Coral Reefs: Anthropogenic Impacts and Restoration in the Caribbean

by

Yana Pikulak

supervised by

Gregory Thiemann

A Major Paper

submitted to the Faculty of Environmental Studies

in partial fulfillment of the requirements for the degree of Master in Environmental Studies

York University, Toronto, Ontario, Canada

July 31, 2019

Abstract

Coral reefs present a multitude of ecosystem services and benefits, but these ecosystems are becoming increasingly threatened. Internationally, coral reefs are facing a multitude of challenges with many of these deriving from or induced by human activities, and this is evident in the Caribbean. Commonly cited impacts include climate change, pollution, development, tourism, and overfishing, while less discussed but also important are marine debris and the ornamental trade. With the rise of restoration initiatives to mitigate coral reef losses, initiatives should present diverse approaches and account for complexity to mimic the intricacy of natural coral reef systems; facilitate stronger management and governance practices; and integrate a focus on novel coral ecosystems. A survey study is conducted of restoration projects located around the Caribbean Sea to apply the literature to practical examples, and outline which restoration approaches are being used, the most common human impacts that coral reefs are facing in the area, and the challenges projects are facing. 11 projects (and 12 individuals) from different locations were surveyed and quantified to depict common trends. Results outline that the majority of restoration projects present diverse, active approaches that are being implemented and or considered. There are improvements that can be made in some areas; however, considering the challenges, complexity and economic strains behind coral restoration, survey results show that achieving multi-faceted approaches requires many non-linear factors with some of the variables being beyond the control of restoration projects themselves. Ultimately, it is necessary that local governments and global networks place a stronger focus on assisting restoration projects with updating regulations and frameworks in regard to human activities, establishing standardized guidelines for restoration, and improving economic support for restoration initiatives.

Foreword

This major paper focuses on anthropogenic impacts on coral reefs and project challenges around the Caribbean Sea area, while looking at the ecosystem services, history and status of Caribbean corals, and restoration initiatives. This topic is based on my Area of Concentration: Anthropogenic impacts on tropical ecosystems. This research is meant to support my own general knowledge development of this topic and focus in on an area under this concentration. Additionally, it can also be used as an informative resource to provide a current overview of human impacts on coral reefs, what restoration approaches projects are utilizing, and challenges projects are facing. This focus on coral reefs in the Caribbean complements my components in my area of concentration (tropical ecology, wildlife conservation, and human-animal relations) and provides an interesting area for knowledge development and research. A general discussion is presented first on coral reefs and ecosystem services, human impacts, and the history and status of Caribbean reefs. This information is then followed by a case study that aims to apply this information to a practical example. The case study consists of a survey that was conducted on restoration projects throughout the Caribbean.

Acknowledgements

I would like to thank Gregory Thiemann for supervising this project and York University for allowing me to conduct this research. I would also specifically like to thank all of the restoration projects that participated in this study, and for sharing their project information, experiences, and insights. Credit must be given to all of the following projects and individuals:

* those that specified they did not want to be identified are not included on this list for privacy purposes but are credited as well. This project would not have been possible without the participating organizations. *

Doug Marcy and Krista Shoe from Coral Restoration Panama (Caribbean Coral Restoration Center, Inc- Panama)

Ana Giró from Healthy Reefs for Healthy People (Guatemala)

Mélina Soto from Healthy Reefs for Healthy People (Mexico)

Don Stark from Turks and Caicos Reef Fund

Dr. Shannon Gore from Association of Reef Keepers BVI (BVI Coral Restoration Programme)

Andrew Myers from Montserrat Reef Project

Aaron Hunt Eco Divers Reef Foundation (Cayman Islands)

Tripp Funderbunk from Bay Islands Reef Restoration (supported by Turquoise Bay Resort) (Honduras)

Victor Galvan from Fundacion Grupo Punta Cana (Dominican Republic)

Nathan Cook from Reef Ecologic (Australia)

Dr. Dave Vaughan from Plant a Million Coral Foundation (Florida Keys)

Table of Contents

Figures

1.0 Introduction

Coral reefs are not a single life form but are built up and supported by many different species (similar to forests), with corals being the primary biota (Sheppard, 2014). Corals are considered to be the main supporting species of reefs, being responsible for the majority of the structural complexity on which thousands of other species depend on for habitat and protection (Hall et al., 2015). The reef corals themselves are also diverse, which creates complex, interactive, and biodiverse reef systems that rely on this variation and diversity to thrive (Sheppard, 2014). Coral reefs occupy a small amount of space (approximately 284,000 square kilometers). This is less than 2% of the ocean, and under 1% of the Earth's surface (Ocean Portal Team, 2018), primarily because of their specific requirements to survive and flourish (Sheppard, 2014) with temperature, light, and depth being all important factors for coral reefs (Osborne, 2012). For example, they require temperatures of above 23° C and not below 18° C; are absent from areas that have upwelling of cold seawater; are typically found in clear waters that are less than 50m deep (although maximum diversity is between 15m and 30m (Osborne, 2012)); cannot tolerate freshwater discharge, thrive best in areas with moderate to high wave action where seawater gets aerated; and are only located through-out tropical ecosystems (Sheppard, 2014; Mladenov, 2013). Although corals themselves can and do grow in colder temperatures, they do not form reefs as they cannot deposit limestone or calcium due to the cold temperatures and lack of light (and subsequently lack of zooxanthellae algae) (Osborne, 2012).

Coral reefs are considered to be some of the most biodiverse ecosystems (Carpenter et al., 2008; Rinkevich, 2005), with the Caribbean being the second highest in diversity after the Indo-Pacific (Osborne, 2012; Knowlton, 2008). The reefs support approximately 6,000 fish species (Hughes et al. 2017), and roughly a quarter of marine species depend on reefs for shelter and food (Ocean Portal Team, 2018). They are very important ecologically but also for human communities by providing ecosystem services (Barbier et al., 2011; Moberg and Folke, 1999). Island and coral coastal communities derive an extensive amount of their protein from coral reefs, and they are also a significant source of income and protection from coastal erosion (Barbier et al., 2011; Cinner, 2014). However, coral reefs are not fixed in time and space, having evolved over millions of years, transforming species and colonies (Graham et al., 2013; Sheppard, 2014; Osborne, 2012; Carpenter et al., 2008).

Human impacts on coral reef ecosystems have a fairly long history (Graham et al., 2014;

Carpenter et al., 2008). However, over the last few decades coral species and reefs have begun facing increasing impacts and challenges deriving from anthropogenic activities which catalyze the effects of impacts and degradation, and reduce resiliency (Carpenter et al., 2008; Hughes et al., 2017). The Anthropocene era is developing a multitude of human stressors on ecosystems, including coral reefs (Wilkinson, 2006), via climate change, local stressors, and additional issues stemming from globalization/migration (Hughes et al., 2017; Alvarez-Filip et al., 2009). Numerous influencers of ecosystem change like overharvesting, climate change, pollution, tourism, development, international trade, and or invasive species introduction result in species and population abundance alterations and declines (Graham et al., 2014, p. 9; Bellwood et al., 2004; Knowlton, 2001). Some impacts are still being evaluated and or are mentioned less frequently among literature such as microplastic pollution impacts on corals (e.g. Hall et al., 2015; Lamb et al., 2018) and the ornamental trade (e.g. Moberg and Folke, 1999, Thornhill, 2012). Unfortunately, regardless of their incredibly high biodiversity, coral reefs are susceptible to losses in functionally significant species (Hughes et al., 2017, p. 86). The International Union for Convention of Nature's Red List of Threatened Species (IUCN Red List, 2019) argues that 33% of reef corals, or approximately one-third, are currently threatened (also confirmed by Carpenter et al., 2008); however, this does not account for all coral species and thus this number is probably higher in reality.

Various restoration efforts have been launched and there is an increase in research and conservation initiatives (Hein et al., 2017), but there are still many knowledge gaps. Coral restoration initiatives should use a multitude of approaches and species in restoration efforts (Rinkevich, 2005), as well as improve monitoring (Hein et al., 2017; Hughes et al. (2017), governance and management techniques for degradation and restoration (Graham et al., 2014; Hein et al., 2017; Hughes et al., 2017), societal changes and global coordination (Hughes et al., 2017; Knowlton, 2008), increased active restoration globally (Hughes et al., 2017; Shafir et al., 2006) and generally more research. However, there must be a generally stronger, realistic focus placed on the constraints of restoration projects themselves in relation to the overwhelming amount of impacts and complexity behind coral restoration, and more focus on putting pressure not just on restoration projects themselves, but also on government and global support in order to deal with the scale of impacts on coral reefs in an efficient and timely manner.

A survey is conducted in an effort to apply academic literature to a practical, field-based example, and to gain a better understanding of the status of restoration projects throughout the Caribbean (primarily the Caribbean Sea) in regard to restoration methods, human impacts, and challenges. Participants were asked a variety of questions relating to the age of the project, which restoration techniques and species are utilized in initiatives, stakeholder engagement, project challenges, human impacts, marine debris status, and the health status of coral reefs in each project's area. Survey areas include Panama, Honduras, Mexico, Guatemala, Haiti, Turks and Caicos, Curacao, British Virgin Islands, Cayman Islands, Montserrat, and Dominican Republic. 11 projects (and 12 individuals in total) participated and are counted in the survey tallies. Survey results show that projects were fairly compatible with the academic literature in relation to the human impacts and need for complexity. However, achieving multi-faceted approaches requires many factors which are not necessarily straight-forward, with some of the variables being beyond the control of restoration projects themselves, such as sociocultural and economic issues. The vast amount of human impacts identified in the case study (see section 7.7 of case study) is also another example of complexity and non-linearity, challenging coral health and efficiency of restoration efforts. Thus, there needs to be stronger consideration from government agencies and global bodies to support restoration and coral reef conservation from not only a financial standpoint, but also legal/management frameworks that improve regulation of human activities, impacts, and overall project management.

2.0 Ecosystem Services and Significance

There is a strong relationship between the impacts of anthropogenic activities on ecosystems, and the reliance of humans on ecosystems for services that support human well-being such as food and water security, spiritual and aesthetic purposes, environmental protection, and income (Hughes et al., 2017, p. 84; Barbier et al., 2011). Coral reefs play a very important role environmentally, economically, and socially. They are considered to be the most biodiverse marine systems (Hoegh-Guldberg et al., 2014; Carpenter et al., 2008; Knowlton and Jackson, 2008; Knowlton, 2001) and are a keystone species (Sheppard, 2014; Mladenov, 2013). For this reason, these ecosystems are often viewed as the "rainforests of the sea" (Mladenov, 2013; Knowlton, 2001; Shafir et al., 2006), supporting a complex web of marine life, including their own development, and high productivity rates (Mladenov, 2013; Sheppard, 2014; Knowlton, 2001) which support ecosystem services (Alvarez-Filip et al., 2009). Unfortunately, they are prone to losing functionally significant species (Hughes et al., 2017, p. 86; Pratchett et al., 2014). With habitat degradation and loss, species that are important for maintaining habitats are being lost and replaced with less complex organisms which also impacts fish stocks and population abundance that human communities rely on (Pratchett et al., 2014). As the structural complexity of reefs becomes altered and complexity is reduced, it is highly likely that continuing human impacts and local stressors will pose negative impacts on ecosystem services (Graham et al., 2013; Bellwood et al., 2004; Hoegh-Guldberg et al., 2007; Alvarez-Filip et al., 2009).

Coral reefs, when healthy, maintain very high rates of production (Sheppard, 2014) which not only maintain healthy ecosystem function but also provide ecosystem services to human communities (Carpenter et al., 2008; Moberg and Folke, 1999; Barbier et al., 2011; Hoegh-Guldberg et al., 2007). Ecosystem services (services perceived to be economically, socially, and ecologically valuable by humans) deriving from coral reefs are an integral part of human societies, especially for coastal communities (Sheppard, 2014; Barbier et al., 2011), producing food, economic gain via tourism and trade, habitat protection, and maintenance of human wellbeing and livelihoods (Moberg and Folke, 1999; Hoegh-Guldberg et al., 2007; Carpenter et al., 2008; Mumby et al., 2008; Bellwood et al., 2004; Barbier et al., 2011; Cinner, 2014). However, with human activities and increasing environmental issues jeopardizing coral health, these ecosystem services are becoming increasingly threatened (Carpenter et al., 2008; Hoegh-Guldberg et al., 2007; Barbier et al., 2011; Knowlton, 2001). Ensuring ecosystem services are available for future generations is necessary; however, this is challenging as there must be improvement in governance and conservation frameworks in regard to ecosystem management (Hughes et al., 2017). This becomes even more challenging in the tropics, where there are many developing areas with high amounts of biodiversity hotspots who need to simultaneously account for both conservation needs and human development (Hughes et al., 2017). It is important to note that there are still many gaps in relation to evaluating the true income and amount of ecosystem services deriving from coral reefs as well as other coastal ecosystems (Barbier et al., 2011; Rinkevich, 2005). However, even with current estimates (see 2.2) and outlined services, there is a vast amount of contribution from coral reefs to human communities.

2.1 Social Benefits

Coral reefs provide vast amounts of social benefits to human populations. Coastal communities, for example, are heavily reliant on marine ecosystems and coral reefs for well-being, including aesthetic connection[1], sustenance, livelihood, and environmental protection (although this factor is also a category on its own). Local island and coral coast communities typically obtain an extensive amount of their food sources and protein intake from fishing or harvesting species at low tides (Sheppard, 2014, p. 2; p.18). However, coral reefs also provide a significant amount of food globally, as approximately 10% of all fish consumed globally are caught on coral reefs (Mladenov, 2013; Moberg and Folke, 1999), with some areas (as in Indonesia) having up to 25% reef-based fish (Moberg and Folke, 1999). Coral reefs support a variety of species that humans rely on for consumption such as mussels, fish, crustaceans, sea cucumbers, and sea weed (Moberg and Folke, 1999). Corals are also collected by pharmaceutical companies for possible links to anticancer, anti-inflammatory, antimicrobial, and anticoagulant properties, as well as bone grafting operations in the medical field from coral skeletons (Moberg and Folke, 1999). Coral reefs also hold aesthetic value as well as cultural and spiritual value, with some tropical coastal communities using the perspective of traditional management and appeasing nature gods taking priority and influencing environmental management practices such as in fisheries (Moberg and Folke, 1999). Unfortunately, the increasing degradation of coral reefs on a global scale is a large conservation issue with increasing human activities and pressure. There are various estimates for the amount of people living around coral reefs. Estimates suggest that approximately 450 million people live close to coral reefs (although distance is not specified) (Pandolfi et al. 2011), 1/8 of humans (about 875 million people) live around 100 km (Mladenov, 2013), and in 2014 approximately 275 million people were living within 30km of reefs. Regardless, this is a high population, with the majority living in developing countries and island communities (Mladenov, 2013) that rely heavily on coral reefs for food security and overall livelihood (Lamb et al., 2014; Pandolfi et al., 2011). However, this number may have risen since with increasing development of coastal communities and growing tourism, placing more demand on reefs.

---

[1] Aesthetic connection is discussed here in cultural and psychological terms. Some cultures have a strong connection to their natural spaces, including coral reefs and their health. Psychologically, many avid divers, snorkellers, and marine ecosystem enthusiasts derive happiness from being around or seeing healthy coral ecosystems.

2. 2 Economic Benefits

Coral reefs play a significant role in the global economy through tourism and trade (Sheppard, 2014, p. 1; Mladenov, 2013, p.77; Barbier et al., 2011; Hoegh-Guldberg et al., 2007). Many coral reefs are close to coastal communities and reef tourism can account for approximately 40 to 80% of national income for some coral island nations (Sheppard, 2014, p. 18). In 1990, tourism in the Caribbean accounted for $8, 900, 000, 000 US and provided jobs for over 350 000 people (Moberg and Folke, 1999). Globally, these ecosystems are believed to value approximately 30-172 billion US annually in jobs, tourism, medicine, aesthetic pleasure, environmental support, and food (Ocean Portal Team, 2018), while Cinner (2014) states that global estimates put the total amount at 375 billion. Considering reefs provide 10% of global fish consumptions globally as well (Mladenov 2013; Moberg and Folke, 1999), with some areas being even higher, this no-doubt accounts for a plentiful amount of economic gain for human communities in the global fish market (Barbier et al., 2011). Red coral, for example, was heavily prized in the ornamental trade in the 80s and 90s, with roughly 1500 tons of coral imported to the US back in 1988 for the souvenir trade and 250 000 live coral imported in 1991 (Moberg and Folke, 1999). Diving-based tourism is a large source of income and this sector may be impacted with increasing coral degradation (Graham et al., 2013; Hoegh-Guldberg et al., 2007). With escalating coral degradation and human impacts coupled with the ecological changes on the reef, there is a rising demand for establishing alternative sources of income from marine ecosystems and curbing destructive practices (with some looking to ecotourism, although tourism itself comes with its own share of issues of human impacts on ecosystems) (see section 3.5) (Lamb et al., 2014).

