MARINE PROTECTED AREAS AND ARTIFICIAL REEFS: A HOPE FOR CORAL RESTORATION AND FISH REPOPULATION IN BOCAS DEL TORO, PANAMA

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Marine ecosystems are diverse, complex, and fundamental to human populations; however, they are impacted directly and indirectly through human activities and environmental changes. Coral reefs and fish populations are two groups that experience tremendous pressure and ongoing exploitation issues. These stressors primarily include but are not limited to, climate change, pollution, over-harvesting, development (and the associated impacts), and tourism [1-3].

Internationally, fish stocks have been significantly reduced and exploited [4] while coral reef coverage has declined by roughly 50% [5,6], with predictions of up to 90% loss by 2050 [5-7]. In the Caribbean, these numbers are just as drastic, amounting to approximately 50% coral loss in some areas from 1980s levels [8], while 50% or more of the commercial fish stock are considered to be overexploited or exhausted, and 40% are considered to be fully drained [9]. Unfortunately, in 2021, it is probable that these percentages are now higher. In Bocas del Toro, Panama, fish populations are overexploited and coral reef populations have declined at high rates, with communities impacted throughout history and still continuing to be affected by various factors and human activities today. The bleaching events in 2020 impacted 90% of the analyzed coral in the interior archipelago and resulted in 50% loss. The Caribbean Coral Restoration Center (CCRC) organization is working to mitigate these declines and improve marine ecosystem health, but the project requires more support at the national and municipal levels in Panama, including regional government leaders, mayors and village representatives, and community members.

The issues impacting coral reefs and fish stocks in Bocas del Toro are often interrelated and require holistic approaches to build healthier and more resilient ecosystems. Two field-based initiatives that CCRC is currently advocating for are artificial reefs and marine protected areas (MPAs). Artificial reefs and MPAs, when organized and managed effectively, can both help to regenerate biodiversity, fish populations, and coral reefs while simultaneously improving ecosystem health and ecological resilience to stressors [10,11].

Through this report, our goal is to convey the urgency and need to tackle ongoing ecological loss among coral and fish communities around Bocas del Toro, show the benefit of utilizing artificial reefs for marine habitat and coral restoration through a case study of the CCRC project, and advocate for the regulated implementation of MPAs and MPA networks around Bocas del Toro.
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Introduction

Although ecosystems have historically faced various natural pressures, human activities are degrading many environments faster than they can naturally recover. This is notable among many coral reefs and fish populations as they are exposed to increasing pressures, with excessive stress stemming from anthropogenic practices. Some of these activities can be considered direct such as overfishing, pollution, tourism, development, and general exploitation of resources, and some can be indirect such as climate change [8].

Coral reefs have internationally degraded by approximately 50%, while roughly up to 75% face damage from anthropogenic impacts [1,12]. Seafood consumption is also on the rise while fish stocks are decreasing [4]. This is highly problematic for numerous reasons. Apart from coral reefs supporting biodiversity and maintaining healthy marine ecosystems, they also provide extensive ecosystem services and help to promote ecological integrity (definition on p. 4) [13-16]. Healthy fish stocks are also important for maintaining balance in marine food webs as well as supporting both coastal and international communities socially, economically, and environmentally [17].

In the Caribbean, coral loss has been taking place from local stressors such as fishing and land development at least decades prior to the widespread account of coral loss in the last few centuries [18].
Coral degradation appeared to begin drastically increasing in the 1970s [13,19] and in the 1980s the impacts from human activities and climate change on coral reefs were more evident [8,18]. Since then, coral reef coverage has declined by roughly 80% in the Caribbean [18]. Unfortunately, historic and chronic exposure to stress can make coral reefs and ecosystems less resilient to climate change and other ecological changes. In Bocas del Toro, there has been an extensive decline in both coral reef and fish communities. With the increasing human population, rising demand on, and overuse of natural resources [61] in conjunction with climate change and other local stressors, coral restoration initiatives and marine protected areas (MPAs) are suggested to help mitigate the rapid depletion of coral and fish in the Bocas del Toro region.

