Climate Change Moving Forward: The Impacts on the Great Barrier Reef and Restoration Methods

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Abstract

The Great Barrier Reef located on the north-eastern part of Australia is one of the most ecologically diverse ecosystems on the planet. Unfortunately, the reef faces various threats including rising ocean temperatures, ocean acidification, starfish outbreaks, harmful fishing practices, and land-based run-off. However, there are restoration efforts being made to help the reef combat these threats. These efforts include coral gardening, larval-based restoration, assisted evolution, crown-of-thorns starfish control, and land-based runoff management. There are policies and regulations that need to be enforced before implementing any restoration efforts for the protection of the reef. The Australian government has created a few pieces of legislation intended to manage and protect the Great Barrier Reef such as the Great Barrier Reef Marine Park Act 1975. The reef's ecological, economic, and cultural benefits are extremely valuable and should be protected. Working collaboratively with various countries, researchers, scientists, and natives will help create restoration efforts and solutions that will keep the reef's hopes alive.

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Introduction

Coral reefs like the Great Barrier Reef are one of the many ecosystems that the Earth's oceans contain. Coral reefs are some of the most diverse ecosystems on the planet containing thousands of fish species, hundreds of coral species, and many other species of wildlife (National Oceanic and Atmospheric Administration (NOAA), 2021). Some notable species that live in coral reef ecosystems include clownfish, sea turtles, reef sharks, eels, crabs, lobsters, and sea horses. Around 4,00 fish species, 800 hard coral species, and hundreds of other species live and depend on coral reefs (US Environmental Protection Agency (EPA), 2021). Coral reef ecosystems are built by organisms known as stony coral. Stony corals are built by thousands of polyps (living organisms) that use calcium to build coral skeletons (US EPA, 2017). Over time, the polyps continue to grow the coral skeletons and expand their range to create coral reefs. The polyps form symbiotic relationships with zooxanthellae which is a microscopic algae. In this symbiotic relationship, the polyps get energy when photosynthesis is done by the zooxanthellae meanwhile the zooxanthellae benefit by being able to live on the coral. There are various types of stony coral (US EPA, 2017). These types include hydrocorals, octocorals, and antipatharians.

Coral reefs provide for and benefit an enormous diversity of organisms by giving them homes, food, and other essential resources. These ecosystems also bring many benefits to the human population. Coral reefs may provide medicines for diseases and health problems such as cancer and other illnesses (NOAA, 2024). People around the world may have their lives saved and diseases cured due to the help of resources coming from coral reefs. Additionally, coral reefs are the basis of coastal populations because they provide food and a livelihood through jobs in

tourism, eco-tourism, recreation, and fishing to provide for families. Lastly, the structure of coral reefs also helps protect shores from the damage of waves and storms, which in turn protects coastal cities and communities. People living on shores will have increased protection from violent shores which will minimize the loss of life during intense storms.

Coral reefs can be found around the planet, mostly in tropical and subtropical waters. Most coral reefs are found in places such as Australia, Indonesia, Philippines, and Gulf of Mexico (NOAA, 2020). ***Figure* 1** shows the different locations where reefs are located around the world. The Great Barrier Reef, as shown in ***Figure* 2**, is located on the coasts of Queensland, Australia, is the largest barrier reef ecosystem on the planet. The Reef 2050 Long-Term Sustainability Plan explains how the Great Barrier Reef consists of a network of reefs, mangroves, marshes, sponge gardens, and wetlands (Australian Government and Queensland Government, 2022). This reef helps support the Australian people by providing tourism and recreation jobs, providing resources, and being culturally significant to the indigenous people. Unfortunately, the Great Barrier Reef, like many other reefs worldwide, is being destroyed and experiencing a decline.