2. 3 Ecological Benefits

Coral reefs evidently come with a plethora of ecological benefits and are fundamental to environmental protection. As a keystone species, they are interconnected to many other species of fish, seagrasses, mangroves and other flora and fauna. As briefly mentioned above, they are known to be one of the most biologically rich systems in the world and therefor help to support biological diversity and species richness, acting as fundamental breeding, spawning, nursery, and feeding areas (Moberg and Folke, 1999; Barbier et al., 2011; Knowlton, 2001). As complex keystone ecosystems, they house an extensive amount of species, supporting roughly one quarter of all marine plant and animal life (or approximately 2 million different marine species) (Mladenov, 2013). Furthermore, they provide protection against land erosion by acting as a mitigator against hurricanes, and minimizing wave intensity and storm impacts (Sheppard, 2014; Mladenov, 2013; Moberg and Folke, 1999; Hoegh-Guldberg et al., 2007; Graham et al., 2013; Barbier et al., 2011; Hoegh-Guldberg et al., 2007; Alvarez-Filip et al., 2009). In turn, this helps seagrass and mangroves establish which then help to mitigate fresh water discharge and act as absorbers of pollutants and excess nutrients, making water more clear and nutrient-poor, allowing coral reefs to further grow (Moberg and Folke, 1999; Barbier et al., 2011). They also act as important land builders, specifically in tropical areas where they contribute to the formation of islands and expansion of shorelines (Osborne, 2012). Similar to trees, coral reefs also act as a carbon sink but can be sources of CO2 (although the comparison to human emissions is extremely miniscule), and they can act as detoxifiers of water, sequestering waste deriving from human impacts (Moberg and Folke, 1999; Barbier et al., 2011).

3.0 Corals, Reefs and Human Impacts

Corals and reefs are some of the most threatened ecosystems (Pratchett et al., 2014; Knowlton and Jackson, 2008), facing a multitude of challenges that are globally degrading and structurally altering their compositions at an accelerating rate (Hein et al., 2017; Pratchett et al., 2014; Bellwood et al., 2004; Knowlton, 2001). The IUCN Red List (2019) suggests that 33% are threatened but this does not account for the overall degradation rate, and approximately a quarter are considered dead while another half are degraded (Sheppard, 2014, p. 19). Climate change, development, overfishing, tourism, pollution from sewage runoff and sedimentation, and diseases are some of the common threats and stresses on corals and reefs that are discussed in literature (e.g. Hoegh-Guldberg et al., 2007; Lamb et al., 2014; Hughes et al., 2017; Altieri et al., 2017; Seemann et al., 2014; Bellwood et al., 2004; Avarez-Filip et al., 2009; Carpenter et al., 2008, Knowlton, 2001; Wilkinson, 2006). However, there are other factors which are mentioned less but are also impacting corals and reefs such as marine debris and plastic (macro and micro plastics) pollution (e.g. Richards and Beger, 2011; Gall and Thompson, 2015; Hall et al., 2015; Lamb et al., 2018) and the wildlife/ornamental trade (e.g. Thornhill, 2012; Dee et al., 2014). Additionally, impacts are also often compounding and can feed off of each-other (Hughes et al., 2017; Lamb et al., 2014), making management relatively difficult. Historical impacts such as overfishing or land-clearing, for example, can influence how some corals respond to modern issues such as climate change, making impacts more prominent (Cramer et al., 2012; Hughes et al., 2017; Carpenter et al., 2008).

Connecting coral disease outbreaks directly to humans can be fairly challenging due to little baseline data and the extensive number of pathogens (Knowlton, 2001). However, it is argued that coral diseases and outbreaks can be related to coral reef degradation associated with increasing human impacts such as run-off, as this places additional stress on coral and increases vulnerability (Knowlton and Jackson, 2008; Knowlton, 2001; Wilkinson, 2006). As human activities lead to environmental changes, this may reduce the ability of corals to combat microbial diseases and pathogens (Lamb et al., 2014; Knowlton, 2001). Proximity to human communities, alteration of coastal land, runoff from terrestrial sediment and agricultural chemicals, human sewage run-off, aquaculture, sunscreens (Lamb et al., 2014; Wilkinson, 2006) and marine debris (Lamb et al., 2018) are contributors to this. These human impacts do not solely impact coral diseases, but also coral reefs as a whole on multiple scales. All of these impacts influence coral health, composition, and ultimately resiliency (Bellwood et al., 2004; Hughes et al., 2017; Carpenter et al., 2008). Some argue that there are still populations of coral reefs in unpopulated, uninhabited areas that may be in good condition (e.g. Graham et al., 2014). However, others (e.g. Hughes et al., 2017; Knowlton and Jackson, 2008) argue that at this point, tropical ecosystems and many coastal populations have been impacted to some extent and there are probably few colonies that have been completely untouched or unaffected, even those in remote areas.

Although research on coral reefs and restoration is increasing, it is still limited in comparison to other fields and due to the rising degradation issues, it is argued that biological research on coral reefs may be time sensitive (Sheppard, 2014). However, it is also pointed out that coral reefs are evolving in response to stressors and their colonies are becoming modified structurally and biologically (Graham et al. 2014; Bellwood et al., 2004). The degradation and alteration of coral reefs by human impacts has been occurring for centuries (Graham et al., 2014; Hughes et al., 2017; Cramer et al., 2012). Accounting for these structural and biological changes and noting the scale of human communities and other species coral reefs support, their importance in marine ecosystems and environmental stability, and the increasing impacts they are facing, coral research and conservation is crucial. Global commitment is necessary and

Hoegh-Guldberg et al. (2007) adds that coastal resource policies and reef managers need to focus on reducing local stressors to management reef degradation. However, although there are projects focusing on restoration, unfortunately there is still a lack of serious commitment by governments and authorities to focus on coral protection and mitigate coral degradation and impacts on reefs (Sheppard, 2014).

However, in order to address the scale of impacts ecosystems are facing, there must be a stronger socio-ecological management framework that emphasizes distal[2] human activities (e.g. human population, markets, socio-economic development, cultural values, and governance) instead of just proximal drivers [3] (e.g. fishing, pollution, climate change) (Hughes et al., 2017; Bellwood et al., 2004). This is problematic as core issues are reduced and simplified into primarily ecological and biological issues, but do not effectively address the underlying causes (Hughes et al., 2017). This factor is evident in many environmental management approaches, and Sheppard (2014) argues that one of the main issues that is rarely discussed is the issue of human population (in regard to the excess resource consumption and scale of environmental degradation). This relates to how we identify and disentangle human impacts and ecological stresses and is evident in coral conservation. Connecting stressors to possible causes in order to mitigate coral decline and manage health is difficult (Lamb et al., 2014), such as with coral bleaching for example. Pigmentation issues in coral tissue has been connected to basic immune responses to pathogens or physical damage such as from diving or snorkeling (Lamb et al., 2014). Management strategies focusing on reducing or restricting activities that impact coral health can also be challenging as many coral reefs are located in low-income countries, making enforcement problematic as placing restrictions on natural resources can be detrimental to local community livelihoods (Lamb et al., 2014, p. 94). These human impacts and some of these challenges are evident throughout the Caribbean as the case study depicted (see section 7.6 and 7.7).

3.1 Climate change

Climate change is considered to be one of the primary issues impacting the health of

[2] Distal drivers: "traits in social systems that indirectly influence how people interact with coral reefs" (Hughes et al., 2017, p. 84)
[3] Proximal drivers: facts that "directly affect coral reef ecosystems" (Hughes et al., 2017, p. 84)

oceans, and simultaneously corals and coral reefs on an international scale by altering sea surface temperatures, metabolic rates and oxygen levels (Weis, 2015, p. 163;165), fresh water input levels and an increase in thermoclines (Seemann et al., 2014), and storm intensity and frequency (Wilkinson, 2006) which impacts coral growth and their ability to survive rising sea levels (Knowlton, 2001). Some of these changes can then act as a gateway to other issues such as bleaching (Seeman et al., 2014), hypoxia (Altieri et al., 2017), diseases (Knowlton and Jackson, 2008; Wilkison, 2006) etc. Although climate change is one of the more prominent issues discussed, other anthropogenic threats are also significant to ecosystem functioning, biodiversity, and ecosystem services of coral reefs, and impacts are typically compounding (Hughes et al., 2017; Pandolfi et al., 2011; Wilkinson, 2006). In regard to climate change, the historical degradation of coral reefs through overfishing and pollution has already left an impact on some colonies (Cramer et al., 2012; Knowlton and Jackson, 2008) and thus with added climate change placing further stress (Carpenter et al., 2008), resiliency and stress-coping ability is reduced (Pandolfi et al., 2011; Anthony et al., 2011). Some argue that climate change will decimate reefs completely; however, this varies among species, the extent of impacts some species or colonies have faced historically and more recently and can vary based on geographic locations, global rise in temperature and sea surface temperatures (Graham et al., 2014; Bellwood et al., 2004). However, there are range shifts occurring where the sea surface temperature changes from climate change and other environmental conditions (e.g. currents) being altered, creating a shift towards to poles for coral reefs and establishing new compositions (Hughes et al., 2017, Graham et al., 2014; Knowlton and Jackson, 2008). Cramer et al. (2012) similarly outlines that the decline of coral reefs in the Caribbean began decades prior to impacts of coral disease and bleaching linked to human-induced climate change, with historical stresses including land-clearing and overfishing. However, the increasing issue of climate change exacerbates the historic impacts of local disturbances (Cramer et al., 2012).

One factor that must be outlined however is that coral reefs have already faced three pan-tropical episodes of intense coral bleaching over the last three decades (1997-1998, 2010, 2015-2016) due to warming by 1 degree Celsius above pre-industrial levels (Hughes et al., 2017, p. 82). The target of the Intergovernmental Panel on Climate Change (IPCC) (COP 21 Paris agreement) outlines initiatives to limit temperature increases to 1.5 degrees Celsius; however, these measures are deceptive when it comes to understanding future changes in coral reef colonies due to the variation of warming between oceans and land, their latitudinal gradients, and overall geographical differences in temperature (Hughes et al., 2017). These variations depict that there is no global safety standard for how much warming or emissions coral reefs can handle and there will be future differences of temperature increases across time and space (Hughest et al., 2017). However, ultimately, climate change can pose a variety of issues for corals and reefs can result in a multitude of effects.

3.1.1 Coral Bleaching

Coral bleaching is considered to be a common effect arising from climate change and global warming that is seen on corals and reefs. Bleaching events are connected to rising water temperatures and are characterized by corals expelling the photosynthetic symbiotic algae called zooxanthellae (Sheppard, 2014; Neal et al., 2017; Weis, 2015; Hoegh-Guldberg et al., 2007; Knowlton and Jackson, 2008). The white discolouration seen on the coral reefs during or following bleaching events is the underlying limestone skeleton. Zooxanthellae are very sensitive to stress (including temperature changes), and when they die or become expelled, the bleached corals are typically not able to achieve their required energy levels by sole filter feeding (Weis, 2015). Research has shown that these bleaching events result in reduced growth (Knowlton and Jackson, 2008) (short or long-term depends on colony and scale of bleaching), decreased reproduction, colony fragmentation, and a rise in coral diseases (Neal et al. 2017; Hoegh-Guldberg et al., 2007). Depending on the extent of stress of coral reefs, sometimes zooxanthellae can return, and corals can survive (Weis, 2015; Hoegh-Guldberg et al., 2007), but their health might still be impacted and leave them less resilient (Hoegh-Guldberg et al., 2007). In instances of repeated or long-term stress, the corals will not be able to recover. Unfortunately, with increasing ecological changes deriving from human-induced climate change and other local stressors, bleaching events and related mortality rates are predicted to become more frequent and intense (Neal et al., 2017; Hoegh-Guldberg et al., 2007; Anthony et al., 2011).

Some coral colonies/species appear to be more tolerant of climate change and heat stress than others (as noted above). Interestingly, there is genetic diversity among zooxanthellae, and it is outlined that some colonies of zooxanthellae may also be more heat tolerant than others (Weis, 2015; Knowlton, 2001). Certain proteins in zooxanthellae can react suddenly and intensely to temperature stress and can be used as indicators of stress, while some heat-resistant genes can allow some corals in particular areas to persist in conditions that might kill eliminate other corals (Weis, 2015). However, as temperatures increases, it is predicted (and already evident in some areas like Florida peninsula and the Gulf of Mexico with the *Acropora* genus) that coral reefs will begin shifting towards the poles (Graham et al., 2014; Hughes et al., 2017).

Phytoplankton are impacted as well, with predictions that increasing ocean temperatures will result in diversity and abundance reductions in tropical ecosystems, and movement towards the poles as well, ultimately impacting feeding among coral colonies (Weis, 2015). Linking stressors with their potential causes can sometimes be difficult however due to compounding effects (Lamb et al., 2014). As briefly mentioned above, bleaching is one example of this where the process of bleaching has been connected to a variety of stressors including temperature and light changes, ocean acidification, bacterial infections, herbicides, and sunscreen (Lamb et al., 2014). Bleaching events do not only impact coral, however, but also the species that rely on the reefs. Coupled with other impacts such as eutrophication, sedimentation, and turbidity, an increase in bleaching intensity and regularity can lead to a loss of organisms that associate with the impacted species such as fish and other invertebrates, or larger keystone species such as nurse sharks (Seemann et al., 2014). This is exemplified in the increasing loss of *Siderastrea siderea* (massive starlet coral) as nurse sharks use these larger coral species for shelter (Seemann et al., 2014, p. 1761). Coupled with other human stressors and acidification, coral bleaching can change coral dynamics and reduce resiliency among coral reefs (Anthony et al., 2011).

3. 1. 2 Acidification

Acidification is another impact on coral reefs deriving from human-induced climate change that is commonly discussed (Knowlton and Jackson, 2008; Anthony et al., 2011) as approximately 25% of anthropogenic CO2 emissions is absorbed by the oceans (Hoegh-Guldberg et al., 2007). Similar to warming, ocean acidification impacts on corals are also exacerbated by local issues and human activities (Pandolfi et al., 2011). Ocean acidification is caused by increasing CO2 in the atmosphere which makes the seawater more acidic (Mladenov, 2013; Anthony et al., 2011). This process makes it more difficult for coral reefs to create their calcium carbonate skeletons which is damaging to hard, reef-building corals (Mladenov, 2013; Anthony et al., 2011; Knowlton and Jackson, 2008). To build their skeletons, reef-building corals combine calcium ions and carbonate ions that are dissolved in the seawater; however, CO2 reacts with the water to create carbonic acid (Mladenov, 2013; Hoegh-Guldberg et al., 2007). This creates a positive feedback loop in which the acid reacts with the carbonate ions and turns them into bicarbonate ions and protons that further react with carbonate ions to create more bicarbonate ions, reducing availability for corals (Mladenov, 2013; Hoegh-Guldberg et al., 2007). Subsequently, corals must use excess energy to create their skeletons and this reduces their growth rates while simultaneously creating more stress and making them more open to diseases and other impacts (Mladenov, 2013). This reduction in resiliency in corals impacts system dynamics, especially in combination with other local stressors (Anthony et al., 2011). It is suggested that with increasing CO2 levels and acidification, corals and other organisms with calcium carbonate skeletons will stop growing altogether and result in death (Mladenov, 2013). Although this may be species-dependent as in the case of reactions to temperature among coral species, by 2050 it is suggested that carbon dioxide levels will increase to the point where only some sections of the ocean will be habitable for reef-building corals (Mladenov, 2013). Acidification is also outlined to be a possible catalyst for coral bleaching (Anthony et al., 2011).

Interestingly, some argue that ocean acidification is a less pressing issue for coral reefs than typically described. Altieri et al. (2017) for example note that coral reefs can generally endure a variety of pH level fluctuations and that coral survival rates are not strongly impacted by acidic conditions. Hughes et al. (2017) further argues that although increasing acidic conditions will have some effects, pollution, overfishing, and warming are more pressing in contributing to mass bleaching events. There is a needed improvement in experiments focusing on temperature and ocean acidification to gain a stronger understanding of how impacts interact on coral reefs (Hughes et al., 2017; Knowlton and Jackson, 2008), especially since coral reactions to acidification can vary (Hoegh-Guldberg et al., 2007; Pandolfi et al., 2011). But considering the general connection of acidification (and warming) to coral degradation over time, it is argued that both global and local impacts contribute to reduced resiliency (Anthony et al., 2011).

3. 2 Pollution

Various forms of pollution can impact the health of corals and reef communities as they are vulnerable to pollution impacts (Richards and Beger, 2011). Marine pollution exists from various human activities like agricultural run-off and excess nutrients, substance pollution (e.g.

oil spills), excess sedimentation from development and other activities (e.g. tourism), and marine debris and plastic pollution (Carpenter et al., 2008; Barbier et al., 2011; Hall et al., 2015; Lamb et al., 2018; Sheppard, 2014). Although some species and colonies can respond differently to stressors (as discussed above), pollution impacts still pose numerous challenges to corals and reefs on a variety of levels. Diseases in corals for example are often linked to added pathogens, nutrients, or other pollution associated with wastewater (Lamb et al., 2014); however, they can also be linked to increases of plastic waste that harbor pathogens (Lamb et al., 2018). Marine debris can also cause physical harm to corals (Gall and Thompson, 2015; Richards and Beger, 2011; Donohue et al., 2001) through abrasions or entanglement which can further reduce light and oxygen availability for corals (Richards and Beger, 2011), or be ingested in the case of microplastics (Hall et al, 2015).

