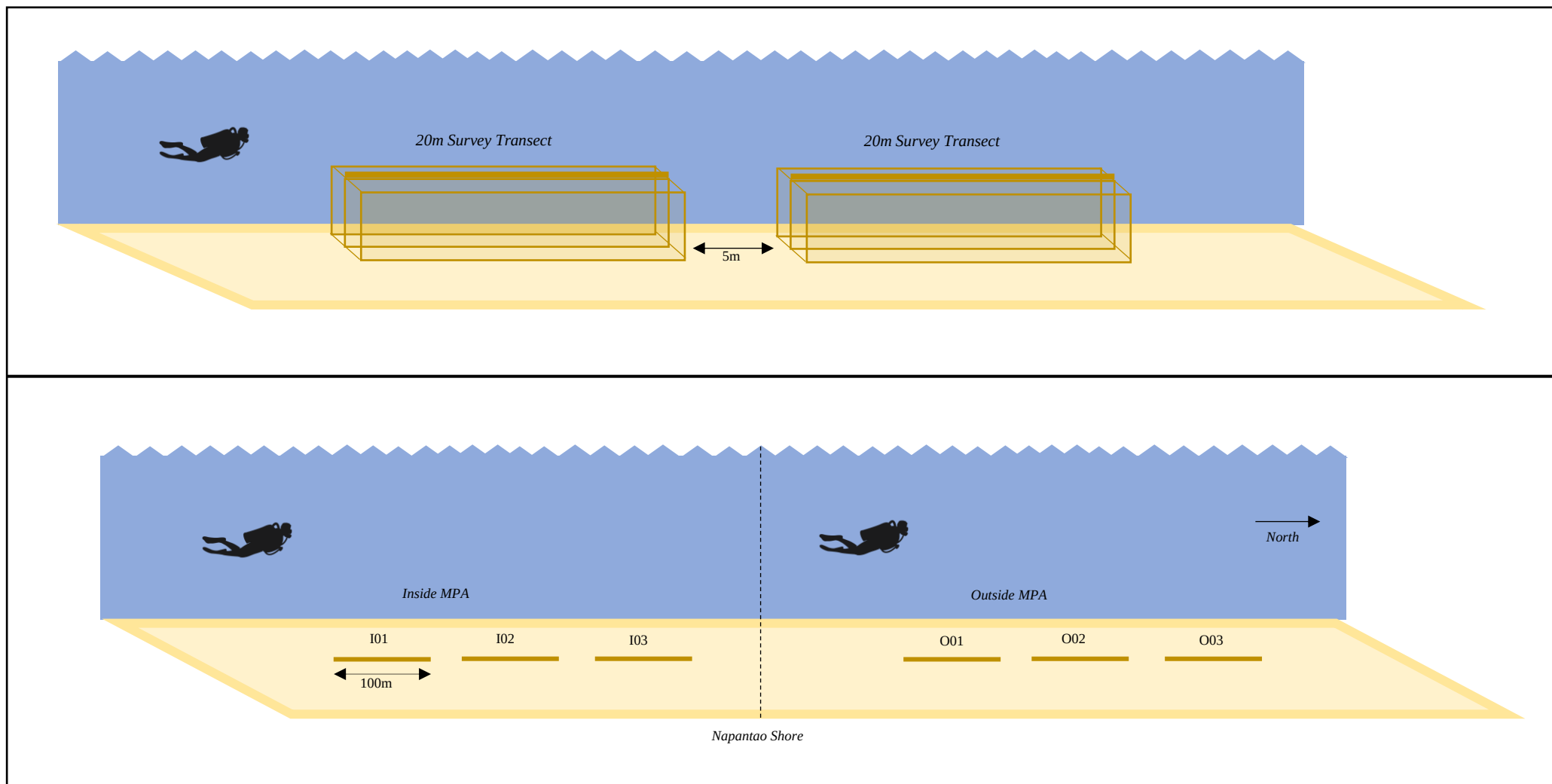


Figure 4: Two 20m replicates separated by a 5m un-surveyed gap (Top). Configuration of the six permanently staked transects inside and outside of the Napantao MPA (Bottom).

2. Survey Methods

The survey period for this study occurred between March 2013 and March 2019, with the reefs being surveyed twice yearly, once in March before the start of Habagat, and then again in October, immediately after the Habagat season had ended. All surveys were conducted between 07:45 and 15:30 with one exception (Transect O03 surveyed in March 2014) with the vast majority taking place in the morning between 08:00 and 11:00.

Data for this study was collected using an enhanced version of the reef check methodology. Surveys were conducted by highly trained citizen scientists SCUBA divers who, in the two weeks prior to conducting surveys, undertook extensive training to equip them with the skills and knowledge required by the methodology (Knowles and Dallison, 2020).

As described by Hodgson et al. (2006), the reef check methodology consists of four separate surveys at each transect. This includes a site description; a fish belt transect; an invertebrate belt transect, and a substrate line transect. This paper uses data collected using the site description and substrate line transect surveys and as such these are described in more detail below.

2.1. Site Description

Surveyors collect meta-data at each transect including location, latitude/longitude, temperature, weather, and the human impacts present at the site. Human impacts are subdivided into various impact categories including fishing methods, tourism, sewage and industrial pollution and the presence of motorised boats (Hodgson et al., 2006).

2.2. Benthic Composition

Benthic composition is determined using a substrate line transect. This involves a buddy pair of surveyors laying out a tape along the transect, about 1m above the sea floor. Surveyors then use a ‘point sampling’ method to determine substrate type, whereby the substrate that lies directly below the tape at each 0.5m interval is recorded. This method is used because it is the least ambiguous, the fastest and is easiest for non-scientists to learn (Hodgson et al., 2006).

To avoid bias caused by the back-and-forth movement of the tape as it swings in the surge, a plumb line is used (see Figure 5). A plumb line consists of a small metal weight tied to a 1.5m long woven nylon or cotton string. The line is held at each interval on the tape and the weight dropped. Surveyors then record the substrate type that the weight lands on (Hodgson et al., 2006).

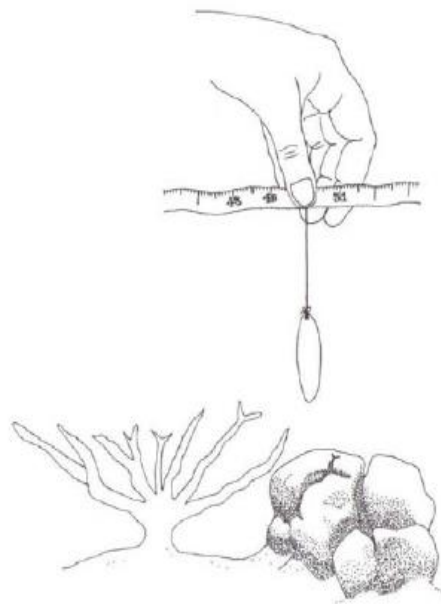


Figure 5: Plumb Line is dropped at each 0.5m interval along the tape. Image Source: (Hodgson et al., 2006).

3. Data Consolidation

Data collected by surveyors was amassed by CCC and tabulated on Microsoft Excel, before being shared for this analysis. The data shared included meta-data and impact data collected during the site description surveys as well as benthic composition data collected during the substrate line transect surveys.

The data collected by these latter surveys recorded the substrate type at each survey point as one of 10 biotic or abiotic categories (see Hodgson et al., 2006). The ‘Hard Coral’ category has then been further sub-classified, resulting in 23 substrate categories (see Figure 6). It should be noted, that *Heliopora* (Blue Coral), *Millepora* (Fire Coral) and *Tubipora* (Organ-Pipe coral) are genera of non-scleractinian corals. They have been sub-classified as ‘Hard Corals’ alongside true scleractinian corals because they are considered ‘reef builders’ (Hodgson et al., 2006).

