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Quantifying threats to reef-building corals in the Visayan Sea by examining the probable on-natural and anthropogenic marine stressors

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Declaration

I can confirm that any contribution of results from others that are presented in this report have been acknowledged and that otherwise this report is entirely my own work.

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1.0 Abstract

Coral reefs are large marine ecosystems, ecologically viable for more than 25% of marine species and habitats. Scleractinian are of the most important. These are reef-builders characterised by their ‘hard’ structural exterior of polyp colonies - marine invertebrates on their skeleton thriving off of calcium carbonate stored in oceans from successive colonies. The significance of corals stems far beyond the reef and marine life itself, serving ecosystem services to fisheries and eco-tourism as well as a form of coastal defence and carbon capture. Recent literature has highlighted the stress reefs are facing, through both demand and exploitation of services and increasing severity of natural events. Here we examine coral reefs abundance and impacts with the help of marine NGO People and the Sea in the Coral Triangle on Malapascua Island in the province of Cebu, Philippines – an area equally dependant on the value of marine life and hotspot for typhoons and recreational activity. Our results project an increase of coral reef-builders of 0.9% compared to 2017, however those of which are impacted have increased by nearly 2%. Coral predation seems to be among the most prevalent and baleful impacts to the reefs in the Visayan Sea, where predators combined accounted for more than half of the observed impacts. Our results also look into the extent of ramifications influenced by climate change, water quality and tourism.

2.0 Introduction

Coral reefs are large marine ecosystems, characterised by a profusion of colours and striking statures. Situated in tropical oceans within propinquity of the Equator, reefs encompass one of the most diverse ecosystems across the globe and ecologically supportive of a third of all marine life (Veron *et al*. 2009). Coral have become seriously threatened across the globe due to array of different factors. This study analyses some of the different threats to reefs in the Coral Triangle with specific interest and comparison against the abundance of reef-building corals and their mortality.

2.1 Corals and their Importance

2.1a Coral Biology

The biology of reefs as a structural marine ecosystem expresses an enigma of interactions between diminutive sea creatures and properties within the water column. Most reefs are facilitated by very small organisms living on their outer structures called polyps, which feed on plankton in the midst of pelagic waters which begin to create the vibrant display of carbonate structures. Not all reef ecosystems are coined with this same semblance – where some are inaugurated by an assemblage of other sea biota and other members of the Cnidarian phylum which hold a variety of coral species which do not calcify or reproduce in separated colonies (Morrissey, Sumich and Pinkard-Meier, 2018). Anthozoans are the class which contain reef-building corals. These are functionalised by utilising calcium carbonate and calcareous deposits from successive colonies to create their hard exterior and thus framework of a reef. Despite sharing similar morphology not all Anthozoans are liable for creating coral reef networks. This ability is largely isolated to the order Scleractinia of subclass Hexacorallia otherwise referred to as stony corals for the hardened physique. These stony corals are distinguished by a range of formations from: branching structures, encrusting, massive and sub-massive, solitary forms, foliaceous, columnar or digitate. The growth rate of these corals is largely determined by a variety of factors such as surface temperatures, salinity, planktonic food concentrations for the living polyps and survival of stressors (Kuanui *et al*. 2015) but most importantly the availability and intensity of light resources, concurrently governed by parameters of depth, waves and turbidity. Light availability is an imperative component of coral growth and a fundamental element in permitting the symbiotic relationship between unicellular algae zooxanthellae in hermatypic reef-builders. The mutualistic association between corals and these algal symbionts is facilitated by photosynthesis, where the coral tissues provide protected areas and sufficient nutrients for masses of these dinoflagellates and in return supplying the corals with food resources where tropical waters are poor in nutrients (Small and Adey, 2001; Berkelmans and van Oppen, 2006).

2.1b Coral importance

Biodiversity

For centuries coral reefs have posed great importance in both the aquatic world and onshore. Often considered the rainforests of the ocean coral reefs are home to around 25% of all marine life (Morrissey, Sumich and Pinkard-Meier, 2018; Coker, Wilson and Pratchett, 2013). Reefs house a plethora habitats and niches for species living in and around their environments, hosting a range of obligate and facultative relations (Bailey, 2019) where organisms are solely dependent on the coexistence of each other or merely benefit from their presence. Many species optimise the reefs for their protective structures and nutrients, others utilise these biomes for access to residing symbionts; such as the relationships between remoras and pelagic fish which use their suction filament derived from their dorsal fin to attach to mobile hosts for opportunistic feeding, preservation of energy demands and mate pursual in exchange for scouring its host (Beckert, Flammang and Nadler, 2015). Other mutualistic interactions include shrimpfish feeding on sea urchins (Jensen *et al*., 2018), anemonefishes seeking refuge and incubation in anemones (Frisch *et al*., 2016) as well as corallivorous species such as mucus feeding *Trapezia* crab species, utilising coral tissue whilst offering defensive services against reef-building predators (Mckeon and Moore, 2014). Corallivorous fishes such as grazers of butterflyfishe species feed on coral tissues and scrapers such as parrotfishes tear tissues and small parts of the coral skeleton (Rice, Ezzat and Burkepile, 2019). Some of these consumer interactions are integral for reef fitness and have been suggestive to benefit asexual reproduction (Enochs and Glynn, 2017) whereas others have been associated with the regulation of preying behaviours and algal maintenance (Vine, 1974; Littler, Taylor and Littler, 1989). Excessive rates of corallivory however from predative fish species can be detrimental to the growth and physical health of hard coral reefs and is arguably a contributor to global reef stress – causing spatial competition (Cox, 1986), vulnerability to pathogens, spread of disease and energetic costs (Knoester, Murk and Osinga, 2019; Cole et al. 2009; Cole, Pratchett and Jones, 2008). Corallivorous invertebrates have been known to pose far more acute damage when predating on reef-building corals which has largely influenced their abundance and mortality (Rotjan and Lewis, 2008).

Coastal Defence

In adjunction to housing a surplus of biodiversity, the importance of these biomes extends way beyond life under water. For centuries coral reefs have hosted a range of different ecosystem services additional to their biotic functions (Moberg and Folke, 1999). Their structure and distribution hold great importance to coastal communities where fringing reefs in particular can act as a natural form of breakwaters in coastal defence (Reguero *et al*., 2018) aiding the retention of waves and sediment trap – saving billions each year from devastations (Martins *et al*., 2019).

Fishing and Trade

Many communities living near coastal environments have relied greatly on these ecosystem functions, with evidence from Australian aboriginals and Polynesians in the Eastern Pacific harvesting fish and crustaceans for food resources as well as shells for building materials (Wells and Hanna, 1992). In other areas during the early stages of globalisation in Indo-Pacific regions species of marine molluscs, the money cowrie and ring cowrie *Cypracea annulus* were a valuable commodity and used as a money currency and bartering tool, exploited from the Maldives Islands (Boomgaard, Kooiman and Nordholt 2008) and commonly traded between Nomadic Arabian tribes (Hiskett, 1966), highlanders in Papua New Guinea (Schmidt, 2014) and several global markets (Johnson, 1970). Queen conch *Strombus gigas* shells and oysters and sometimes coral skeletons were also a useful resource in the making of cement (Eziefula, Ezeh and Eziefula, 2018; Chandrasiri, Yehdego and Peethamparan, 2019) and in some areas of the Caribbean this bio-cement was fundamental in the construction of houses (Wells and Hanna, 1992).

Medicinal Uses

As well as facilitating local commerce, reefs are also theorised to display a range of health benefits. On-going research in modern medicine practises are investigating the usefulness coral reef properties in today's medical research. Currently sea sponges have been used in the synthesis of antiviral and anticancer drug ara-A and ara-C, which has been used in the treatment of various cancers from: leukaemia, pancreatic cancer, lung, breast and bladder (Anjum *et al*., 2016). Prostaglandins, a biological compound found in Alcyonacea species of sea fans and sea whips in the Caribbean (Valmsen *et al*., 2001) have approved clinical applications in gynaecology and haemorrhage treatment (Bajaj, 1978) and early stages of treatment in cardiovascular, respiratory and gastrointestinal disease (Herman, 1983). Similarly, sea whips have been identified to possess pseudopterosins, anti-inflammatory agents which have potential pharmaceutical use in pain killers (Look *et al*., 1986; Look *et al*., 1987). Lastly calcium carbonate from coral skeletons could soon be used as a component in medical skin grafts, with trials and technology advancing the CHACC developed material derived from corals and coralline hydroxyapatite (Fu *et al*., 2013).

Tourism

Reefs undoubtably have a variety of diverse functions and importance and still remain a valuable source of income to many coastal environments predominantly through tourism and fisheries. Several thousands of tourists will visit coastal environments each year for recreational activities which heavily supports local livelihoods and a larger contributor to foreign exchange in developing countries (Rhormens, Pedrini and Ghilardi-Lopes, 2017). With global seafood sales on the rise these marine habitats are increasingly important in aquaculture (Kelsch, 2017). From prehistoric ages people living in proximity to reef environments have successfully utilised their elements to meet their demands. Though through globalisation, the westernisation of countries and population growth, paired with these activities, the needs for such resources is increasing.

Despite their vigorous exterior corals are extremely frangible, where the outer living tissue the cenosarc encasing the calcareous polyps and coralllite skeleton is easily subject to impair (Morrissey, Sumich and Pinkard-Meier, 2018c). Coupling their delicate structures with heavy dependence from marine life, demand from livelihoods and recreational activities, prompts overexploitation – of which is beginning to critically impede their distributions and health.

2.2 Coral Decline

Coral reefs are divided into three major categories: fringing reefs which grow closely with coastlines parted by bodies of water, barrier reefs, which are formed further away but parallel to coastlines and atolls which are colonies of corals situated in areas of the sea (Gardiner, 1904). As a whole these areas are facing copious amounts of pressure through ongoing exploitation of their services, the onset indirect climatic events and fierce predation beyond what is sustainable. Reports have disclosed a further 15% of reefs are subject to being seriously threatened and potentially lost within 10-20 years, in conjunction to the 19% of reefs were already considered decimated in 2008 (Wilkinson, 2008). The onset of this decline will inevitably hinder the structural integrity of coral reefs and compromise the future ability for reefs to functionalise with added pressure from local and global stressors; as these habitats are extremely sensitive to minute changes in oceanic composition and direct distress (Estrada-Saldívar *et al*., 2019; Burke *et al*., 2011).

2.2a Anthropogenic Impacts

Overfishing

Coral reefs facilitate ecosystem structure and protection to a range of fishes, crustaceans and molluscs that are continually harvested in coastal communities and on larger scales to meet fishing quotas for exports or ornamental trade (Dee, Horii and Thornhill, 2014). The relationship between fisheries and coral reefs is that of concern for both the ecosystem and quotas as demand struggles to meet productivity due to coral degradation caused by direct and indirect implications to reefs (Rogers, Blanchard and Mumby, 2017). The pursuit of fisheries bares various consequences stretching far beyond designated target species (Liang and Pauly, 2017). Many non-target species are trapped in nets and trawls known as bycatch, usually important herbivorous species such as species of surgeon fishes and parrotfish

(Johnson, 2010) and many reefs are fragmented due to explosive fishing techniques using cyanide and dynamite (Bailey and Sumaila, 2015; Barber and Pratt, 1998; Wells, 2009).

The most significant alterations to reefs are caused by fluctuations in biodiversity composition (Jennings, Grandcourt, Polunin, 1995) causing what is known as a phase shift in coral communities, which regards the dominance of microalgae as a result of overharvested herbivorous and predatory fish (Fenner, 2012). The impact of overfishing has led to huge disruptions in marine food webs – by reducing the abundance of herbivorous fishes which control algal growth with their consumption (Kaplan, 2009). Increased algae encourage algal competition and the prospect of algal blooms when permitted with additional temperature stressors of which is hugely detrimental to corals by limiting oxygen supply to their tissues, which can cause stress related responses such as bleaching (Zaneveld *et al*., 2016).

Urbanisation, Pollution and Eco-Tourism Blight

More than 40% of the world's population are now living within close proximity to coastlines, in which are undergoing intensive rates of coastal development involving: dredging activities, land filling and coral mining to meet the demands of urbanisation and population growth (Krishnamurthy *et al*., 2019; Heery *et al*. 2018; Polónia, 2014). Many reefs and similar habitats such as mangroves face serious stress as a result of changes in coastal development which has caused direct mortality of shallow water reefs, from land reclamation to create resorts, airports, ports and various other industrial structures (Valadez-Rocha and Ortiz-Lozano, 2013). More than 80% of hard coral cover along inshore reefs in Jakarta have been compromised by these activities according to studies from 2015 (Baum *et al*., 2015). The processes associated with coastal development have indirect impacts to reef environments by promoting influxes of sediment abundance and transportation, limiting light availability in the water column for photosynthetic zooxanthellae and ultimately reducing coral productivity, growth, calcification and subsequently, coral mortality (Rogers, 1990; Risk and Edinger, 2011; Ho, 2017). Eutrophication is a causative agent of many heterotrophs and microbial oxygen consuming organisms like algae, which are more commonly occur in oceans as a result of sewage pollution from ships, resorts, oil spills and toxic waste– in serious cases, concentrations can kill corals through hypoxia (Dubinsky and Stambler, 1996; Cowburn *et al*., 2018). In many parts of the developing world and in particular in the Philippines, tourism hugely governs the economic infrastructure. Renowned for its picturesque beaches, recreational SCUBA diving, surfing hotspots and distinctive Whale shark *Rhincodon typus* and Thresher shark *Alopiidae Bonaparte* attractions, coral reefs within these favourable localities are more subject physical fragmentation by boats, anchors and carless treading (Wong *et al*., 2018; Fabinyi, 2010; Roche *et al*., 2016; Sarmento and Santos, 2011).

Climate Change

Up to 70% of coral reef stressors are products of human-induced activities, a significant proportion of which is directly related to changes in the world's climate which rapidly enhance local level threats (Haw, 2015). The earth's climate has been warming at unprecedented rates, increasing by 0.85°C between 1880 and 2012, reported in the Fifth Assessment Report (United Nations, 2019) – a result of ongoing greenhouse gases concentrations. Average oceanic temperatures are rising and are onset to meet catastrophic targets proposed by the Intergovernmental Panel on Climate Change (IPCC) if not well reformed. In the meantime, paired with natural oceanic oscillations, creating intolerable environments for reef-builders, promoting coral bleaching (Hoegh-Guldberg, 2011). Bleaching occurs where the photosynthetic symbionts of scleractinian corals, the zooxanthellae are expelled from the coral polyps in which they reside as a response to thermal stress (Lough and Oppen, 2009). Global-scale coral bleaching events (GCBE) occurring in 1998 and more recently, renowned for its prolonged effects between 2013 and 2017 were a result of a combination of thermal stress and caused significant global mortality, particularly to reef structures in the Great Barrier Reef, where 50% of corals were lost between 2016 and 2017 (IUCN, 2019) and increased coral vulnerability to disease (Eakin, Sweatman and Brainard, 2019). With global warming comes the increase of atmospheric CO_2 of which a third of excess carbon is absorbed by the oceans (Thompson, 2017). Greenhouse gas emissions are of high global concern (Heogh-Guldberg *et al*., 2018) with international conventions set in place in by policymakers in attempt to reverse the effects it is having on the earth. Estimates have shown atmospheric CO_2 have been a problem since the preindustrial era – at 30% greater than level should be (Albright and Langdon, 2011). If atmospheric concentrations are not well managed, surpassing a 1.5 °C temperature increase as set out by the IPCC (2018) many reefs may face absolute depletion by the end of this century (Allemand and Osborn, 2019) as continuing warming affects alters the optimum environment required by reef-building corals. Increasing ocean acidity results in lower oceanic pH and

aragonite concentrations, making calcium carbonate less available for the structural growth of hard corals skeletons. Studies have suggested up to 54% of carbonate could be lost from the oceans with the increase of CO_2 – prohibiting growth and enervating corals structural composition (Raven *et al*. 2005; Hoegh-Guldberg, 2011; Heogh-Guldberg *et al*. 2017).
Many of these impacts coincide with each other and may involve the augmentation of several stressors to drive coral decline.