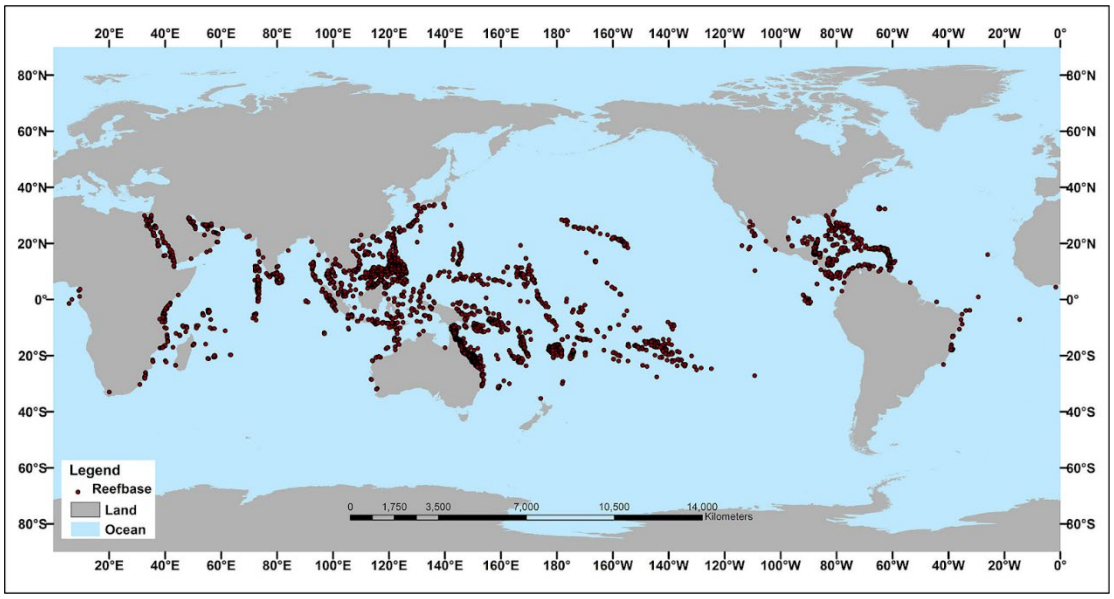

***Figure* 1** shows all the locations on the planet that contain coral reefs. Most coral reefs are located on the Pacific Ocean. https://oceanservice.noaa.gov/education/tutorial_corals/media/supp_coral05a.html#:~:text=The%20majority%20of%20reef%20building,coral%20reefs%20of%20the%20world

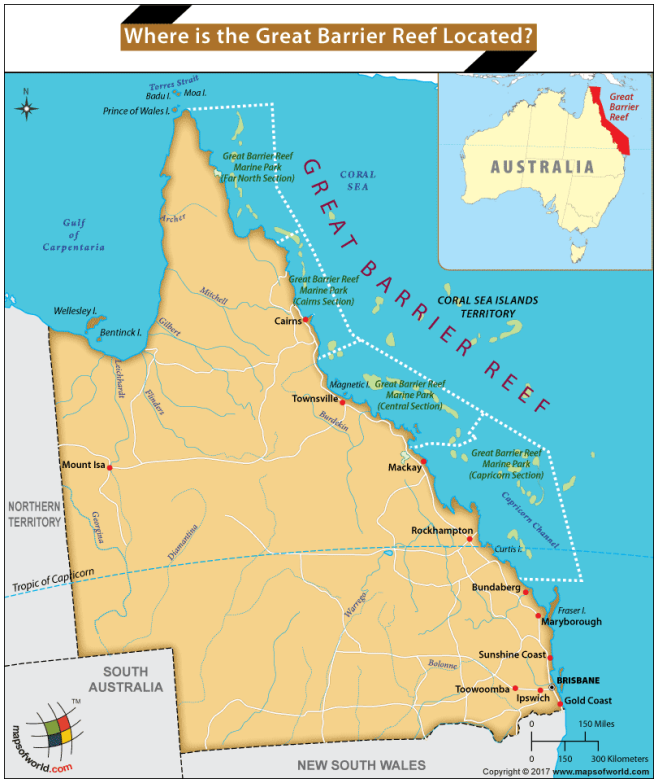

***Figure* 2** shows the location of the Great Barrier Reef. It is located on the top right of Australia and is separated into four sections. https://www.mapsofworld.com/answers/world/where-is-great-barrier-reef-located/#

Threats to the Great Barrier Reef

There are various threats to reefs around the world, including the Great Barrier Reef. These threats that are harming the Great Barrier Reef include a) increasing ocean temperatures, b) ocean acidification, c) outbreaks of crown-of-thorns starfish, d) harmful fishing practices, and e) land-based runoff. These threats to the Great Barrier Reef are putting not only the huge biodiversity of the ecosystem at risk, but also the methods of income and ways of life of many people.