The artificial reefs and restoration areas by Caribbean Coral Restoration Centre (CCRC) show significant potential for repopulating local fish populations and working as bases for coral regrowth. However, official marine protected areas (MPAs) are an essential addition to achieving conservation goals due to the extent of human activities and subsequent impacts on marine ecosystems [20], as evident locally in Bocas del Toro. Combined, these two methods can help repopulate coral reefs and fish communities, support general biodiversity, and subsequently assist in maintaining natural resources for the local island communities.

Ecological Integrity:
The ability of an ecosystem to uphold ecological processes and support species diversity. [60]

**Environmental Impacts**

There are numerous anthropogenic activities that are contributing to coral degradation and fish stock depletion internationally, around the Caribbean, and in the Bocas del Toro region.

Some of the main human impacts present around Bocas del Toro:

**Pollution/Debris**

Pollution and debris are connected to various human activities including but not limited to industrial output, chemical pollutants [21], construction and development, natural resource extraction, sewage and runoff [15], fisheries (active and passive), aquaculture, tourism and leisure [3], boating and ships, and general litter [22]. Sewage run-off and pollution around coral communities are considered strong stressors because run-off often carries oxygen-depleting substances [23, 24, 3]. Coral disease and mortality have also been linked to increased organic input [25], tourism, sedimentation [25, 3, 59], and plastic pollution [26, 27].
Plastics, for example, can cover corals and suffocate them, create entanglement issues, and be accidentally ingested by marine species. Plastic debris can also carry pathogens, increasing the chances of coral disease [26], and even result in microplastic ingestion by corals [27]. All of the pollutant sources mentioned above are detrimental to healthy marine ecosystems, including coral and fish habitats.

Coastal Development

Rapid coastal land use and development is another big threat to marine ecosystems, coral communities, and fish populations [20,1]. Coastal development is often close to coral reef communities and subsequently increases inputs of freshwater, sediment, nutrients, and other pollutants [2].

Excess deforestation around coastal areas, for example, escalates erosion and sediment run-off. Corals can be negatively impacted by sediment as the sediment particles settle on polyps, burying coral or reducing light, and decreasing oxygen accessibility, possibly stimulating algal growth (eutrophication) [2].

Climate Change

Rising temperatures from increasing greenhouse gas emissions are contributing to many climatic changes which influence ecological processes and species. Coral reefs are particularly sensitive to change [59] and susceptible to warming temperatures, and tropical marine species, in general, are more sensitive to thermal variations [17] which can alter species dominance [28] and influence species migration [17]. Marine food webs, for example, can face challenges as phytoplankton is sensitive to temperature, light, and nutrient availability; thus, greenhouse gas (GHG) emissions will have a significant influence on the biomass of marine species [17]. Warming, reduced oxygen (hypoxia), and acidification are also connected to climate change. Rising CO2 levels in the atmosphere from anthropogenic activities have raised oceanic acidity and contribute to a rise in extreme weather events, leading events to become more frequent and prolonged [17]. Over the last 5 years, Bocas del Toro has faced extensive heat stress. The result from excessive heat can be coral bleaching, diseases [13], and increased susceptibility to other stressors. Although some colonies can recover from such events, climate change-related heat events are predicted to increase in occurrence and intensity which results in many coral reef communities having insufficient recovery time and possibly resulting in colony collapses [29]. Many of the colonies identified containing Elkhorn and Staghorn coral have collapsed following bleaching events within a very short time frame.

Overfishing

Excessive fishing practices and poor regulation in the Caribbean have led to many fish stock issues as fish populations dwindle. Overfishing on coral reefs, including destructive fishing, is considered to be the leading local human stressor, and already affected over 55% of global coral populations in 2011 [1]. Please see page 9 (under overfishing issues) for further details.

Coral Reefs

Coral reefs contribute many services that humans rely on such as coastal protection, raw materials and goods, tourism, fisheries, nutrient cycling, research opportunities, and education [30,14,31]. However, they are restricted to growing in particular environmental...
conditions and are highly sensitive to stress and changes in those conditions [2]. Some of these changes include alterations in the food web structure that often stems from the over-harvesting of predators (top-down effects) and from diseases, climate change, and nutrient influx [2,15]. Other factors influencing coral health directly are overfishing, general pollution, coastal development [3,15], tourism [3], and the souvenir trade [1,33,3].