2.2b Natural Impacts

Coral Disease

Coral disease is a prevalent factor afflicting on reefs. Only discovered since in the mid 1960s (Sutherland, Porter and Torres, 2004) various diseases prey on these underwater ecosystems, which have eradicating 80% of reefs in the Caribbean in previous decades (Miller and Richardson, 2014) and large component towards the 50% coral cover decline of the Great Barrier Reef in the Pacific (Work and Meteyer, 2014). Gauging the pathology of coral disease is vaguely understood, but largely correlated with being a cofounding product of environmental instability, relentless thermal stress and sewage pollutants (Bruno *et al*., 2003; Miller *et al*., 2009; Bruno, 2015; Morrissey, Sumich and Pinkard-Meier, 2018). Caribbean reefs are particularly suspectable to zoonoses. Studies in the Caribbean where much disease is most prevalent (Aronson and Precht, 2006; Cramer *et al*. 2012) have identified the decline in hard coral species *Acropora palmata* was due to the infestation of bacterium *Serratia marcescens* causing the onset of white pox disease found in faeces and sewage discarded in the ocean and corallivorious predative snails, *Coralliophila abbreviata* (Patterson *et al*., 2002; Rogers, Sutherland and Porter, 2005; Sutherland *et al*., 2010). Contrarily, other infamous diseases inflicting species of Scleractinia include the Black Band Disease (BBD) caused by cyanobacterium *Photmidium corallyticum* and less commonly sulphur-oxidising bacteria *Beggiatoa* or fungi (Kuta and Richardson, 1996; Richardson 1998). BBD is most prevalent in the Caribbean, Belize and Bermuda since the 1970s with more recent outbreaks in Florida Keys and in the Indo-Pacific. BBD manifests as a bacterial canvas plastered over corals which degrades coral tissues over a successive amount of time (Antonius, 1985; Frias-Lopez *et al*., 2003; Kuta and Richardson, 2003; Richardson, 2004). The BBD is one of the only diseases to have preventative measures (Hudson, 2000) unlike the White Band Disease, which its pathogenic course is yet to be established (Lentz, Blackburn and Curtis, 2011). The White Plague on the other hand has theorised elusive microbial and pathogenic agents (Ainsworth *et al*., 2006; Roder et al., 2014).

Predation and Invasive Species

As previously mentioned, corallivory by fishes and invertebrates is a common interaction of predation in coral reefs ecosystems. A cycle intensified by both the overharvesting of predative fish which encourage further predation from scrapes and grazers and local overfishing of those species advancing corallivory from invertebrates, which weaken reef-builders through bioerosion and in turn increasing their vulnerability to other stressors (Rice, Ezzat and Burkepile, 2019; Shantz, Steir and Idjadi, 2011). Human intervention is largely responsible for predative outbreaks by forging unorthodox populations in the sea and increasing coral susceptibility (McClanahan, 1994). Sea snail *Drupella spp* have been abrading on hard corals since sightings in 1980s, impacting nearly 75% of hard corals in the Indo-Pacific. *Drupella* outbreaks are seemingly successful due to their population blooms and greed of various hard coral forms, even those experiencing stress and disease, using their radula feeding apparatus (Bassey *et al*., 2018) – exuberating corals by feeding on tissues, leaving grazing scars and possible vector for coral diseases (Nickolet *et al*. 2013; Bettarel *et al*., 2018; Nickolet *et al*. 2018).

Similarly, sea star Crown-of-Thorns (CoT), *Acanthaster planci* have caused widespread outbreaks on reefs across the globe. Their causative agents are largely open to debate. Various experimental hypothesis propose such outbreaks are a result increased larval survivorship subsequent to oceanic changes in pH, temperature, salinity, acidification and sometimes flooding events – not only creating optimum environments for larval growth but enhancing planktonic food concentrations, yielding greater potential for their growth and dispersal (Miller *et al*., 2015; Uthicke *et al*., 2015). Research into larval succession on the cause of *A.planci* outbreaks remains varied. With some concluding temperature and acidification have little to no effect on the success of CoT larvae (Kamya *et al*. 2014) and others highlighting their vulnerability to predation by planktivorous damselfish (Cowen *et al*., 2016; Cowen *et al*. 2020), ameliorating research into the 'predator removal hypothesis' as opposed to nutrient and terrestrial runoff based assimilations (Brodie *et al*., 2005) - suggestive large outbreaks particularity those noticeable in the Great Barrier Reef are a result of overharvesting of the CoT predator, the Pacific triton *Charonia tritonus* for commerce since the 1950s, leading to increased abundance of the adult sea star (Cowen *et al*., 2017). Ultimately there is no hypotheses more triumphant, and the combination of nutrient supply, natural causes, terrestrial runoff, predator removal hypotheses and so forth (Babcock, 2016) all exacerbate the intensity of CoT outbreaks, paired with rash removal strategies irrespective of spawning periods or post-oviposition which have shown mass release of CoT gametes in response to stress (Bos *et al*., 2013; Dumas *et al*., 2016).

Oceanic Variables and Natural Disasters

Natural disasters and oscillations are among the other factors that impede on coral zonation and development. Hurricanes and tropical storms, occurring in subequatorial regions have been known to cause significant immediate destruction to coral reefs and with many reefs undergoing multiple stressors they severely impact their future development (Gardner *et al*., 2005). In periods of these events heavy wind, rainfall and swell are induced, where surges of turbulent waves cause mechanical breakage of corals and the increase suspension of sediments – increasing turbidity which reduces light for photosynthesis and abrading corals during the process (Dollar, 1982; Scoffin, 1993; Wall *et al*., 2012). Areas in the Pacific are particularly vulnerable to the adversity of these effects as they are situated in a hotspot of both tropical cyclones, typhoons and the Intertropical Convergence Zone, a belt of low pressure bringing seasonal monsoons (Merrifield *et al*., 2019). Typhoon prone Palau is a paradigm of storms and their effects, where almost all coral cover of eastern Palau had been decimated by 2012 Bopha (Doropoulos *et al*., 2014). Reefs in and around the Pacific are also vulnerable to the El Niño–Southern Oscillation, driven by global warming forcings causing the heating of surface temperatures of the Pacific Ocean (Cobb *et al*., 2013; Timmermann *et al*. 2018) and responsible for 1997-1998 mass coral bleaching where approximately 16% of the worlds reefs suffered mortality and later again between 2014-2017 (Vargas-Ángel *et al*., 2019). Wave energy dissipated by seasonal storms alter the zonation of windward-leeward margins and development of many Scleractinian corals – windward margins facing greater wave exposure to turbulent waves, destructing shallow water reefs (Yamano *et al*., 2003)

2.3 Malapascua and PepSea

Malapascua Island

Malapascua is one of many picturesque islands in the Philippines. Situated in the Visayan Sea just under 7km from municipality Daanbantayan and province of northern Cebu (Figure. 1). Malapascua spans just over $2km^2$, (Dalongeville, Jorcin and Mills, 2019) and is home to over six thousand citizens in approximately just 600 families. Reefs in the Philippine Sea compose a partial sum of corals within The Coral Triangle, a region in the western Pacific renowned as a biodiversity hotspot for marine flora and fauna and ecosystem services (Cabral and Geronimo, 2018) - an area in which has become increasingly vulnerable to intensive fisheries, climate induced constraints, coastal development and the onset of various other anthropogenic factors (Williams *et al*. 2017) where initiation schemes and management practices are enforced to rejuvenate and limit the stressors on reef ecosystems (Tupper *et al.* 2015).

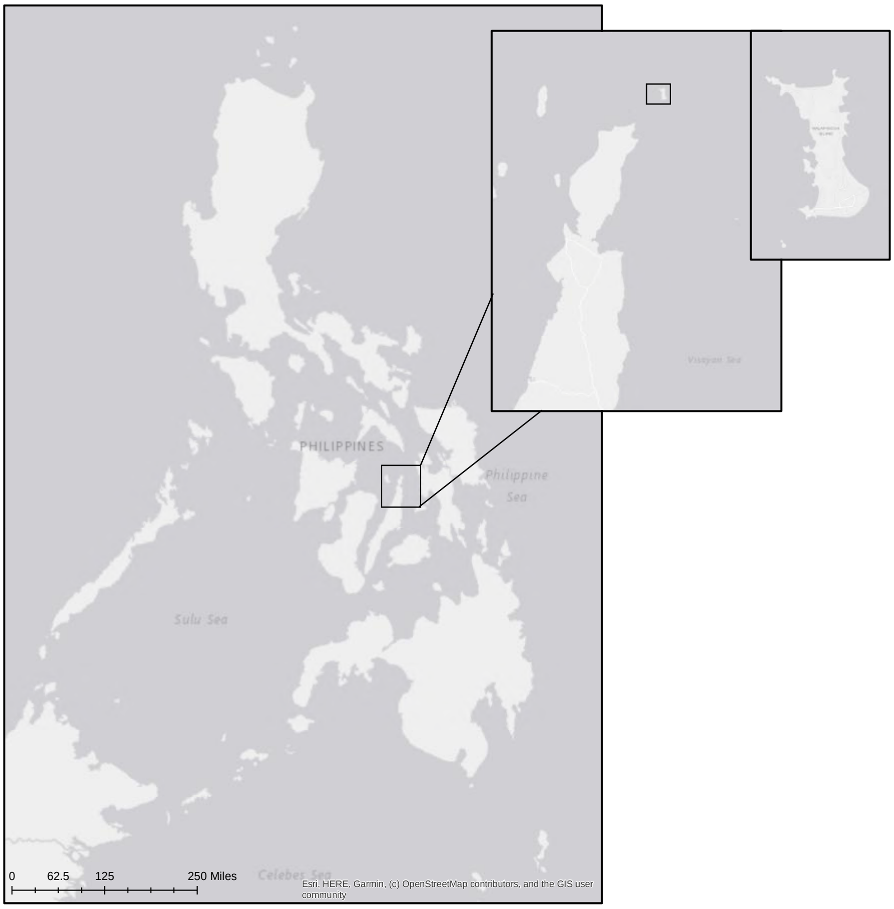


Figure. 1 Map of Malapascua location in the Philippines obtained with ArcGis

At the beginning of the millennium the Philippines was deemed the most vulnerable to coral reef stressors (Tamayo *et al.*, 2018). Malapascua is an apt portrayal of coral reefs threats within the archipelago, with an economy solely reliant on subsistence fishing and tourism predominantly from diving resorts and for sightings of their infamous Thresher sharks *Alopias* in Monad Shoal. The island is infringed with coral reef and thus particularly suspectable to physical damage from fishing debris and destructive techniques as well as anchor placement or carelessness from tourist. Threats to reefs around Malapascua are also suspectable to damage caused by typhoons, such as super-typhoon Yolanda, or Haiyan in November 2013 which had completely devastated many reefs in various municipalities in the Philippines, causing mass landfall in six districts and a death toll of over six thousand (Anticamara and Go, 2016) and more recently typhoon Ursula in December 2019. With the coastal development of resorts to facilitate tourism demand, septic systems and lack of transportation networks which has meant the locality of one waste collection site in the east, pollutants and waste are particularly a problem on the island (van der Graaf, 2017), which could pose threats to surrounding coral reefs. Just under 7000kg of wasted collected during weekly cleans up alone between Janurary and September 2019 (Figure. 2).

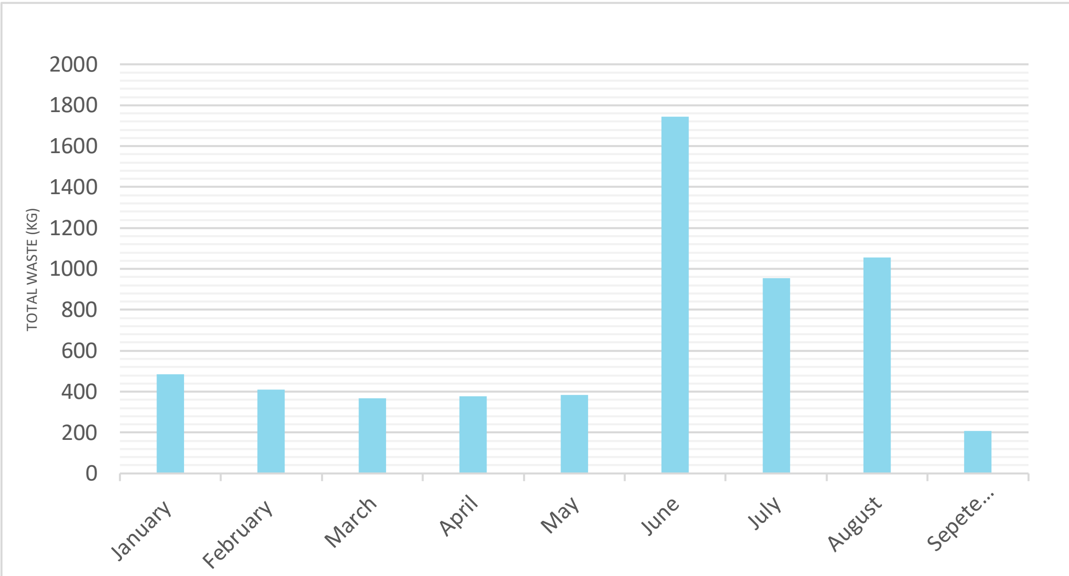


Figure. 2 Proportion of solid waste collected on Malapascua from weekly clean-ups in 2019 including categories of: residuals with potential (i.e. plastic wrappers and sachets), residuals without potential (i.e. cigarette butts), plastic bottles, recyclable glass and metals, diapers and sanitary materials and chemical waste.

People and the Sea

People and the Sea (PepSea) are a marine conservation non-governmental organisation (NGO) founded by holiday goers in 2014 in response to the devastation caused by typhoon Yolanda. Their three main pillars to success include: community empowerment, marine conservation and long-term support with aims of alleviating poverty, through the use of onsite jobs and homestay networks which are used by their volunteers and tourists for local income and promoting both marine and on land management by integrating conservation importance into academia in two elementary schools on the island, use of compost gardens, trash segregation strategies, weekly clean ups and underwater surveys. Through the use of their volunteer program and combined long-term assessment of marine biodiversity, waste management and more recent work with fisherfolk, they have been able to inform local governments and environmental resources to bring about sustainable management initiatives (Dalongeville, Jorcin and Mills, 2019).