Substrate Code	Description	Substrate Code	Description	Substrate Code	Description
ACB	Acropora Branching Coral	CF	Non-Acropora Foliose Coral	NIA	Nutrient Indicator Algae
ACE	Acropora Encrusting Coral	CM	Non-Acropora Massive Coral	RB	Rubble
ACS	Acropora Sub-massive Coral	CMR	Non-Acropora Mushroom Coral	RC	Rock
ACD	Acropora Digitate Coral	CHL	Heliopora (Blue Coral)	SD	Sand
ACT	Acropora Tabulate Coral	CME	Millepora (Fire Coral)	SI	Silt
CB	Non-Acropora Branching Coral	CTU	Tubipora (Organ Pipe Coral)	RKC	Recently Killed Coral
CE	Non-Acropora Encrusting Coral	SC	Soft Coral	OT	Other
CS	Non-Acropora Sub-massive Coral	SP	Sponge	Figure 6: Substrate categories identified during the substrate line survey.	

4. Data Analysis

4.1. Data Manipulation

Using Microsoft Excel, instances of Hard Coral growth forms were identified and collated to create total cover values of each growth form for each replicate (Growth Form Cover [$n = 312$]). These values were then further collated to create total hard coral cover values for each replicate (Hard Coral Cover [$n = 312$]).

Growth Form Cover values were also inserted into Simpson's Diversity Index (D) to calculate the diversity of Hard Coral at each replicate (Hard Coral diversity [$n = 312$]). However, these values are non-linear and are not comparable on their own. Instead, they are an index of diversity in much the same way that radius is an index of the area of a sphere (Jost, 2006). To obtain a quantitative value of diversity that can be compared over space and time the diversity indices need to be converted into *effective number of species* (also known as Hill numbers). For Simpson's Diversity Index this is as simple as finding the reciprocal, sometimes called Simpson's Reciprocal Index (1/D) (Cao and Hawkins, 2019). Hill numbers are a valuable tool for determining diversity, not only do they allow for changes in diversity to be quantified but can also be used to compare diversity values between studies, even if different diversity indices are applied (for conversion formula see Jost, 2006).

Simpson's Diversity Index

$$D = \frac{\sum n(n-1)}{N(N-1)}$$

n = total number of organisms of a species

N = the total number of organisms of all species

Simpson's Diversity Index is usually used a measure of diversity between species. However, identifying corals at the species level requires years of training and does not suit the citizen science methodology adopted by CCC (Knowles and Dallison, 2020). Most Hard Coral found at the survey site was therefore only identified at the growth form level by surveyors and as such, this study uses growth form as a surrogate for species. To this end, it should also be noted that the total cover values for Branching, Encrusting and Sub-massive growth forms are the aggregate of their respective acropora and non-acropora substrates categories (e.g., Branching = ACB + CB). This was done to ensure that Hard Coral Diversity values were not distorted by inflated growth form richness.

4.2. Statistical Analysis

Using IBM SPSS statistics software, descriptive statistics were generated for each of the dependent variables described above at two levels: Area (Barangay Napantao) and Site (Protected and Unprotected). Here the data was also tested to determine whether it was normally distributed. Appropriate statistical tests were then applied to the data to reveal how time and protection status had influenced the coral reefs at Barangay Napantao.

4.3. Ensuring Statistical Robustness

To ensure the validity of the findings, measures were taken to reduce the likelihood of Type 1 and Type 2 errors occurring (see Pallant, 2020, pp. 215-216). To avoid occurrences of Type 1 errors (rejecting the null hypothesis when it is true), an appropriate alpha level was selected (i.e., $p < .05$). To avoid Type 2 errors (accepting the null hypothesis when it is false), steps were taken to increase the power of the tests where possible.

Firstly, outliers (data points with extreme values) were identified with the use of histograms, boxplots and normal Q-Q plots produced using IBM SPSS statistics software. The impact of outliers on statistical tests was then considered and appropriate action taken to reduce their impact on the results (see Tabachnick and Fidell, 2013, pp.106 – 111). Where non-parametric tests were used, the presence of outliers was ignored as they have little impact on the mean ranks used by these tests (Zimmerman and Zumbo, 1990).

As non-parametric tests are less powerful than their parametric alternatives and are therefore more likely to result in a Type 2 error, further efforts were also taken to ensure the robustness of such tests (see Pallant, 2020, p. 215). This was accomplished by ensuring that tests were conducted with as large a sample size as possible (e.g., $n > 20$). For example, in the case of determining whether the dependent variables had changed significantly between the ‘Start’ and ‘End’ of the survey period, data from the first (March 2013, October 2013, March 2014) and last (March 2018, October 2018, March 2019) three-time intervals was inputted into a Wilcoxon Signed Rank Test. In keeping with the efforts made to ensure the robustness of the analysis, these ‘quartiles’ ($n = 36$) were utilised over a single time interval ($n = 12$) because they allowed for a more powerful test to be conducted (Pallant, 2020).

Results

1. Coral Cover

The relationship between Hard Coral Cover (HCC) and time at Barangay Napantao was investigated using a Spearman's Rank Order Correlation. There was found to be a weak, positive relationship between the two variables [$r = .13$, $n = 312$, $p = < .05$] suggesting that HCC at the survey site had increased between the start ($Md = 36.25\% \text{ } 20m^{-1}$) and the end ($Md = 42.50\% \text{ } 20m^{-1}$) of the survey period. However, a Wilcoxon Signed Rank Test that compared HCC values from the first and last quartiles of the survey revealed that this increase was not statistically significant [$z = -.79$, $n = 72$, $p = .71$, $r = .07$].

When investigating the spatial impact of the Napantao MPA on HCC, a Mann-Whitney U Test revealed a statistically significant difference in the amount of HCC according to a reef's protection status, with more coral found inside the MPA than outside [*Protected* ($Md = 42.50\% \text{ } 20m^{-1}$, $n = 156$), *Unprotected* ($Md = 32.50\% \text{ } 20m^{-1}$, $n = 156$), $U = 8672$, $z = -4.39$, $p = < .01$, $r = 0.25$]. The influence of protection status on the coral reefs at Barangay Napantao was further investigated by determining how HCC inside and outside the MPA had changed over time (see Table 1 and Table 2). It was found that HCC on unprotected reefs outside the MPA had increased significantly between the start and end of the survey period, whilst protected reefs inside the MPA had remained unchanged (see Figure 7).

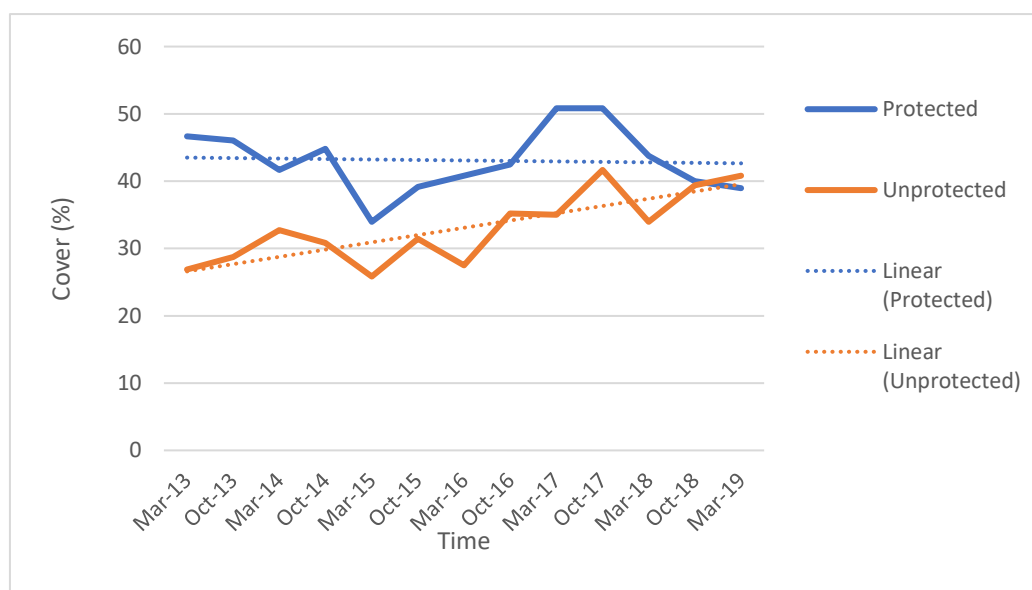


Figure 7: A graph to show the change in average Scleractinian cover inside and outside Barangay Napantao MPA between March 2013 and March 2019.