Internationally, coral reefs are in concerning levels of decline with bleaching events and diseases becoming increasingly more common [2]. Furthermore, historic and current pressure from human activities, climate change, and an increase in bleaching events with reduced time between stress events is also evident and has contributed to a flattening of coral reefs globally and around the Caribbean [13]. Additionally, many coral reef communities are experiencing phase shifts from higher to lower biodiversity that is often accompanied by excessive macro-algae [2,13]. It is estimated that even if warming were to not exceed 1.5 degrees C, 70-90% of reef-building corals will be completely extinguished by the end of this century [17].

In the Caribbean, these changes in coral communities are evident and are influenced by the direct impacts from human activities such as run-off and sediment, nutrient and pollutants, over-harvesting of marine species, and climate change [13]. In 2012, it was outlined that over 70% of coral reefs show some signs
of human-induced stress [2]; however, with increasing global temperatures and human populations [54] that percentage is most likely higher now in 2021. A study conducted by Alvarez-Filip et al. (2009) outlines a steady decline of stony, reef-building corals among different depths and regions across the Caribbean. Over time, these changes can contribute to a flattening of reefs and subsequently reduced biodiversity [13]. Years later, we are still continuing to experience coral colony collapse and fish degradation. Thus, it is imperative that stronger action is taken to protect marine ecosystems like those around Bocas del Toro.

**Fish Communities**

Fish communities are important for both social and physical reef resilience such as through providing environmental protection and ecosystem services [32]. Caribbean fish communities are under enormous pressure. Overfishing, pollution, sedimentation, habitat degradation, invasive species, and climate change-related effects such as acidification, warming, changes in nutrient concentrations, and oxygen depletion can all have adverse effects on tropical fisheries [17]. These issues are increasingly problematic and as human populations rise and demand increases [61] (both among coastal communities and internationally), so does the pressure on fish populations. Reef fish populations, for example, have decreased in many areas primarily from overfishing, pollution, climate-related issues, and exploitation for jewelry and the curio trade [2,33].
Biological and physical stressors can also impact the reproduction, distribution, and abundance of marine species, resulting in both direct and indirect impacts on fisheries [17]. The degradation of coral reef habitats also plays a role in this as coral reefs contribute to maintaining fish and overall marine biodiversity by providing food and shelter for other species [28,34,13].

**Overfishing Issues**

Internationally, fish populations have been significantly drained through exploitation [4]. The global fish catch from marine ecosystems is roughly 80 to 91 million tonnes annually since 1990 and worth approximately US$100 billion per year; however, this average does not account for unreported catches and bi-catch [17]. If these were accounted for, since the 1980s, the global catch levels are estimated to be around 100-130 million tonnes [17]. In the 1990s, global fish catch reached its maximum and since then fish stocks and catches have been declining as some fish populations are completely overfished/exploited or at high rates of exploitation [17].

In a study conducted in 2017 that surveyed coral restoration projects around the Caribbean Sea, 6 out of 12 participants (11 projects total) around the Caribbean directly outlined overfishing as a prominent issue [35]. Overfishing can create top-down effects and be detrimental to food webs. When large species are overfished, for example, this creates an imbalance within ecosystems as natural population management becomes altered. Pressure is then passed on to the next smaller species until large predatory species are extinguished. This ultimately results in smaller yields and catch sizes [2].

Tropical fisheries are a significant source of food and important for livelihoods (especially for coastal communities) and international trade [17]. Unfortunately, climate change and exploitative practices pose various detrimental impacts on tropical fisheries that threaten the resources many communities rely on [16,17]. Out of all the local stressors impacting coral reefs, overfishing is considered to be the highest with over 55% impact globally, followed by coastal development and pollution at 25%, and damage from ships at roughly 10% [1]. However, these numbers may be higher now with these activities increasing globally.

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**Between 2007 and 2016, approximately 50% of the global fish catch was sourced from tropical marine fisheries (worth roughly $96 billion USD) [17].**
Marine Conservation

Marine ecosystems are valuable independently from human utility as they help to regulate climate, biodiversity, and ultimately life on our planet [36]. However, conservation of marine ecosystems is also fundamental because they provide a multitude of social, economic, and ecological services on an international scale. These services contribute a great amount to the global economy, ecological balance, and the maintenance of livelihoods of local and coastal communities that rely on them directly, as well as international communities through trade.