Issues such as excess run-off is another main problem associated with pollution as it depletes oxygen levels and results in eutrophication (Mladenov, 2013; Altieri et al., 2017). In Bocas del Toro, Panama, for example, coral reef communities are heavily degraded in certain areas due to increasing anthropogenic activities (Seeman et al. (2014). Particular areas are exposed to creeks, rivers, and oceanic inlets that transport sediment from rivers connected to Costa Rica and other areas of Panama, and are vulnerable to other human influences like land-use changes and effluents (Seeman et al., 2014). Increasing development of banana and teak plantations, pasture land, and shipping traffic have further resulted in pollution and sedimentation (Seeman et al., 2014). These issues are prevalent throughout the Caribbean as outlined in the case study of this paper (see section 7.7). Two topics associated with pollution are outlined below: dead zones, and plastic/marine debris.

3. 2. 1 Dead Zones

Marine ecosystems, especially coastal areas, are found to be quite stressed from excess nutrient runoff, depleting oxygen levels from marine ecosystems as decomposition occurs (eutrophication) (Mladenov, 2013). The two main nutrients involved in this process are nitrogen and phosphorus, both contributing to algal blooms. Both are heavily related to agricultural run-off from fertilizers that translocate via streams and other waterways, finding their way into lakes and oceans. Excess phosphorus also derives from sewage waste run-off that contains both human and animal waste, while nitrogen further derives from deforestation, burning fossil fuels and organic matter (Mladenov, 2013). As the excess bacteria and plankton from algal blooms dies off, it depletes oxygen levels in marine systems (Mladenov, 2013). If oxygen levels become depleted below what is required to sustain surrounding marine species, temporary or permanent dead zones can occur (Mladenov, 2013).

Algal blooms and dead zones are on the rise globally and are extremely common in areas where there is intensive agricultural activity and sewage run-off (Altieri et al. 2017; Mladenov, 2013); however, there is little known about the extent of the impacts of hypoxic areas on and in tropical ecosystems, nor the possible impacts on coral reefs (Altieri et al., 2017). This is significant as these zones are extremely detrimental to marine life and also impact human activities, resulting in a biodiversity loss, fishery collapse, and increased mortality in fish (Mladenov, 2013). Bioaccumulation of toxins from algal blooms also occurs and further impacts the health of marine species as well as human health as humans that feed on these intoxicated species can develop neurological, gastrointestinal, and respiratory issues (Mladenov 2013).

Hypoxia is connected to coral bleaching, as well as mass mortalities of reefs and other organisms, and it is depicted that stress from hypoxia can be enough to induce coral bleaching and death among corals aside from non-stressful temperatures (Altieri et al., 2017). However, although impacts can be significant, similar to thermal stress, there is variation in coral responses and tolerance to hypoxic stress (Altieri et al., 2017). It is also possible that due to the variations of stress on corals and reefs from human impacts and climatic changes, some corals may respond differently based on former stress levels and adaptability. There can be also be a lag time between when corals experience stress and when they begin to show the signs of that stress, although this can vary among species and colonies (Neal et al., 2017).

Unfortunately, roughly 13% of coral reefs worldwide are at an increased risk of hypoxia due to rising exposure to anthropogenic impacts and low oxygen conditions, as well as their proximity to human settlements and untreated sewage runoff, and semi enclosed bays that can support the formation of dead zones (Altieri et al., 2017). Additionally, large pieces and or amounts of debris can contribute to hypoxia as it prevents gas regulation (Richards and Beger, 2011). Yet, impacts of hypoxic events on coral reefs are not often discussed, nor incorporated into many studies or conservation initiatives (Altieri et al., 2017). This is further coupled with a lack of general scientific research and monitoring in tropical ecosystems in comparison to temperate regions, leading to an underrepresentation of the hypoxic issue (about 10x more reporting in temperate regions over tropical) (Altieri et al., 2017). These factors can be attributed to the historically higher use of fertilizers in developed countries, but coastal communities in developing countries are growing their communities and increasing their agricultural activities and sewage/run-off output, while maintaining poor regulation in regard to human activities and environmental management practices (Altieri et al., 2017). Conservation and restoration projects also typically do not conduct oxygen level testing in monitoring practices which makes it challenging to identify coral mortality rates following hypoxic events (Altieri et al., 2017). Some of these issues were also depicted in the case study results below (see section 7.6 and 7.7) as many of the participating countries have socioeconomic issues and outlined development, sedimentation, and run-off as common issues. This calls for not only a necessity to regulate terrestrial inputs (e.g. regulating agricultural and development activities), but also improving awareness in local communities and monitoring approaches (Altieri et al., 2017). Yet, this must also be coupled with stronger support for restoration projects by governments and global communities (Wilkinson, 2006).

3. 2. 2. Plastic Pollution and Marine Debris

Marine debris derives from both marine and terrestrial sources. Some marine debris derives from littering at-sea such as from cruise lines, fishing boats, and other boats (Mladenov, 2013). Boats are also responsible for debris, as plastic trash is routinely dumped from commercial and recreational boats (Mladenov, 2013) such as fishing lines and nets (Donohue et al., 2001). However, the majority of marine debris comes from land-based sources, with approximately 80% deriving from land (Mladenov, 2013; Richards and Beger, 2011; Donohue et al., 2001; Katsanevakis, 2008), large amounts of discarded plastics are sourced into the oceans either directly or indirectly through waterways (rivers, streams, and lakes feeding into the ocean), overflowing sewers, and storm drains during heavy rainfall (Gall and Thompson, 2015; Katsanevakis, 2008). The persistence of some of this debris is extremely problematic (Gall and Thompson, 2015) impacting not only the quality of water but also marine species, causing entanglement, ingestion issues, physical damage (Richards and Beger, 2011; Gall and Thompson, 2015; Donohue et al., 2001) and bioaccumulation issues (Mladenov, 2013). Plastic pollution is one example of persisting debris. Polystyrene (styrofoam), for example, can break down into micro-plastics, persisting in sediment or suspending and travelling (Mladenov, 2013).

Depending on the size, these particles can bioaccumulate or be ingested by other species (Hall et al, 2015). In the Caribbean, along one kilometer of shoreline there can be roughly 1900 to 11,000 items of plastic debris (Mladenov, 2013) and this does not necessarily account for microplastics. Unfortunately, there is still little research on marine debris impacts on coral reefs (Gall and Thompson, 2015) and this outlines a significant gap in knowledge considering the scale of marine debris pollution.

Although mitigation measures are becoming more prominent through international and local policies that focus on reducing the flow of plastic debris into waterways and banning disposal in the oceans, lack of enforcement is a big issue (Mladenov, 2013). Furthermore, many island communities and or developing countries and regions do not have efficient waste systems (Richards and Beger, 2011; Altieri et al., 2017; Gall and Thompson, 2015) nor monitoring. This makes tackling the issue extremely difficult and an obvious necessity to focus on minimization of impacts and systematic waste improvements.

Some research exists on plastic pollution impacts on corals and reefs, but the focus has been predominantly on other species in regard to entanglement and ingestion studies. Prominent marine debris and plastic impacts on coral are usually outlined to be entanglement-related (e.g. Donohue et al., 2001) or trash covering corals and reefs which then reduces the amount of light they receive, impacting zooxanthellae and the ability to feed, and causing suffocation (Richards and Beger, 2011). However, more research must be conducted on the intricate and complex impacts plastic pollution and marine debris overall may have on corals directly. Microplastics and microplastic ingestion by corals is also an issue. When plastics get broken down into micro-plastics, they can become confused with zooplankton which corals have been found to ingest (Hall et al., 2015). Hall et al. (2015) outline that their study is the first that has been conducted on coral ingestion of microplastics which outlines an extensive gap in research and our understanding of the extent of human plastic pollution impacts on the complex corals and reefs systems.

Microplastics themselves are a large issue in marine ecosystems and globally, and coastal ecosystems (e.g. inshore coral reefs) are particularly affected by this as microplastics generally find their way into marine ecosystems by breaking down from larger plastic items deriving from terrestrial origins (Hall et al., 2014). Tourism and boating practices can also introduce plastics into marine environments from paint chips to fishing equipment (see section 3.5). Unfortunately, the impacts of persisting microplastic accumulation in the environment is still not well understood (Hall et al., 2014). Marine debris and microplastics are also considered harmful because they can act as both toxin carriers and sources of contamination (Hall et al., 2014; Lamb et al., 2018; Gall and Thompson, 2015), and some of these pathogens can lead to disease outbreaks on corals and modify beneficial symbionts like zooxanthellae (Lamb et al., 2018). Plastics are able to absorb and transport contaminants (e.g. heavy metals, persistent organic pollutants), but neither plastics nor some of these contaminants degrade well, resulting in bioaccumulation (Hall et al., 2014).

Coral feeding is argued to be not very selective when it comes to the type of zooplankton captured; however, there is a size preference of <400 μm, with scleractinian corals preferring particles ranging from 10-100 μm (Hall et al., 2014). As microplastics can be found within this range, this can leave corals open to microplastic pollution and contamination (Hall et al., 2014, p. 726). Although there is increasing evidence of microplastic ingestion having negative impacts on organisms, this (like many other impacts), appears to be context or species-specific, but there is strong evidence that corals are able to ingest microplastics and hold these particles in their guy cavity for at least 24 hours (Hall et al., 2014). Further research is required however on whether the intake of microplastics can block the gut cavity and prevent additional feeding (as seen in some larger species who ingested plastics), and how this ingestion impacts the energy expenditure and growth of corals and reefs (Hall et al., 2014).

3.4 Development

Development is another common activity that is placing pressure on ecosystems. Expansions of human communities and activities present numerous issues for natural systems, including coral reefs, through increased sedimentation, dredging and coastal alterations, run-off, tourism activities, deforestation etc. (Seemann et al., 2014; Lamb et al., 2014; Wilkinson, 2006; Jobbins, 2006). Activities taking place prior to extensive climate change, coral diseases, and bleaching events had a fairly large role to play in degrading coral colonies, with land clearing and overfishing being primary culprits (Cramer et al., 2012). In Bocas del Toro, for example, similar to Altieri et al. (2017) and Seemann et al. (2014), Cramer et al. (2012) outline that human populations and deforestation have and continue to increase, contributing to rising sedimentation, pollutants, and nutrients around coral reefs which impacts their health. This resulted in ecological changes and impacts on corals. A change in coral dominance in the area was noted shifting from *Acropora cervicornis* (Staghorn coral, a species that requires clear waters) to *Agaricia tenuifolia* (thin leaf lettuce coral) as water quality shifted from clear to turbid (Cramer et al., 2012). Intensive land-clearing for banana plantations also began to occur in Bocas del Toro in the 20th century, and production quickly increased since the 1980s with tourism and overall population increases (Cramer et al., 2012; Seemann et al., 2014), placing further stress on natural resources and coral reefs. Plantations and export began to grow in 1915 when a port was enlarged in the area and increased shipping traffic in a particular zone (Seemann et al. (2014), resulting in heavy metal pollution and sedimentation (Seemann et al., 2014). The deforestation practices for pasture land and plantations of teak and banana are still occurring on the surrounding larger islands and mainland which has increased pollution, erosion, and sediment leading to changes in marine systems (Seemann et al., 2014). Unfortunately, many of these issues, although localized, are difficult to manage as developing areas tend to have less stringent regulation, enforcement, and environmental management practices.

3.5 Tourism

Tourism and tourism-based activities are growing exponentially, and coral reef tourism is considered to be one of the fastest growing tourism attractions (Lamb et al., 2014). Tourism is a source of income (Bellwood et al., 2004; Cinner, 2014; Jobbins, 2006) and eco-tourism is often viewed as an alternative for other destructive practices; however, since "the majority of coral reefs are located in developing and often undermanaged island and coastal regions, the unrestricted growth and rapid development of reef-based tourism often undermines the conservation priorities necessary to sustain it" (Lamb et al., 2014, p. 88). The increase of global tourism has numerous implications for coral reefs. Coral disease outbreaks, for example, are connected to coral tourism activities. Diving and snorkeling activities were previously thought to pose minimal impacts on corals and reefs, but further research and a tourism boom is now showing that not only is damage physical (Jobbins, 2006), but it is also evident on microbial levels (Lamb et al., 2014). Popular diving and snorkeling areas are outlined to be up to three times more vulnerable to disease and have up to half as much healthy coral than areas with less tourism activity (Lamb et al., 2014). Additionally, Lamb et al. (2014) depicts that high-use sites also increase in sponge overgrowth, physical injury to corals, diseases from increased use and sedimentation (e.g. rapid tissue necrosis (RTN)[4] (or rapid tissue degradation)), and bleaching. Rising tourism can also come with increasing recreational vessel activities which further feeds the pollution issue. This increase can introduce debris into the marine environment by introducing boating accessories such as ropes, nets, lines, and buoys, and occasional damage to boats where paint chips are released into the water (Hall et al., 2014). This outlines a need for improvement in management practices to mitigate increasing development for tourism and infrastructure along coastlines (Lamb et al., 2014), and improve monitoring protocols for tourism activities themselves to ensure regulations are being followed. Some of the surveys in the case study referenced tourism and overall population growth as contributing to impacts on coral reefs (see section 7.7).

3.6 Overfishing

The issue of overfishing is relevant both historically and in the present day. Overfishing, including coral harvesting, poses a variety of issues and it is considered one of the main significant threats to coral reefs, altering species compositions and impacting the size and abundance of reef species (Bruckner, 2001). With a high human population living around coral reefs and relying on them for livelihood (Mladenov, 2013; Pandolfi et al., 2011; Lamb et al., 2014), overfishing is a critical issue. As of 2014, approximately one-third of the world's reefs have been degraded by overfishing and pollution (along with other impacts), leading some colonies to become altered to non-coral states (Graham et al., 2014; Carpenter et al., 2008), and become more open to diseases and pathogens (Wilkinson, 2006) . Larger fish such as groupers or snappers (among others) are considered to be of higher value and these fish are incredibly depleted which impacts the rest of the food chain as fishing practices continue to fish out sizeable fish until the small ones are left, with fewer predatory fish (Mladenov, 2013; Wilkinson, 2006). In the Cayman Islands, for example, Eco Divers (a coral restoration project) shows that decades ago, fishermen in the area depleted the grouper population which subsequently reduced pressure to damselfish, allowing their population to overgrow (see section 7.7). In Bocas del Toro, overfishing and land-clearing were two of the primary issues taking place before coral bleaching and diseases connected to climate change (Cramer et al., 2012; Seeman et al. (2014).

[4] Rapid Tissue Necrosis: “rapidly progressing syndrome, characterized by fast tissue degradation” (Luna et al., 2007, p. 1851).

Many fishing practices are also destructive and not sustainable which results in damage to ecosystems themselves, such as in the case of coral reefs (Seemann et al., 2014). As overfishing continues, coral reefs become less resilient and more vulnerable to other issues and impacts (Mladenov, 2013). This is evident in the Caribbean as the majority of islands are quite populated and the surrounding reefs have faced extensive fishing activities for numerous decades, with a minimum of 60% overfished by 2013 (Mladenov, 2013). With reduced fish availability, other harmful practices began to emerge such as dynamite and cyanide fishing which further damages coral reefs directly (Mladenov, 2013; Barbier et al., 2011; Moberg & Folke, 1999; Thornhill, 2012; Jones and Steven, 1997; Bruckner, 2001; Wilkinson, 2006). Increase in pigmentation changes (e.g. bleaching) (Jones and Steven, 1997) and physical deformities are one example related to cyanide use (Thornhill, 2012). Overfishing is a common human impacts issue listed among restoration projects in the Caribbean (see section 7.7).

3.7 Ornamental Trade

Wildlife trade of coral accounts for a fairly large economic sector, and although the aquarium trade represents a fairly small percentage of the fisheries market, it has significantly grown over the last few centuries (Rhyne et al., 2014; Bruckner, 2001). The ornamental trade of corals is not discussed very often as a human impact in literature in comparison to other issues like climate change, sedimentation, tourism etc., and this market is also understudied (Thornhill, 2012; Dee et al., 2014). This trade is stated to provide income to coastal communities (Dee et al., 2014), contribute to scientific research, and other education purposes (Rhyne et al., 2014). However, these practices also create an impact on corals, reefs, as well as the species that rely on them. Additionally, the majority of coral that is exported to developed countries (primarily the US, followed by Europe and then Japan) (Wood, 2001; Thornhill, 2012) is for the private and not public sector (Thornhill, 2012). In the 1980s, the aquarium trade accounted for 20-40 million dollars annually, with approximately 250,000 live coral imported into the US in 1991 (Moberg & Folke, 1999; Wood, 2001; Barbier et al. 2011). By 2002, the trade expanded to approximately $90-300 million/year (Barbier et al., 2011; Sale, 2002). This includes a market for tourism trinkets and jewelry in which coral and reef habitat species are harvested to fill the demand (Barbier et al., 2011; Thornhill, 2012; Dee et al., 2014). By 2012, approximately 1.5 million live reef-building coral, 65-110 thousand pounds of black and red coral, and 4 million pounds of coral skeleton were removed annually in addition to 14-30 million fish and 9-10 million other invertebrates in order to feed the global ornamental trade for aquariums, jewelry, and décor (Thornhill, 2012; Wood, 2001). Approximately 33.5% of the marine ornamental wildlife trade imports to the US from 2000-2006 were corals and anemones (*Cnidarians*) and 25% fish, making them the highest categories of species in the trade (Thornhill, 2012; Smith et al., 2009). Considering the biodiversity and complexity of coral reefs, that species get removed at all trophic levels for the wildlife trade (Thornhill, 2012), and the harmful fishing practices to obtain some of these species (e.g. mass capture, cyanide, dynamite, as briefly mentioned above in section 3.6) (Rhyne et al., 2014; Bruckner, 2001; Dee et al., 2014; Jones and Steven, 1997), this trade poses large-scale ecosystem impacts as many of these activities impact non-target species as well (Thornhill, 2012; Bruckner, 2001; Dee et al., 2014). Apart from impacting ecological complexities of reefs, physical damage is also done to the coral and reefs as fishermen use crowbars and other tools to break apart the reef and reach down into crevasses to collect fish for the trade, or collect fragments of the reef (Bruckner, 2001).