Table 1 - Relationship between Hard Coral Cover and Time using a Spearman's Rank Order Correlation			
	r	n	p
Protected	.01	156	.84
Unprotected	.24	156	< .01

Table 2 - Comparison of Hard Coral Cover values between the Start and End of the Survey Period using a Wilcoxon Signed Rank Test							
	Start		End		z	p	r
	n	Md	n	Md			
Protected	36	42.50	36	42.50	-1.59	.11	.19
Unprotected	36	28.75	36	42.50	-2.16	< .05	.25

Table 3 - Relationship between Hard Coral Growth Form Diversity and Time using a Spearman's Rank Order Correlation			
	r	n	p
Protected	-.04	156	.61
Unprotected	-.25	155	< .01

Table 4 - Comparison of Hard Coral Growth Form Diversity values between the Start and End of the Survey Period using a Wilcoxon Signed Rank Test							
	Start		End		z	p	r
	n	Md	n	Md			
Protected	36	4.28	36	4.75	-1.78	.08	.21
Unprotected	36	6.23	35	5.17	-3.82	< 0.01	.45

2. Growth-Form Diversity

Using a Spearman's Rank Order Correlation to investigate the relationship between Hard Coral Diversity (HCD) and time, there was found to be a weak, negative correlation between the two variables [$r = -.15$, $n = 311$, $p = <.01$], with HCD at Barangay Napantao decreasing between 2013 ($Md = 5.87\ 20m^{-1}$) and 2019 ($Md = 4.84\ 20m^{-1}$). This was supported by the Wilcoxon Signed Rank Test, which revealed a significant decline in HCD values between the start and end of the survey [$z = -4.07$, $n = 71$, $p = <.01$, $r = 0.34$].

When investigating the effect of the Napantao MPA on HCD, a Mann-Whitney U Test demonstrated that there was a statistically significant difference between HCD values inside and outside the MPA [*Protected* ($Md = 4.14\ 20m^{-1}$, $n = 156$), *Unprotected* ($Md = 5.74\ 20m^{-1}$, $n = 155$), $U = 6484$, $z = -7.07$, $p = <.01$, $r = .40$]. In contrast with HCC, HCD was, on average, higher on the unprotected reef, however experienced a significant decline over the survey period (see Table 3 and Table 4). Diversity on the protected reef remained relatively unchanged.

3. Coral Composition

A Spearman's Rank Order Correlation revealed a weak, positive relationship between time and coral cover for both Branching and Tabulate growth forms (*Branching* [$r = .15$, $n = 312$, $p = <.01$], *Tabulate* [$r = .16$, $n = 312$, $p = <.01$]) and a weak, negative relationship for Encrusting, Fire Coral and Organ Pipe Coral growth forms (*Encrusting* [$r = -.11$, $n = 312$, $p = <.05$], *Fire Coral* [$r = -.15$, $n = 312$, $p = <.01$], *Organ Pipe Coral* [$r = -.12$, $n = 312$, $p = <.05$]). A Wilcoxon Signed Rank Test (see Table 5) confirmed that there had been a significant change in coral cover between the start and end of the survey period for the Branching, Tabulate and Fire Coral growth forms.

A Mann Whitney U Test, used to assess the difference in coral composition between the protected and unprotected reefs, revealed a significant difference in GFC for Branching, Foliose and Mushroom growth forms (see Table 6). The Branching and Foliose growth forms were both more prevalent inside the MPA whilst Mushroom corals was more common on the unprotected reefs outside the MPA (see Figure 8 and Figure 9).

A second Mann Whitney U Test compared GFC data from the first and last quartiles of the survey to determine whether coral composition on the Napantao reefs had become more similar over time. It was found that coral cover for Branching and Fire Coral growth forms differed significantly at the start of the survey but demonstrated no significant difference by the end (see Table 7).

An analysis intended to determine temporal changes to coral composition for both the protected and unprotected reefs revealed that none of the growth forms inside the MPA experienced significant changes in coral cover. Outside of the MPA, only the Branching growth form experienced significant changes, with cover increasing between the start ($Md = 17.17\% \ 20m^{-1}$) and end ($Md = 29.71\% \ 20m^{-1}$) of the survey period (see Table 8 and Table 9).

Table 5 - Comparison of Growth Form Cover values between the Start and End of the Survey Period using a Wilcoxon Signed Rank Test

	Start		End		z	p	r
	n	Md	n	Md			
Branching	72	21.43	72	20.00	-2.55	< .01	.21
Tabulate	72	.00	72	.00	-2.00	< .05	.17
Encrusting	72	6.25	72	.00	-1.43	.15	.12
Fire Coral	72	2.08	72	.00	-2.68	< .01	.22
Organ Pipe Coral	72	.00	72	.00	-1.51	.13	.13

Table 6 - Comparison of Growth Form Cover Values between Protected and Unprotected reefs at Barangay Napantao using a Mann-Whitney U Test

	Protected		Unprotected		U	z	p	r
	n	Md	n	Md				
Branching	312	35.83	312	25.00	9137	-3.81	< .01	.22
Tabulate	312	.00	312	.00	9968	-2.88	< .01	.16
Mushroom	312	.00	312	5.88	9023	-4.20	< .01	.24

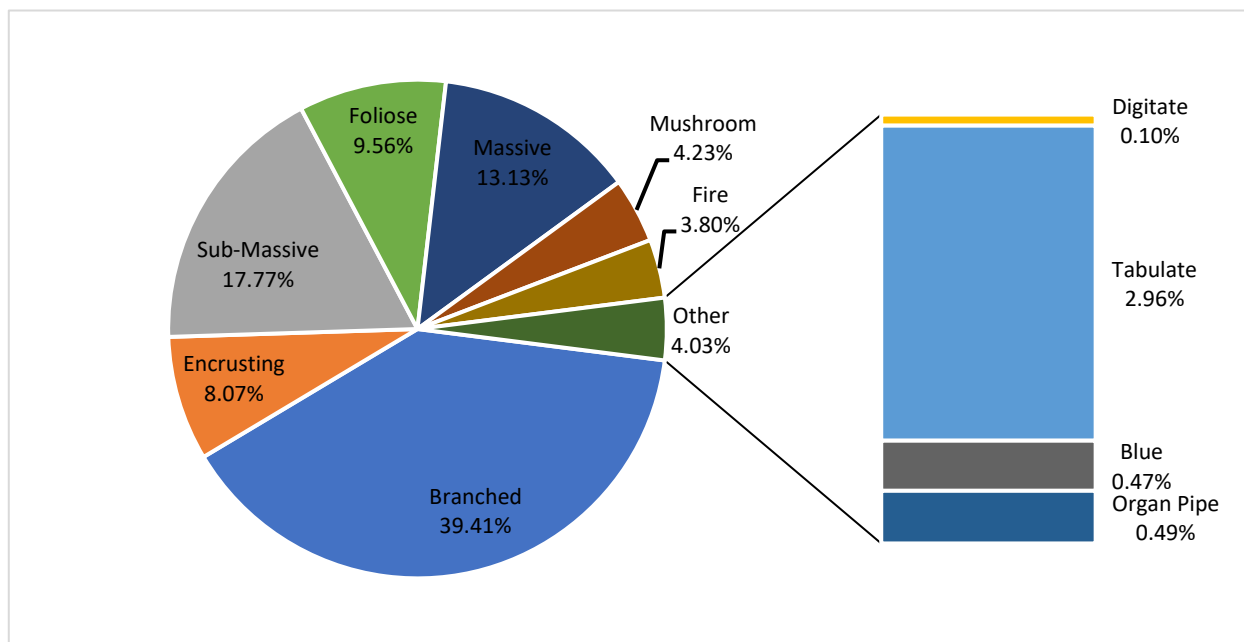


Figure 8: Breakdown of scleractinian growth forms on the protected reef at Barangay Napantao between March 2013 and March 2019.