2.4 Aims and Hypotheses

Reefs around Malapascua and the entirety of the Philippines are undoubtably on the frontline of many destructive effects of both natural causes and threats imposed by human influence. With the aid of NGO PepSea this study aims to assess the current hard coral cover (HCC) and most prevalent subsequent impacts following PepSea's historical data of reef assessments answering the following questions: (i) how has HCC changed since 2017 hypothesising there will be a difference of potential decrease with continued climate change and tourism impacts, (ii) what are the main localised impacts on corals in the Visayan Sea, hypothesising impacts to have increased since 2017, with predative impacts due to recent outbreaks and global warming encouraging bleaching occurrences and lastly understanding (iii) what impacts do ecotourism have on HCC and condition, hypothesising changes in water quality from pollutants and increased damage from recreational activities.

3.0 Methodology

3.1 Survey Sites

As of 2019 PepSea have 18 survey sites infringed around the coasts of Malapascua and surrounding islands Campatoc and Carnaza. With demand and complexities associated with underwater dive surveillance, most of these sites are surveyed annually with only four surveyed twice a year and as close as feasibly possible to the same time each year to avoid bias and improve replicas. Nine of the 18 sites were surveyed per month from January to September 2019 (Figure. 3) which were used in this study to understand recent pressures on reef-building corals. Three of these sites are governed protected areas of snorkelling and no-fishing zones (Dakit Dakit, Coral Garden and Bantigue) and Lapus Lapus protected as a Marine Reserve by Municipal Ordinance, where most of the other excluding Barrio are situated very closely to protected areas. Each of the sites have permanent markings of six 20-metre-long transects which are located on the survey dive to ensure the same area is surveyed.

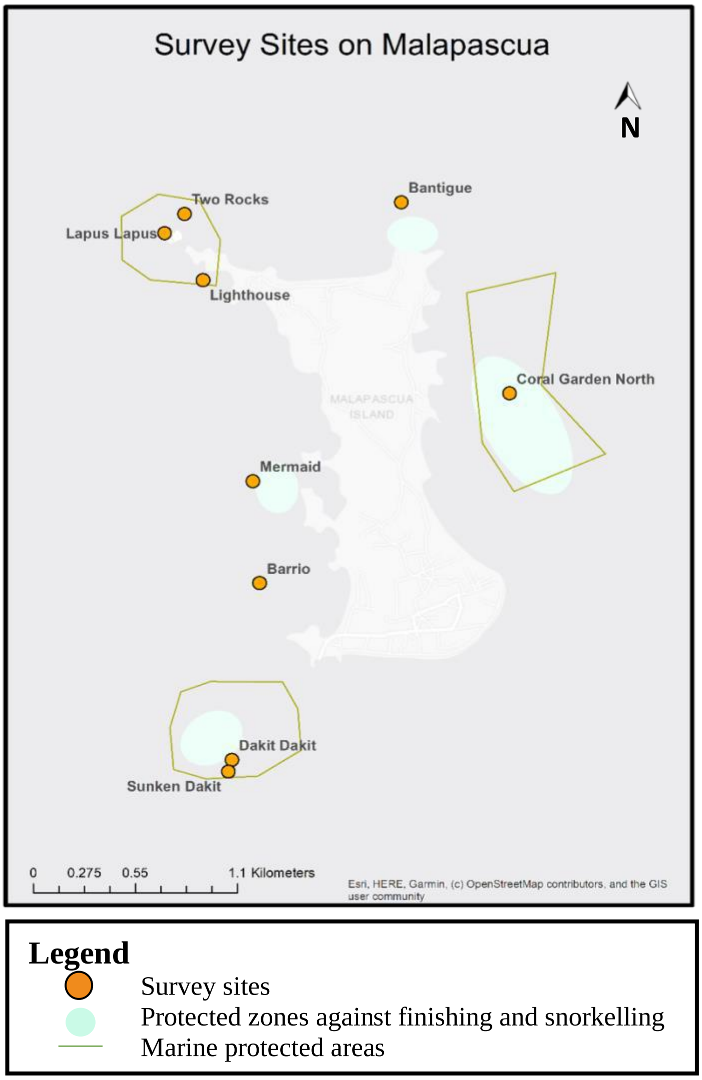


Figure. 3 Survey sites around Malapascua surveyed between Jan-Sept. obtained using ArcGis

3.2 Identification and Training

Prior data collection volunteers undertook a course of identification practices to familiarise with the species needed to identify. Table. 1 summarises the types of invertebrates, coral forms, algae and substrates and fish categories that are observed and surveyed. Coral forms were not identified down to species to aid easy learning for volunteers and so their formations were noted instead, where the transect landed on areas without coral the substrate of the benthic floor, nature of the coral or other biota was recorded instead. A series of tests both on land and underwater with a pass rate of 90% were carried out to ensure volunteers could establish the differences between recorded categories and species. Volunteers who weren't previously SCUBA diving trained had undergone PADI training, gaining Open Water and Advanced certificates to partake in the underwater surveying.

Invertebrates	*Coral and benthic floor*	*Fishes*
Long spinned urchin	Branching	Butterflyfish
Pencil urchin	Encrusting	Coralfish
Collector urchin	Massive	Bannerfish
Flower urchin	Sub-massive	Garden eel
COT starfish	Digitate	Spadefish
Other starfish	Solitary	Sweetlips
Triton trumpet	Table	Wrasse
Tridacna spp	Foliose	Bream
Prickly redfish cucumber	Columnar	Snapper
Greenfish cucumber	Corymbose	Filefish
Pinkfish cucumber	Soft coral	Goat fish
Cucumber other	Crustose algae	Moray
Drupella **spp**	Coralline algae	Angelfish
Coralliophila	Halimeda	Parrotfish
Sea anemones	Nutrient indicator algae	Mackerel
Octopus	Sponge	Lionfish
Squid	Tunicate	Groupers
Cuttlefish	Zoanthid	Soapfish
Nudibranch	Fire coral	Rabbitfish
Cowrie	Blue coral	Barracuda
Banded coral shrimp	Hydroid	Pufferfish
	Corallimorph	Toby
	Anemone	Rays
	Rubble	Sharks
	Silt	
	Sand	
	Rubble	
	Rock	
	Bleached	
	Dead coral algae	
	Recently killed coral	

Table. 1 Summary of coral formations, invertebrates and fish groups surveyed

3.3 Data Collection

Point Intercept Transects (PIT)

SCUBA based surveys had particularly increased in the 1970s, with terrestrial methods adapted for marine research (Roberts *et al*., 2016). PIT surveys are widely used methods in sampling percentage cover of biodiversity, particularly for species richness, abundance and topography where a diver swims along a transect line, systematically surveying benthic properties along the belt (Hill and Wilkinson, 2004). To conduct a PIT survey in the experiment, divers and their dive buddy descended to the transect which was located using global position system (GPS) where one participant orchestrating the benthic survey dropped a plumb line at each 25cm across the 20m transect (Figure. 4), labelling the nature of the sea floor in terms of its hard-coral form, soft coral, type of substrate or other marine organism of which was recorded on their slate – collecting 80 samples per six transects at each site.

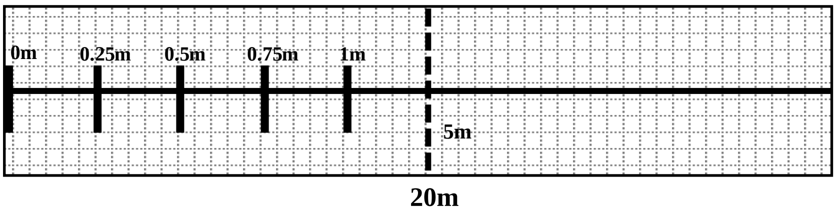


Figure.4 Layout used for the benthic survey using a Point Intercept Transect (PIT), illustrating the intervals along the transect where the plumb line was dropped.

Belt Transects (BT)

Belt Transects are frequently used in ecological sampling for estimates in organism abundance and distribution. In this investigation PepSea use belt transects to track the abundance of 21 different invertebrate and indicator species alongside 10 different types of anthropogenic and natural impacts such as typhoon, boat and anchor damage, bleaching, predation and various littering (Appendix 1). As a dive buddy to those conducting the benthic survey, those surveying the BT swam 2.5m each side of the 20m transect, laid out by a 5m transect deposited at the 10m mark, swimming in U-shaped figure (Figure. 5) to record all sightings of invertebrates and impact occurrence.

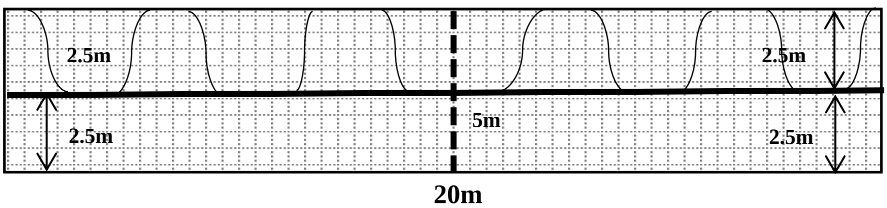


Figure.5 Layout used for the I&I survey (invertebrates and impacts), illustrating the patterns along the transect where divers swam

Underwater Visual Census (UVC)

112 fish species are monitored using the method of UVC, with focus on target species prone to the local area such as various cryptic fishes, corallivores and commercial species exploited by fisheries. Very limited equipment is required for this, merely confidence in identifying species. Once the transect had been deployed, divers would hover for 10 minutes to allow for fishes to regather around the transects then swim approximately 2.5m above the 20m transect observing and recoding the species at 2.5m either side of the transect, surveying at total of $250m^3$ in approximately eight minutes. Transects within the same location weren't surveyed simultaneously to limit chance of counting the same fishes on multiple occasions.

Water Quality and Environmental Readings

During monitoring surveys Pepsea record various environmental parameters of each site and surrounding area. In addition, measures of water quality were obtained at sites by collecting water samples where water quality and inorganic nutrients have been observed to impact bioindicators (Cooper, Gilmour and Fabricius, 2009) such as chlorophyll (Hoegh-Guldberg and Smith, 1989) and macroalgae concentrations (De'ath and Fabricus, 2010), impeding coral growth (Lough and Barnes, 1992; Ferrier-Pagès *et al*., 2000) and diseases (Bruno *et al*., 2003). To test for nutrient enrichment the API Reef Master Test Kit and Saltwater Master Test Kit was used, by adding test solutions to the water samples and observing the colour change to identify the nutrient concentration in the water. Water quality samples were taken at the sites around Malapascua and other popular tourist destinations around Cebu and Malapascua for comparison including, Maya, Monad Shoal, Kalanggaman, Moalboal, Oslob, and Bohol. The following measures were included in each kit.

Reef Master Test Kit:
- Calcium (Ca^{2+})
- Calcium hardness (KH)
- Phosphate (PO_4^{3-})

Saltwater Master Test Kit:
- Water pH range

- Ammonia (NH_3)
- Nitrate (NO_{2-})
- Nitrate (NO_{3-})

A salinity pen was also used to determine measures of salinity.

3.4 Data Analysis

Benthic cover and the proportion of reef-building corals are calculated as percentage averages for each of the six transects per site and invertebrates, impacts and fish density were analysed as total abundance to assess distribution and plenitude. In assessing changes to distinguish current stressors to these Visayan reefs, historical records from Pepsea data in 2017 have been used for comparison where all sites have been previously tested, to better understand reef dynamics, denote temporal differences and even effectiveness of Pepsea engagement strategies. Where some sites are tested biannually throughout the year, averages were taken between the twelve sample sets.

All data was analysed using Minitab version 19.2.0. Normality of data was assessed using Shapiro-Wilk test at p-value 0.05. Where variables were normally distributed, ANOVA is used to assess the analysis of variance between mean reef-building corals percentage in 2017 and 2019 and Pearson's correlation to determine significant correlations between coral stressors. Spearman's correlation is used where data does not fit the normal distribution to determine whether impacts are significantly correlation to hard-coral abundance or mortality. All correlation coefficients are tested against a 0.05 threshold.

4.0 Results and Discussion

Collectively 480 samples of benthic properties were obtained and noted across Malapascua from survey sites in the benthic survey. The majority, approximately 26.8% is accounted for by reef-building corals and impacted corals a marginal 6.4%. The proportion of reef-building corals appears greatest in sites governed as protected areas as set out by Municipal Ordinance in Daanbantayan (Figure. 6) – more than half of percentage coral cover at Lighthouse found of the order Scleractinia.

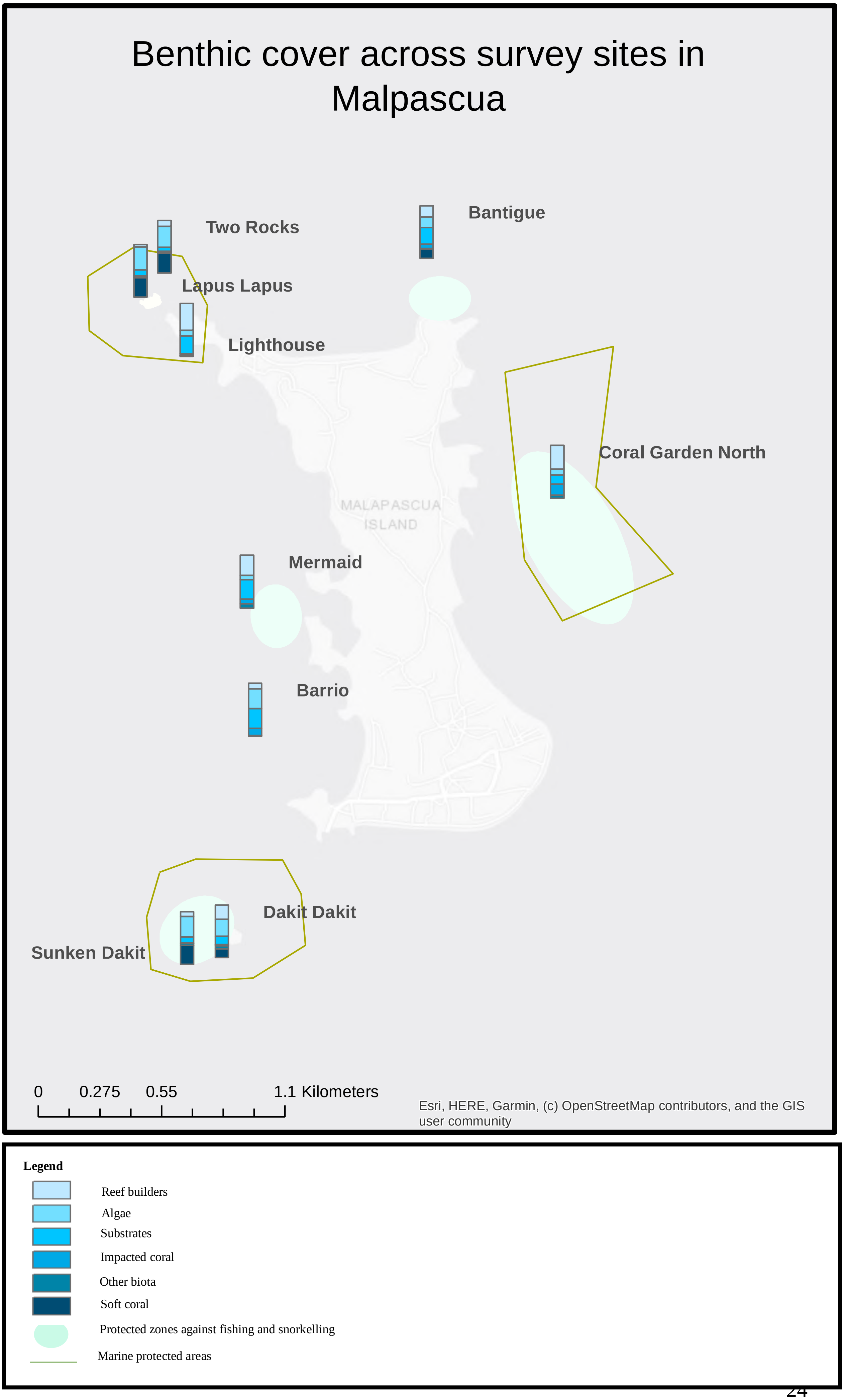


Figure.6 Map of survey sites around Malapascua illustrating the proportion of percentage coral cover generated from findings from the benthic survey using ArcGIS

4.1 Change in Reef-Building Corals Since 2017

Since 2017, the total hard coral cover (HCC) had increased by a meagre 0.9%, however this subtle difference was not significant when analysed using ANVOA (Appendix 2). Comparisons with 2017 are consistent with HCC findings from 2019, in that areas governed as marine protected areas (MPAs) have higher abundance of HCC and have increased more over the past two years (Figure.7).