Yet, marine ecosystems were, and still sometimes are, considered to be boundless sources of resources and areas where one can conveniently pollute [37]. Consequently, with persistent human impacts and rapid ecological changes, it is imperative that we take action to protect these ecosystems to ensure long-term ecological health and human accessibility.

In order to support biodiversity and preserve ecosystems, we must use methods that take ecological complexity into account. The ecosystem approach is a useful perspective for this as it advocates for holistic methods, acknowledging the complex relationship between human systems and biological systems [38], and focusing on systems thinking to tackle environmental and conservation issues. Utilizing both marine protected areas (MPAs) and artificial reef structures (in conjunction with the other initiatives undertaken by CCRC) promotes this approach as these methods maintain that ecosystems are complex and aim to manage ecological issues like coral reef and fish community degradation by promoting biodiversity and ecological resiliency. Additionally, these initiatives also often involve community engagement and education to connect the environmental and social dimensions. This is fundamental as local community and government support, cooperation, and involvement is important to the success of conservation projects [35].
Ecosystem Services

Ecosystem services are the benefits humans derive from ecosystems that include both tangible (e.g. food and unrefined materials) and intangible (e.g. climate regulation) goods [37,36]. Services can be divided into three primary categories: provisioning (food, medicine, etc.), regulating (climate regulation, erosion prevention, etc.), and cultural (spiritual enrichment, aesthetics) [36].

Marine ecosystems in particular provide a substantial amount of ecosystems services. Although the extent of services and derived benefits vary by location [36], estuaries, coastal areas, open oceans, and saline marshes provide approximately 68% of the total economic value of all ecosystem services originating from natural environments [37]. Coral reefs are considered to be highly valuable for their ecosystem services as they are some of the most productive and diverse systems on the planet [37,39,31,40,15,10,1], providing at least $375 billion in services [14] and contributing to maintaining fish stocks and healthy marine ecosystems [15].

Island and coastal communities, for example, obtain a high percentage of protein intake from coral reefs and receive economic gain [14] and protection from coastal erosion [24,30,31]. This is very evident in Bocas del Toro as the community is highly dependent on

Small-scale fisheries supply ~29% ($31 billion USD) of the overall landed fish value within the tropics, and employ ~90% of the hundreds of millions working in marine fisheries [17].
marine ecosystems for sustenance, tourism and economic stability, and environmental protection (e.g. coral reefs protecting from land erosion).

In tropical areas, marine fisheries are especially important for coastal communities because there is a high reliance on these fisheries for food security, culture, economic wellbeing, and overall livelihood [17]. These services can and are being disrupted, however. There is a clear connection between biodiversity and ecosystem services and the loss of biodiversity is linked to the alteration of many ecological processes [37, 31,13,16]. Within the tropics, these ecological changes have the potential to drastically affect these services and the human populations that rely on them [36,17]. Human-related issues such as pollution, overfishing, and climate change, for example, can all alter natural processes and ecosystem services, resulting in possible detrimental impacts on marine ecosystems, and ultimately on fisheries and human populations [17]. Climate change, for instance, can impact marine ecosystems by altering water temperature and acidity levels, influencing the marine biodiversity and fish stock productivity and dispersal levels [4].
Coral Restoration and Fish Repopulation

Coral restoration, fish repopulation, and overall marine conservation are now absolutely fundamental. Restoration efforts, however, can be difficult. This is due to a variety of reasons, including the slow growth of many coral species, as well as the historic human impacts combined with modern effects of climate change, sea temperature changes, acidification and other factors [11].

With increasing lengths and intensity of warming events, coral reefs do not have sufficient recovery time [29] and as stress accumulates, recovery may become more challenging [29]. However, there is promise in focusing on restoration and conservation efforts. These efforts can promote ecological resiliency to stressful events and help to encourage fish stock repopulation. In turn, this helps sustain human communities and economies.
Artificial Reefs and Fish Management/Propogation

Approaches to restoring degraded reefs and fish populations can vary based on the location and intensity of degradation as there is no one-size-fits-all system [32]. However, focusing on improving structural complexity and coral cover while using a diverse set of restoration techniques such as artificial structures and transplantation are considered to be very effective [32]. Artificial reef structures can be useful long-term tools for restoring fish communities, mitigating wave intensity to help prevent shoreline erosion [41], and rebuilding coral reefs by acting as a base for corals to grow on [11]. In doing so, these structures help contribute to biodiversity and ecological complexity, even in areas that have faced sedimentation and reef instability [11].