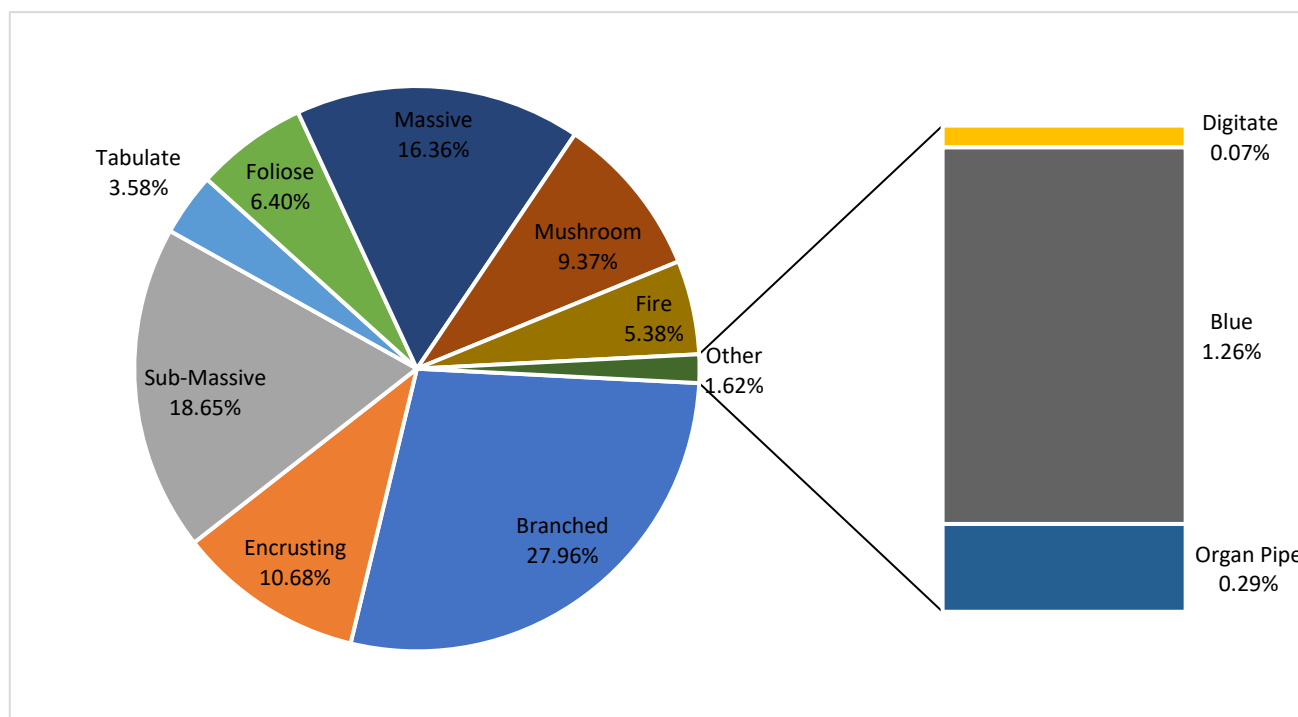


Figure 9: Breakdown of scleractinian growth forms on the unprotected reef at Barangay Napantao between March 2013 and March 2019.

Table 7 - Comparison of Growth Form Cover Values between Protected and Unprotected reefs at the Start and End of the Survey Period using a Mann-Whitney U Test									
		Protected		Unprotected		U	z	p	r
		n	Md	n	Md				
Start	Branching	72	40.18	72	17.16	425	-2.52	< .05	.30
	Fire coral	72	5.56	72	.00	441	-2.45	< .05	.29
Finish	Branching	72	35.83	72	29.71	583	-.73	.46	.09
	Fire coral	72	.00	72	.00	648	-.01	1.00	> .01

Table 8 - Relationship between Hard Coral Growth Form Diversity and Time using a Spearman's Rank Order Correlation				
		r	n	p
Protected	Fire Coral	-.17	156	< .05
	Organ Pipe Coral	-.16	156	< .05
Unprotected	Branching	.24	156	< .01
	Tabulate	.23	156	< .01

Table 9 - Comparison of Growth Form Cover values between the Start and End of the Survey Period using Wilcoxon Signed Rank Test								
		Start		End		z	p	r
		n	Md	n	Md			
Protected	Fire Coral	36	5.56	36	.00	-1.54	.12	.18
	Organ Pipe Coral	36	.00	36	.00	-.54	.59	.06
Unprotected	Branching	36	17.17	36	29.71	-3.64	< .01	.43
	Tabulate	36	.00	36	.00	-1.53	1.27	.18

Discussion

This study assessed the impact that the Napantao Fish Sanctuary has had on the coral reefs that fringe Barangay Napantao between March 2013 and March 2019. This was accomplished by analysing the temporal-spatial biophysical data collected and provided by Coral Cay Conservation. The results of this study should be considered in the long-term marine management strategy of both the Barangay Napantao MPA and other MPAs within the Southern Leyte Coral Reef Conservation Project.

1. *Hard Coral Cover*

Scleractinian corals form the basis of entire reef ecosystems, making HCC an excellent indicator of the architectural complexity and overall health of a reef (Komyakova et al., 2013; Magdaong et al., 2014). Between 2013 and 2019, Hard Coral at Napantao constituted a mean average of 38% of the benthic substrate, significantly greater than the national average of 23% recorded between 2014 and 2017 (Licuanan et al., 2019). Indeed, HCC was found to be well above the national average regardless of protection status, suggesting that the reefs at Barangay Napantao have not been greatly impacted by the human-induced environmental stressors that have caused large-scale degradation and decline of shallow-water reefs elsewhere in the world (Hughes et al., 2017). This is further supported by the fact that coral reefs at Napantao appear to be expanding, with HCC increasing by 3% between 2013 and 2019. As the Philippines has witnessed an overall decline in coral cover, losing an estimated third of its coral reefs over the last decade (Licuanan et al., 2019), we can reasonably conclude that local conditions at Napantao are allowing at least some coral species at the site to survive and thrive.

Notably, the increase in coral cover seen at the Napantao site is predominantly focused outside the MPA, with mean HCC increasing from just 27% in March 2013 to 41% in March 2019, an average increase of 2.33% per year. Mean average coral cover inside the MPA is higher than that outside, although there has also been no significant change over time, with values remaining relatively stable throughout the survey period (see Figure 7). Indeed, in March 2019, the percentage of hard coral found outside the MPA surpassed that inside, demonstrating that it has become equally prevalent at both sites. The difference in growth rate between the sites demonstrates that the expansion of coral reefs at Napantao has been influenced by protection status, suggesting

that the presence of the MPA, rather than a common environmental factor, is largely responsible for the positive changes seen over the survey period.