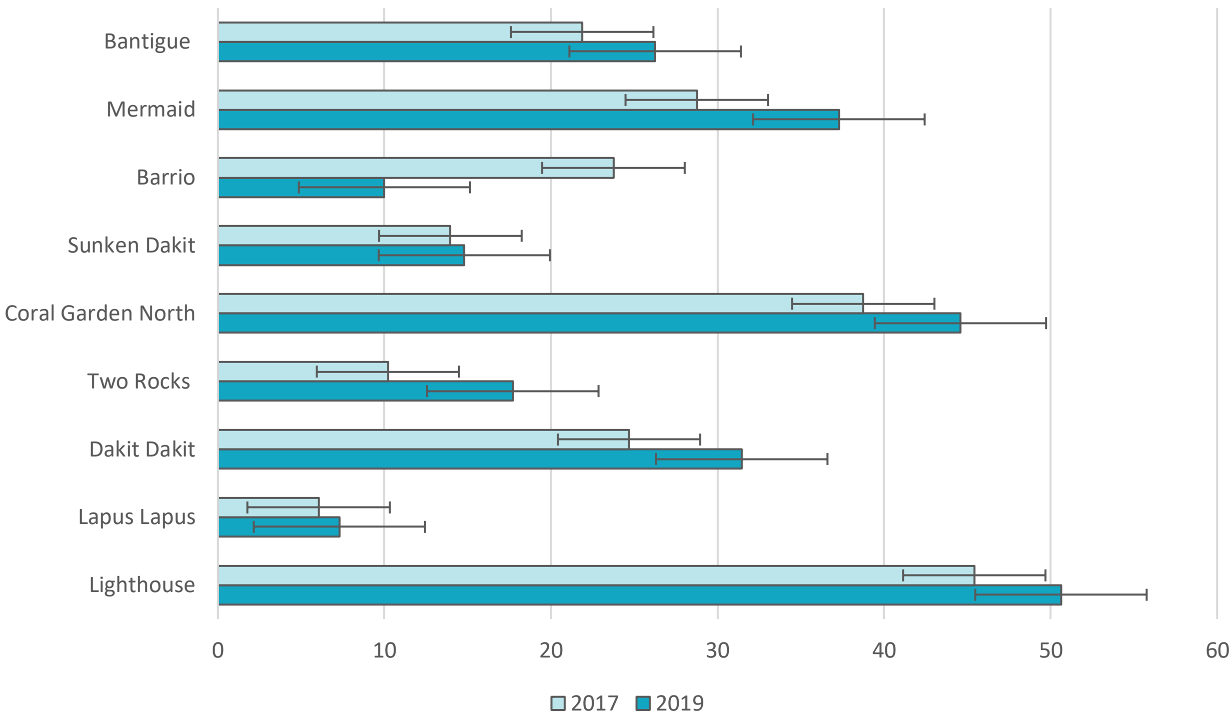


Figure.7 Average percentage HCC abundance from 2017 to 2019 across survey sites

There are currently over 1,000 MPAs in the Philippines run and led by communities or local governments most of which an extension of the Coral Triangle Initiative devised in 2007 to preserve and mitigate impacts to the highly diverse epicentre to marine fauna and flora (Mills *et al.*, 2010). MPAs are marine areas governed by local authorities to manage, reform and restore the natural environment, its species and ecological functions – by restricting uses and access (no-take MPAs) or merely limiting its practical functions (White *et al.*, 2014). Empirical reviews of MPAs suggest marine biodiversity and density is better established in these reserves; encouraging shifts in population dynamics of coral reef fish seen in Raja Ampat, Indonesia (Varkey, Ainsworth and Pitcher. 2012) and doubling coral cover, fish population and catchment area outside of the reserve by enriching yields in adjacent waters evident on Sumilon Island, Philippines (Post, 2018). In this instance, these protected areas particularly at Lighthouse, Dakit Dakit, Coral Garden North and Mermaid with the highest increase of HCC highlight the how MPAs can benefit ecosystem population and diversity harmoniously – where Barrio on the west coast showed nearly 14% reduction, an area still very heavily fished and polluted. Effectiveness of these MPAs however is unclear. Although providing temporal control over coral reef status and re-establishing coexistence amongst populations, shifts in population dynamics caused by the implementation of MPAs such as the influx of predatory fishes as a result of fishing prohibition as seen at marine sanctuary on Apo Island in the Philippines (Russ and Alcala, 1996) and increased larval connectivity amongst reserves (Weeks *et al*., 2009) are likely to increase impacts from predation. For this reason, rather mitigating stressors to marine ecosystems entirely MPA networks are more beneficial for restoration and slowing this process down, requiring a compilation of contextual approaches and more regimented management and legal framework which has been previously faulted (White, Aliño, and Meneses, 2006; Jones, 2014; Reefbase, 2015).

4.2 Summary of Localised Impacts to Visayan Reefs

Approximately 6.4% of corals surveyed during the benthic survey were considered impacted, quantified by either being either hard coral bleached (HCB), recently killed (RKC) or covered in dead coral algae (DCA) – an increase just shy of 2% from 2017. Where HCC is most abundant impacts also tend to be more renowned in comparison to areas rich in soft coral like Two Rocks and Lapus Lapus however there was no significant relationship between HCC and abundance of impacted corals (Appendix 3). Coral Garden appears of the most impacted whereas Barrio and Bantigue experiencing steep influxes, with a combined increase of over 17% (Figure. 8). These results adhere to uncertainty when evaluating the effectiveness of MPAs and on-going impacts.

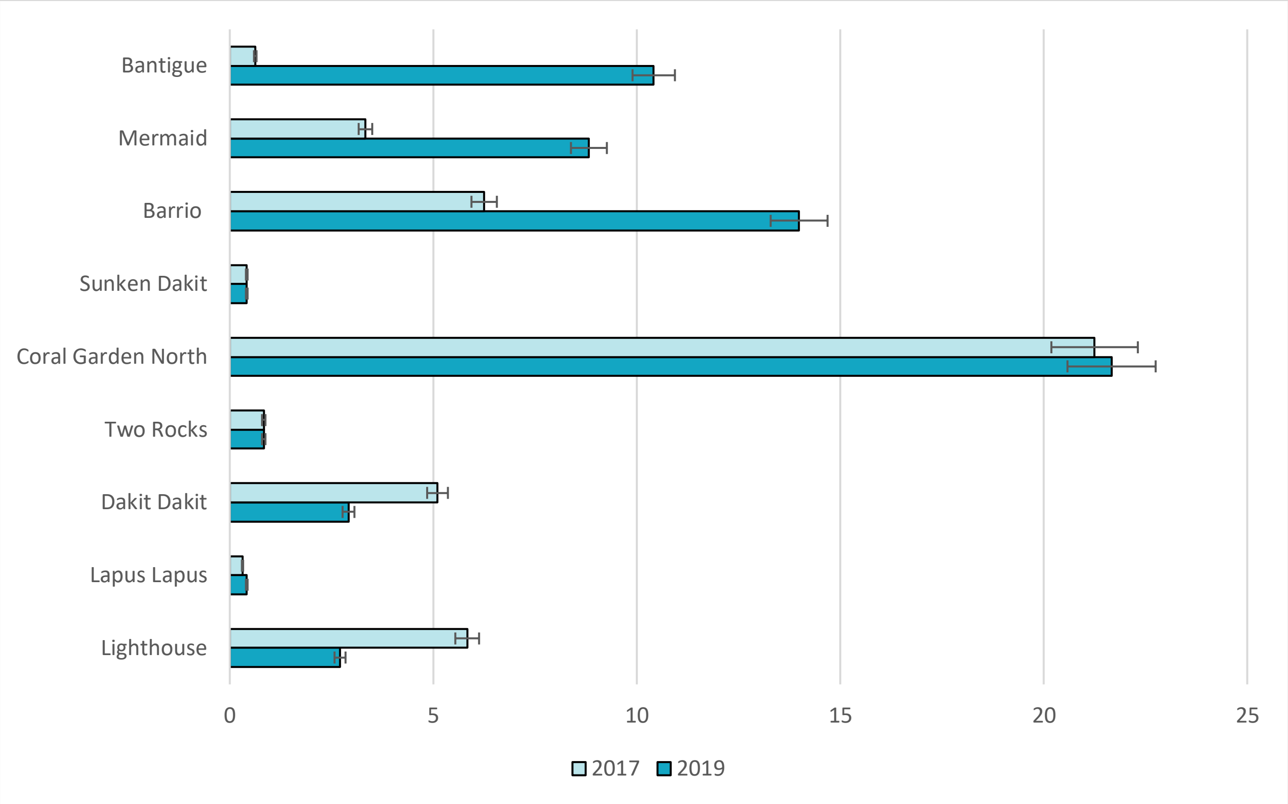


Figure.8 Average percentage of impacted corals across sites

Of all surveyed impacts, predation by the three surveyed invertebrates: Crown of Thorns *A.planci*, *Drupella spp* and Coralliphila sea snails alongside predation observation by unknown predators are accountable for more than half of the impacts quantified around Malapascua followed by incidences of disease and bleaching (Figure. 9). A large proportion of the impacts surveyed however are denoted to categories of unknown coral damage and unknown recently killed. With over 26% of impacts unknown, there is a gap in understanding the entirety of stressors to these Visayan reefs. Perceptual differences from volunteers (Kleypas and Eakin, 2007) or stressors to reefs understudied using these methods such as the physical constraints caused by wave dynamics and velocity (Tunnicliffe, 1982) must be considered.

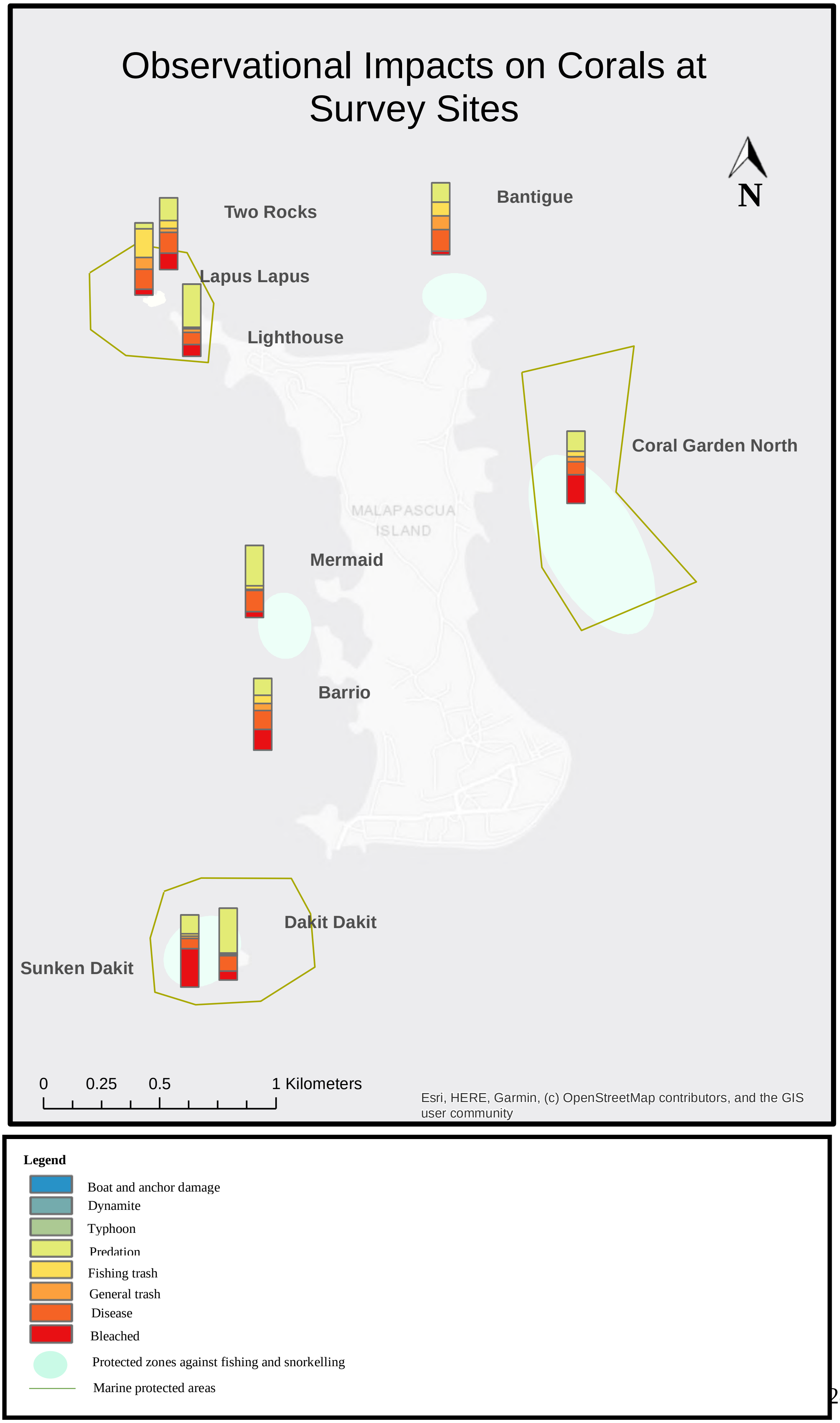


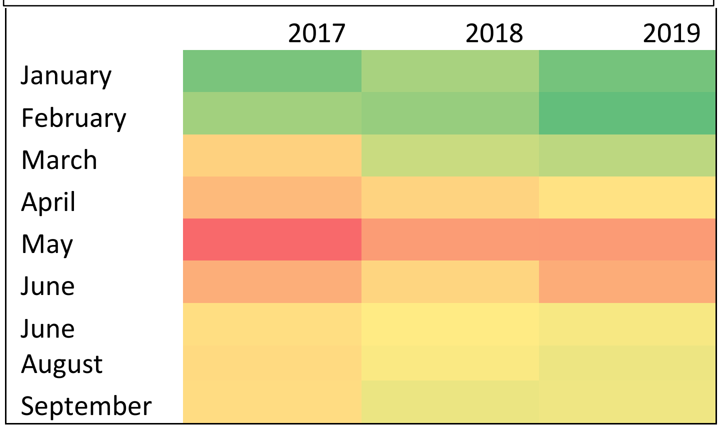
Figure. 9 Percentage average of various impacts surveyed in the I&I survey in 2019, generated using ArcGIS

4.3 Effect of Natural Impacts

Temperature

Bleached corals account for more than 5% of the impacts surveyed around Malapascua of which has increased marginally since 2017. Despite not of the most serve to these this relatively surprising as average temperatures appear to have cooled (Figure. 10). The most significant bleaching event to affect the Philippines was caused by ESNO indecent in 1998 (Schuttenberg and Obura, 2001) of which most corals have recovered or remain bleached. Emitting a relatively weak positive correlation (Figure. 11), the relationship between the amount of bleached corals with surface temperature was not significant (Appendix 4).