A) Rising Ocean Temperatures

The first threat to the Great Barrier Reef is the rise of ocean temperatures. Temperatures have been greatly increasing over the past century primarily due to human activities releasing greenhouse gases into the atmosphere in large amounts (US EPA, 2021). Human activities and practices that contribute to greenhouse gas emissions include the burning of fossil fuels, agricultural practices, livestock, and various other industrial practices.

This increase in the Earth's surface temperatures due to the rising greenhouse gas levels directly increases the ocean's temperatures as well. The continuing rise in temperature is a detrimental problem to the Great Barrier Reef and creates a process known as coral bleaching (NOAA Climate, 2024). Coral bleaching is a process by which coral lose their zooxanthellae which then causes the coral to lose its color and become completely white (Hoegh-Guldberg, 1999). The increasing ocean temperatures create a situation where zooxanthellae cannot tolerate the water temperatures. The zooxanthellae leave the coral and weaken the coral, leaving it in a

situation where they are more likely to die. This can affect the entire colony of corals, especially reef-building corals that are essential to the survival of coral reefs. Coral bleaching has caused mass bleaching events around the world including the Great Barrier Reef.

***Figure* 3** shows a reef in the American Samoa that is a part of the Great Barrier Reef. In this picture, the coral reef is healthy by the end of 2014, but then experiences a bleaching event early in 2015 that eventually kills the reef by the middle of 2015. https://mashable.com/article/great-barrier-reef-mortality

The bleaching of the reefs that make up the Great Barrier Reef can be detrimental to both the wildlife and people that depend on the reefs for survival, resources, and income. Marine wildlife that depended on reefs for food, homes, and other resources will be forced to find other reefs to survive and could potentially lead to the deaths of most wildlife that was living on the reef. Some examples of wildlife that live in the Great Barrier Reef include the parrotfish that feeds on coral, the clownfish that have a symbiotic relationship with anemone, surgeonfish, coral cod, rays, sharks, and sea turtles. As coral bleaching events become more common, various

species of wildlife can become endangered or even extinct if coral reefs are the only ecosystems they can survive in.

People who depend on the Great Barrier Reef to provide them with food or as sources of income will also struggle to survive. The Great Barrier Reef generated around $5.2 billion from tourism and around $240 million in recreation (Deloitte Access Economics, 2013). When coral reefs go through bleaching events, tourists and visitors will not want to visit the reefs as they will not be as appealing meaning that the locals will not earn as much money or anything at all. Those that depended on the reefs for seafood to eat will also struggle to catch anything to feed themselves and their families as much of the wildlife would die if the reef were not able to recover.

B) Ocean Acidification

Ocean acidification is another threat to the Great Barrier Reef. The oceans absorb carbon dioxide from the Earth's atmosphere (Angela Colbert, 2023). The amount of carbon dioxide being absorbed by the Earth's Oceans has been increasing. This is because human practices have continued to increase the amount of carbon dioxide and other greenhouse gases in the atmosphere. The problem that comes with increased carbon dioxide levels is ocean acidification. This is a process in the Earth's oceans that creates a shift in the water's pH levels making it more acidic.

Oceans acidification is detrimental to coral reef ecosystems because it puts corals in more vulnerable states. Ocean acidification decreases the density of a coral's skeleton (United States National Science Foundation (USNSF), 2018). This puts corals in vulnerable states because having thinner skeletons means that corals are more likely to break or be harmed by waves, storms, and organisms. Humans can cause further damage to the weakened corals by using

fishing practices and gear that can damage corals (NOAA, 2023a). Coral skeletons have a reduction in density when carbon dioxide levels in the ocean are increased is because corals have a harder time forming aragonite. Coral form aragonite, which is a form of calcium carbonate, that they use to create crystals to stack and build their skeletons (USNSF, 2018). They then create more crystals to strengthen their skeletons. Now that the levels of carbon dioxide in the water have increased, the coral have a much harder time forming aragonite for their skeletons.