Interestingly, the changes in coral cover observed at Napantao over the survey period contrast with changes seen at the national level in the three decades prior. A meta-analysis by Magdaong et al. (2014), found that between 1981 and 2010 there was a general increase in coral cover across the Philippines. However, when the protection status of the study's sites was considered, it was found that increases in coral cover were exclusively focused on reefs that were situated within an MPA; coral cover at unprotected and partially protected reefs saw little or no positive change. Assuming that coral reefs at Barangay Napantao have previously expanded in a similar manner to those studied by Magdaong et al. (2014), the difference in coral cover observed at the site between 2013 and 2019 suggests that the way the Napantao MPA influences local coral reefs is changing.

This change can be rationalised by utilising two complimentary ecological concepts. The first, 'carrying capacity', is defined as a quasi-quantitative amount denoting the upper limit of growth for a population (see Chapman and Byron, 2018) and can explain the lack of HCC growth observed on the protected reef. Whilst the protection offered by the MPA is facilitating coral expansion and thereby preventing a decline in HCC, a scarcity of resources within the MPA has prevented further expansion of the protected reef. In the case of coral, the limiting resource is likely to be hard substrate, which is essential for coral recruitment (Veron, 2011).

Importantly, this effect is not limited to Barangay Napantao. The findings presented by Magdaong et al. (2014, p. 10) for example, demonstrate that regardless of location or protection status, HCC rarely rose above 50% at any of the study's sites. This implies that the lack of coral expansion on the protected reef at Barangay Napantao is not a failing of the MPA, but rather the result of the local carrying capacity being reached. This is a promising indicator that the Napantao MPA has been successful at establishing a healthy and stable marine ecosystem within its borders.

A second concept, referred to as the 'recruitment effect' (or 'spill-over effect') (see da Silva et al., 2015), provides a rationalization for the significant increase in HCC observed on the unprotected reef over the survey period. The recruitment effect posits that given enough time, areas surrounding a protected area will benefit from the over-production of taxa (Bradshaw, 2010), ultimately resulting in a similar population increase to the one observed in this study. Whilst there is already plenty of evidence demonstrating that MPAs can and have

facilitated the export of fishes (Colléter et al., 2014; Di Lorenzo et al., 2016; Di Lorenzo et al., 2020), the number of studies that provide evidence for the exportation of sedentary organisms is currently underwhelming, highlighting the importance of this study's findings.

As sedentary organisms, corals are unable to migrate to new areas in the traditional sense. However, coral larvae released into the water column have the potential to travel hundreds or thousands of kilometres in currents before they eventually colonise new substrate (Jones et al., 2009). The proximity of the protected and unprotected reefs suggest that it is entirely plausible that coral larvae released inside the MPA have begun to colonise available substrate outside the protected area. The expansion of coral on the unprotected reef therefore provides evidence that the Napantao MPA has been successful at not only conserving the marine ecosystem within its borders, but also facilitating the recovery of reefs outside as well.

2. Hard Coral Diversity and Reef Composition

Whilst the expansion of coral cover at Barangay Napantao suggests that the MPA has produced positive results concerning the condition of the local marine ecosystem, a study that relies on a single metric limits the insights we can derive from it, especially when exploring a topic as complex as the health of coral reefs. Whilst a reef with high percentages of coral cover may appear to be healthy, if it is dominated by a particular growth form(s), it would in fact exhibit low spatial complexity, provide a poor habitat for other marine organisms, and result in an ecosystem that is less resilient to change (Nyström et al., 2008; Komyakova et al., 2013). Diversity indices are therefore an important tool that allow ecologists to quantify diversity within a community and in turn provide a more accurate assessment about its overall complexity and health (Tabugo et al., 2016).

Compared with other coral diversity studies conducted within the coral triangle (see Table 10), the reef protected by the Napantao MPA exhibited far less diversity overall than reefs at other protected sites, although was still significantly more diverse than unprotected sites elsewhere in the Philippines. The same cannot be said for the unprotected Napantao reef, which was on average significantly more diverse than the reef protected by the Napantao Fish Sanctuary, exhibiting a similar level of diversity to protected reefs examined by Luthi and Anugrah (2017) and Padernaga (2019). However, over the survey period the unprotected Napantao reef has also seen a decline in diversity, with HCD dropping by 19% between March 2013 and March 2019.

As previous surveys conducted by CCC between 2002 and 2012 demonstrated high coral diversity across the Sogod Bay (Dallison and Tyley, 2021), these findings would appear to suggest that the Napantao MPA has caused a decline in diversity and that historically, diversity would have been comparable with the other protected sites elsewhere in the Philippines. This is further supported by Assad et al. (2018) (see Figure 10), who classified Sogod Bay as an area of greater ‘biodiversity importance’ than the other three protected sites described in Table 10, indicating that HCD values at Barangay Napantao should be higher than those currently observed. Currently, there is no evidence within academic literature that suggests that MPAs actively cause a decline in marine biodiversity and as such this paper aims to offer a rationalisation to explain this unexpected trend.

It is possible that the low HCD observed at Barangay Napantao is a result of MPAs’ inability to prevent climate-driven coral bleaching. MPAs are designed to limit the impact of coral bleaching events by restricting damaging anthropogenic activities (e.g., fishing and boat anchoring), thereby reducing the stress placed on recovering reefs (Bates et al., 2019). However, they cannot prevent coral bleaching events from occurring in the first place. Mass bleaching events are highly selective and effect some coral species more than others, causing changes to the community structure of coral assemblages (McCowan et al., 2012). After a bleaching event, ‘stress tolerant corals’ are favoured during reef recovery, resulting in decreased diversity as they replace other, less tolerant corals. It is conceivable that the Napantao MPA has experienced a similar phenomenon, resulting in the low diversity observed on the protected reef. As coral bleaching occurs on a large scale and resistant corals dominate coral assemblages, stress tolerant corals are also the most likely to be exported by the MPA. This would sufficiently explain the declining diversity observed on the unprotected reef.

Initial analysis of the changes to coral composition observed at the study site appears to support this hypothesis. Overall, the composition of the unprotected reef at Barangay Napantao appears to have changed to become more like that of the protected reef, which itself has remained largely unchanged over the survey period (see Figure 11 and Figure 12). This has mostly been driven by an increase in the proportion of branching coral on the unprotected Napantao reef which, by the end of the survey, was equally prevalent at both sites. These findings demonstrate that local conditions favour branching corals over other growth forms and suggests that branching corals are the most resilient growth form to coral bleaching events.

Table 10: Comparing Coral Reef Diversity at Barangay Napantao Marine Protected Area with other surveyed sites in the Coral Triangle						
Location	Coordinates	Survey Period	Protection Status	Mean Diversity Value	Percentage Difference	Reference
Barangay Napantao, Panaon Island, Philippines	N 10°04'00", E 125°08'00"	March 2013 – March 2019	Protected	4.28	-	-
Barangay Napantao, Panaon Island, Philippines	N 10°04'09", E 125°08'01"	March 2013 – March 2019	Unprotected	5.59	+ 31%	-
Cabuan, Camiguan Island, Philippines	N 09°07'11", E 124°48'23"	August 2016	Protected	5.26	+ 23%	Paderanga, 2019
Olele, Sulawesi, Indonesia	N 00°24'23", E 123°09'11"	April 2013	Protected	8.33	+ 95%	Reza and Sancayaningsih, 2017
Karanag Pakiman, Bawean Island, Indonesia	S 5°48'26.3", E 112°46'27.3"	May 2014	Protected	5.58	+ 31%	Luthi and Anugrah, 2017
Calangahan, Lugait, Philippines	N 08°22'07", E 124°15'39"	April 2015	Unprotected	3.13	- 27%	Tabugo et al., 2016
Illigan City, Malaybalay, Philippines	N 08° 25'00", E 124°4'60"	September 2012	Unprotected	3.12	- 27%	Ganaway and Lacuna, 2014