Figure.10 Mean surface temperatures during surveyed months where green represents temperatures between 27-28$_{o}$C, yellow for temperatures around 29$_{o}$C and orange to red for temperatures >30$_{o}$C



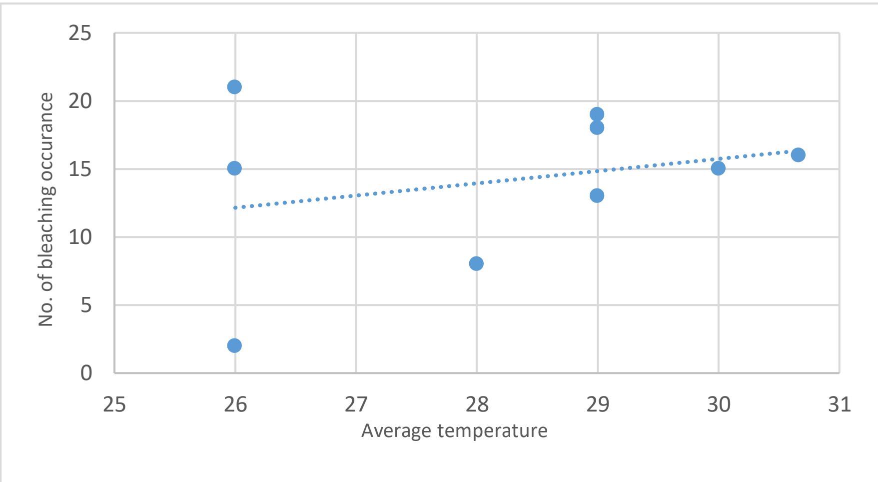


Figure. 11 Average surface temperature correlated against the number of bleaching occurrences from sites

Since the increase of bleached coral only increased by 0.6%, this small-scale incidence raises concerns with internal validity. Bleached coral is often confused with live stressed corals (Egner, 2020), recorded in this survey as RKC, recently killed corals. Volunteers are trained to differentiate between the two, where bleached corals are whiter with visible polyps from where the coral has expelled their zooxanthellae – however this can be easily confused when at great depth with reduced visibility. With a passing percent rate of identifying corals with PepSea at 90%, there is still margin of chance for their volunteers to experience these mistakes. It is important to consider that other stressors can produce similar responses to bleaching; such as reduction of light predominately associated with increased turbidity or light pollution, known to cause coral discolouration or mortality (Browne *et al*., 2017; Courtial *et al*., 2018; Rosenberg, Doniger and Levy, 2019).

Predation

More than half of live coral cover is lost or damage due to predation around Malapascua from a combined effort of corallivorous sea snails, sea star CoT and various corallivorous fish listed in Appendix 5 (Figure. 12). Correlations between predators, reef-builder abundance and coral morality were analysed (Appendix 6). Although all of these predators cause ramifications and exacerbate bioerosion, it was found CoT *A.planci* were the only predator significantly correlated to corals recently killed.

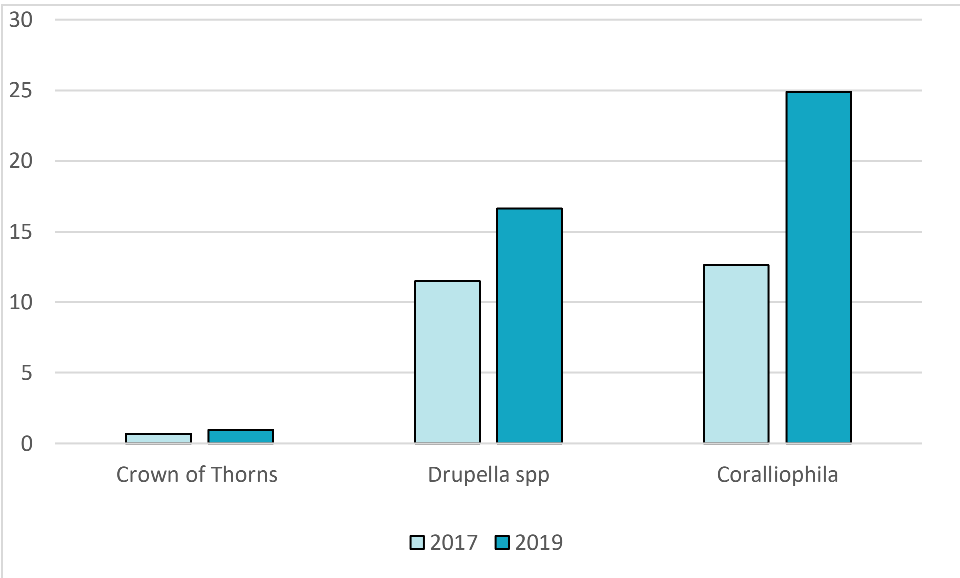


Figure. 12 Total abundance of predator species CoT *A.planci*, *Drupella spp* and Coralliophila compared against 2017 and 2019.

CoT have been problematic to these reefs periodically where management isn't sustained causing an outbreak – most recently, surveyed in January 2018 where removal strategies had been put in place on the East coast of Malapascua where the outbreak occurred until March 2019 (Kensington, 2019) and later resumed in September 2019 shortly after the survey, which would explain their low numbers. Direct management of sea snails however has not been impeded. Drupella spp have been known to cause large aggregations in areas where branching coral species dominate due to their fast growth (Cumming, 2009) although no true trend was identified in our findings (Appendix 7). Little is known regarding the population dynamics for Coralliphila snails, however the majority of outbreaks of gastropods have been associated with anthropogenic alterations encouraging terrestrial run-off and changes in fishing dynamics where consumers of these predators and their larval have been over-fished (Turner, 1994). Various hypotheses have been put forward in understanding these outbreaks. As findings are limited to expressing explicit correlations between predator abundance and coral mortality it is important to consider cofounding variables in the nature of this research. Since sites are survey at different times of the year, seasonal variance particularly associated with spawning periods should be considered. Research into *Drupella* spawning behaviours noted a peak during months June and July (Baomar, Abdullah Al-Sofyani and Wilson, 2017). With a 15-day post-oviposition (Sam *et al.*, 2017) combined with larval success due to compromised fishing and increased larval connectivity due to protected areas (Catano *et al.*, 2015), may explain influxes of gastropods in Mermaid (Figure. 13) which was surveyed in August, where populations earlier in the year could be a result of previous spawning periods. There is little evidence to understand distribution characteristics although sites around protected areas do tend to have higher rates of predation – consistent with research criticising their effectiveness and potential aid of dispersal and connectivity (Christie *et al.*, 2010).

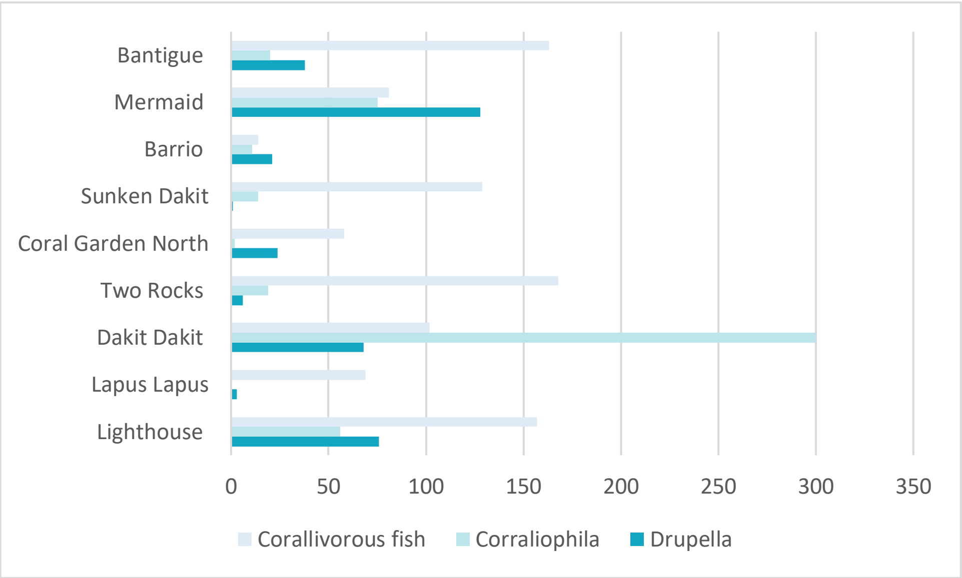


Figure. 13 Comparison of predator abundance excluding CoT between sites

4.4 Effect of Anthropogenic Impacts

Water Quality

Nine water samples were collected at each survey site and an additional six were taken at popular tourist locations from smaller locations around Malapascua such as Thresher shark sighting location Monad Shoal and infamous sandbar Kalanggaman and four other locations on mainland Cebu including the port to Malapascua at Maya, sardine and turtle sightings destination in Moalboal on the west coast of southern Cebu, Oslob in southern Cebu popular for their Whale shark attraction and Bohol an island off of the southern east coast.

Here we wanted to assess the water quality between sites which may elude to the impact of pollution caused by run-off, for example in sites closer to resort density, or any relations between coral abundance and mortality or rate of disease. Little assumptions can be made from the findings collected as very little differences were observed neither could its reliability be ensured. pH levels appeared more acidic in the locations outside of the survey sites around Malapascua, although remain at safe reading of above 7 (Appendix 8). 0.25 ppm ammonia was observed present in Two Rocks, Coral Garden North and Oslob as well as 20 ppm NO_{3^-} found in Two Rocks water samples and 5pmm at Coral Garden. There is no supporting evidence however to suggest this has severely reduced the water quality at these areas or had any impact on coral nature or encouragement of disease.

The API test kits are better used in diagnostics for saltwater or reef aquariums. Little is known on their uses outside of aquariums where more rigours techniques are often used. In assessing water quality in future, it would be more beneficial to use more reliable techniques such as fluorometers in measuring chlorophyll-a, nephelometers for turbidity, or even isotope analysis to understand pollutive effluents and origination (Udy *et al*., 2005; Phinn *et al*., 2005; Meng *et al*., 2008; Cooper, Glimour and Fabricus, 2009).

Recreational Activities

No coral damage was found caused by boat or anchor damage during the surveys in 2019, having decreased by the mere 1% observed in 2017. In most sites mooring anchors or fixtures are already in place to avoid anchors being distributed carelessly which would explain their low impact to corals. As previously mentioned, roughly 26% of coral impacts go unknown – 16% is attributed to physical damage which couldn’t be determined at the time of the survey. It is highly likely on an island centred around SCUBA diving that a proportion of unknown physical damages. The National Oceanographic and Atmospheric Administration (NOAA) had classified recreational influenced impacts as moderately high in locations in the Caribbean and Oceania (Rudd, 2013).

4.5 Future Research

PepSea hold a foundation of sustainable monitoring in an area where monitoring and management of coral reefs is limited. PepSea alongside most NGOs lack funding to acquire resources and materials to extensive surveying, with heavy reliance on volunteers and community support. To elaborate on these findings, additional techniques of sampling would be used for a more conclusive understanding to stressors upon reefs. This would include more reliable methods of quantifying water quality analysis and research into areas understudied using PepSea parameters such as turbidity measures and wave flow to reduce the proportion of impacts ‘unknown’. A disadvantage to collecting samples distinguished by form instead of species level disregards potential adaptions certain species have acquired to withstand certain pressures such as malate dehydrogenase enzyme present in submissive coral *Platygyra verweyi* associate with thermal resistance (Wang *et al*., 2019) as well as various other proteins or defensive enzymes that protect the zooxanthellae and subsequently its coral host (Brown, 1997).

5.0 Summary and Conclusions

Summary

- Reef-building corals have decreased since 2017
- Predation is the most significant impact to these Visayan reefs, responsible for over 50% of surveyed destruction
- Temperature was not significantly correlated to bleaching events, posing questions that other coral impacts may induce bleached responses
- No correlations were found between reduced water quality and reef-builder abundance, mortality or disease
- Recreational impacts have reduced since 2017 with no evidence of boating or anchor damage

Conclusion

Although natural impacts are numerically a greater threat, they generally involve or are trigged by human behaviours. These stressors will continue to degrade coral reefs and marine environments where management strategies are not successfully managed and monitored. Ultimately, we have not been able to accept our hypotheses of an (i) decrease in hard coral cover and (ii) significant impacts caused by reduced water quality and recreational activity; where characteristics of reefs around Malapascua varied against recent scientific literature. Research into reefs around Malapascua provide a pioneering insight to the prospect of reef reformation. However, our findings over the course of a two-year period, combined with further research reiterate this is a timely process – requiring consistent intervention from either management or monitoring strategies paired with community engagement to reduce the impacts, reform specie populations and rejuvenate the reef environment.

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7.0 References

References are formatted in Harvard refencing style

Ainsworth, T., Kramasky-Winter, E., Loya, Y., Hoegh-Guldberg, O. and Fine, M., (2006). Coral Disease Diagnostics: What's between a Plague and a Band?. *Applied and Environmental Microbiology*, **73**(3), pp.981-992.

Albright, R. and Langdon, C., (2011). Ocean acidification impacts multiple early life history processes of the Caribbean coral Porites astreoides. *Global Change Biology*, **17**(7), pp.2478-2487.

Allemand, D. and Osborn, D., (2019). Ocean acidification impacts on coral reefs: From sciences to solutions. *Regional Studies in Marine Science*, **28**.

Anjum, K., Abbas, S., Shah, S., Akhter, N., Batool, S. and Hassan, S., (2016). Marine Sponges as a Drug Treasure. *Biomolecules & Therapeutics*, **24**(4), pp.347-362.

Anticamara, J. and Go, K., (2016). Impacts of super-typhoon Yolanda on Philippine reefs and communities. *Regional Environmental Change*, **17**(3), pp.703-713.

Antonius, A., (1985). Coral Diseases in the Indo-Pacific: A First Record. *Marine Ecology*, **6**(3), pp.197-218.

Aronson, R. and Precht, W., (2006). Conservation, precaution, and Caribbean reefs. *Coral Reefs*, **25**(3), pp.441-450.

Babcock, R., Dambacher, J., Morello, E., Plagányi, É., Hayes, K., …Pratchett, M., (2016). Assessing Different Causes of Crown-of-Thorns Starfish Outbreaks and Appropriate Responses for Management on the Great Barrier Reef. *PLOS ONE*, **11**(12), p.e0169048.

Bailey, R. (2019). *When Both Benefit: Mutualism Explained*. [online] ThoughtCo. Available at: https://www.thoughtco.com/mutualism-symbiotic-relationships-4109634 [Accessed 5 Dec. 2019].

Bailey, M. and Sumaila, U., (2015). Destructive fishing and fisheries enforcement in eastern Indonesia. *Marine Ecology Progress Series*, **530**, pp.195-211.

Bajaj, P., (1978). Clinical uses of prostaglandins in human reproduction. *Nurs J India*, **69**(9), pp.197-199.

Barber, C. and Pratt, V., (1998). Poison and Profits: Cyanide Fishing in the Indo-Pacific. *Environment: Science and Policy for Sustainable Development*, **40**(8), pp.4-9.