Monitoring of trade and trafficking is difficult. The Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) works to regulate trade (Knittweis and Wolff, 2010; Bruckner, 2001). Hard corals in the order *Coenothecalia* (massive calcareous corals), *Stolonifera* (organ-pipe), *Milleporina* (fire coral), *Scleractinia* (stony corals), *Stylasterina* (lace corals), and black coral species (*Antipatharia*) are all listed under Appendix II of CITES[5], while soft corals (*Alcyonaria* order), sea fans, false corals (*Zoantharia* subclass), and sea plumes and deep-water corals (*Gorgonacea* order) are not currently listed under CITES (Bruckner, 2001). Over 2000 hard corals are currently listed under Appendix II, while four *Corralium* species were listed under Appendix III in China in 2008 which require additional export permits (Dee et al., 2014). Unfortunately, species can be easy to misidentify, and fragmentation of corals adds to this complexity as some species may require different regulations than others, and overall regulation and monitoring is not very efficient (Thornhill, 2012; Smith et al., 2009; Rhyne et al., 2017). Additionally, many species have not been evaluated and many that are part of the ornamental trade are not listed under CITES which reduces the effectiveness of regulation (Dee et al., 2014; McClenachan et al., 2012; Rhyne et al., 2017; Tissot et al., 2010).

---

[5] Appendix II of CITES: species that are not necessarily threatened with extinction but may become so if trade is not regulated

There is also a lot of illegal activity in the coral ornamental trade as many fishermen are unlicensed and overharvest (Knittweis and Wolff, 2010), as well as overall under-reporting and inefficient management (Bruckner, 2001; Dee et al., 2014). Additionally, there is not much accountability for tourists harvesting wild coral fragments for souvenirs and no monitoring.

4.0 Coral Reefs in the Caribbean

Coral reefs in the Caribbean have gone through a plethora of changes, with populations and species being altered over millions of years. However, while historic changes could be attributed to natural causes, modern alternations are more relevant to human-induced changes placing additional pressures and stress on corals and reefs. Although alterations of coral reefs exist throughout history, the rate of current environmental changes appears to be degrading coral reefs are a much quicker rate.

4.1 Changes over time

The reefs are living, dynamic ecosystems but they are not fixed in time—they are constantly changing and have evolved throughout history (Sheppard, 2014; Graham et al., 2017; Osborne, 2012, p. 375-). There appears to be some discrepancy between some of the statistics, but accurate identification is difficult due to lack of historic data collection and monitoring (Pandolfi and Jackson, 2006), and the drastic change in coral compositions over time (Knowlton, 2001). Some note that calcified organisms are absent from fossil records during the early Triassic era when there was a large spike in CO_2 (higher than today) but corals themselves survived the Permian-Triassic extinction (although without calcified skeleton species) (Hoegh-Guldberg et al., 2007). While others state that coral fossils do not appear until after the Permian-Triassic extinction event (252 million years ago), but scleractinian corals begin to dominate around the mid-Triassic era about 240 million years ago (Sheppard (2014; Hoegh-Guldberg et al., 2007). The next mass extinction period (K-T extinction) during the Cretaceous period (66 million years ago) is argued to have killed off about 70% of corals and suppressed re-establishment and growth of reefs for a long time (Sheppard, 2014), but Carpenter et al. (2008) state that the percentage was 45%, with primarily reef-building corals impacted. During the Pleistocene (about 2.58 million - 11,700 thousand years ago), coral reef communities were fairly stable (Graham et al. 2017; Pandolfi and Jackson, 2006). However, since this time, Caribbean coral coverage has been reduced by approximately 80% (Cramer et al., 2012; Wilkinson, 2006) and species of branching corals *Acropora* and *Porites* corals became replaced by species of non-branching corals *Agaricia* and *Porites* (Cramer et al., 2012). Although corals that developed during the mid-Triassic era existed during a period where CO2 was much higher than today, there is no confirmation that they existed in low-carbonate areas and one of the main issues today is that colonies cannot adapt quick enough to the rapidly growing CO2 concentrations (Hoegh-Guldberg et al., 2007). Thus, even though coral reefs have changed throughout history, human impacts are the primary factor that have altered and increased the rate of community changes in coral reefs over the last few thousand years (Pandolfi and Jackson, 2006).

The extensive exploitation of coral reef flora and fauna in the Caribbean began well before European settlement and Columbus' arrival in 1492 (Cramer et al., 2012; McClenachan et al., 2010). However, the effects of human activities on coral reefs in the Caribbean did not start becoming evident until the 1980s (Cramer et al., 2012). In the early 20th century, as discussed above, human activities began to be more prominent through land changes, extensive fishing practices, human population growth, and ultimately increasing demand for resources and products, leading to added pressures on ecosystems. The decline of Caribbean reefs and the increase in disease prevalence is often directly connected to climate change; but the numerous historic pressures are also a factor. In the case of Bocas del Toro, changes date back to the 1900s (especially in the case of the *Acropora* genus), with coral cover changes before and after the 1960s (Cramer et al., 2012). This exemplifies the fact that other impacts were already taking place in this area, with correlations to land clearing and fishing (Cramer et al., 2012). In Bocas, the increase in land clearing for banana production has continued to increase since the 1980s for tourism and development (Cramer et al., 2012; Seeman et al., 2014).

Increasing human activities contributed to rising greenhouse gas emissions and in the 1980s and 1990s, Elkhorn coral (*Acropora palmata)* faced a massive die-out with global warming suggested as the most likely cause (Sheppard, 2014). Later, in 2010 there was a global bleaching event which resulted in large-scale mortality and deterioration of coral reefs locally and globally (Seemann et al., 2014). With climate change and additional interacting anthropogenic drivers, it is now unlikely that coral reef colonies will be able to restore themselves to healthy historic conditions (Graham et al., 2017; Hughes et al., 2017). As briefly discussed above, there are also coral range-shifts taking place in the Caribbean attributable to rising temperatures, with corals shifting towards the poles (Graham et al., 2014), and it is assumed this will continue with increasing impacts (Hughes et al., 2017).

As coral reef communities are evolving in response to stresses, new species and reef formations are becoming more prominent (Hughes et al., 2017). *Acropora cervicornis* and *Acropora palmata* were once the dominant species on the Caribbean reefs but have faced extensive loss (Carpenter et al., 2008; Pandolfi and Jackson, 2006) with climate change, overfishing practices, bleaching events, diseases, and other impacts having reduced their numbers, and it is questionable whether these species will recover and dominate the Caribbean again (Pandolfi and Jackson, 2006; Graham et al., 2014, p. 10; Hughes et al., 2017). Additional impacts from changes in predator dynamics, storms, and sedimentation increase further contribute to the alteration of new reef compositions and functions, and if impacts continue without proper regulation, fewer reefs may be dominated by corals (Graham et al., 2014).

4.2 Status of Caribbean Reefs

Coral reef communities and coral cover in the Caribbean are generally in decline (Pandolfi and Jackson, 2006; Alvarez-Filip et al., 2009); and Knowlton (2008) outlines that roughly 80% of coral cover in the Caribbean has been reduced over the last three decades. Although there is degradation of coral reefs globally, this has been especially prevalent in the Caribbean where there has been widespread loss of reefs and reef-builder species such as *Acropora palmata*, *Acropora cervicornis* (Pandolfi and Jackson, 2006; Alvarez-Filip et al., 2009; Knowlton, 2001), and Orbicella spp. (Lirman and Schopmeyer, 2016; Pandolfi and Jackson, 2006). Reduction of reef-building species continues to impact the structures and functions of reefs, fish habitats, biodiversity as a whole, and coastline protection (Lirman and Schopmeyer, 2016; Alvarez-Filip et al., 2009). The combination of stressors and variation in responses to stress among species can make it challenging for research and restoration initiatives, with some colonies also depicting a delayed response to stress[6] (Neal et al., 2017).

Although not all coral reef colonies are impacted evenly from bleaching, those that were impacted by a bleaching event in 2005 appear to be generally more acclimatized to the bleaching event in 2010, while those that appeared unaffected in 2005 were more impacted in 2010 (Neal et al. (2017). But again, this can vary among species and colonies. Although this acclimatization

[6] Neal et al. (2017) define this delayed response to stress as a “postdisturbance factor”.

in some colonies presents some positivity for coral restoration and dealing with impacts of sea temperature rise, there was still a net loss of tissue (Neal et al., 2017). It is not quite certain to which extent these stress events will become more frequent and intense but with the long recovery time for stony coral to fully regrow their tissue and gain positive net growth again (approximately 32-128 years assuming there is no other disturbance), the progressive rise in sea temperature will be detrimental for coral reefs in the Caribbean, possibly to the point of functional collapse (Neal et al., 2017). Some studies outline local re-establishment of coral cover through restoration activities, but this is usually on a small-scale basis (e.g. Hein et al., 2017; Hughes et al., 2017). Restoration projects in the case study below (see section 7.5) outline both decline, variance, and improvement (although the improvement generally varies by area and in spots where restoration is taking place, but no mention of large-scale improvements).

As briefly discussed above, the historical impacts of land-clearing, overfishing, and development, in addition to the expansion of these activities and introduction of others (Cramer et al., 2012) are leading to ecological, structural changes through live coral loss long-term and structural changes leading to non-coral dominated reefs (Graham et al., 2014). In addition to general resource exploitation and overall development practices, many areas in the Caribbean are also exposed to river run-off carrying sedimentation, and other land-use changes that contribute to erosion, nutrification, and pollution from heavy metals, fertilizers, pesticides etc. Since the Caribbean is dominated primarily by areas that are considered to be developing and with complex socioeconomic issues, there is also general lack of efficient management and enforcement when it comes to environmental protection. There is an evident need for improved protection and management of the local disturbances (e.g. human waste run-off/sewage management) and inputs in order to reduce pressure off of reefs and foster resiliency to local impacts and global pressures such as climate change (Cramer et al., 2012; Altieri et al., 2017).

5.0 Coral Restoration and Management

Coral restoration initiatives are increasing in response to dealing with the growing impacts on and degradation of coral reefs (Hein et al., 2017; Lirman and Schopmeyer, 2016). There are many improvements that can be made to coral restoration initiatives through improved research, evaluation of restoration success, monitoring, and utilization of multiple methods and species. However, as socioeconomic issues are prevalent among restoration projects, these suggestions should be coupled with multi-level governance and support from the global community.

5.1 Restoration Initiatives

There are numerous techniques which are being explored and utilized. Passive (e.g. protected areas, listing species as under protection) and active forms of restoration exist (e.g. coral nurseries and propagation). Here, discussion is focused on transplantation and coral gardening/fragmentation, with brief mention of other approaches. Passive approaches, such as marine protected areas for example, are not sufficient to deal with large-scale degradation, and active restoration activities are necessary and have begun to grow internationally (Hein et al., 2017; Bellwood et al. 2004; Rinkevich, 2008), but they have yet to be applied on a large-scale globally (Hughes et al., 2017). Hein et al. (2017) outlines that coral transplantation (the process of moving/transplanting coral fragments on reefs) is one of the most common strategies, growing exponentially over the last 30 years. However, it is also argued that coral colonies are much too complex, and restoration transplantation alone is not enough to recover colonies at the scale at which they are being degraded (Hein et al. (2017; Lirman and Schopmeyer, 2016). Projects initially collected fragments from surviving colonies or harvested from other locations which were then added to limestone and cement restoration structures; however, these practices come with economic expense, permit issues, and other logistical considerations that can often cause issues and take numerous years to establish (Lirman and Schopmeyer, 2016). Furthermore, harvesting fragments from donor communities can result in physical damage (Shafir et al., 2006). The difficulties surrounding restoration in regard to required resources for recovering particular areas appears to fall in-line with the argument that although some of the species-targeted approaches can be effective in particular areas, this may still be inefficient on a global-scale (Lirman and Schopmeyer, 2016; Bellwood et al., 2004) unless the underlying issues are tackled as well. However, this does not take away from the fact that coupling coral transplantation, for example, into a multi-faceted, long-term adaptive management framework can still be a useful technique for gaining scientific knowledge and rebuilding coral reef networks (Hein et al. 2017).

Coral gardening has become a popular technique among coral restoration initiatives (Lirman and Schopmeyer, 2016; Page et al., 2018). This method is outlined as having two parts: collecting and cultivating coral fragments in nurseries, and out-planting the grown fragments onto reefs that have been degraded (Lirman and Schopmeyer, 2016; Shafir et al., 2006). A small amount of wild fragments are collected, fragmented, and regrown in nurseries and are either used to create more fragments or are out-planted (Page et al., 2018). This process is typically used on select species such as those with a faster growth rate and can establish ecological recovery quicker (Page et al., 208). However, these species are typically more sensitive to thermal stress and thus more focus must be placed on other species for restoration such as massive, slow-growing types (e.g. boulder coral) (Page et al., 2018). Hein et al. (2017) outlines that coral gardening is the most common form of transplantation. However, Lirman and Schopmeyer (2016) distinguish the two, outlining that coral gardening is different from past ecological restoration initiatives that focused on transplanting corals from donor communities to degraded areas, as coral gardening relies on propagating corals in nurseries before out-planting. The growth of coral in nurseries is significant because it provides a sustained growth for coral fragments which further reduces the need for wild harvesting (Lirman and Schopmeyer, 2016). Other techniques are currently being used such as microfragmentation, artificial structures and coral trees, although the coral trees are used within nurseries. Microfragmentation is becoming more common as this technique can also be used to grow massive, slow growing corals (Page et al., 2018). Fragments are cut down to smaller pieces (sometimes as small as a single polyp) before growing in nurseries and being out-planted (Page et al., 2018). This provides space and reduces competition and predation (Barton et al., 2015). This process allows for coral to grow much quicker in comparison to natural rates (e.g. months versus years) and provide rapid restoration (Page et al., 2018). However, Page et al., (2018) further argue that in order to be used on large-scale and long-term restoration, microfragmentation must depict that it can rapidly restore colonies, maintain resiliency, and be as efficient as the macro fragments in restoration. Sexual propagation is also possible by collecting the coral gametes during spawning events (1-2 times per year) (Barton et al., 2015). This increases the genetic pool in colonies, but asexual methods such as fragmentation is a more common and more affordable approach (Barton et al., 2015).

The methods utilized by the restoration projects in the Caribbean case study outlined below depict a variety of approaches including coral trees, nurseries, gardens, and fragmentation (see section 7.3). Although Lirman and Schopmeyer (2016) outline coral gardening as a lower-cost alternative to initial forms of transplantation, the whole process of coral restoration itself is very costly regardless of techniques used and this is a big challenge for restoration initiatives (see section 7.6 of case study), especially since a variety of approaches are preferred for restoration (Rinkevich, 2005) to help diversify the restoration efforts and support complexity. Fragmentation, for example, can assist in reproducing and spreading asexual fragments, but it may not be economically viable to many due to the fairly high mortality and lowered reproduction rates of fragments (Knowlton, 2001). To improve some of these socioeconomic issues and restoration on a global scale, there must be stronger global coordination for establishing management strategies and frameworks, and overall stronger support to reduce human impacts and foster resiliency (Bellwood et al., 2004; Knowlton and Jackson, 2008, p. 0219).

5.2 Measuring success

Standardized measurement of recovery success is still difficult and lacking rigor which can make monitoring and evaluating restoration challenging. Growth and survival rates of coral fragments are used as the most common indicators of success as there are currently no global standard measurement frameworks for restoration success (Hein et al., 2017). Subsequently, the lack of guidelines is detrimental to figuring out what is and is not effective in coral restoration (Hein et al. 2017, as cited in Edwards, 2010).

However, since impacts are diverse and coral responses to stress vary, it should be noted that techniques may need to be evaluated before implementation, based on the situation. Hein et al. (2017) outline 10 socioecological indicators to measure long-term success of restoration initiatives (coral diversity, herbivore biomass and diversity, benthic cover, recruitment, coral health, reef structural complexity, reef user satisfaction, stewardship, capacity building, and economic value) and argue that structural complexity, coral cover, and coral algae are also important for consideration (Hein et al., 2017). A measurement in sociocultural and economic factors is also outlined as an important part in measuring success, but these topics are often unexplored (Hein et al., 2017). These components are significant for consideration because they can incorporate initiatives to increase local livelihood opportunities and engagement. Thus, it is argued that being able to recognize the socioeconomic, stakeholder, and overall governance factors is fundamental to connecting the community to the project and obtaining essential feedback which is necessary for additional input on the success of coral restoration projects

(Hein et al., 2017). Although stronger focus on socioeconomic initiatives and improved measurement through added ecological complexity considerations is most certainly necessary, it may not be feasible for many restoration projects/initiatives for self-implementation--at least not yet. Considering that many coral reef communities are located in areas that can be considered developing and or depict difficult socioeconomic issues, and as outlined through the surveys conducted in this study of Caribbean projects (see case study, section 7.6), many restoration initiatives face various challenges that makes improving activities such as monitoring and long-term evaluations of success, for example, fairly difficult, even at basic levels. Thus, these approaches must be coupled with not only engagement from restoration projects, but also from governmental bodies and global communities as a whole to improve frameworks, regulate human activities, and provide socioeconomic support (Wilkinson, 2006).