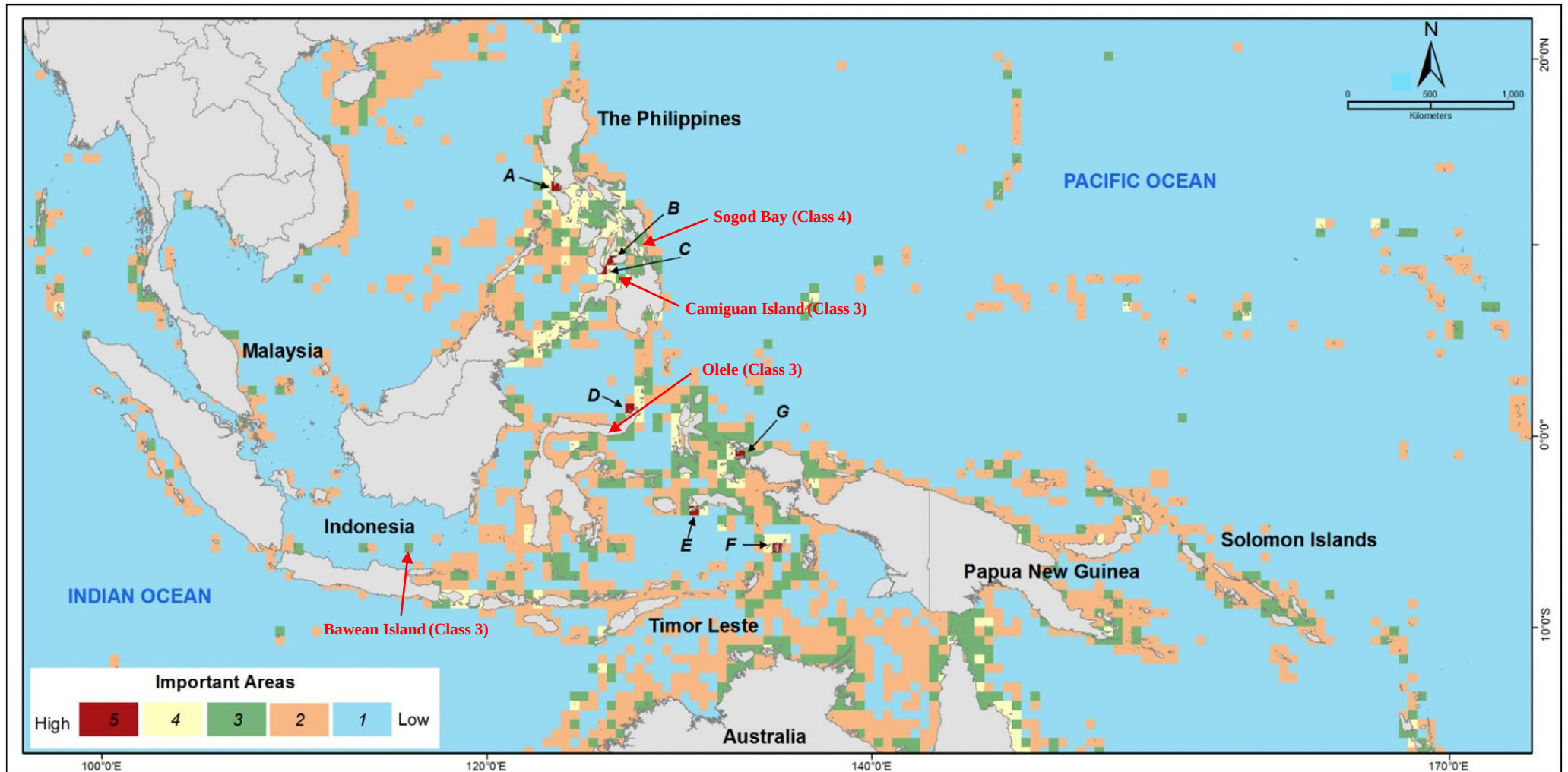


Figure 10: Map showing sites of biodiversity importance in the Coral Triangle, with each site defined using half-degree cells. Analysed based on unweighted sum of biodiversity score derived from five ecological criteria. The cells were ranked into five equal interval class to allow unbiased comparisons between criteria and prioritization scheme, from high to low biodiversity values: Class 5 (red), 4 (yellow), 3 (green), 2 (light brown) and 1 (light blue). The most significant sites include: (A) Verde Island Passage (between Luzon and Mindoro Island), (B) Negros Island, (C) Cebu Island, (D) Northern tip of Sulawesi, (E) Ambon Island, (F) Kei Islands, and (G) Raja Ampat Archipelago of Indonesian Papua. Image Source: (Assad et al., 2018, p. 207).

However, this conclusion would contradict our current understanding of coral biology. Branching corals are usually the most susceptible growth form to bleaching and experience the highest rates of mortality once bleached (McCowen, 2012). In addition to their sensitivity to heat stresses, branching corals are also much more susceptible to pollutants and mechanical stress from wave action than other growth forms (Rachello-Dolman and Cleary, 2007). As branching corals are the most dominant growth form at Barangay Napantao, this would imply that local stressors rarely affect the Napantao reefs, and that branching corals are excelling because Barangay Napantao lacks the environmental pressures required to drive declines in biodiversity.

Whilst it is unclear whether the presence of the MPA is responsible for shielding the local reefs from these adverse environmental pressures, the spatial-temporal changes to branching coral cover suggests that it has had, at least in part, a role to play. Additionally, as branching corals offer more intricate structures than other coral growth forms (Darling et al., 2017), the expansion of branching corals at Barangay Napantao will have undoubtedly improved local reefs' architectural complexity, indicating that the Fish Sanctuary has had a role in establishing healthy coral reefs both inside and outside its borders.

The fact that branching corals are thriving at Barangay Napantao also suggests that other marine organisms that rely on the coral reefs are also succeeding and that diversity values at the site should be much higher than those observed. As HCD trends contradict all other evidence observed at Barangay Napantao, a failure within CCC's reef check methodology, namely their use of growth form to identify coral, could provide a more reasonable rationalisation for the declining diversity.

Whilst a useful metric, growth form cannot fully capture a coral's geometric complexity and does not consider intraspecific variation in shape (Zawada et al., 2019). For instance, a single growth form category may be assigned to many coral species which possess similar, but functionally different geometric shapes (see Figure 13). A coral species may also exhibit phenotypic plasticity, whereby the coral grows in different ways depending on local environmental conditions (see Figure 14). When taken together, these details demonstrate that categorising corals by growth form has the potential to mask or distort diversity values. If corals had been identified at the species level instead, HCD values are likely to have been substantially higher, perhaps even equal, or greater than the other protected sites described in Table 10. The low HCD values observed in this study do not therefore explicitly indicate that the Napantao MPA has lowered functional or genetic diversity on the local reefs and so the ecosystem's resilience to future threats is therefore still in question.

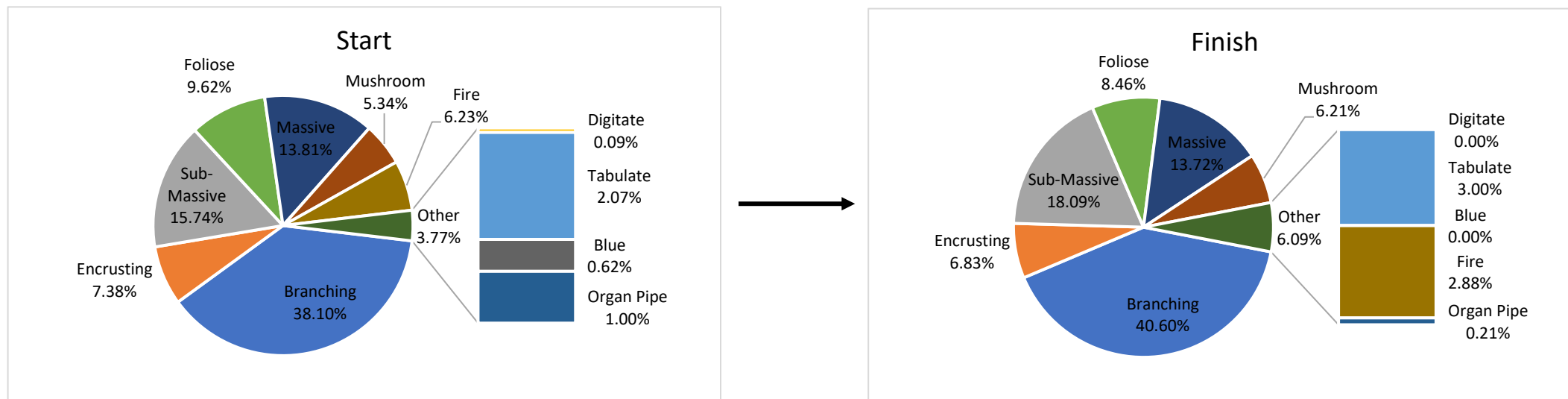


Figure 11: Pie Charts that show the change in mean average Growth Form breakdown of the protected reef at Barangay Napantao between the first and last quarters of the survey period.