Baum, G., Januar, H., Ferse, S. and Kunzmann, A., (2015). Local and Regional Impacts of Pollution on Coral Reefs along the Thousand Islands North of the Megacity Jakarta, Indonesia. *PLOS ONE*, **10**(9)

Beckert, M., Flammang, B. and Nadler, J. (2015). Remora fish suction pad attachment is enhanced by spinule friction. *Journal of Experimental Biology*, **218**(22), pp.3551-3558.

Bessell-Browne, P., Negri, A., Fisher, R., Clode, P. and Jones, R., (2017). Impacts of light limitation on corals and crustose coralline algae. *Scientific Reports*, **7**(1).

Bessey, C., Babcock, R., Thomson, D. and Haywood, M., (2018). Outbreak densities of the coral predator Drupella in relation to in situ Acropora growth rates on Ningaloo Reef, Western Australia. *Coral Reefs*, **37**(4), pp.985-993.

Bettarel, Y., Halary, S., Auguet, J., Mai, T., Van Bui, N., … Christelle, D., (2018). Corallivory and the microbial debacle in two branching scleractinians. *The ISME Journal*, **12**(4), pp.1109-1126.

Berkelmans, R. and van Oppen, M. (2006). The role of zooxanthellae in the thermal tolerance of corals: a 'nugget of hope' for coral reefs in an era of climate change. *Proceedings of the Royal Society B: Biological Sciences*, [online] 273(1599), pp.2305-2312. Available at: https://royalsocietypublishing.org/doi/full/10.1098/rspb.2006.3567 [Accessed 5 Dec. 2019].

Boomgaard, P., Kooiman, D. and Nordholt, H., (2008). Early globalisation Cowries as currency, 600 BCE-1900. *Linking Destinies: Trade, Towns And Kin In Asian History*. Leiden: BRILL, pp.13-28.

Bos, A., Gumanao, G., Mueller, B. and Saceda-Cardoza, M., (2013). Management of crown-of-thorns sea star (Acanthaster planci L.) outbreaks: Removal success depends on reef topography and timing within the reproduction cycle. *Ocean & Coastal Management*, **71**, pp.116-122.

Brodie, J., Fabricius, K., De'ath, G. and Okaji, K., (2005). Are increased nutrient inputs responsible for more outbreaks of crown-of-thorns starfish? An appraisal of the evidence. *Marine Pollution Bulletin*, **51**(1-4), pp.266-278.

Brown, B. (1997). Adaptation of Reef Corals to Physical Environment Stress. *Advances in Marine Biology*, **31**, pp221-299

Bruno, J., Petes, L., Harvell, C. and Hettinger, A., (2003). Nutrient enrichment can increase the severity of coral diseases. *Ecology Letters*, **6**(12), pp.1056-1061.

Bruno, J. F. (2015). Marine biology: The coral disease triangle. *Nature Climate Change*, ***5***(4), 302-303

Burke, L., Reytar, K., Spalding, M., Perry, A., (2011). 'Reefs at Risk Revisited', World Resources Institute, pp-15-21

Cabral, R. and Geronimo, R., (2018). How important are coral reefs to food security in the Philippines? Diving deeper than national aggregates and averages. *Marine Policy*, **91**, pp.136-141.

Catano, L., Gunn, B., Kelley, M. and Burkepile, D., (2015). Predation Risk, Resource Quality, and Reef Structural Complexity Shape Territoriality in a Coral Reef Herbivore. *PLOS ONE*, **10**(2), p.e0118764.

Chandrasiri, C., Yehdego, T. and Peethamparan, S., (2019). Synthesis and characterization of bio-cement from conch shell waste. *Construction and Building Materials*, **212**, pp.775-786.

Christie, M., Tissot, B., Albins, M., Beets, J., Jia, Y., … Ortiz, D., (2010) Larval Connectivity in an Effective Network of Marine Protected Areas. *PLoS ONE*, **5**(12)

Cobb, K., Westphal, N., Sayani, H., Watson, J., Di Lorenzo, E., Cheng, H., … Charles, C., (2013). Highly Variable El Niño–Southern Oscillation Throughout the Holocene. *Science*, **339**(6115), pp.67-70.

Coker, D., Wilson, S. and Pratchett, M. (2013). Importance of live coral habitat for reef fishes. *Reviews in Fish Biology and Fisheries*, **24**(1), pp.89-126.

Cole, A., Chong Seng, K., Pratchett, M. and Jones, G. (2009). Coral-feeding fishes slow progression of black-band disease. *Coral Reefs*, **28**(4), p.3.

Cole, A., Pratchett, M. and Jones, G. (2008). Diversity and functional importance of coral-feeding fishes on tropical coral reefs. *Fish and Fisheries*, **9**(3), pp.286-307.

Courtial, L., Planas Bielsa, V., Houlbrèque, F. and Ferrier-Pagès, C., (2018). Effects of ultraviolet radiation and nutrient level on the physiological response and organic matter release of the scleractinian coral Pocillopora damicornis following thermal stress. *PLOS ONE*, **13**(10), p.e0205261.

Cowburn, B., Moritz, C., Birrell, C., Grimsditch, G. and Abdulla, A., (2018). Can luxury and environmental sustainability co-exist? Assessing the environmental impact of resort tourism on coral reefs in the Maldives. *Ocean & Coastal Management*, **158**, pp.120-127.

Cowan, Z., Dworjanyn, S., Caballes, C. and Pratchett, M., (2016). Predation on crown-of-thorns starfish larvae by damselfishes. *Coral Reefs*, **35**(4), pp.1253-1262.

Cowan, Z., Pratchett, M., Messmer, V. and Ling, S., (2017). Known Predators of Crown-of-Thorns Starfish (Acanthaster spp.) and Their Role in Mitigating, If Not Preventing, Population Outbreaks. *Diversity*, **9**(1), p.7.

Cowan, Z., Ling, S., Caballes, C., Dworjanyn, S. and Pratchett, M., (2020). Crown-of-thorns starfish larvae are vulnerable to predation even in the presence of alternative prey. *Coral Reefs*,.

Cox, E. (1986). The effects of a selective corallivore on growth rates and competition for space between two species of Hawaiian corals. *Journal of Experimental Marine Biology and Ecology*, **101**(1-2), pp.161-174.

Cooper, T., Gilmour, J. and Fabricius, K., (2009). Bioindicators of changes in water quality on coral reefs: review and recommendations for monitoring programmes. *Coral Reefs*, **28**(3), pp.589-606.

Cramer, K., Jackson, J., Angioletti, C., Leonard-Pingel, J. and Guilderson, T., (2012). Anthropogenic mortality on coral reefs in Caribbean Panama predates coral disease and bleaching. *Ecology Letters,* **15**(6), pp.561-567.

Cumming, R.,(2009). Population outbreaks and large aggregation of *Drupella* on the Great Barrier Reef. *Great Barrier Reef Marine Park Authority*

Dalongeville, A., Jorcin, A. and Mills, I., (2019). Coral Reef Monitorings Report 2018, *People and the Sea*

De'ath, G. and Fabricius, K., (2010). Water quality as a regional driver of coral biodiversity and macroalgae on the Great Barrier Reef. *Ecological Applications*, **20**(3), pp.840-850.

Dee, L., Horii, S. and Thornhill, D., (2014). Conservation and management of ornamental coral reef wildlife: Successes, shortcomings, and future directions. *Biological Conservation*, **169**, pp.225-237.

Dollar, S., (1982). Wave stress and coral community structure in Hawaii. *Coral Reefs*, **1**(2), pp.71-81.

Dubinsky, Z., and Stambler, N., (1996). Marine pollution and coral reefs, Global Change Biology, **6**(2)

Dumas, P., Moutardier, G., Ham, J., Kaku, R., Gereva, S., …Adjeroud, M., (2016). Timing within the reproduction cycle modulates the efficiency of village-based crown-of-thorns starfish removal. *Biological Conservation*, **204**, pp.237-246.

Eakin, C., Sweatman, H. and Brainard, R., (2019). The 2014–2017 global-scale coral bleaching event: insights and impacts. *Coral Reefs*, **38**(4), pp.539-545.

Egner, S., (2020). *Differentiating Coral Bleaching And Coral Mortality*. [online] Alert Diver - Divers Alert Network. Available at: <http://www.alertdiver.com/coral_bleaching_coral_mortality> [Accessed 11 April 2020].

Enochs, I. and Glynn, P. (2017). Corallivory in the Eastern Pacific. In: P. Glynn, D. Manzello and I. Enochs, ed., *Coral Reefs of the Eastern Tropical Pacific*. Springer Netherlands, pp.315-337.

Estrada-Saldívar, N., Jordán-Dalhgren, E., Rodríguez-Martínez, R., Perry, C. and Alvarez-Filip, L., (2019). Functional consequences of the long-term decline of reef-building corals in the Caribbean: evidence of across-reef functional convergence. *Royal Society Open Science*, **6**(10), p.190298.

Eziefula, U., Ezeh, J. and Eziefula, B., (2018). Properties of seashell aggregate concrete: A review. *Construction and Building Materials*, **192**, pp.287-300.

Fabinyi, M., (2010). The Intensification of Fishing and the Rise of Tourism: Competing Coastal Livelihoods in the Calamianes Islands, Philippines. *Human Ecology*, **38**(3), pp.415-427.

Fenner, D., (2012). Challenges for Managing Fisheries on Diverse Coral Reefs. *Diversity*, **4**(1), pp.105-160.

Ferrier-Pagas, C., Gattuso, J., Dallot, S. and Jaubert, J., (2000). Effect of nutrient enrichment on growth and photosynthesis of the zooxanthellate coral Stylophora pistillata. *Coral Reefs*, **19**(2), pp.103-113.

Frias-Lopez, J., Bonheyo, G., Jin, Q. and Fouke, B., (2003). Cyanobacteria Associated with Coral Black Band Disease in Caribbean and Indo-Pacific Reefs. *Applied and Environmental Microbiology*, **69**(4), pp.2409-2413.

Frisch, A., Rizzari, J., Munkres, K. and Hobbs, J. (2016). Anemonefish depletion reduces survival, growth, reproduction and fishery productivity of mutualistic anemone–anemonefish colonies. *Coral Reefs*, **35**(2), pp.375-386.

Fu, K., Xu, Q., Czernuszka, J., Triffitt, J. and Xia, Z., (2013). Characterization of a biodegradable coralline hydroxyapatite/calcium carbonate composite and its clinical implementation. *Biomedical Materials*, **8**(6), pp.065007.

Gardiner, J., (1904). The Formation of Coral Reefs. *Nature*, **69**, pp.371-373

Gardner, T., Côté, I., Gill, J., Grant, A. and Watkinson, A., (2005). HURRICANES AND CARIBBEAN CORAL REEFS: IMPACTS, RECOVERY PATTERNS, AND ROLE IN LONG-TERM DECLINE. *Ecology*, **86**(1), pp.174-184.

Haw, J., (2015). *The Effects Of Climate Change On Coral Reef Health*. [online] Scientific American Blog Network. Available at: <https://blogs.scientificamerican.com/expeditions/the-effects-of-climate-change-on-coral-reef-health/> [Accessed 16 December 2019].

Hudson, J., (2000). First aid for massive corals infected with black band disease, *phormidium corallyticum:* and underwater aspirator and post-treatment sealant to curtail reinfection. [online] Rubicon Research Respiratory. Available at: http://archive.rubicon-foundation.org/xmlui/bitstream/handle/123456789/6627/aaus_2000_5.pdf?sequence=1 [Accessed 8 Jan. 2020]

Heery, E., Hoeksema, B., Browne, N., Reimer, J., Ang, P., Huang, D., … Todd, P., (2018). Urban coral reef: Degradation and resilience of hard coral assemblages in coastal cities of East and Southeast Asia. *Marine Pollution Bulletin*, **135**, pp.654-681

Herman, A., (1983). Clinical Use of Prostaglandins in Perspective. *Acta Clinica Belgica*, **38**(2), pp.75-79.

Hill, J. and Wilkinson, C. (2004) Methods for Ecological Monitoring of Coral Reefs,Austrialina Insitiute of Marine Science. Pp. 36

Hiskett, M., (1966). Materials Relating to the Cowry Currency of the Western Sudan—II. *Bulletin of the School of Oriental and African Studies*, **29**(2), pp.339-366.

Hoegh-Guldberg, O. and Smith, G., (1989). Influence of the population density of zooxanthellae and supply of ammonium on the biomass and metabolic characteristics of the reef corals Seriatopora hystrix and Stylophora pistillata. *Marine Ecology Progress Series*, **57**, pp.173-186.

Hoegh-Guldberg, O., (2011). Coral reef ecosystems and anthropogenic climate change. *Regional Environmental Change*, **11**(S1), pp.215-227.

Hoegh-Guldberg, O., Poloczanska, E., Skirving, W. and Dove, S., (2017). Coral Reef Ecosystems under Climate Change and Ocean Acidification. *Frontiers in Marine Science,* **4**.

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., … Zhou, G., (2018). 'Impacts of 1.5oC Global Warming on Natural and Human Systems', in Masson-Delmotte, V., Zhai, P., Pörtner, H., Roberts, D., Skea, J., Shukla, P., … Waterfield, T., (eds.) *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*.pp. Korea, Incheon, IPCC, pp.183-209

Ho, T., (2017). 'Dredging Land Reclamation Causing Mucus Development in Massive Spherical Corals in the Spratly Islands, South China Sea: The Effects on China's Fishing Industry'. Undergraduate Thesis, Virginia Commonwealth University.

IUCN., (2019) Coral reefs and climate change. [online] iucn.org. Available at: https://www.iucn.org/resources/issues-briefs/coral-reefs-and-climate-change [Accessed 17 Dec. 2019]

Jennings, S., Grandcourt, E. and Polunin, N., (1995). The effects of fishing on the diversity, biomass and trophic structure of Seychelles' reef fish communities. *Coral Reefs*, **14**(4), pp.225-235.

Jensen, K., Taylor, J., Barry, R., D'Abramo, L., Davis, D. and Watts, S. (2018). The value of sea urchin, Lytechinus variegatus, egesta consumed by shrimp, Litopenaeus vannamei. *Journal of the World Aquaculture Society*, **50**(3), pp.614-621.

Johnson, M., (1970). The Cowrie Currencies of West Africa Part I. *The Journal of African History*, **11**(1), pp.17-24.

Johnson, A., (2010). Reducing bycatch in coral reef trap fisheries: escape gaps as a step towards sustainability. *Marine Ecology Progress Series*, **415**, pp.201-209.

Jones, P. (2014): *Governing Marine Protected Areas: Resilience through Diversity*. Abingdon, Oxon: Routledge.

Kamya, P., Dworjanyn, S., Hardy, N., Mos, B., Uthicke, S, and Byrne, M. (2014). Larvae of the coral eating crown-of0thorns starfish, *Acanthaster planci* in warmer-high Co2 ocean. *Global Change Biology*, **20**(11).

Kaplan, M., (2009). Overfishing linked to algal blooms. *Nature*, [online] Available at: <https://www.nature.com/news/2009/091201/full/news.2009.1116.html> [Accessed 8 December 2019].

Kelsch, C., (2017). A Rising Tide: InnovaSea is poised to help aquaculture meet the growing global deman for seafood protein. Food and Drink, [online] pp.90. Available at: https://go.gale.com/ps/i.do?p=ITOF&u=rdg&id=GALE%7CA511509975&v=2.1&it=r&sid=summon [Accessed 7 Dec. 2019].