5.3 Monitoring and Additional Research

Improving research on coral reefs and restoration approaches is still necessary. Monitoring of restoration initiatives and success is one area that can be improved as the majority of restoration initiatives depict fairly basic and short-term monitoring of restoration success rates when there should be a stronger focus on long-term and complexity (Hein et al., 2017). Another area that lacks monitoring and research in reef initiatives is the monitoring of other environmental conditions that can impact corals. Hypoxic events, as discussed above, outline knowledge gaps in this field pertaining to research and monitoring, especially in developing areas, which make it difficult to quickly identify hypoxia-based mortality and collect data (Altieri et al., 2017). Moving forward with restoration, identifying novel coral reef systems is outlined as a topic of importance in dealing with globally-changing reef systems and coral colonies. Although there are significant knowledge gaps in our understanding of future coral reef compositions, being able to identify changing reef systems and how these changes might impact ecological processes is necessary for successful long-term management initiatives (Graham et al., 2015). However, considering the constraints of restoration projects themselves, this research should be coupled with global support on a multi-level scale as it is challenging for restoration projects to manage restoration initiatives and organizations, conduct research and monitoring, and collect data in a rate fast enough to meet the changing ecosystems, especially considering the many socioeconomic constraints.

5.4 Improving Management

There are a variety of necessary improvements to be made in coral restoration, and a diversity of suggestions for how restoration projects could improve on a social, ecological, and economic basis. One of the core challenges to restoration initiatives are the interacting human impacts and the lack of sufficient management of these activities. Apart from improving research, monitoring, and restoration approaches, there is a great need for improving protection of ecosystems and management of anthropogenic disturbances (Cramer et al., 2012) including managing local outputs (e.g. sewage and agricultural run-off) and anthropogenic activities in more low socio-economical areas (Altieri et al., 2017; Hoegh-Guldberg et al., 2007; Knowlton, 2008). For places near increasing human communities and subsequent outputs, there needs to be stronger management of sediment and eutrophication (Seemann et al., 2014). Current approaches are too linear and do not challenge the core issues, and changes to social and ecological factors is necessary for improving regulation and governance (Hughes et al., 2017). Without improving management of anthropogenic activities and fixing basic social issues (e.g. waste outputs), coral degradation and morality will increase, resulting in reduced biodiversity of coral reef flora and fauna and the relevant economic gains (Seemann et al., 2014). Despite high biodiversity, coral reefs are susceptible to losing functionally important species and identifying the fundamentals necessary to sustain reef ecosystems is useful for restoration management (Hughes et al., 2017). Restoration initiatives should also present complex approaches in their restoration methods (Rinkevich, 2005). These suggestions are fundamental for improving restoration data and initiatives; however, the challenges faced by restoration projects can make meeting these proposed improvements quite difficult. At this moment, restoration projects in the Caribbean are facing a multitude of challenges and are focusing on managing dying colonies with generally minimal resources. But focusing on identifying altering coral systems, functional species, and utilizing diverse methods are certainly factors that should be considered in management for long-term initiatives.

6.0 Coral Restoration in the Caribbean (Case Study)

This case study applies the information discussed above to a field-based example. A study is conducted of coral restoration projects throughout the Caribbean in an effort to create an outline for which methods and species are being used for coral restoration initiatives, which human impacts are most prominent throughout the study areas, which challenges restoration projects are facing, debris status, and the conditions of the coral reefs. In doing so, this research aims to determine whether restoration initiatives present complex approaches to coral restoration and which are being used (e.g. more than one approach and species used/considered for restoration and conservation), outline commonalities among human impacts, and point out common difficulties projects are facing. I aim to create an outline of the approaches being utilized and the challenges which can be used as a reference or guide. It is important to note that this study asked general questions to obtain an overview of the projects and challenges and did not evaluate nor analyze the effectiveness of the coral projects themselves nor their approaches.

6.1 Methods

To conduct this research, two main methods were used: 1) a general internet search; and 2) surveys of restoration projects throughout the Caribbean, specifically around the Caribbean Sea. Another minor method used was referral in which some projects referred me to other initiatives. A general internet search was used to locate restoration projects throughout the Caribbean and generate a list of possible projects. The keywords "coral", "restoration", and "Caribbean" were used, occasionally followed by the country name to help narrow down the search if the search results were unclear (e.g. "Coral Restoration Caribbean Panama"). This search generated 61 results, with 49 being official, independent projects and not an off-set collaborative project through or with regulating bodies (e.g. marine protected area or park); however, some of these were under one international organization that hosted numerous projects globally[7]. Out of these, only 29 projects were contacted for participation (but some of these organizations host numerous restoration projects in the Caribbean. With these accounted for the total of initiatives would be 38), and another eight participants were contacted by referral (although 6 of these were under the same project), leading to a total of 31 projects contacted. The rest were not contacted because others did not provide clear information on the project or the separate projects under a particular organization, did not provide clear contact information (this includes both online and social media) and thus were difficult to contact. Restoration projects

[7] Due to privacy reasons, this list is kept private as per privacy regulations.

were primarily contacted by electronic mail (email) with a request for participation, with a couple contacted by Facebook through their organization page. Out of those contacted, some were not used in the study because they did not directly work with coral restoration (e.g. some focused on fish restocking), the project was cancelled or no longer active, or there was no response.

Out of those contacted, 13 organizations/projects and 14 staff members in total participated in the survey; however, two of the projects did not reside in the Caribbean study zone (one on the Great Barrier Reef and one in Florida Keys) and were therefore unable to be included directly in the data tallies. Thus, overall, there were 11 separate projects and 12 participants tallied. Two of the projects are under the same umbrella restoration organization, with 1 having different management and locations and thus were counted separately, and 1 under the same project and location and thus those responses were tallied as one or separately[8]. Project survey locations consisted of Panama, Haiti, Honduras, Mexico, Guatemala, Turks and Caicos, Curacao, British Virgin Islands, Cayman Islands, Montserrat, and Dominican Republic. Participants include staff from the coral restoration projects and consist of project managers/directors/coordinators, presidents and founders, and communications coordinators. The study itself is survey-based (see figure 1.0 on page 61) and was provided to individuals who agreed to participate. The survey asks a variety of questions including when the restoration project began, which methods are being use in restoration activities, which species are being used in restoration activities, which human impacts on coral and reefs are most prominent in the project's area, if there is community engagement, which challenges the project is facing, if plastic/debris pollution is an issue and which plastic items are commonly found, and what overall health status the corals and reefs are generally in (e.g. declining, improving, variations, or no change). Responses were collected and tallied by organizing the answers by survey question and using commonalities and keywords to organize responses into categories in order to outline most common statements and themes.

7.0 Results and Discussion

[8] Some were tallied together as one because they pertained to project information directly (e.g. starting year of the project), while others were tallied as separate responses because the questions pertained more to individuals rather than projects as a whole (e.g. noted pollution items).

Although there are evidently some differences, the surveys outline a variety of commonalities and themes that are important for consideration. Despite the majority of projects being relatively new, they generally show a focus on applying multi-faceted restoration approaches and are conscious of using a complexity of species. There are still improvements that can be made in regard to complex thinking and approaches; however, many of the core challenges influencing not just restoration expansion and project improvement but also basic activities to run the projects appear to come down to primarily economic reasons. The diversity of human impacts on corals and reefs make restoration initiatives even more challenging from not only a coral conservation standpoint but also socioeconomically, as a vast amount of outlined impacts derive from poor management of human activities, inefficient environmental management, or other socioeconomic issues. Restoration initiatives do require improved research, guidelines, and regulation frameworks but this must also be coupled with improvement of management of human activities and outputs into ecosystems which is generally beyond the scope of restoration projects. Considering the majority of reefs are located either in or close proximity to areas that are considered developing, more focus must be placed on supporting restoration projects through stronger government and global community involvement.

7.1 Project Locations

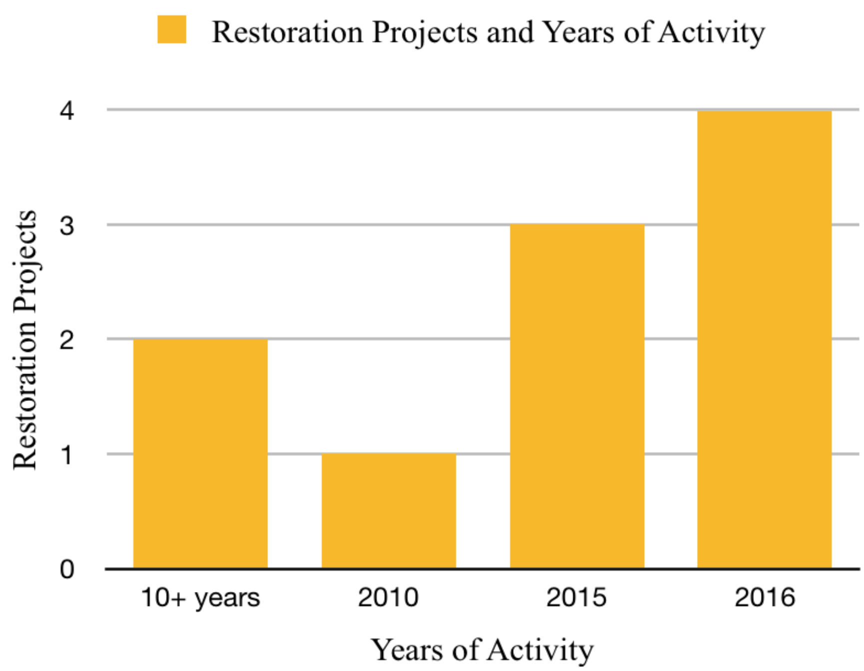
Participants were asked to list the main location for their restoration project as well as any others they have. This question was primarily to obtain an idea of the scale of the restoration projects and restoration efforts. However, geographical scale and land mass was not taken into account in this question and thus whether a project has 1 or more initiatives scattered throughout their area may not necessarily provide a clear idea of the diversity of a particular restoration initiative. Thus, this question provides more of an insight on the current status and scale of restoration initiatives rather than efficiency, but still useful for consideration as complexity and ecological networks are important. Figure 2.0 outlines a tally of the responses: Five projects listed 1 main location, 3 listed 2 locations, and three listed 3 or more locations (see figure 2.0). Since the majority of projects outline 1 or two main sites, this outlines a possible need for more implementation of and support for active restoration initiatives. However, simply adding restoration locations or projects requires various factors and is not a straightforward process—environmental, social, and economic factors are involved. Furthermore, whether a project has outlined one-two locations or three or more, in this case a conclusion cannot necessarily be made about whether projects with more than one location are more successful with restoration than a single site as this study did not analyze restoration success and did not compare those results to the amount of restoration sites. This question could have also been misinterpreted as some could have included a count for restoration out-planting sites, while others focused on the organization headquarters location.

Figure 2.0: Number of project locations per restoration project. The majority of projects have one main location.

7. 2 Years of Activity

Figure 3.0 outlines when the restoration projects began, with the majority of the restoration projects only being a few years old, depicting primarily short-term activities thus far. 4 restoration projects have been active since 2016 (3 years), 3 since 2015 (4 years), 1 since 2010 (9 years), and 2 running more than 10 years. One of the out-of-zone participating projects that was not tallied also noted over 10 years; however, the majority of the projects surveyed are still fairly new which poses a bit of a challenge for long-term monitoring of project success (as discussed above). However, apart from increasing restoration, monitoring, or research activities, many of the projects outlined challenges in regard to starting the project and running it, which make certain activities including basic project setup and management quite difficult. Furthermore, it is important to note that due to many of these challenges (see section 7. 6), although the start date may have been officially during a given time period, some projects also did not begin active restoration until a year or two later due to challenges surrounding funding, staffing, and permits—with many of these still persisting.

Figure 3.0: This chart outlines the number of years restoration projects have been active and their start dates. Four projects are 3 years old; three projects are 4 years old; one project is 9 years old; and 2 projects are over 10 years old.



7. 3 Restoration Techniques

Projects outlined a variety of techniques for their restoration initiatives. Figure 4.0 outlines a table of the different coral restoration methods mentioned in survey results. Column A outlines the main restoration methods, column B outlines the number of projects that stated they use the outlined methods, and column C outlines the number of sub-category approaches and materials that were mentioned to conduct the restoration methods in column A. Coral trees were the most common restoration initiative mentioned (6 projects mentioning it, with one using this as a sole technique). Nurseries and fragmentation/propagation were the second more common approach (5 mentions each) (fitting with Hein et al. (2017) and Lirman and Schopmeyer (2016) as common techniques). Nurseries include land-based and marine-based while others were not specified. It is important to point out that although some projects may not have directly mentioned using nurseries, they mentioned other initiatives that typically may utilize some sort of "coral nursery" for coral rehabilitation. Coral trees for example might use nurseries before transplanting fragments to the "trees", but because nurseries are a base[9] approach for restoration, they may have not been specifically identified as a direct approach. Nonetheless, nurseries were counted here because it was the second most common approach mentioned, but this may ultimately not be a true representation of projects utilizing this technique and in reality, their utility is most likely much higher. Similar to nurseries, fragmentation is generally a base technique that is utilized for many restoration methods such as in coral trees and thus may have not been mentioned by all survey respondents even if it is being utilized (especially for regular fragmentation). Due to the common reference to fragmentation/propagation and various techniques, this was included as a main category with sub-categories of regular fragmentation (main approach), followed by micro-fragmentation, and sexual reproduction (less common and not considered a base technique), all noted two times each. Use of frames was referenced twice by 3 separate projects and specific materials and methods include a-frames, metal tables, and use of rebar and bamboo in some frames. Artificial structures were mentioned twice, with main materials being cement and PVC. Reef balls were also cited twice, and coral ladders, coral gardens, and discs were all mentioned once. Although many of these can technically fall under "artificial structures", they were separated based on the received survey responses. It is also important to note here that although this chart provides an outline of restoration initiatives which can be used to deduce common methods, the small sample size of projects and the survey's lack of clarity in providing standardized options for selection may have resulted in an inaccurate representation of the overall initiatives of coral restoration projects around the Caribbean. However, it is outlined that coral trees appear to be one of the most popular approaches to

[9] A base restoration approach is defined here as a core restoration technique that is widely utilized and often mandatory for primary coral restoration efforts (e.g. coral nursery).

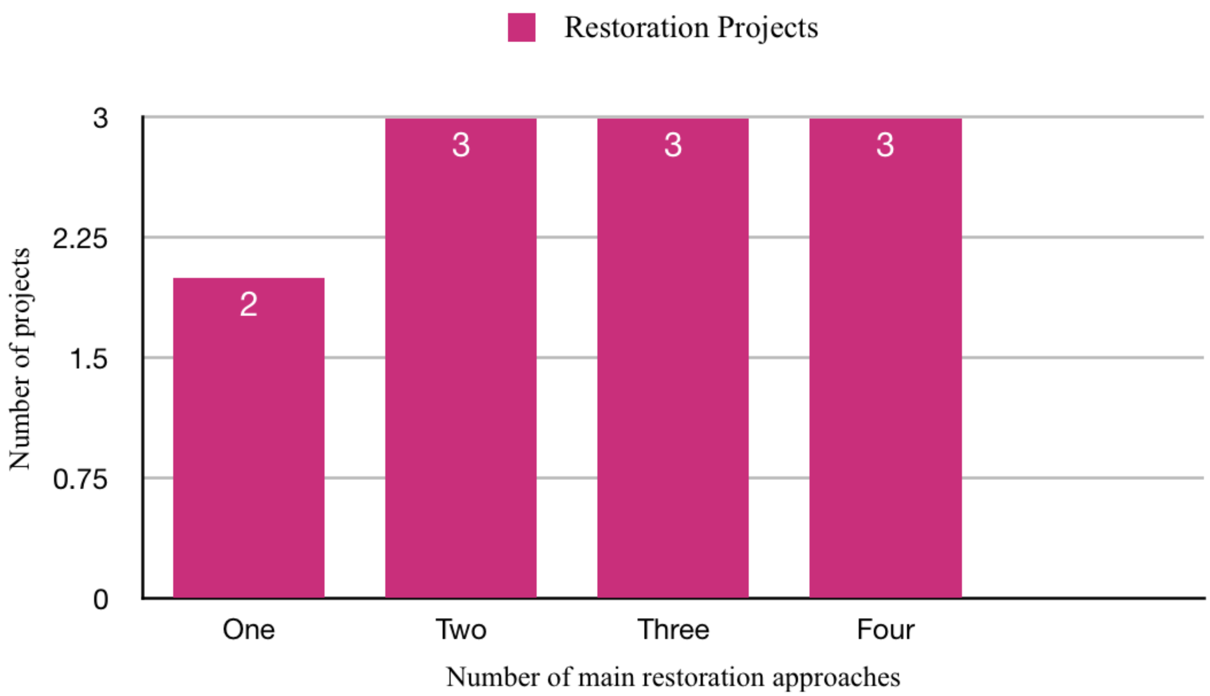
restoration techniques, followed by nurseries and fragmentation.