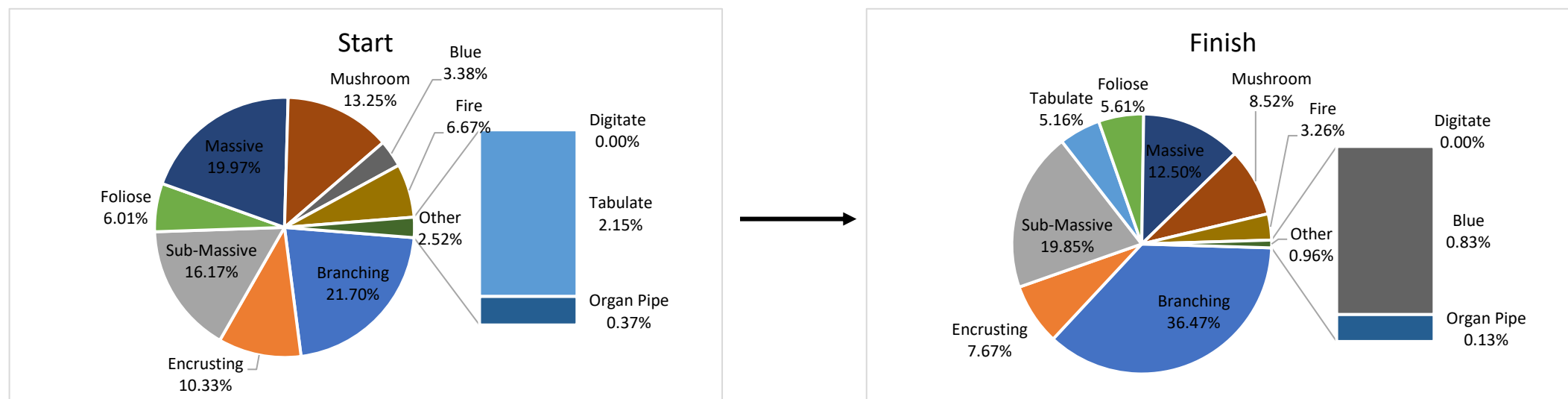


Figure 12: Pie Charts that show the change in mean average Growth Form breakdown of the unprotected reef at Barangay Napantao between the first and last quarters of the survey period.

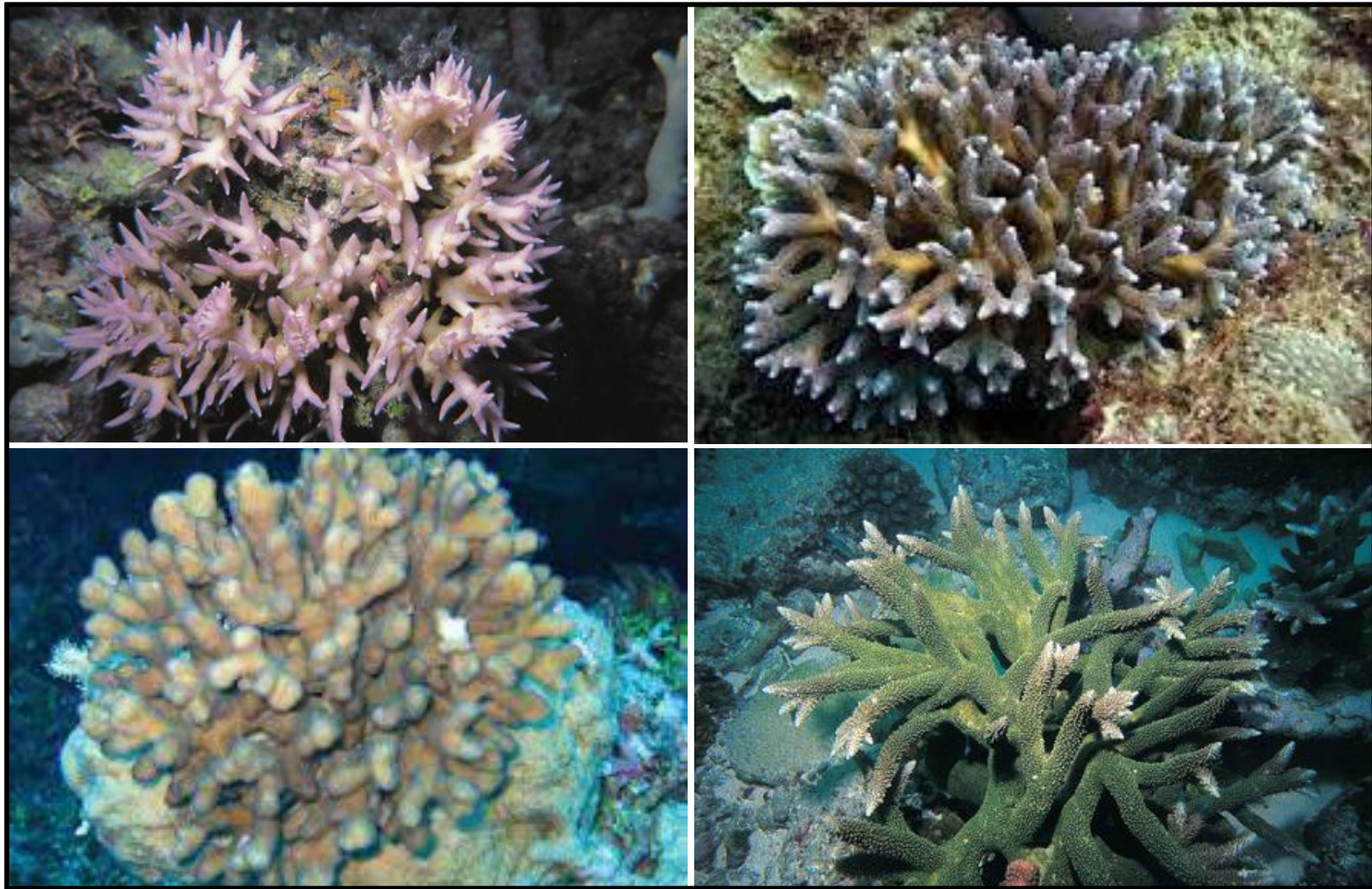


Figure 13: Branching coral species found in the Tropical Pacific. Scleractinian corals are geometrically complex and exhibit significant diversity even when categorised by growth form. Top Left: *Seriatopora hystrix* (Veron et al., 2016a). Top Right: *Seriatopora caliendrum* (Veron et al., 2016b). Bottom Left: *Stylophora pistillata* (Shick, 2013). Bottom Right: *Acropora robusta* (Veron et al., 2016c).