Ocean acidification is a big issue for the health of the Great Barrier Reef. Ocean acidification is creating devastating circumstances for coral and reducing their chances of survival. This means that wildlife that depend on the reef will lose their homes, food, and other resources if the corals are not able to survive increasing temperatures and acidification. The more acidic waters would also impact calcifying organisms, such as clams or oysters, that also require calcium carbonate to form their shells by making it much harder for them to form them (US EPA, 2022b) explains. Acidification will eventually lead to the loss of coral reefs which will cause the collapse of the entire ecosystem.

Ocean acidification will also reduce the amount of income, food, and resources that local people get from the reef. The Great Barrier Reef contributes around $6.4 million to Australia (Deloitte Access Economics, 2013). The loss of the reef ecosystem would mean that many local fisheries, tourism activities, and other aquatic activities would not be able to function effectively. Thus, Australia would lose a significant contributor to their economy. Therefore, many people who work in these sectors could lose their jobs and will struggle to feed their families and make a livelihood.

C) Starfish Outbreaks

A threat specific to the Great Barrier Reef is the outbreaks of the Crown-of-thorns starfish (*acanthaster planci*). These starfish are a native species to the Great Barrier Reef. They have a defensive mechanism of toxic thorns along their backs, have approximately 21 arms, and eat primarily hard coral (Australian Institute of Marine Science (AIMS), 2023). The outbreaks of Crown-of-thorn starfish can lead to the loss of 90 percent of the corals in reefs (Ibid). The are two main reasons why these outbreaks occur. The first is due to the larvae of the starfish having increased survival due to increased phytoplankton, which is the larvae's food source. The increased survival rate occurs because of increased nutrients in the water. The increase in runoff from the surface serves as a food source for phytoplankton (Wooldridge and Brodie, 2015). The abundance of nutrients allows for the phytoplankton population to increase. The juvenile Crown-of-thorns-starfish feed on phytoplankton (Ibid). As the starfish's' food source becomes more available, the chances of survival of the crown-of-thorns starfish increases.

The second reason for the increase of outbreaks is because there are less predators in the ecosystem due to human extraction (Wooldridge and Brodie, 2015). This means that there are fewer threats to the Crown-of-thorns starfish increasing their likelihood of survival. A reduction in predators creates opportunities for starfish outbreaks to occur more frequently and become more devastating to the Great Barrier Reef.

Crown-of-thorns starfish are a direct threat to the coral in reef ecosystems and add on to the pressures that coral reefs face due to climate change (AIMS, 2023). Rising ocean temperatures cause coral bleaching and water becomes more acidic as carbon dioxide levels increase. This means that corals and entire coral reef ecosystems like the Great Barrier Reef will struggle to survive when they have all these problems to face. Many organisms will die and potentially become extinct meanwhile locals will struggle to make a living from the reef and its

resources. Some of the organisms that are threatened by the degradation of the Great Barrier Reef include keystone species like the bumphead parrotfish (bolbometopon muricatm). These fish feed on seaweed or microalgae that compete with corals for resources (NOAA, 2017). These parrotfish make sure that the microalgae do not overgrow reef-building corals. Thus, action needs to be taken by the people to help restore the damage that has already been done to the Great Barrier Reef and minimize any future harm that could be done to this crucial ecosystem.