A tally was also conducted of the total number of restoration techniques a project outlined in the surveys and utilizes in the field. This factor is useful as utilizing a variety of approaches supports diversity and reef complexity, especially since coral reefs can respond differently based on geographical area or stressors. Mélina Soto from the Healthy Reefs Healthy People Initiative (HRHP) outlines in the survey responses that "coral reef restorations project need to [have] multi techniques, you have to recover the live tissue cover as quickly as possible, but you also have to ensure genetic diversity" (June 4, 2019). However, it is essential to note that some projects listed certain activities in greater detail than others. This made the tallying process difficult as, similar to above, certain projects mentioned certain techniques that others did not even if they are being utilized (e.g. nursery; out-planting techniques) which impacted the tally. Additionally, some responses focused more on the fragmentation/propagation process while others provided more detail on the process of out-planting of fragments. The tally is thus to be used as an insight to the general number of approaches utilized to depict an overarching outline and results should not be used or viewed as fixed, wholly representative numbers. In an attempt to create a fair representation of responses, the main approaches are grouped into the same categories as outlined in figure 4.0 and tallied. Figure 4.1 outlines a chart of the number of techniques generally used per organization/project, numbered one to four. 1 method in coral restoration was the least common, while 2, 3, and 4 approaches were most common (utilized by three projects each). This outlines that the majority of projects use at least two to four approaches in restoration. However, it must be stressed that this tally only accounts for main approaches (e.g. coral trees, artificial structures etc.) and does not calculate the variance of subcategory approaches (e.g. varieties of nurseries, types of artificial structures etc.). If all of the subcategory approaches were calculated, the number of overall approaches will be different. However, this calculation is not possible here because the survey responses were highly varied and thus a true representation of techniques is not possible unless another survey is conducted to specifically analyze techniques alone.

Figure 4.0 Table of restoration initiatives mentioned by project. A) Restoration Methods: outlines the different restoration methods under main categories; B) Number of projects using this method: outlines how many projects in total listed a particular method used as part of their restoration initiatives; C) Sub-category approaches: outlines other secondary approaches or materials used that were listed and fall under a main category.

A) Restoration Methods	B) Number of projects using this method	C) Sub-category approaches and materials
1) Coral Trees	6	PVC 1 Fiberglass rods 1 Material not specified 4
2) Nurseries	5 *one project uses both marine and land-based nurseries but counted once for the nursery approach*	Land-based 2 Marine-based 1 Not Specified 3
3) Fragmentation/Propagation	5	Standard Fragmentation/Prop 2 Microfragmentation 2 Sexual reproduction 2
4) Frames	3 *one project uses both rebar and bamboo but counted once for frame approach*	A-frames 2 Rebar 1 Bamboo 1 Metal tables 1
5) Artificial Structures	2	Cement 2 PVC 1
6) Reef Balls	2	N/A
7) Coral Ladders	1 *used in nursery*	Mid-water Ropes 1 Other (not specified) 1
8) Coral Gardens	2	N/A
9) Discs	1	N/A

Figure 4.1 Number of core restoration techniques that are outlined by restoration projects. One equates to 1 approach, two to 2 approaches and so on. Projects with 1 approach were least common with two projects stating they use 1 approach, while three projects stated that they use 2, 3, or 4 approaches.



7. 4 Species used in restoration activities

There is a variety of species used in restoration activities. The amount of species used in restoration activities, similar to methods, is important as well because utilizing numerous species in restoration helps to ensure restoration initiatives are accounting for ecosystem complexity and fosters genetic diversity (Rinkevich, 2005). Corals and reefs are extremely complex and diverse and thus restoration initiatives should account for this in order to support the diversity of life and processes that coral reefs maintain. Similar to restoration techniques, the tallying of data collection for this was fairly challenging because of the high diversity of species, and some responses provided exact scientific names of the species, while others provided the common names. This factor posed a challenge to data tally as I was not sure whether the projects that provided common names only focused on one species or more in the genus or focused on the entire genus as whole (depending on what was found or available for restoration use). Thus, figure 5.0 depicts a chart that is organized by common name first (column A), and scientific names (both genus and species) mentioned are organized in column C.

Figure 5.0 shows there is a focus on using primarily Staghorn (*Acropora cervicornis)* and Elkhorn (*Acropora palmata*) in restoration approaches. This may be due to a variety of reasons including biological, social, and economic (e.g. heavily degraded, permit-related, lower cost to focus on two of the main species etc.). Both *A. cerviconis* and *A. palmata* are the two main species of focus in coral restoration with 9 out of 11 projects directly listing these species as being used in their restoration initiatives. Their focus is probably due to them being significantly degraded in the Caribbean, being important reef-building species, and their critically endangered status under the International Union for Conservation of Nature (ICUN) as they're considered to be particularly sensitive to human impacts including temperature fluctuations (including climate change) and pollution (sedimentation and runoff being key players). Boulder and star corals (including *Orbicella and Montastraea*) (grouped together because some species are titled as both (e.g. star boulder coral) or are part of the same genus), and brain corals (including *Pseudodiploria, Diploria,* and *Colpophyllia*) were both mentioned by three projects. Leaf/plate corals (including *Agaricia*) and small polyp stony corals (*Porites*) were both mentioned by two projects each as being utilized in their restoration efforts. Soft corals, pillar coral (*Dendrogyra*), and "any" (no specific species identified) are all noted once.

Plant a Million Coral (an organization which was not tallied here due to being outside the study zone), run by Dr. David Vaughan in Florida Keys, identifies the species used in their project (some of those outlined in column E) which depicts a high diversity of species use in restoration efforts. However, even if this calculation would be included in the overall total, Staghorn and Elkhorn would still be the most common species used. This outlines that although there is some species diversity in restoration efforts, it could be higher as Staghorn and Elkhorn use is significantly higher than the utilization of other species. Figure 5.1 outlines a tally of the total number of coral groups projects are utilizing. The tally was conducted based on the coral species and types restoration projects outlined. The most common number of species utilized for restoration initiatives was 2 species, with 5 projects outlining they used two primary species. Staghorn and Elkhorn are the most noted, with the exception of one who noted leaf/plate coral (*Agaricia*) and Small Polyp Stony corals (*Porites*) as their main species restoration approach. 2 projects outlined using three types, and five, six, and eight types were all noted once each. One project outlined “any” for any species that becomes fragmented naturally is used for restoration.

The lack of utilization of species diversity for restoration measures may be problematic with increasing human impacts on corals and reefs as restoration efforts need to account for the ecosystem complexity of these systems, functionally-important species, and novel ecosystem development. However, this may not be a straight-forward path as restoration projects face many challenges which can impact their ability to increase restoration approaches. Furthermore, reef ecosystems are increasingly being altered, and are evolving into new formulations in response to impacts (Graham et al., 2014). With this in mind, reefs most likely will not be able to be restored to their previous states and coral species colonies will shift (Graham et al., 2014). This was not discussed in the survey results; however, there was no specific question relating to this. Thus, it is additionally important that focus be placed not solely on restoration projects for improvements but also social and economic factors, local and federal-level governments and authorities, as well as local communities (education and project involvement being main factors) in order to mitigate human impacts as well as be able to provide support for restoration projects and other conservation entities in a time of rapidly evolving ecosystems, such as in the case of coral reef conservation and research.

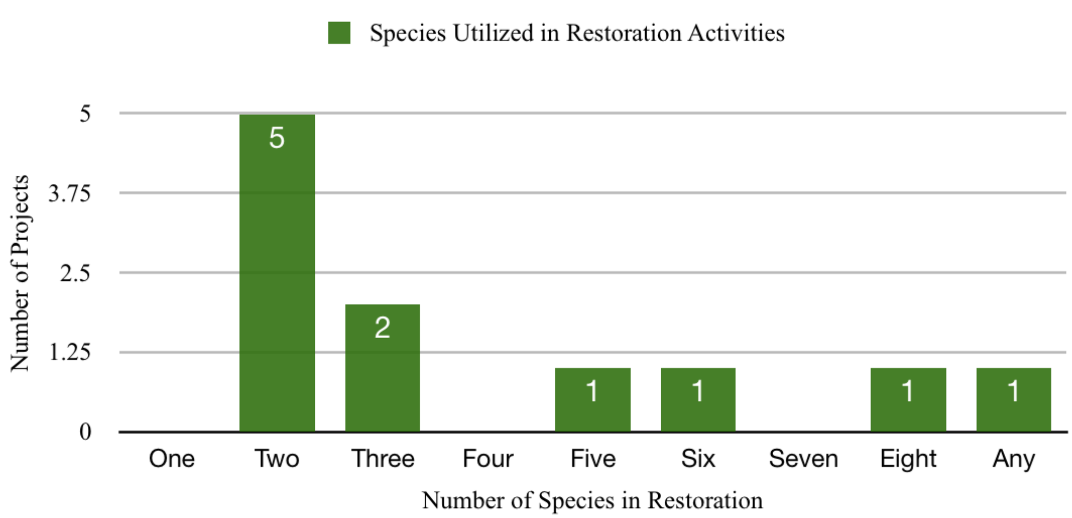
It is important to note that although some organizations only specified either the common names of species or outlined the genus (e.g. brain coral; *Orcibella*) that is used in restoration, they may work with many various species that fall under that genus but did not elaborate/specify seeing as a short survey was provided. Thus, improving the survey questions to account for this will greatly improve clarification and data in the future. However, it should still be kept in mind that although this data provides an insightful overview of the current restoration practices of species used in restoration activities, considering the high contrast between the amount of focus on staghorn (*A. Cervicornis*) and elkhorn (*A. Palmata*) in comparison to other species, it is an important factor for consideration and provides a general insight into the trend of the types of coral used in restoration.

Figure 5.0 Coral species that are used by restoration projects. Column A: common species name/group; Column B: Genus of species that column A falls under; Column C: Scientific names of the species mentioned by projects; Column D: The number of projects that mentioned using the identified species/group. Important note: this is not an exhaustive list of species under each genus listed but is solely focused on the species mentioned by restoration projects.

Coral Species used in Restoration Initiatives				
A Common Species Name (general group)	B Number of Projects Listed Using This	**C** Genus	D Number of projects that specified genus	Scientific Name(s)
Staghorn	9	Acropora	2	Acropora cervicornis
Elkhorn	9	Acropora	2	Acropora Palmata
Boulder and Star Corals	3	Orbicella (boulder and star corals)	2	Orbicella faveolata (Mountainous star coral) Orbicella annullarsi (Boulder star coral) 1
		Montastraea (greater star coral)	2	Montastraea Cavernosa 1
Brain Corals	3	Pseudodiploria	1	Diploria clivosa (knobby brain coral) 1 Diploria strigosa (symmetrical brain coral) 1
		Diploria	N/A	Diploria labyrinthiformis (grooved brain coral)
		Colpophyllia	N/A	Colpophyllia nations (boulder brain coral or large-grooved brain coral)

Coral Species used in Restoration Initiatives				
Leaf/Plate Corals	2	Agaricia	1	Agaricia agaricites (lettuce or tan coral) Agaricia fragilis fragile saucer coral) Agaricia graham (Graham's sheet coral) Agaricia humilis (thin leaf lettuce coral)
Soft Corals	1	Various/Not specified	N/A	N/A
Small Polyp Stony Corals (branching/ finger corals)	2	Porites	2	Porites furcata 1 Porites porites (finger or hump coral) 1 Other/not specified 1
Pillar	1	Dendrogyra		Dendrogyra cylindrus
Any	1	N/A	N/A	N/A

Figure 5.1 Number of coral groups used (x axis) by restoration projects (y axis). 5 projects noted two types, 2 noted three, 1 noted 5, 1 noted 6, 1 noted 8, and 1 noted "any" and thus was placed as a separate category.



7. 5 Stakeholder Engagement

Stakeholder engagement is an important factor for conservation and coral restoration. Participants were asked whether their project has collaboration initiatives with local communities, local authorities, governments, and overall stakeholder participation, as well as what those initiatives entail. All 11 participating projects identified that they have stakeholder engagement. Other than a yes/no category, these results are not fully quantified due to the extensive areas of engagement and descriptions, but a general tally was completed. Coordination with local and or national government was the most common initiative, being listed by 6 separate projects. Collaboration with dive shops and local hotels, as well as community engagement through education (e.g. presentations, workshops etc.) was the second most common initiative, being mentioned 4 times each by separate projects. General coordination with stakeholders was the third most common initiative, being mentioned by 3 separate projects. Other initiatives include a sustainable fishing plans, local youth engagement, community tours, marine protected areas, direct partnership with local schools, partnership with local businesses, collaboration with other organizations, direct tourism engagement with hotel guests, and local beach cleanups.

Community engagement activities are very diverse, as evident from the community activity descriptions, with some projects conducting more activities than others. Some also have more local youth engagement and government engagement. The government engagement activities vary from permit and documentation relationships, to tourism and community involvement, and monitoring and evaluation of certain restoration activities. It is fundamental to outline here that like restoration methods and approaches, community engagement is not necessarily straight-forward and can involve various factors such as the need for funding to run certain activities. Numerous challenges arise that can be related to lack of funding, lack of community or government support, lack of staff and others (see section 7. 6). Because of the numerous factors involved with stakeholder engagement and the variety in responses, this study category is not a very efficient way to measure restoration project engagement, but it does provide an overview of what is being conducted and whether involvement is incorporated.

7. 6 Restoration Project Challenges

Restoration projects face many different challenges from proposing the project, starting the restoration initiatives, and running the project (especially long-term). Some studies have discussed the need for complex, diverse restoration approaches and use of species in restoration (Rinkevich, 2005) (including this paper), engaging communities, as well as the long-term activities restoration projects should be placing more focus on such as monitoring the success of restoration initiatives (Hein et al. 2017). However, like many other conservation projects, there are many challenges to overcome not just in establishing restoration initiatives but also sustaining them. In order to identify some main issues restoration projects face, participants were asked which main challenges they confront. Figure 7.0 outlines the issues from most common to least common. Survey answers were organized by key words and placed into main categories.

The main issue restoration projects are facing is funding. Every project (11 projects) that participated in the survey referenced lack of funding or lack of sustainable funding as a primary issue. Numerous projects outlined that they are either self-funded, donations-based, rely on grants which does not maintain a sustainable income flow to fund the restoration projects, or are generally bound to socioeconomic constrains of the community they reside in. Coral Restoration Panama for example outlines in the survey that the "project is totally supported by private donations, so to maintain consistent cash flow is problematic. We have instigated programs to monetize the development and placement of artificial reef structures to supplement the needs of the Coral Restoration aspect of the project." (Doug Marcy, 2019). The lack of funding is a huge issue as it also extends to being able to initiate more restoration methods, work with more species for restoration, and initiate more community engagement activities. Mélina from HRHP outlines that "Funding is the main issue in the region, although the costs are constantly reducing, those actions are still expensive. The lack of continuity of funding, going from one grant from another generate gaps that threatens the ongoing activities and the monitoring of the restored sites" (Caribbean Restoration Project (CRP) survey, Mélina Soto, 2019). This is echoed in the Guatemala HRHP location as the project there began in 2016 but had to end in 2017 due to lack of funding (CRP survey, Ana Giró, 2019). Thus, although the concept of rapidly improving restoration initiatives alongside other activities to mitigate human impacts and conserve corals and reefs is ideal, there is an urgency for restoration projects to have more support financially. Coral reefs are considered to be some of the most expensive ecosystems to restore (Knowlton, 2001), and assuming projects will be able to efficiently conduct all the necessary research and restoration activities as well as run community engagement initiatives to improve local participation and education is unrealistic without additional support. The project in Montserrat, for example, is unable to expand due to lack of funding. This factor is not always discussed in research studies that focus on the efficiency of coral reef restoration initiatives; however, it is evidently a very large issue that needs to be considered and addressed.

Lack of funding is often coupled with insufficient government support and involvement. There was a total of 3 projects that mentioned government-related issues. Poor government support was mentioned by 2 projects (although for one project this has now improved after they were able to show that the project has merit and positive outcomes for ecosystems and restoration). 1 project mentioned an issue with government regulations and permits (although the permit issue was also mentioned a second time by the Plant a Million Coral project in Florida Keys, but was not tallied here due to being out of the study zone. Melina from HRHP states that there is "confusion in [the] regulation framework and permit granting as some species are protected so under the authority of Natural Resource Authority, the sea is under authority of the Marine Army and Fisheries Authority etc…We need a straight forward legal framework that is [easy] to follow but also ensures that the ecosystem and species are protected" (Caribbean Restoration Project survey, 2019).