These structures can come in a variety of shapes and sizes, with cement being a favoured compound due to its similarity to natural coral limestone and durability [43]. Various coral restoration organizations are using this technique. In Bocas del Toro, Panama, these structures are being successfully utilized to repopulate fish habitats and as coral restoration bases by CCRC (Figure 1 (p. 15), figure 2 (p. 23), and p. 19 show some of the artificial structure designs created and used by CCRC).

In 2018, a brief ecological monitoring study was conducted at the restoration site in front of CCRC. Prior to the installation of the artificial reefs and designation of the area as a restoration site, the zone was predominantly home to turtle sea grass, a few sponges, and occasional fish [42]. However, with active restoration efforts, this area is now home to various fish species, including a nurse shark, and there is a distinct biodiversity difference between the restoration zone and adjacent areas [42].

What should and shouldn't be used in coral restoration?

Some initiatives and proposals for coral restoration aim to utilize old boats, cars, planes and other objects; however, it is imperative to point out that this can possibly be counterproductive as objects must be non-toxic and stable long-term [43].
Paint and chemicals, for example, can leach from some objects, possibly causing harm to the environment and marine species. Items such as cars and other metal alloy objects, for example, will degrade fairly quickly in saltwater and can possibly leach toxins. Thus, it is important that coral restoration methods are well-researched and shown to be both effective and safe long-term for marine ecosystems. CCRC uses primarily special polyfibre and special cement mix to ensure all structures are ecologically safe and durable.

Figure 1 (top right, bottom left and right): Some of the artificial reef structures created by CCRC
Our oceans and coral reefs are some of the most threatened ecosystems [20,40,10] from climate change and other human-related activities [16,15] and require stronger protection [20]. Marine protected areas (MPAs) are useful methods for marine conservation and fish repopulation, especially in tropical and developing countries [44], and a way to provide further protection from direct human activities [2,15,10] and climate change [20]. The management or restriction of fishing activities and other human pressures through the establishment of protected areas has shown to improve fish populations, especially in conservation-target species [2]. It is also suggested that MPAs can promote enough spawn to help repopulate nearby fishing areas [2]. The implementation of large MPAs, for example, can rebuild migratory species populations such as sharks [45]. Herbivory (e.g. grazing, macroalgal browsing, sediment removal, etc.) is also an important part of healthy coral reef systems and in combination with local management, this has been shown to indirectly increase with MPAs as well as MPAs promote local fish biodiversity [46,10].

MPAs are very diverse and can vary based on objectives, stakeholder involvement, management and enforcement, human/ ecological components, and where they are created geographically [47]. Designating marine protected areas requires cooperation among many stakeholders and efficient enforcement as proper management and enforcement are
imperative for successful MPA administration, compliance [48], and protection of marine resource [44]. With the extent of ecological degradation, rising climate-related issues, and increasing coastal development and environmental pressures, it is arguable that MPAs are now a necessary approach to restoring and maintaining fish populations, coral reefs, and other marine species in order to support biodiversity, build ecosystem resiliency, and maintain ecosystem services. This applies internationally, but also in the Caribbean and in the Bocas del Toro archipelago.

Governance and Designation

A thorough analysis of MPA design and establishment can be a complex process which is beyond the scope of this particular report. There are some main points that are can be noted, however:

Compliance is important in determining MPA effectiveness [48]. There are also no one-size-fits-all MPA designs that ensure success or compliance—rather, these factors are often connected to social and institutional aspects [48]. Larger areas are preferable [45,49], but may not always be feasible. Small protected areas can still be beneficial, but they are not sufficient enough to conserve and maintain biodiversity of entire ecosystems [49]. It is thus recommended that MPAs are established in a series of networks [49], which is the goal of CCRC in Bocas del Toro. Creating a series of connected protected areas (networks) increases ecological resilience and boosts biodiversity by linking habitats to allow for increased protection and species migration (including larval dispersal) [49]. Location and designation are also important factors and protected areas should ideally be established to embody the species and habitats being conserved [2]. Zoning is an important topic here. The designation of protected areas can be zoned to mitigate activities within and/or around particular spaces (see page 21 for a description of our restoration site restrictions as an example). Habitats with more sensitivity, for instance, can receive stronger protection and visitors can be directed to areas that are less sensitive [2]. It should also be noted that biomass was shown to be higher in MPAs where commercial harvesting is illegal [44] and thus it is preferable activities do not surpass the buffer zones. Older, large, no-take zones have also shown to grow more coral cover [15]. Within the buffer zone, activities such as controlled fishing may be allowed [2]. Furthermore, although challenging, MPAs with a greater number of incentives and penalties within the governing system typically show higher fish biomass and density, and higher compliance among fishermen and local communities in comparison to those with fewer incentives/penalties [44]. This is important because non-compliance is typically the main cause of MPA failures [44,48]. Benefits of strict protection is also evident in relation to climate change as MPAs with strict restrictions are shown to be more resilient to changes stemming from climate change [50].
Illegal fishing is a common problem among MPAs; however, one of the main management factors that can be implemented to curb this issue is stakeholder and local community involvement from the initial stages of planning, through to implementation and management [48]. Involving the local fishing community and other stakeholders into every stage of the MPA process is fundamental for success as this accounts for different perspectives, social geographical contexts, and ultimately improves compliance [48].

Monitoring is also an important factor for outlining effectiveness because success rates and species compositions can change[11].

MPA Challenges

Although MPAs are a common approach used for marine conservation, some outline that there are still many inconsistencies in regard to long-term success as it is difficult to monitor and evaluate efficiency [47, 45, 51], there is questionability in the effectiveness of MPAs against climate change long-term [55], or that MPA success is hindered in areas of high sedimentation and coastal development [59]. The designation and creation of many protected areas is also sometimes seen as haphazard, with many not accounting for ecological concepts pertaining to species and or habitats that are supposed to be under protection [2], exercise poor enforcement and regulation [51], or don’t effectively consider connectivity [45].

Another reason MPAs may not be achieving the desired outcomes is that there are not enough diverse efforts being used for and insufficient land dedicated to conservation. Long-term, there must be international partnerships for effective marine resource management as the range for efficient reef management and conservation should be more than just small, single conservation spots [2]. In areas such as the Caribbean and South-East Asian archipelagos, MPAs and reserves should ideally be as large as possible, connected [45], and extend over international boundaries [2,20]. Although this is ideal, this requires a long, complex process that may not always be immediately feasible and the current pressing priority at CCRC is to begin conservation actions locally and work with the local community.
Furthermore, these are not so much issues with MPAs themselves as they are with external factors and decisions that ultimately impact their efficiency. Fortunately, many of the issues pertaining directly to MPAs can be improved with more effort put on consistent regular evaluations and monitoring [47], stronger enforcement, and improved cooperation among stakeholders and the local community [51,48].

It is important to point out that rather than being viewed as a solution to fully solve fish stock depletion and coral degradation, MPAs should be seen as a tool for conserving marine ecosystems by improving biological complexity and ecological resiliency. Furthermore, considering the rapid increase of resource depletion and impacts, making an effort is still considered a better option than not doing anything at all [47] and many institutions and organizations have outlined MPAs as an effective tool for marine conservation [20]. A further in-depth discussion and analyzation on MPAs in Bocas del Toro will be presented separately outside of this report.
The Caribbean (including Bocas del Toro) has experienced anthropogenic pressure throughout history; however, human impacts are considered to be biggest factors behind coral reef changes over the last few hundred thousands years [58]. Activities such as coastal development, pollution, run-off, increased boat traffic, population rise and tourism, and overfishing have all played a role in impacting the health of marine ecosystems and coral reef communities over the years [52,18]. In Almirante Bay, for example, climate change, coastal development, and local run-off has contributed to increasing hypoxic (dissolved oxygen depletion) events, leading to poor water quality and species impacts such as coral tissue necrosis (skin deterioration followed by mortality) [53]. Coral loss and degradation was becoming increasingly more notable in the Caribbean around the 1970s/1980s [18,8]. Unfortunately, with rising global temperatures and climate change, pressure on already-stressed ecosystems contributes to further degradation. Coral reefs and fish communities in the area have shown to already be impacted from the local practices mentioned above; however, global pressures such as climate change amplify historic stressors.
and reduces resiliency to further stress [8]. Over the last 5 years, Bocas del Toro has faced more excessive heat events that have devastated coral colonies.