D) Harmful Fishing Practices

The next threat to the Great Barrier Reef is harmful fishing practices including overfishing and illegal fishing. Overfishing is detrimental to the Great Barrier Reef because it takes away species that have important roles that keep the reef in good health (NOAAb, 2023). These species can include the bumphead parrotfish that feeds on algae as well as groupers and reef sharks that predate on the smaller fish populations. When species, such as the groupers and reef sharks are overfished and taken out of the reef ecosystem, fish populations at the middle and lower trophic levels can overpopulate the reef. The mid-level fish species would greatly reduce herbivorous (low-level) fish populations that feed on microalgae, which could cause the destruction of the reef (Woods Hole Oceanographic Institution (WHOI), n.d.). For example, if the reef shark that is a natural predator to the parrotfish is taken out of the barrier reef ecosystem, the parrotfish that feed on corals can begin to overpopulate the reef. This could lead to the parrotfish eating too many corals which could severely damage the coral reef.

Another threat to the Great Barrier Reef is illegal fishing that often involves the use of destructive fishing techniques. There are certain fishing techniques that can greatly damage marine ecosystems including coral reefs and seagrass beds (NOAAb, 2023). These fishing techniques include blast fishing and trawling. Blast fishing involves using explosives to detonate

underwater and scare fish out of hiding to catch (NOAA, 2019). The explosions are detrimental to coral reefs because they can destroy corals and kill other organism that were in the vicinity of the explosion. The calcium carbonate that makes up the coral skeletons is destroyed by the blasts (Fox et al., 2003). This can lead to the endangerment and loss of many species and can destroy a coral reef if continuously done.

The next harmful fishing technique known as trawling involves a fishing net being dragged across the bottom of the sea floor to catch any fish that come across its path (NOAA, 2019). Trawling is detrimental because as the net is dragged along the seafloor, landscape, plants, and wildlife are all affected (Oberle, 2016). The seafloor has its root systems teared, coral reefs have their corals broken, and wildlife have their habitats destroyed. This means that entire ecosystems including coral reefs can be completely decimated. Locals that depend on the Great Barrier Reef as their source of income and food will also be harmed by these practices because they will find it much more difficult to find food, fish, and do tourism.

E) Land-Based Run-Off

Land-based run-off is another threat to the Great Barrier Reef. Agricultural practices are the main contributor to run-off including nutrients, sediments, and pesticides (Department of Environment and Science, 2012). Land run-off in the form of nutrients, such as nitrogen and phosphorus, can negatively impact the Great Barrier Reef. Phosphorus and nitrogen run-off usually come from the use of fertilizer in agriculture (Ibid). An excessive amount of these nutrients can create a situation where algae have an abundance of food resources and create more algal blooms. Phytoplankton also thrives when there is an abundance of nutrients to feed on. This directly impacts the crown-of-thorns starfish population because they will also have an

abundance of phytoplankton to feed on (Wooldridge and Brodie, 2015). Excess nutrients only add to the pressures that the Great barrier Reef is facing.

Sediment run-of is another problem for the Great Barrier Reef. Although sediments are a natural part of the ecosystem, an excess amount of the wrong types of sediments, including those that are very fine, can be suspended in water, and can be transported throughout long distances, can create issues (Department of Environment and Science, 2012). Sediment run-off primarily comes from grazing and streambank erosion and flooding can worsen the situation by bringing even more sediments into the system (Ibid). The problems that excess sediments cause is increasing turbidity and decreasing water clarity, which reduces the amount of water that can reach past the surface (Ibid). This means that corals and other marine plants will not receive the sunlight that they need to go through the process of photosynthesis which will hinder coral growth. The excess sediments can also damage coral in their early stages when they settle and can bring more nutrients into the system (Ibid).

The next detriment to the Great Barrier Reef is pesticide run-off. Pesticides are used in agriculture to kill pests like weeds and insects that hinder crop growth and yields. For this reason, pesticides can also harm aquatic organisms if they reach the ocean (Ibid). Farmers use pesticides that stop the process of photosynthesis to kill weeds. When these types of pesticides reach the reef ecosystem, they can also affect other species that also need to photosynthesize to survive (Ibid). This means that pesticides can harm the different parts of the reef ecosystem including both plants and animals. If pesticide run-off continues to increase, more coral reefs could be killed in the future. However, further research is needed to understand the pesticide exposure on corals.