Socioeconomic issues, lack of awareness, and other logistical issues were all mentioned once each by separate projects. Some logistical issues are connected to economic setbacks, but others are also related to not having enough support staff to run the project, and this was pointed out by a couple of projects. Considering that many of the coral reef ecosystems are located in areas that are considered to be developing, these issues are not surprising. However, they do pose significant hurdles for restoration projects to start and run restoration projects. If a community has socioeconomic challenges, a lack of awareness of environmental issues (especially relating to coral reefs), and these are coupled with other logistical issues that the projects must deal with (see examples that were mentioned in figure 7.0, column C, under "other logistics"), this can make restoration initiatives quite difficult to run long-term and efficiently. Another interesting issue noted by a couple projects was the rise in restoration initiatives that are either fraudulent or deceptive and inefficient in regard to restoration activities themselves. Thus, more focus must be placed overall on supporting restoration projects with not only funding, but stronger restoration frameworks that engage governments and communities, and help to regulate and monitor activities.

Figure 6.0 List of issues (Column A) mentioned by restoration organizations and calculated by the number of projects that mentioned a particular issue (Column B). Column C outlines additional sub-issues that were listed and fall under column A.

Identified Issues Facing Restoration Projects			
A) **Issue Identified**	**B)** **Number of Projects that Identified this Issue**	**C)** **Sub-Issues**	**Additional Notes**
Lack of Funding	11	Self-funding Donations-based Reliance on grants Socioeconomic standing of community	
Government- Support	2	Lack of government support	Project 1) this has now changed after project was able to show positive results. Project 2) It is an ongoing issue.
Fraudulent/Mismanaged Restoration Projects	2	Fraudulent projects Projects not contributing to restoration efforts as advertised	
Government-Regulation/Permits	1	Regulation framework confusion Permit granting	
Socioeconomic	1	Lack of access to basic resources	

Lack of Awareness	1	Lack of awareness of coral issues	
Other Logistics	1	Access to qualified divers/regular qualified assistance Volunteer liability issues Nursery locations	Nursery location issues refer to finding safe locations for coral nurseries that will not be impacted by sedimentation, anchor damage, or specific bottom substrates

7.7 Human impacts affecting corals and reefs in surveyed areas

A multitude of human impacts affect corals and reef communities by influencing their growth, resilience, and overall health. The participants were asked to identify which human activities are having the largest influence on corals and reefs in their area and although some responses varied, many identified numerous common issues which outlines that some of these issues are problematic around the Caribbean Sea as a whole. In the previous questions, projects were tallied individually because the questions were more related to projects themselves. However, for this question responses were tallied by participants in order to obtain a stronger holistic perspective of issues and because various issues can impact local areas differently and thus it is beneficial to have a greater overview of the issues. This change only impacts one project as that project is the only one that had two participants from the same location. Figure 8.0 outlines the responses by key terms, outlined from most to least common as identified through survey responses. 12 participants are tallied here, and 12 main human impacts were identified, with additional issues that fall under the main headings. Some issues were mentioned together in the surveys and thus responses are grouped under the main keyword provided. For example, some specified pollution but a primary source such as sewage, and thus they were grouped under pollution but sub-categorized as sewage.

Not surprisingly, climate change is noted as the most common human impact and threat to corals and reefs, mentioned by 8 individuals. Development was the second biggest human impact identified with 7 participants noting this issue. Specific issues mentioned under this category are increasing sedimentation from development near coastlines, proposals to build cruise ship docks to host rising tourism, and a general growing population without proper management of sewage, sanitation, environmental protection. Sedimentation was noted 3 separate times but generally related to another human activity such as development and run-off (with the exception of one project who noted it independently as a main issue); thus, it was grouped under "development" as it can relate to a diversity of increasing human activities in this category. Overfishing received 6 indications, with most noting general overfishing issues. One project specifically noted that groupers have been overfished in their area which resulted in a dramatic increase of damselfish that are now damaging to corals (Caribbean Restoration Project Survey, Eco Divers, 2019). Pollution was the fourth biggest threat, being identified 5 times with sub-categories including sewage run-off, plastic pollution, bilge water from cruise ships, or no specification (just general pollution). Sedimentation could also fit under pollution but is placed under development as it relates to these activities. Tourism increase was also mentioned 5 times, with some noting a rise in general tourism and divers/snorkelers. Run-off and effluents were mentioned 4 times, with poor management of run-off noted as a sub-category factor. Boat anchoring, sargassum/macroalgae[10], and inadequate water treatment/management was listed twice. The inadequate water treatment issue was not specified in the survey results and thus was made into a separate category; however, if coupled with the run-off section, the overall impact of poor water treatment/management is a very common issue. Reduced water flow, volcanic activity, and sunscreen impacts are all mentioned once each.

It is important to note that although the results provide a general outline for which human impacts are most common overall through the Caribbean Sea zone, the primary impacts affecting particular areas varies. For example, for some overfishing is the primary issue, while for others population growth or sedimentation was noted as one of the main issues (although these can go hand-in-hand). Furthermore, many of these human activities and pressures are interrelated and thus to gain a clearer understanding and quantification of the overall impacts, more research must be conducted on this topic independently.

[10] Sargassum: genus of brown macroalgae that exists around shallow waters and coral reefs

Figure 7.0 Outline of participant responses to human impacts in their area. Column A outlines the primary human impacts mentioned; column B outlines the number of individuals that cited the particular impact; and column C outlines the sub-category impacts that were outlined by restoration projects but generally fall under a main category.

Human Impacts Affecting Corals/Reefs in Surveyed Locations		
A) **Human Impacts**	**B)** **Number of Individuals that noted the Impact**	**C)** **Sub-categories of Human Impacts mentioned**
1) Climate Change	8	Temperature fluctuations
2) Development (Coastal and Overall)	7	Sedimentation (1 project mentioned this as one of the main issues) Development for cruise ship -docks Growing population without proper sewage/sanitation/environmental protection/run-off management
4) Overfishing	6	General overfishing Damselfish overpopulation
4) Pollution	5	Sewage Plastic pollution Bilge water from cruise ships Not directly specified
5) Tourism increase	5	Rise of overall tourism Rise of divers/snorkelers
6) Run-off/Effluents	4	Poor management of run-off
7) Boat Anchoring	2	
8) Inadequate Water Treatment/Management	2	
9) Sargassum/Macroalgae	2	
10) Reduced water flow	1	
11) Sunscreen Impacts	1	
12) Volcanic Activity	1	

7.8 Marine/Plastic Debris Among Coral Reefs

Marine debris and plastic pollution is a prominent issue in both terrestrial and marine ecosystems. Pollution can include run-off and effluents, debris, or other inputs. Plastic pollution, however, has received relatively little attention in regard to coral and reef impacts in comparison to some issues like climate change (see section 3.2.2). As discussed above, debris and plastic pollution (both macro and micro) can impact corals and reefs in a variety of ways from entanglement to microplastic ingestion. Participants were asked if they have seen any plastic or marine debris among coral reefs, and to list any specific items they could recall. Similar to the last question regarding human impacts, quantification was done by individuals rather than by projects. Figure 9.0 outlines the total responses, grouped into 3 categories: yes, no, and very little debris/not specified exactly. 10 out of 12 participants (83%) answered “yes”; 0 answered “no” (0%); and 2 answered “very little” or did not specify exactly (17%). Figure 9.1 outlines the items that were mentioned by participants. The majority of items mentioned were plastic-based as nearly all respondents mentioned some sort of plastic debris including bottles, bags, cups, styrofoam containers, water sachets, hard plastics, microplastics, single-use cutlery, and straws. One participant mentioned that microplastics have been found in the local reef fish (Caribbean Restoration Project Survey, HRHP (Mexico), 2019). Fishing gear is also mentioned often, including nets, line, and lobster traps. Other debris includes wrappers, glass, cigarette butts, and other miscellaneous items (see figure 9.1 for details).

It is unclear how many of these items were actually found among the reefs as some participants outlined the general trash seen or specified that the majority of marine trash is located closer to human settlements. Thus, further research would need to be conducted on this to clarify. One participant specified that they had seen a bamboo “eco-friendly" Japanese lantern directly on the reef and although the paper was dissolved, the frame was still held together down to sixty feet and had smothered a large brain coral, killing off the majority of it (Caribbean Restoration Project Survey, Eco-Divers, 2019). However, whether these trash items were seen directly on the reef or around marine ecosystems does not take away from the issue of marine debris and pollution that pose biological and physical impacts marine species, including coral reefs, both on a macro and micro level. All participants except one (who focused directly on reefs) noted some trash that they had seen in or near marine ecosystems.

Figure 8.0 Participant answers regarding whether they have seen plastic debris among corals and/or reefs (or in general around the area as some outlined generally but did not specify corals or reefs exactly). Responses were grouped into three categories: yes, no, or very little/not specified.

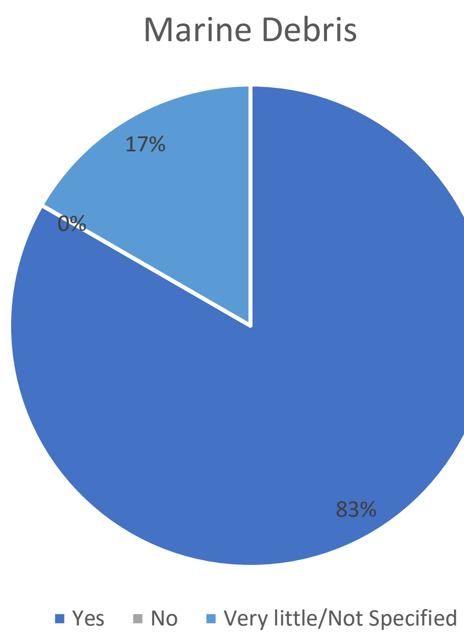


Figure 8.1 Items listed by participants that have been seen around marine ecosystems and or corals/reefs. The left column depicts the main items, while the right column outlines the items listed by participants that are found under the principal items.

Debris on/around Coral Reefs	
Fishing Gear	nets monofilament line lobster fishing traps
Plastics	plastic bottles plastic bags plastic cups styrofoam containers water sachets

	deep-water harder plastics microplastics single-use cutlery straws
Wrappers	snack wrappers plastic wrappers rice bags
Metals	appliances cans
Miscellaneous	General surface trash structural trash hurricane debris electronics yacht/cruise-line items (towels, cooking wear etc.) Japanese lantern
Glass	Bottles
Smoking Items	Cigarette butts

7.9 Status of Corals Reefs in the Caribbean

Participants were asked to state whether the overall health of coral reefs in their area is showing decline, improvement, no major change, or varies by area. It is fundamental to state that there may be variations based on coral species, reef communities, and geographic locations as not all species and areas are impacted equally or to the same extent (as outlined in the discussion above prior to the case study). This is evident in the results as nearly half of the projects listed two options. This question helps to provide an overview of the general status of the reefs throughout the Caribbean, although obtaining more participants here would be helpful in the future in order to improve accuracy.

Figure 10.0 provides a table outline of the responses, depicting the status options, numbers of projects which chose a particular option, and a section for additional responses as some projects provided extra details to their reasoning behind choosing certain options. The "varies by area" section contains the most additional detail as many projects provided information and reasoning on why they selected two options. It should also be noted that for the "varies by area" section, some responses did not specifically state "varies by area" but rather provided two options, including "declining" improving" or "no change" based on particular areas or depths. Thus, this is counted as a variance rather than two separate options in order to quantify the data more efficiently. This question is also tallied by projects and not by individuals, and results outlined from greatest to lowest tallies.

Varies by Area:

7 separate projects outlined "varies by area" specifically or by outlining two survey options and thus are placed into this category. 6 out of these 7 projects outlined two separate options (primarily "declining" and "improving", with two also mentioning "no changes"), citing additional information on the reef communities, temperature and hurricanes, coral disease/bleaching, volcano activity, sea urchin/fish biomass, macroalgae biomass, and restoration activities for their choices (see the "additional notes from participating projects" column).

Declining:

"Declining" was the second most noted option, noted individually with 4 projects directly outlining this. One project noted "probably declining" as they were in the process of conducting a survey on 29 different sites which have not been surveyed formally since 1999 and did not yet have the updated results. Others directly noted overall decline in coral reef health. Plant a Million Coral Foundation [PMC], although not directly tallied here, also noted overall decline. Doctor David Vaughan, founder of PMC, works in collaboration with other restoration projects on a global basis and outline general decline, and refers the issue of stony coral tissue loss (SCTL) breakout which another project has mentioned as well. Vaughn points out that there has been partial improvement but only in the resilient species strains that have been out-planted (Caribbean Project Survey, PMC, 2019). One significant factor to note here is that although the "declining" tally number is lower than the "varies by area" tally, 8 participating projects did mention coral decline directly (but not solely) which still depicts a general trend in coral health decline, although a more thorough study of the extent of decline must be conducted.

Improving:

Only one project solely chose "improving" under this particular question; however, in "additional comments" they elaborated, stating that areas that are part of restoration efforts appear to be improving, but other areas have shown no major changes for the past 3 years. Thus, they were tallied as "varies by area" since two answers were provided for the same topic.

No Change:

No project chose "no change" independently. This response was noted two times but only in connection with another response and thus was categorized under "varies by area" as this outlines a variation in coral health.

Figure 9.0 Status of coral reef health identified by projects.

Health Status of Coral Reefs by Project Responses		
Status	**Number of Projects**	**Additional Notes from Participating Projects**
Varies by Area	7	Decline in some areas due to past bleaching events but other areas stable for past few years. However, there is concern for Stony Coral Tissue Loss (SCTL) Overfishing of reefs resulting in decline, but decreasing volcanic activity and increasing sea urchin populations have improved some areas Decrease near shores from hurricanes (20ft or less) but may increase in deeper water (20ft plus) due to less visitors and vessels (also due to hurricanes) (but more research must be conducted on this) Improvement of coral cover in some areas but macroalgae and low fish biomass resulting in poor reef health) Restoration activities are improving particular areas where initiatives are taking place, while some outline no major changes in other areas in the past few years
Declining	4	Decline probable for one area: One project is in the process of

		conducting a site survey which has not been assessed since 1999 but outline the overall status is probably "declining". Shallow lagoon areas were outlined to be primarily stressed by one project most likely due to past heating and bleaching events. Others outline general decline
Improving	0	Some projects mentioned improvement in areas of restoration activities but because another additional option was selected, responses were grouped into "varies by area" since there is evident variance.
No Change	N/A	N/A

8.0 Study Limitations

There are two primary challenges that arose during this research study which may have impacted the results and the overall accuracy of data: 1) survey design, and 2) low participation. One of the main challenges to this study was the organization of information which came down to survey design. The survey used to conduct this research of the restoration projects and human impacts (see figure 1.0 on page 59) was too general which made it difficult to categorize and quantify some of the answers and ensure all of the responses were being reflected accurately as best as possible. Some survey responses were very detailed and elaborate about their methods, challenges, and human impacts while others were short responses and provided point form responses. For example, question 4 of the survey asked "is there collaboration with local community, stakeholders, and/or local authorities? Are there any community engagement activities/initiatives? If so, how and what?", responses ranged from point form to very detailed. All answers were useful and insightful, this issue simply made it challenging to organize the data. Furthermore, multiple terms were also used to describe the similar activities and some responses fell into multiple categories which made classification fairly difficult at times.

Another study limitation was the low participation. 61 projects were identified around the Caribbean Sea zone through a general internet search. Yet, this is a grave disconnection from the 11 projects that actually participated in the survey (13 including those outside the study zone). Even assuming many of these would not be qualified to participate for various reasons, a higher participation percentage is required to obtain a clearer depiction and accuracy of data. Due to the low amount of participation, although still insightful and useful for data collection, the overall data conclusions may not fully represent the extent of human impacts and variance in restoration approaches (both restoration approaches, species used in restoration, and community involvement) throughout the Caribbean.

Thus, if this study and the survey is to be conducted again, a helpful measure would be to make the surveys more direct and or focus more on specific topics (e.g. human impacts or restoration methods) and attempt to obtain a larger project participation population. Providing direct survey options for participants to choose from rather than leaving the questions generally open ended for participants would allow for easier categorization and tally of data for this type of study, reduce any margins of error, and improve overall accuracy of responses, while ensuring participant responses are represented with the fullest precision. Obtaining a larger amount of participation from projects would also tremendously improve the accuracy of results and ensure stronger accuracy of data. By obtaining a larger population participation and ultimately more data to analyze, there is a stronger representation of human impacts and restoration initiatives which would also reduce the margin of error.

One final limitation is more-so related to research itself. There are a lot of statistics pertaining to coral and reefs; however, there is some small discrepancy in the numbers and percentages in relation to some topics (e.g. the full amount of corals and reefs lost, historic extinction rates, and amount generated from ecosystem services and people relying on reefs). Many of these numbers of difficult to quantify, however, as mentioned in the above discussion. The figure for the actual coral amount loss may be fairly difficult to tally overall however, as again, coral species may react differently to some disturbances, with some being more resilient than others. This also depends on geographical locations and thus providing an overall, accurate statistical number may be difficult, but considering the promoted scale of the coral reef degradation issue, it is mandatory to begin creating an updated, valid global analysis and degradation monitoring. It is further challenged by the lack of long-term monitoring and historical losses can be difficult to tally. Again, this will take commitment from not only restoration organizations, but also must be a collaboration with and supported by governments and global communities.