Although many of these issues require local and international cooperation and coordination, this report only tackles the local because local action is urgent to implement, and these initiatives can be immediately supported and guided by CCRC. However, it is important to note that although local efforts are imperative, these efforts alone will not fully solve coral degradation and fish stock depletion issues. Yet, they are imperative for managing the rate of degradation. Efforts in this region must be diverse to tackle coral decline and mortality rates. In addition to establishing and enforcing more MPAs/MPA networks, it is also important that local stressors (e.g. agriculture, tourism activities, coastal development etc.) are also analyzed and regulated [30] in order to give local marine ecosystems the chance to sufficiently recover. Regardless, the effort for restoration and conservation is still more beneficial than no effort as at the very minimum, these initiatives can help to stabilize dying marine ecosystems and improve biological complexity [11].

**What is CCRC Doing?**

Our ultimate current goal is to repopulate coral reefs and fish stocks around the Bocas del Toro area, and in doing so, we simultaneously encourage economic and social empowerment within the local community. We aim to do this through an ecosystem-based approach which utilizes a holistic perspective to conservation and acknowledges ecological complexity and the interconnection between ecological, social, and economic factors.

**Our Approach(es)**

We use a combination of approaches for coral restoration including artificial reef structures, coral trees, nurseries, and fragment out-plants. When used together, these techniques have shown to be very effective [32] and this has been evident in our field experience.

Marine protected areas and networks are a crucial factor in our restoration plan in order to deal with excessive fishing practices and ecological degradation in the region.

CCRC also focuses on coordinating with stakeholders including the general public, community leaders, and the Panamanian government sectors in the planning and implementation of restoration initiatives.
Areas of Concentration at CCRC

1) Implementing Coral Restoration Sites and MPAs

Using various techniques, our head restoration base on Isla Solarte, Bocas del Toro contains both land (ex-situ) and marine-based (in-situ) nurseries, and acts as a main hub for artificial reef construction, fragment collection and cloning, and coral reef structure installations. The waterfront zone also acts as a fish repopulation and coral restoration zone. The artificial structures are designed in various shapes and sizes and utilize biomimicry (definition p. 22) in an attempt to replicate the complexity of coral reefs (see Figure 1 (p.14) and figure 2 (p. 22) for structure examples). These initiatives have shown to increase fish biomass and improve coral populations in the area.

Additionally, our restoration sites are approved by government permission and maintained as restoration areas with fishing restrictions. The marine zone in front of the restoration spot, for example, is a restoration area by permissions and considered a no-take-zone. It houses artificial restoration structures, as well as contributes fragments for regrowth and cloning. This allows us to effectively enhance, monitor and manage our restoration initiatives. This zone has also provided us with field experience that shows an improvement of fish and coral biomass since we have begun these restoration initiatives. We also currently have 1 zone by Isla Crystobal where fishing is accessible from 2 dock sites and 1 fish is allowed per person each day.

However, these zones must be expanded to include more sites in order to deal with the area’s issues of other overfishing and human-related issues. MPA networks have been outlined to be an ideal method of MPA design and implementation because they allow for movement among migratory species, and permit marine species to move more easily between protection zones which enhances conservation efforts, biodiversity, and resilience. CCRC aims to establish MPA networks as a chain in areas that had or currently have healthy coral and fish communities for repopulation, with the eventual aim that the connection zones in between the MPAs can have controlled fishing.

If you would like more specifics about our organization, please visit our website to find out more about our team and our current initiatives.

2) Local Empowerment and Stakeholder Engagement

CCRC recognizes the intricate connection between the success of ecological conservation initiatives, local empowerment, and stakeholder engagement. Long-term conservation success is highly dependent on local community and governmental support. Therefore, our vision is not only to focus on marine conservation, but also to educate and support the local communities.

Biomimicry: Using elements of nature in human engineering/problem solving
Figure 2: Artificial reef structures by CCRC
We currently offer a paid local apprenticeship program particularly in sustainable fisheries management, rooted in the concept that this education can be used to foster economic growth by providing the knowledge and skills required to allow local individuals to work as artificial reef suppliers or utilize these tools for ecological and responsible tourism.