Kensington, N. (2019). 'An assessment of the population of crown-of-throns starfish (Acanthaster planci L.) around the island of Malapascua, Republic of the Phillippines'. Bsc Research Project, The University of Dublin

Kleypas, J. and Easkin, M. (2007). Scientists' perception of threats to Coral Reefs: Results of a survey of Coral Reef researchers. Bulletin of Marine Science-Miami, **80**(2), pp.419-436

Knoester, E., Murk, A. and Osinga, R. (2019). Benefits of herbivorous fish outweigh costs of corallivory in coral nurseries placed close to a Kenyan patch reef. *Marine Ecology Progress Series*, **611**, pp.143-155.

Krishnamurthy, R., Johnathan, M., Srinivasalu, S. and Glaeser, B., (2019). Coastal Management: Global Challenges And Innovation. *Academic Press*, pp.21-38.

Kuanui, P., Chavanich, S., Viyakarn, V., Omori, M. and Lin, C. (2015). Effects of temperature and salinity on survival rate of cultured corals and photosynthetic efficiency of zooxanthellae in coral tissues. *Ocean Science Journal*, **50**(2), pp.263-268.

Kuta, K. and Richardson, L., (1996). Abundance and distribution of black band disease on coral reefs in the northern Florida Keys. *Coral Reefs*, **15**(4), pp.219-223.

Lentz, J., Blackburn, J. and Curtis, A., (2011). Evaluating Patterns of a White-Band Disease (WBD) Outbreak in Acropora palmata Using Spatial Analysis: A Comparison of Transect and Colony Clustering. *PLoS ONE*, **6**(7), p.e21830.

Liang, C. and Pauly, D., (2017). Fisheries impacts on China's coastal ecosystems: Unmasking a pervasive 'fishing down' effect. *PLOS ONE*, **12**(3), p.e0173296.

Littler, M., Taylor, P. and Littler, D. (1989). Complex interactions in the control of coral zonation on a Caribbean reef flat. *Oecologia*, **80**(3), pp.331-340.

Look, S., Fenical, W., Jacobs, R. and Clardy, J., (1986). The pseudopterosins: anti-inflammatory and analgesic natural products from the sea whip Pseudopterogorgia elisabethae. *Proceedings of the National Academy of Sciences*, **83**(17), pp.6238-6240.

Look, S., Fenical, W., Matsumoto, G. and Clardy, J., (1987). ChemInform Abstract: The Pseudopterosins (I): A New Class of Antiinflammatory and Analgesic Diterpene Pentosides from the Marine Sea Whip Pseudopterogorgia elisabethae (Octocorallia). *ChemInform*, **18**(29).

Lough, J. and Barnes, D., (1992). Comparisons of skeletal density variations in Porites from the central Great Barrier Reef. *Journal of Experimental Marine Biology and Ecology*, **155**(1), pp.1-25.

Lough, J., and van Oppen, M., (2009) *'Introduction: Coral Bleaching — Patterns, Processes, Causes and Consequences'*, in van Oppen M.J.H., Lough J.M. (eds) Coral Bleaching. Ecological Studies, vol 205. Berlin, Springer

Martins, K., Pereira, P., Esteves, L. and Williams, J. (2019). The Role of Coral Reefs in Coastal Protection: Analysis of Beach Morphology. *Journal of Coastal Research*, **92**(sp1), p.157.

McClanahan, T., (1994). Coral-eating snail Drupella cornus population increases in Kenyan coral reef lagoons. *Marine Ecology Progress Series*, **115**, pp.131-137.

McKeon, C. and Moore, J. (2014). Species and size diversity in protective services offered by coral guard-crabs. *PeerJ*, **2**, pp.1-10.

Meng, P., Lee, H., Wang, J., Chen, C., Lin, H., …Hsieh, W., (2008). A long-term survey on anthropogenic impacts to the water quality of coral reefs, southern Taiwan. *Environmental Pollution*, **156**(1), pp.67-75.

Merrifield, S., Schramek, T., Celona, S., Villas Bôas, A., Colin, P. and Terrill, E., (2019). Typhoon-Forced Waves Around a Western Pacific Island Nation. *Oceanography*, 32(4), pp.56-65.

Mills, M., Pressey, R., Weeks, R., Foale, S. and Ban, N., (2010). A mismatch of scales: challenges in planning for implementation of marine protected areas in the Coral Triangle. *Conservation Letters*, **3**(5), pp.291-303.

Moberg, F. and Folke, C. (1999). Ecological goods and services of coral reef ecosystems. *Ecological Economics*, **29**(2), pp.215-233.

Morrissey, J., Sumich, J. and Pinkard-Meier, D. (2018). *Introduction to the biology of marine life*. 11th ed. United States of America: Jones & Bartlett Learning, pp.299-326.

Miller, A. and Richardson, L., (2014). Emerging coral diseases: a temperature-driven process?. *Marine Ecology*, **36**(3), pp.278-291.

Miller, I., Sweatman, H., Cheal, A., Emslie, M., Johns, … Osborne, K., (2015). Origins and Implications of a Primary Crown-of-Thorns Starfish Outbreak in the Southern Great Barrier Reef. *Journal of Marine Biology*, pp.1-10.

Nicolet, K., Hoogenboom, M., Gardiner, N., Pratchett, M. and Willis, B., (2013). The corallivorous invertebrate Drupella aids in transmission of brown band disease on the Great Barrier Reef. *Coral Reefs*, **32**(2), pp.585-595.

Nicolet, K., Chong-Seng, K., Pratchett, M., Willis, B. and Hoogenboom, M., (2018). Predation scars may influence host susceptibility to pathogens: evaluating the role of corallivores as vectors of coral disease. *Scientific Reports*, **8**(1).

Patterson, K., Porter, J., Ritchie, K., Polson, S., Mueller, E., … Smith, G., (2002). The etiology of white pox, a lethal disease of the Caribbean elkhorn coral, Acropora palmata. *Proceedings of the National Academy of Sciences*, 99(13), pp.8725-8730.

Phinn, S., Dekker, A., Brando, V. and Roelfsema, C., (2005). Mapping water quality and substrate cover in optically complex coastal and reef waters: an integrated approach. *Marine Pollution Bulletin*, **51**(1-4), pp.459-469.

Polónia, A., (2014). 'The Impact of Urbanisation on Coral Reef Ecosystems'. PhD Thesis, University of Porto.

Post, K. (2018) Increasing the Resilience of Marine Ecosystems: Creating and Managing Marine Protected Areas in the Philippines. *Marine Conservation Philippines,* pp.3-29

Raven J, Caldeira,K., Elderfield, H., Hoegh-Guldberg, O., Liss, P., … Watson, A., (2005) '*Ocean acidification due to increasing atmospheric carbon dioxide'*. Royal Society Report. Royal Society, London, UK

REEFBASE (2015): *Regional Summary Report for MPAs in East Asia and Micronesia.*

Reguero, B., Beck, M., Agostini, V., Kramer, P. and Hancock, B. (2018). Coral reefs for coastal protection: A new methodological approach and engineering case study in Grenada. *Journal of Environmental Management*, 210, pp.146-161.

Rhormens, M., Pedrini, A. and Ghilardi-Lopes, N., (2017). Implementation feasibility of a marine ecotourism product on the reef environments of the marine protected areas of Tinharé and Boipeba Islands (Cairu, Bahia, Brazil). *Ocean & Coastal Management*, **139**, pp.1-11.

Rosenberg, Y., Doniger, T. and Levy, O., (2019). Sustainability of coral reefs are affected by ecological light pollution in the Gulf of Aqaba/Eilat. *Communications Biology*, **2**(1).

Rice, M., Ezzat, L. and Burkepile, D. (2019). Corallivory in the Anthropocene: Interactive Effects of Anthropogenic Stressors and Corallivory on Coral Reefs. *Frontiers in Marine Science*, **5**, pp.1-9.

Richardson, L., (1998). Coral diseases: what is really known?. *Trends in Ecology & Evolution*, **13**(11), pp.438-443.

Richardson, L. and Kuta, K., (2003). Ecological physiology of the black band disease cyanobacterium Phormidium corallyticum. *FEMS Microbiology Ecology*, **43**(3), pp.287-298.

Richardson, L., (2004). Black Band Disease. In: Rosenberg ,E. and Loya, Y. (eds) Coral Health and Disease. Springer, Berlin, Heidelberg

Risk M., and Edinger E., (2011). 'Impacts of Sediment on Coral Reefs', In: Hopley D. (eds) *Encyclopedia of Modern Coral Reefs*, Springer, Dordrecht.

Roberts, T., Bridge, T., Caley, M. and Baird, A., (2016). The Point Count Transect Method for Estimates of Biodiversity on Coral Reefs: Improving the Sampling of Rare Species. *PLOS ONE*, **11**(3), p.e0152335.

Roche, R., Harvey, C., Harvey, J., Kavanagh, A., McDonald, M., … Turner, J., (2016). Recreational Diving Impacts on Coral Reefs and the Adoption of Environmentally Responsible Practices within the SCUBA Diving Industry. *Environmental Management*, 58(1), pp.107-116.

Roder, C., Arif, C., Daniels, C., Weil, E. and Voolstra, C., (2014). Bacterial profiling of White Plague Disease across corals and oceans indicates a conserved and distinct disease microbiome. *Molecular Ecology*, **23**(4), pp.965-974.

Rogers, C., (1990). Responses of coral reefs and reef organisms to sedimentation. *Marine Ecology Progress Series*, **62**, pp.185-202.

Rogers, C., Sutherland, K. and Porter, J., (2005). Has white pox disease been affecting Acropora palmata for over 30 years?. *Coral Reefs*, **24**(2), pp.194-194.

Rogers, A., Blanchard, J. and Mumby, P., (2017). Fisheries productivity under progressive coral reef degradation. *Journal of Applied Ecology*, **55**(3), pp.1041-1049.

Rotjan, R. and Lewis, S. (2008). Impact of coral predators on tropical reefs. *Marine Ecology Progress Series*, **367**, pp.73-91.

Rudd, A., (2013). *What Risks Do Tourists Pose To Coral Reefs? Are We Loving The Reefs To Death?* [online] Nature.com. Available at: <https://www.nature.com/scitable/blog/saltwater-science/what_risks_do_tourists_pose/> [Accessed 9 March 2020].

Russ, G. and Alcala, A., (1996). Do marine reserves export adult fish biomass? Evidence from Apo Island, central Philippines. *Marine Ecology Progress Series*, **132**, pp.1-9.

Sam, S., Toh, T., Kikuzawa, Y., Ng, C., Taira, D., Afiq-Rosli, L., … Chou, L., (2017). Egg capsules and veligers of the corallivorous muricid gastropod Drupella rugosa (Born, 1778). *Invertebrate Reproduction & Development*, **61**(3), pp.164-171.

Sarmento, V. and Santos, P., (2011). Trampling on coral reefs: tourism effects on harpacticoid copepods. *Coral Reefs*, **31**(1), pp.135-146.

Schmidt, M., (2014). Sibbele Hylkema, Cowries among the Me or Ekagi. The Impact of a New Currency on a Group of Central Highlanders in Papua, Indonesia. Edited, and with an introduction and appendix by Anton Ploeg. Münster: Lit Verlag, (2012), ix + 194 pp. [Comparative Anthropological Studies in Society, Cosmology and Politics Volume 8]. ISBN 9783643902009. Price: EUR 29.90 (paperback). *Bijdragen tot de taal-, land- en volkenkunde / Journal of the Humanities and Social Sciences of Southeast Asia*, **170**(4), pp.580-582.

Schuttenberg, H. and Obura, D. (2001). Ecological and socioeconomic impacts of coral bleaching: a strategic approach to management, policy and research responses, Coral Bleaching: *Causes, Consequences and Response*

Scoffin, T., (1993). The geological effects of hurricanes on coral reefs and the interpretation of storm deposits. *Coral Reefs*, **12**(3-4), pp.203-221.

Shantz, A., Stier, A., and Idjadi, J., (2011). Coral density and predation affect growth of a reef-building coral. *Coral Reefs,* **30**(2), 363-367.

Small, A. and Adey, W., (2001). Reef corals, zooxanthellae and free-living algae: a microcosm study that demonstrates synergy between calcification and primary production. *Ecological Engineering*, **16**(4), pp.443-457.

Sutherland, K., Porter, J. and Torres, C., (2004). Disease and immunity in Caribbean and Indo-Pacific zooxanthellate corals. *Marine Ecology Progress Series*, **266**, pp.273-302.

Sutherland, K., Porter, J., Turner, J., Thomas, B., Looney, … Lipp, E., (2010). Human sewage identified as likely source of white pox disease of the threatened Caribbean elkhorn coral, Acropora palmata. *Environmental Microbiology*, **12**(5), pp.1122-1131.

Tamayo, N., Anticamara, J. and Acosta-Michlik, L., (2018). National Estimates of Values of Philippine Reefs' Ecosystem Services. *Ecological Economics*, **146**, pp.633-644.

Thompson, A., (2017). Increasing Acid Could Kill Most Coral By 2050. [online] *livescience.* Available at: https://www.livescience.com/2135-increasing-acid-kill-coral-2050.html [Accessed 14 Dec. 2019]

Tunnicliffe, V., (1982). The effects of wave-induced flow on a reef coral. *Journal of Experimental Marine Biology and Ecology*, **64**(1), pp.1-10.

Tupper, M., Asif, F., Garces, L. and Pido, M., (2015). Evaluating the management effectiveness of marine protected areas at seven selected sites in the Philippines. *Marine Policy*, **56**, pp.33-42.

Turner, S., (1994). Spatial variability in the abundance of the corallivorous gastropod Drupella cornus. *Coral Reefs*, **13**(1), pp.41-48.

Udy, J., Gall, M., Longstaff, B., Moore, K., Roelfsema, C., … Albert, S., (2005). Water quality monitoring: a combined approach to investigate gradients of change in the Great Barrier Reef, Australia. *Marine Pollution Bulletin*, **51**(1-4), pp.224-238.

United Nations., (2019). *Climate Change*. [online] Un.org. Available at: <https://www.un.org/en/sections/issues-depth/climate-change/> [Accessed 14 Dec. 2019].

Uthicke, S., Doyle, J., Duggan, S., Yasuda, N. and McKinnon, A., (2015). Outbreak of coral-eating Crown-of-Thorns creates continuous cloud of larvae over 320 km of the Great Barrier Reef. *Scientific Reports*, **5**(1).

Valadez-Rocha, V. and Ortiz-Lozano, L., (2013). Spatial and Temporal Effects of Port Facilities Expansion on the Surface Area of Shallow Coral Reefs. *Environmental Management*, **52**(1), pp.250-260.

Valmsen, K., Jarving, I., Boeglin, W., Varvas, K., Koljak, R., …Samel, N., (2001). The origin of 15R-prostaglandins in the Caribbean coral Plexaura homomalla: Molecular cloning and expression of a novel cyclooxygenase. *Proceedings of the National Academy of Sciences*, **98**(14), pp.7700-7705.

van der Graaf, A. (2017). The Issues of Solid Waste Management on Small Islands: Malapascua Island Philippines as a Case Study. *UC San Diego: Center for Marine Biodiversity and Conservation*.