9.0 Conclusion

Coral reefs are considered to be some of the most threatened ecosystems. Although they account for a multitude of ecosystem services, they are becoming increasingly impacted by human activities, and are degrading and or shifting into novel ecosystems. In the Caribbean, corals and reefs have been impacted biologically and structurally throughout history, but continuous inputs of human pressures are pushing their threshold of resiliency. The case study of human impacts and restoration activities in the Caribbean (specifically around the Caribbean Sea) connects coral reef literature on this topic to a real example. It provides an overview of the restoration projects' initiatives and complexity, prominent human impacts in their area, and the health status of coral reefs in their area. The health status of reefs appears to differ slightly from the overall academic consensus that corals and coral reefs are facing wide-spread degradation in that projects outline a lot of variance. However, the variance still depicts large-scale degradation issues as no projects outlined improvement on a mass-scale, only in relation to restoration areas. All human impacts outlined by projects correlate to academic literature and studies in regards to being a main detriment for corals and reefs, and although plastic pollution was less discussed under human impacts than other factors, nearly all projects noted some form of debris in and or around coral reefs which outlines possible knowledge gaps and an area for improving management. Although restoration projects face numerous challenges, economic constraints are outlined to be the most common as it was referenced by every participating project.

In order to improve the accuracy of data and obtain a stronger representation throughout the Caribbean, more project participation is needed, and survey questions must reduce vagueness and focus on more specifics in the future. However, the case study does provide an interesting overview of the restoration initiatives, human impacts on coral reefs, and project challenges, ultimately outlining that although improvements could and should be made in reference to long-term monitoring and utilizing more species in restoration initiatives, numerous challenges and setbacks can prevent these improvements. Restoration initiatives and improvements must be coupled with governmental and global support as many of the challenges relate to socioeconomic setbacks. Rather than responsibilities falling primarily to restoration projects, governments and international communities must support restoration not only financially but also politically and scientifically by providing stronger assistance for scientific research, and through improved frameworks, guidance, regulations, and ideally improvement of numerous socioeconomic issues (such as regulation of waste outputs, for example).

Figure 1.0 Coral Restoration: Caribbean Survey

Researcher Contact: Yana Pikulak
MES Candidate
York University
yanapikulak@gmail.com

Please fill out the following questions to the best of your ability. English is preferred but Spanish accepted. Short answer and point form please. Por favor complete las siguientes preguntas lo mejor que pueda. Se prefiere el inglés pero se acepta el español. Respuesta corta y formulario de puntos por favor.

Organization/Project Name (Nombre de la organización / proyecto):

Your name (Tu nombre):
this information will be kept anonymous /esta información se mantendrá anónima

Your Position with the Project *(Tu posición con el proyecto)*:

Main Project Location (Ubicación principal del proyecto):

Secondary Location(s) *(ubicación secundaria (s))*:

1. When did the restoration project begin (*¿Cuándo comenzó el proyecto de restauración?)*?:

2. What kind of restoration techniques are being used (e.g. coral garden, reef ball, coral trees, structures?). List all that apply.*(¿Qué tipo de técnicas de restauración se utilizan (por ejemplo, jardín de coral, bola de arrecife, árboles de coral, estructuras?)*? *Liste todos los que apliquen.*

3. Which coral species are being used in restoration activities? (e.g. Staghorn, Elkhorn, boulder corals?) *(Si corresponde, ¿qué especies de coral se están utilizando en actividades de restauración? (¿por ejemplo, Staghorn, Elkhorn, corales de roca?))*

4. Is there collaboration with local community, stakeholders, and/or local authorities? Are there any community engagement activities/initiatives? If so, how and what? *(¿Existe colaboración con la comunidad local, las partes interesadas y/o las autoridades locales? ¿Hay actividades / iniciativas de participación comunitaria? Si es así, ¿cómo y qué?)*.

5. What main issues does the restoration project face (e.g. lack of government support, local conflict, lack of funding etc.)? *(¿A qué problemas principales se enfrenta el proyecto de restauración (¿por ejemplo, falta de apoyo gubernamental, conflicto local, falta de financiamiento, etc.?)*.

6. Which human impacts appear to be impacting/putting pressure on coral reefs most in your area (e.g climate change, pollution, tourism, trafficking)? List all that apply *(¿Qué impactos humanos parecen estar afectando / ejerciendo presión sobre los arrecifes de coral en su área (¿por ejemplo, turismo, cambio climático, contaminación, el tráfico? Liste todos los que apliquen)*.

7. Have you seen any plastic/marine debris among coral reefs? If you recall specific items, please list them *¿Has visto algún residuo plástico / marino entre los arrecifes de coral? Si recuerdas elementos específicos por favor enumerar*

8. Is coral reef health in your area showing decline, improvement, or no major changes? This can

vary within zone and by species. Please circle the most relevant of 4 options:*¿La salud de los arrecifes de coral en su área muestra declive, mejoría o ningún cambio importante? Esto puede variar dentro de la zona y por especie. Por favor circule la más relevante de las 4 opciones:*

Declining (*Declinante)*

Improving (*Mejorando)*

No major changes (*No hay cambios importantes)*

Varies by area/species (*Varía por área /especie)*

Additional Comments (Optional)

References

Altieri, A. H., Harrison, S. B., Seemann, J., Collin, R., Diaz, R. J., & Knowlton, N. (2017). Tropical dead zones and mass mortalities on coral reefs. *PNAS, 114*(14), 3660-3665.

Alvarez-Filip, L., Dulvy, N. K., Gill, J. A., Cote, I. M., Watkinson, A. R. (2009). Flattening of Caribbean coral reefs: region-wide declines in architectural complexity. *Proceedings of the Royal Society B: Biological Sciences, 276*(1669), 3019-3025

Anthony, K. R. N., Maynard, J. A., Diaz-Pulido, G., Mumby, P. J., Marshall, P. A., Cao, L., & Hoe-Guldberg, O. (2011). Ocean acidification and warming will lower coral reef resilience. *Global Change Biology, 17*, 1798-1808.

Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs, 81*(2), 169-193.

Barton, J. A., Willis, B. L., & Hutson, K. S. (2015). Coral propagation: A review of techniques for ornamental trade and reef restoration. *Reviews in Aquaculture, 0,* 1-19.

Bellwood, D. R., Hughes, T. P., Folke, C., & Nystrom, M. (2004). Confronting the coral reef crisis. *Nature, 429*(6994), 827-833.

Bruckner, A. (2001). Tracking the trade in ornamental coral reef organisms: The importance of CITES and its limitations. *Aquarium Sciences and Conservation, 3,* 79-94.

Carpenter, K. E., Abrar, M., Aeby, G., Aronson, R. B., Banks, S., Bruckner, A., Chiribogs, A., Cortes, J., Delbeek, C., DeVantier, L., Edgar, G. J., Edwards, A. J., Fenner, D., Guzman,

H. M., Hoeksema, B. W., Hodgson, G., Johan, O., Licuanan, W. Y., Livingstone, S. R., Lovell, E. R., Moore, J. A., Obura, D. O., Ochavillo, D., Polidoro, B. A., Precht, W. F., Quibilan, M. C., Reboton, C., Richards, Z. T., Rogers, A. D., Sanciangco, J., Sheppard, A., Sheppard, C., Smith, J., Stuart, S., Turak, E., Veron, J. E., Wallace, C., Weil, E., & Wood, E. (2008). One-third of reef-building corals face elevated extinction risk from climate change and local impacts. *Science*, *321*(5888), 560-563.

Cinner, J. (2014). Coral reef livelihoods. *Current Opinion in Environmental Sustainability, 7,* 65-71.

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

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

Donohue, M. J. (2001). Derelict fishing gear in the Northwestern Hawaiian Islands: Diving surveys and debris removal in 1999 confirm threat to coral reef ecosystems. *Marine Pollution Bulletin, 42*(12), 1301-1312.

Edwards, A. J. (ed.) (2010). *Reef Rehabilitation Manual*. Coral Reef Targeted Research & Capacity Building for Management Program: St Lucia, Australia.

Gall, S. C., & Thompson, R. C. (2015). The impacts of debris on marine life. *Marine Pollution Bulletin, 92*, 170-179.

Graham, N. A. J., & Nash, K. L. (2013). The importance of structural complexity in coral reef ecosystems. *Coral Reefs, 32*, 315-326.

Hall, N. M., Berry, K. L. E., Rintoul, L., & Hoogenboom, M. O. (2015). Microplastic ingestion by scleractinian corals. *Marine Biology, 162*, 725- 732.

Hein, M. Y., Willis, B. L., Beeden, R., & Birtles, A. (2017). The need for broader ecological and socioeconomic tools to evaluate the effectiveness of coral restoration programs. *Restoration Ecology, 25*(6), 873-883.

Hoegh-Guldberg, O., Mumby, P. J.,Hooten, A. J., Steneck, R. S., Greenfield, P., Gomez, E., Harvell, C. D., Sale, P. F., Edwards, A. J., Caldeira, K., Knowlton, N., Eakin, C. M., Iglesias-Prieto, R., Muthiga, N., Bradbury, R. H., Dubi, A., & Hatziolos, M. E. (2007). Coral reefs under rapid climate change and ocean acidification. *Science, 318*(5857), 1737-1742.

Hughes, T. P., Barnes, M. L., Bellwood, D. R., Cinner, J. E., Cumming, G. S., Jackson, J. B. C., Kleypas, J., van de Leemput, I. A., Lugh, J. M., Morrison, T. H., Palumbi, S. R., van Nes, E. H., & Scheffer, M. (2017). Coral reefs in the anthropocene. *Nature, 546*, 82-90.

International Union for Conservation of Nature's Red List Species [IUCN Red List]. (2019). The IUCN red list of threatened species. Retrieved from https://www.iucnredlist.org/

Jobbins, G. (2006). Tourism and coral-reef-based conservation: can they coexist? In I. M. Côté & J. D. Reynolds (Eds.), *Coral Reef Conservation* (237-263). New York, NY: Cambridge University Press.

Jones, R. J., & Steven, A. L (1997). Effects of cyanide on corals in relation to cyanide fishing on reefs. *Marine and Freshwater Research, 48*(6), 517-522.

Katsanevakis, S. (2008). Marine debris, a growing problem: Sources, distribution, composition, and impacts. In T. N. Hofer (Ed.), *Marine Pollution: New Research*, 53-101. New York, NY: Nova Science Publishers, Inc.

Knittweis, L., & Wolff, M. (2010) Live coral trade impacts on the mushroom coral Heliofungia actiniformis in Indonesia: Potential future management approaches. *Biological Conservation, 143*(11): 2722–2729.

Knowlton, N. (2001). The future of coral reefs. *PNAS, 98*(10), 5419-5425.

Knowlton, N. (2008). Coral reefs. *Current Biology, 18*(1), R13-R18.

Knowlton, N. & Jackson, J.B.C. (2008). Shifting baselines, local impacts, and global change on coral reefs. *PLoS Biol., 6*(2), 215–220.

Lamb, J. B., Willis, B. L., Fiorenza, E. A., Couch, C. S., Howard, R., Rader, D. N., True, J. D., Kelly, L. A., Ahmad, A., Jompa, J., & Harvell, D. C. (2018). Plastic waste associated with disease on coral reefs. *Science, 359*(6374), 460-462.

Lamb, J. B., True, J. D., Piromvaragorn, S., & Willis, B. L. (2014). Scuba diving damage and intensity of tourist activities increases coral disease prevalence. *Biological Conservation, 178*, 88-96.

Lirman, D., & Schopmeyer, S. (2016). Ecological solutions to reef degradation: Optimizing coral reef restoration in the Caribbean and Western Atlantic. *Peer J*, 2597.

Luna, G. M., Biavasco, F., Danovaro, R. (2007). Bacteria associated with the rapid tissue necrosis of stony corals. *Environmental Microbiology, 9*(7), 1851-1857.

McClenachan, L., Cooper, A. B., Carpenter, K. E., & Dulvy, N. K. (2012). Extinction risk and bottlenecks in the conservation of charismatic marine species. *Conservation Letters, 5*(1), 73-80.

Mladenov, P. (2013). *Marine biology: A very short introduction.* United Kingdom, UK: Oxford University Press.

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

Mumby, P. J., Broad, K., Brumbaugh, D. R., Dahlgren, C. P., Harborne, A. R., Hastings, A., Holmes, K. E., Kappel, C. V., Micheli, F., & Sanchirico, J. N. (2008). Coral reef habitats as surrogates of species, ecological functions, and ecosystem services. *Conservation Biology*, *22*(4), 941-951.

Neal, B. P., Khen, A., Treibitz, T., Beijbom, O., O'Connor, G., Coffroth, A. M., Knowlton, N., Kriegman, D., Mitchell, B. G., & Kline, I, D. (2017). Caribbean massive corals not recovering from repeated thermal stress events during 2005-2013. *Ecology and Evolution, 7*(5), 1339-1353.

Ocean Portal Team. (2018, April). *Corals and coral reefs*. Retrieved from https://ocean.si.edu/ocean-life/invertebrates/corals-and-coral-reefs

Osborne, P. L. (2012). *Tropical ecosystems and ecological concepts (*2nd ed.). United Kingdom, UK: Cambridge University Press.

Page, C. A., Muller, E. M., & Vaughan, D. (2018). Microfragmenting for the successful restoration of slow growing massive corals. *Ecological Engineering, 123*, 86-94.

Pandolfi, J. M., Connolly, S. R., Marshall, D. J., & Cohen, A. L. (2011). Projecting coral reef futures under global warming and ocean acidification. *Science, 333*(6041), 418-422.

Pandolfi, J. M., & Jackson, B. C. (2006). Ecological persistence interrupted in Caribbean coral reefs. *Ecology Letters, 9*(7), 818-826.

Pratchett, M. S., Hoey, A. S., & Wilson, K. S. (2014). Reef degradation and the loss of critical ecosystem goods and services provided by coral reef fishes. *Current*

Opinion in Environmental Sustainability, 7, 37-43.

Rhyne, A. L., Tlusty, M. F., & Kaufman, L. (2014). Is sustainable exploitation of coral reefs possible? A view from the standpoint of the marine aquarium trade. *Current Opinion in Environmental Sustainability, 7,* 101-107.

Rhyne, A. L., Tlusty, M. F., Szczebak, J. T., & Holmberg, R. J. (2017). Expanding our understanding of the trade in marine aquarium animals. *Peer J,* 5:e2949, 1-36.

Richards, Z. T., & Beger, M. (2011). A quantification of the standing stock of macro-debris in Majuro lagoon and its effects on hard coral communities. *Marine Pollution Bulletin, 62*, 1693-1701.

Rinkevich, B. (2005). Conservation of coral reefs through active restoration measures: Recent approaches and last decade progress. *Environmental Science & Technology, 39*(12), 4333-4342.

Rinkevich, B. (2008) Management of coral reefs: we have gone wrong when neglecting active reef restoration. *Marine Pollution Bulletin, 56*(11), 1821 – 1824. (have yet to use this source)

Rinkevich, B. (2014). Rebuilding coral reefs: does active reef restoration lead to sustainable reefs? *Current Opinion in Environmental Sustainability, 7,* 28 – 36. (haven't used this yet)

Sale, P. F. (2002). *Coral reef fishes: Dynamics and diversity in a complex ecosystem*. San Diego, CA: Academic Press.

Seeman, J., Gonzalez, T. C., Carballo-Balaños, R., Berry, K., Heiss, G. A., Struck, U., & Leinfelder, R. R. (2014). Assessing the ecological effects of human impacts on coral reefs in Bocas del Toro, Panama. *Environmental Monitoring Assessment, 186*(3)*:* 1747-

1763.

Sheppard, C. (2014). *Coral reefs: A very short introduction*. United Kingdom, UK: Oxford University Press

Shafir, S., Van Rijn, J., Rinkevich, B. (2006). Steps in the construction of underwater coral nursery, an essential component in reef restoration acts. *Marine Biology, 149*, 679-687.

Smith, K. F., Behrens, M., Schloegel, L. M., Marano, N., Burgiel, S., & Daszak, P. (2009). Reducing the risks of the wildlife trade. *Science, 324*(5927), 594-595.

Thornhill, D. J. (2012, December 12). Ecological impacts and practices of the coral reef wildlife trade. Defenders of Wildlife. Retrieved from https://defenders.org/sites/default/files/publications/ecological-impacts-and-practices-of-the-coral-reef-wildlife-trade.pdf

Tissot, B. N., Best, B. A., Borneman, E. H., Bruckner, A. W., Cooper, C. H., D'Agnes, H., Fitzgerald, T. P., Leland, A., Lieberman, S., Amos, A. M., Sumaila, R., Telecky, T. M., McGilvray, F., Plankis, B. J., Rhyne, A. L., Roberts, G. G., Starkhouse, B., Stevenson, T. C. (2010). How U.S. ocean policy and market power can reform the coral reef wildlife trade. *Marine Policy, 34*, 1385-1388.

Weis, J. (2015). Marine pollution: What everybody needs to know. New York, NY: Oxford University Press.

Wilkinson, C. (2006). Status of coral reefs of the world: Summary of threats and remedial action. In I. M. Côté & J. D. Reynolds (Eds.), *Coral Reef Conservation* (3-39). New York, NY: Cambridge University Press.

Wood, E. (2001). Collection of coral reef fish for aquaria: Global trade, conservation issues, and management strategies. Marine Conservation Society, UK.

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.467.6465&rep=rep1&type=
pdf