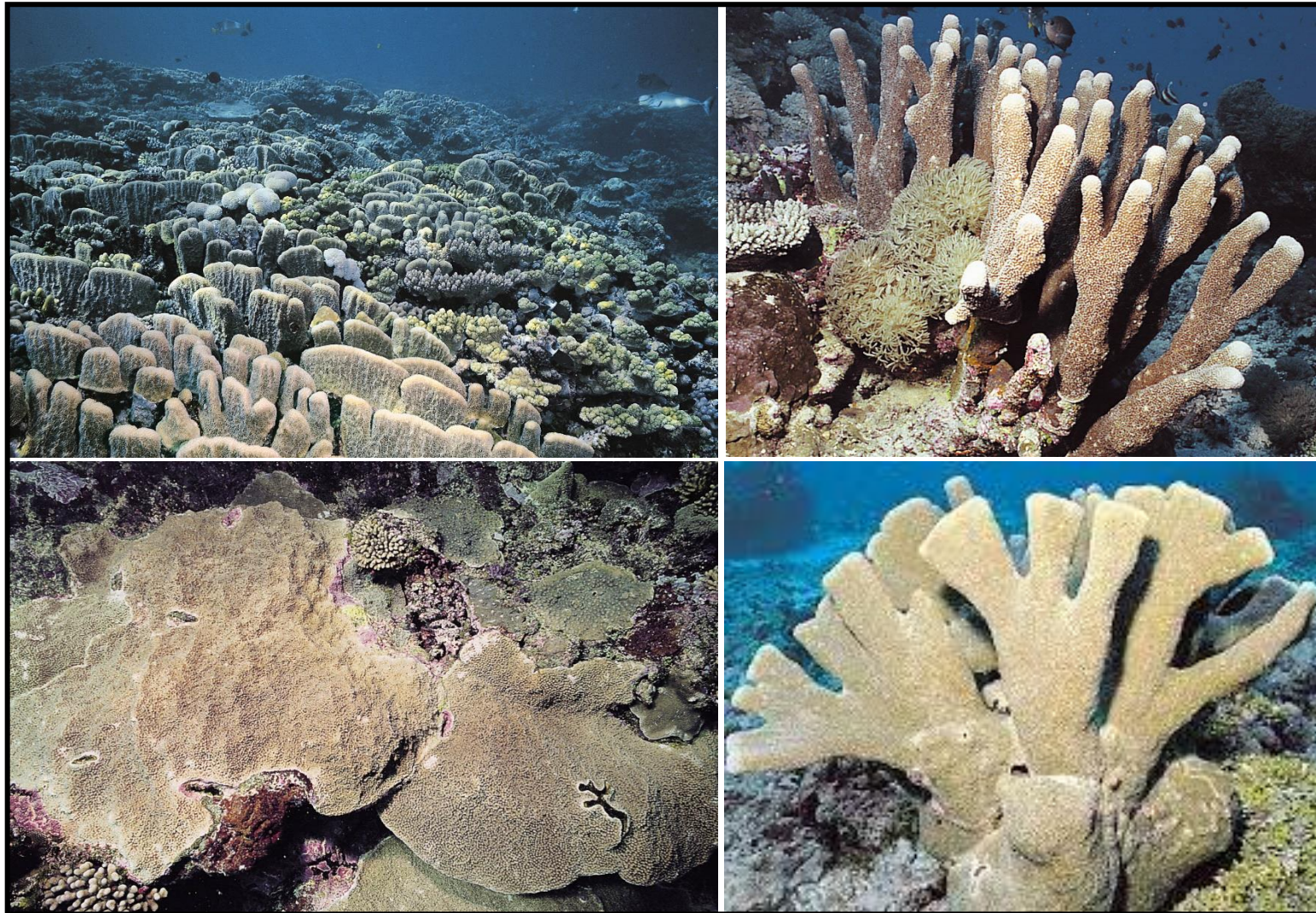


Figure 14: Many corals exhibit phenotypic plasticity and can present in significantly different forms depending on local environmental conditions (Zawada et al., 2019). *Isopora palifera* (above) is one such coral. Image Source: (Veron et al., 2016d).

3. Further Research

The apparent failure of CCC's methodology highlights the need for further investigation of the Napantao Fish Sanctuary. For instance, to address the questions that remain around the Napantao reefs' diversity, spatial complexity and resilience to future threats, further research that addresses the limitations of CCC's methodology will be required. Ideally, such an investigation would seek to replicate the methodology employed in this study, replacing coral growth form data with coral species data collected between March 2013 and March 2019 to inform trends in diversity. This could then be compared with observations from this study to conclusively determine how the Napantao Fish Sanctuary has affected coral diversity.

As CCC is unlikely to have collected coral species data for the time-period specified, an investigation that compared coral growth form diversity and coral species diversity would also be appropriate. Such an investigation would compare these two sets of values to determine whether CCC's methodology is indeed at fault. Of course, such a study would require changes to the way CCC conducts benthic substrate surveys, as the skill required to collect such detailed data cannot be easily garnered by the citizen scientists usually employed to survey the Napantao Reef.

Additional further research to cement the findings of this current study would also be advisable. This could involve investigating changes to other substrate types referred to in Figure 6. Analysing changes to Recently Killed Coral (RKC) for example could be used to investigate the influence of climate change and abundance of coral bleaching on the Napantao reefs. Alternatively, Sponges (SP), Soft Coral (SC) and Nutrient Indicator Algae (NIA) could be used as further indicators of the health of reefs and quality of the local environment. Sponges, for example, thrive in low water-quality environments making them an excellent indicator species for pollution and turbidity. Similarly, SC and NIA can severely affect the health and abundance of hard coral by competing for space, inhibiting hard coral recruitment, and altering the structural strength of the reef stratum by not contributing to coral accretion and so provide excellent indicators of an imminent failure of scleractinian populations (Plass-Johnson et al., 2016). Together, such indicators can provide context to a site and help explain changes that occur on the reef over space and time.

Conclusion

This study, using survey data supplied by Coral Cay Conservation, investigated how the presence of an MPA, the Napantao Fish Sanctuary, has influenced local coral reef assemblages between March 2013 and March 2019.

Overall, this investigation found strong evidence to conclude that the Napantao Fish Sanctuary has succeeded in supporting healthy and productive coral reefs in the Sogod Bay. Inside the MPA, hard coral populations have remained high throughout the survey period and were consistently dominated by architecturally complex growth forms, providing an excellent habitat for other marine organisms, and demonstrating that the reef has been shielded from many of the environmental and anthropogenic stressors that plague other coral reefs in the region.

Outside the MPA, the effects of the Fish Sanctuary have been even more profound. Over the survey period, this study has observed clear and significant growth of hard coral on the unprotected reef to the point that in March 2019, the total coral cover on the unprotected reef exceeded that on the protected reef. Over the survey period, the composition of corals on the unprotected reef has also definitively changed, with branching corals becoming progressively dominant. Coral composition has become increasingly homogenous across both reefs and this, coupled with the significant expansion of hard corals on the unprotected reef, provides ample evidence that the MPA is able to export sedentary biomass, a phenomenon that is otherwise poorly documented within academic literature.

Despite its evident success however, it remains unclear how the Napantao Fish Sanctuary has affected the diversity of coral reefs at the site. Observations from this study depict low or falling coral diversity on the reefs, contradicting the increases observed to the reefs' overall cover and structural complexity. Whilst this would appear to highlight a significant failing of the Napantao MPA, there is a distinct possibility that failures within the methodology are at fault and that true diversity values are much higher than those demonstrated in this study.

With complimentary studies to address this apparent failure and explore other important indicators of coral reef health, this investigation can provide academics, conservationists, and managers with an excellent insight into the impact and efficacy of a small-scale MPA. It is clear then that the Napantao Fish Sanctuary has had some significant and wide-reaching impacts on local coral reefs, and it is hoped that this success can further advance global efforts towards healthier and more productive oceans.

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