Additionally, the extensive environmental issues in Bocas del Toro can have a lasting impact on tourists who may be disappointed with the scale of ecological degradation or impacts including excessive pollution, degrading marine life, and or the lack of apparent consideration for environmental protection. This is already evident with whale-watching tours in Bocas del Toro (specifically dolphin) as operators and tour guides display low compliance with guidelines [57], and tourists voiced the need for stronger regulation enforcement for whale-watching activities and environmental protection [56]. These restoration efforts present a fantastic opportunity to improve tourism perception as ecotourism revenue is increasing internationally. Thus, investing in coral restoration and MPAs in Bocas del Toro can be a very effective selling-point for tourists as Bocas del Toro is a popular destination for marine and tropical tourism.

3) Government Support

Coordinating efforts among the different branches within the government of Panama can be challenging; however, the success of conservation initiatives (including our restoration efforts) is highly dependent on this engagement and coordination.
MiAMBIENTE Panama has provided support for CCRC and we hope to further grow this engagement.

Our public status reports and documents are shareable with government bodies and stakeholders in an attempt to ratify gaps of knowledge and disconnection. It is our hope that making our knowledge and information available to participating government bodies and engaging the different levels of regulation in Panama will contribute to greater understanding and involvement from all parties.

4) Local to International

The ecological issues present around Bocas del Toro are also evident on an international scale as pressure is both local and global, and often interconnected. Human impacts on marine ecosystems and coral degradation is a growing international problem that transcends social geographical boundaries.

As necessity grows for coral restoration and fish repopulation, a prominent goal for our restoration project is to share what we learn and establish baselines that other restoration projects and initiatives can utilize or replicate for their own marine conservation projects.
Expand coral restoration sites and nurseries around the archipelago, focusing mainly on restoration of Acropora corals.

Maintain at least 50 coral trees that each contain 100 or more fragments of both Acropora and Elkhorn coral.

Install a minimum of 6 active in-situ nursery sites with a minimum of 4 genotypes for restoration-target species.

Add 5 additional coral species inside the nursery and shallow in-situ (water-based) nursery sites.

1 in-house restoration reef restoration site.

Partake in on-going collaboration and coordination with local authorities and indigenous communities to implement a sustainable fisheries program.

Setup sustainable funding for future operations.

Designate every restoration/reef zone that is currently operated by CCRC an official MPA with surface markers that outline “limitations active at this site” and a no-fishing zone for 40 meters around the MPAs (with possible increase or decrease in the future).

Establish MPA networks.

Acting as regional consultants and sharing baseline data with other practitioners locally and globally.
Conclusion

Coral reefs and fish populations are in a unique position where our next steps will have a great determining factor on how these communities look in the future. These ecosystems are extremely important for the balance of healthy marine ecosystems, biodiversity, and ecological complexity, as well as the services they provide to humans. Ecosystems are heavily interconnected, and the mass degradation of coral reefs and fish stocks poses grave threats for ecological processes and human communities as we all rely heavily on these resources. In the Caribbean, the decline of healthy coral reefs and fish populations is evident and the subsequent effects on ecosystems and local island communities are notable. Human impacts contributing to this ecological degradation need to see improved management and regulation; however, this also needs to be coupled with conservation and restoration efforts.

Marine conservation is fundamental to help mitigate and slow the degradation process, as well as encourage ecological resiliency and biodiversity. At CCRC, we are using a combination of techniques including artificial structures, nurseries, and out-plants coupled with restoration zones. These efforts have shown success; however, with increasing temperature spikes, bleaching events, overfishing, and other human stressors, our restoration efforts alone will not be sufficient. As a result, we are proposing a designation of official MPAs and no-take zones that will be used

Current Position and Updates

- Currently have 5 nursery sites with approximately 3000 clones. These sites are used for restoration, education, and research.
- Conducting restoration information sessions with various education institutions
- Acting as consultants and sharing knowledge with 2 international restoration programs
as restoration areas to help repopulate fish and coral communities. Using MPAs and artificial reefs, CCRC aims to mitigate fish and coral population degradation, improve ecological resiliency, and help maintain long-term access to ecosystem services in Bocas del Toro.

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