Vargas-Ángel, B., Huntington, B., Brainard, R., Venegas, R., Oliver, T., … Cohen, A., (2019) . El Niño-associated catastrophic coral mortality at Jarvis Island, central Equatorial Pacific. *Coral Reefs*, **38**(4), pp.731-741.

Varkey, D., Ainsworth, C. and Pitcher, T., (2012). Modelling Reef Fish Population Responses to Fisheries Restrictions in Marine Protected Areas in the Coral Triangle. *Journal of Marine Biology*, pp.1-18.

Veron, J., Hoegh-Guldberg, O., Lenton, T., Lough, J., Obura, … Rogers, A. (2009). 'The coral reef crisis: The critical importance of<350ppm CO2' , Marine Pollution Bulletin, **58**(10), pp.1428-1436.

Vine, P. (1974). Effects of algal grazing and aggressive behaviour of the fishes Pomacentrus lividus and Acanthurus sohal on coral-reef ecology. *Marine Biology*, **24**(2), pp.131-136.

Wall, M., Schmidt, G., Janjang, P., Khokiattiwong, S. and Richter, C., (2012). Differential Impact of Monsoon and Large Amplitude Internal Waves on Coral Reef Development in the Andaman Sea. *PLoS ONE*, **7**(11), p.e50207.

Wang, J., Wang, Y., Keshavmurthy, S., Meng, P. and Chen, C., (2019). The coral Platygyra verweyi exhibits local adaptation to long-term thermal stress through host-specific physiological and enzymatic response. *Scientific Reports*, **9**(1).

Wells, S., (2009). Dynamite fishing in northern Tanzania – pervasive, problematic and yet preventable. *Marine Pollution Bulletin*, **58**(1), pp.20-23.

Wells, S. and Hanna, N. (1992). *The Greenpeace book of coral reefs*. New York: Sterling Pub. Co., pp.36-144.

White, A., Aliño, P. and Meneses, A. (2006). Creating and managing marine protected areas in the Philippines. Fisheries Improved for Sustainable Harvest Project, Coastal Conservation and Education Foundation, Inc. and University of the Philippines Marine Science Institute, Cebu City, Philippines, pp.83

White, A., Aliño, P., Cros, A., Fatan, N., Green, A., Teoh, S … and Wen, W., (2014). Marine Protected Areas in the Coral Triangle: Progress, Issues, and Options. *Coastal Management*, **42**(2), pp.87-106.

Williams, S., Ambo-Rappe, R., Sur, C., Abbott, J. and Limbong, S., (2017). Species richness accelerates marine ecosystem restoration in the Coral Triangle. *Proceedings of the National Academy of Sciences*, **114**(45), pp.11986-11991.

Wilkinson, C., (2008). *Status Of Coral Reefs Of The World*. Townsville, Australia: Global Coral Reef Monitoring Network, Reef and Rainforest Research Centre.

Wong, C., Conti-Jerpe, I., Raymundo, L., Dingle, C., Araujo, Baker, D., (2018). Whale Shark Tourism: Impacts on Coral Reefs in the Philippines. *Environmental Management*, **63**(2), pp.282-291.

Work, T. and Meteyer, C., (2014). To Understand Coral Disease, Look at Coral Cells. *EcoHealth*, **11**(4), pp.610-618.

Yamano, H., Abe, O., Matsumoto, E., Kayanne, H., Yonekura, N. and Blanchon, P., (2003). Influence of wave energy on Holocene coral reef development: an example from Ishigaki Island, Ryukyu Islands, Japan. *Sedimentary Geology*, **159**(1-2), pp.27-41.

Zaneveld, J., Burkepile, D., Shantz, A., Pritchard, C., McMinds, R., … Thurber, R., (2016). Overfishing and nutrient pollution interact with temperature to disrupt coral reefs down to microbial scales. *Nature Communications*, **7**(1).

8.0 Appendices

Appendix 1

List of species and impacts surveyed in the I&I survey

Invertebrates
Crown of Thorns *Acanthaster planci*
Other Starfish
Triton trumpet *Charonia*
Tridacna spp
Prickly redfish cucumber *Thelenota ananas*
Pinkfish cucumber *Holothuria edulis*
Cucumber other
Drupella spp
Coralliophila
Sea anemones
Octopus
Squid
Cuttlefishes *Sepiida*
Nudibranch *Nudibranchia*
Cowries
Banded coral shrimp *Stenopus hispidus*

Impacts
Coral damage boat/anchor
Coral damage dynamite fishing
Coral damage typhoon
Coral damage predation
Coral damage unknown
Recently killed unknown
Fishing trash
General trash
Coral Disease
Coral bleached

Appendix 2

Analysis of Variance (ANOVA) of percentage of reef-building corals in 2017 and 2019

Analysis of Variance

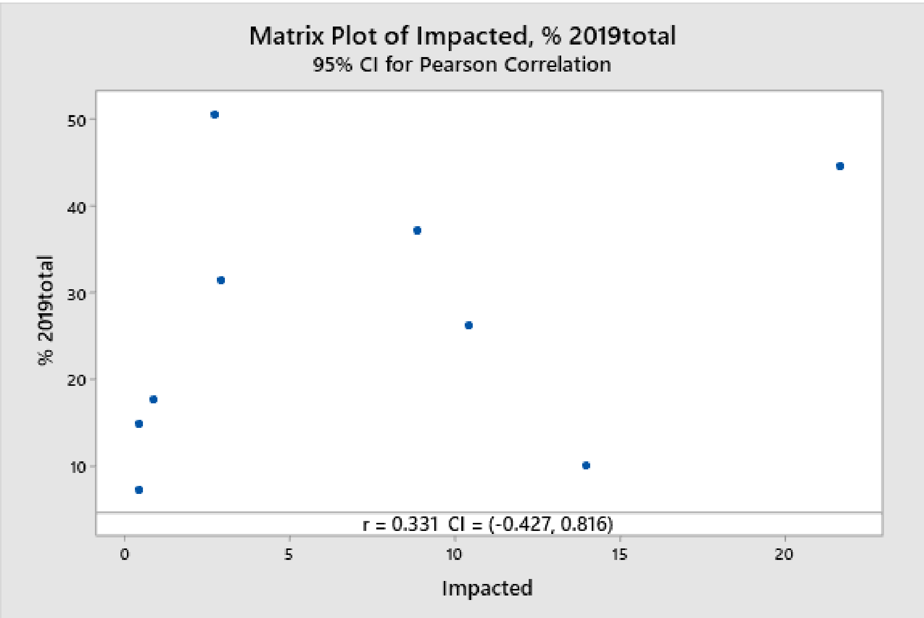
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	39.20	39.20	0.19	0.665
Error	16	3222.14	201.38		
Total	17	3261.33			

Appendix 3

Pearson's correlation between percentage of reef-builders and impacted corals

Correlations

	Impacted
% 2019total	0.331

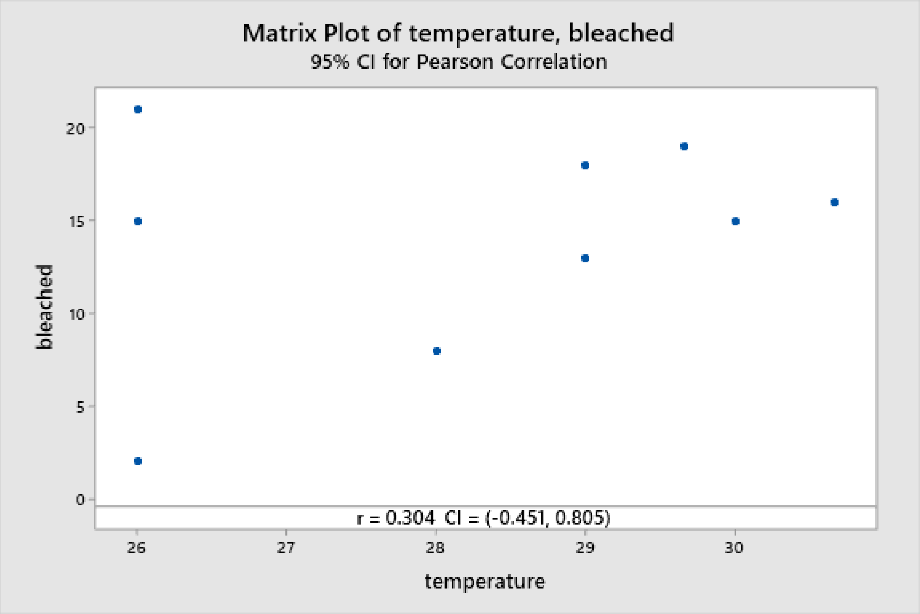


Appendix 4

Pearson's correlation for average surface temperatures and number of bleaching occurrences

Correlations

	temperature
bleached	0.304



Appendix 5

List of corallivorous fish species surveyed during the fish survey

	Corallivorous fishes
Triggerfishes	Bridled Triggerfish *Sufflamen fraenatum* Picasso triggerfish *Rhinecanthus aculeatus* Orange-lined triggerfish *Balistapus undulatus* Clown triggerfish *Balistoides conspicillum* Titan triggerfish *Balistoides Viridescens* Black triggerfish *Melichthys niger* Pinktail triggerfish *Melichthys vidua* Redtooth triggerfish *Odonus niger* Yellow margin triggerfish *Pseudobalistes flavimarginatus* Blackpatch triggerfish *Rhinecanthus verrucosus* Flagtail triggerfish *Sufflamen chrysopterum*

	Scythe triggerfish *Sufflamen bursa*
	Triggerfish unidentified
	Black-backed butterflyfish *Chaetodon melannotus*
	Chevroned butterflyfish *Chaetodon trifascialis*
	Eastern triangular butterflyfish *Chaetodon baronessa*
	Eclipse butterflyfish *Chaetodon bennetti*
	Eightband butterflyfish *Chaetodon octofasciatus*
	Long-beaked copperband butterflyfish *Chelmon rostratus*
Butterflyfishes	Meyer's butterflyfish *Chaetodon meyeri*
	Redfin butterflyfish *Chaetodon lunulatus*
	Spot-tail butterflyfish *Chaetodon ocellicaudus*
	Vegabond butterflyfish *Chaetodon vegabundus*
	Latticed butterflyfish *Chaetodon rafflesii*
	Raccon butterflyfish *Chaetodon lunula*
	Spot banded butterflyfish *Chaetodon punctatofasciatus*
	Panda butterflyfish *Chaetodon adiergastos*
	Bluestreak wrasse *Labroides dimidiatus*
	Crescent wrasse *Thalassoma lunare*
Wrasses	Humphead wrasse *Cheilinus undulates*
	Red-breasted wrasse *Cheilinus fasciatus*
	Scribbled filefish *Aluterus scriptus*
	Longnose filefish *Oxymonacanthus longirostris*
Filefishes	Barred filefish *Cantherhines dumerilii*
	Blackhead filefish *Pervagor melanocephalus*
	Filefish unidentified
	Bumphead parrotfish *Bolbometopon muricatum*
Parrotfishes	Bicolor parrotfish *Cetoscarus bicolor*
	Parrotfish general
	Blackspotted puffer *Arothron nigropunctatus*
	Blue-spotted puffer *Arothron*
	Map puffer *Arothron mappa*
Pufferfishes	Star puffer *Arothron stellatus*
	Whitespotted puffer *Arothron hispidus*
	Striped puffer *Arothron manilensis*
	Reticulated puffer *Arothron reticularis*

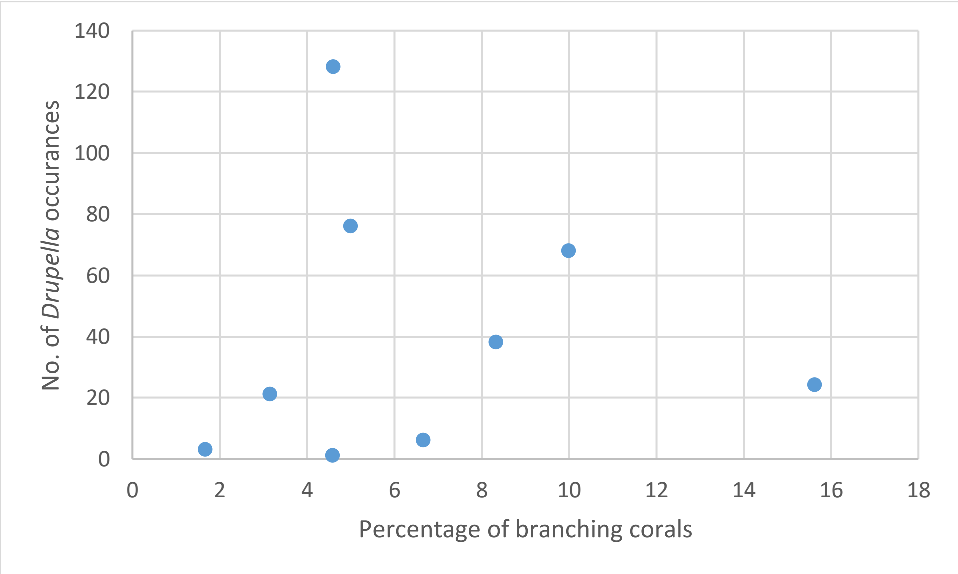
Appendix 6

List of predation correlations against percentage of reef-buildings, impacted corals and coral recently killed where those in *grey italics* were tested using Spearman's correlation those in regular text tested suing Pearson's and those in **bold** significant using Pearson's. All test were tested to a confidence level of 95%.

Variables		***Correlation coefficients***
Total predation	*Percentage of reef builders*	*0.619*
Drupella	Percentage of reef builders	0.656
Crown of thorns	Percentage of reef builders	0.329
Corallivorous fish	Percentage	0.546
Coraliophila snails	*Percentage reef builders*	*0.550*
Total Predation	*Impacted corals*	*0.412*
Total predation	*Recently killed*	*0.624*
Crown of thorns	**Recently killed**	**0.058**
Drupella	Recently killed	0.751
Corallivorous fish	Recently killed	0.193
Coraliphila snails	*Recently killed*	*0.411*

Appendix 7

Relationship between *Drupella* occurrences and percentage of branching corals



Appendix 8

Water quality data from survey sites around Malapascua and popular locations around Cebu

	Reef Master Test Kit				Saltwater Master test kit			
	pH	Ammonia (ppm)	Nitrate NO_{2}^{-} (ppm)	NitrateNO_{3}^{-} (ppm)	Calcium	Calcium hardness	Phosphate (ppm)	Salinity
Lighthouse	8	0	0	0	520	161.1	0.25	27.5
Lapus Lapus	7.8	0	0	0	440	179	0.25	27.4
Dakit Dakit	8.4	0	0	0	400	143.2	0.25	27.9
Two Rocks	7.4	0.25	0	20	440	107.4	0.25	28.9
Coral Garden	8.2	0.25	0	5	520	161.1	0.25	28.4
Sunken Dakit	8.2	0	0	0	480	161.1	0.25	28
Barrio	8	0	0	0	420	196.9	0.25	29.4
Mermaid	8.2	0	0	0	440	196.9	0.25	29.1
Bantigue	8	0	0	0	400	179	0.25	27.8
Monad Shoal	7.8	0	0	0	440	179	0.25	29
Kalanggaman	7.4	0	0	0	400	107.4	0.25	29.9
Moalboal	8	0	0	0	440	107.4	0.25	28.7
Oslob	7.4	0.25	0	0	400	143.2	0.25	29
Bohol	7.8	0	0	0	440	143.2	0.25	29
Maya	7.4	0	0	0	360		0.25	29