Restoration Efforts

There are various coral reef restoration efforts that are currently being developed and improved upon to help protect these precious ecosystems. Many of these can be implemented into the Great Barrier Reef. The coral reef restoration efforts that will be reviewed in this paper include a) coral gardening, b) larval-based restoration, c) assisted evolution, d) Crown-of-thorns starfish control, and e) land-based run-off management.

A) Coral Gardening

The first restoration method that could be used to restore the coral in the Great Barrier Reef is known as coral gardening. Coral gardening is the process of taking a coral fragment from a donor reef and transplanting it onto a recipient reef (McLeod et al., 2022). Multiple coral fragments are taken from donor reefs to be put into recipient reefs and grow. This would lead to the construction of a new coral reef or help restore a coral reef that had been declining. This would allow organisms to continue living in the Great Barrier Reef because organisms would not be forced to leave the reef they currently live on due to it declining and losing resources. Coral gardening would create circumstances for the fragments to grow and help keep the reef alive allowing the ecosystem to thrive.

However, coral gardening has its drawbacks. The first issue with coral gardening is that it could be potentially detrimental to donor reefs or reefs that had their coral fragments taken from (Boström-Einarsson, 2020). This means that taking away portions of a coral could directly harm it causing fatal consequences. This would in turn ruin the idea of restoration as the process of fragmenting could kill the donor corals, which could lead the loss of entire reefs if done continuously and in large amounts. This means that there is a need for small scale projects that only take a certain number of coral fragments so that the donor reef is not negatively impacted. Monitoring of both the donor and recipient reef would also be required to understand the benefits

and drawbacks of oral gardening to both reefs. Another drawback of transplantation is the high mortality and failure of attachment of transplanted corals (Abelson, 2006). This means that not only could the donor corals be harmed from the transplanting process, but the transplanted corals are not very likely to survive or attach themselves to the recipient reef.

To combat this, however, small fragments (micro-fragments) are taken and raised in nurseries. The nurseries will protect corals from harmful conditions so that they are ready to be planted into damaged reefs after their vulnerable stage is complete (Boström-Einarsson, 2020). In these nurseries, the coral fragments can grow rapidly, doubling or quadrupling in size in a short period of time (Knapp et al., 2022). This would allow for safer circumstances for the small coral fragments because they would both be more likely to survive before being implemented into the recipient reef.

B) Larval-based Restoration

The next restoration method that could be used to help with the restoration of the Great Barrier Reef is larval-based restoration. Larval-based restoration is using methods that help increase or promote coral fertilization by supplying coral larvae to damaged reefs (McLeod et al., 2022). The plan is that the larvae will be more likely to settle onto the coral and therefore increase the number of corals that are produced in the future. This would mean that the coral reefs would be able to maintain and even increase their population of corals.

An issue with larval-based restoration is ensuring that larvae are not swept away from reefs. To avoid this, a method of collecting embryos and larvae during spawning times in holding tanks or other devices on the reef is used (Boström-Einarsson, 2020). The embryos and larvae are then released back into the reef over target substrates that are wanted to reproduce and increase the population of corals during settlement periods (Ibid). This means that catching corals'

embryos and larvae could be collected and then released over certain parts of reefs or even different reefs that have been damaged and need to be restored. The use of a controlled release of embryos and larvae for the degraded reef to establish a breeding population (Ibid). This will help increase the coral population and create an increase of embryos and larvae for the coral reef in the next spawning event.

C) Assisted Evolution

Another restoration method that could be implemented into the Great Barrier Reef is assisted evolution. Assisted evolution refers to the improvement of coral survivability by accelerating their evolution through human intervention (McLeod et al., 2022). Some of the methods of assisted evolution include selective breeding and preconditioning. Selective breeding refers to sexual reproduction methods that favor beneficial traits for organisms (Ibid). Selective breeding for corals would include the breeding of corals of the same species or different species to improve the population's heat tolerance. This means that the next generation of corals would have the heat tolerant trait that would increase their survivability in an environment with increasing temperatures.

The next method of assisted evolution is preconditioning. This is a process where organisms are placed in harsh conditions or high levels of stress to allow them to build their tolerance to those conditions (McLeod et al., 2022). This would allow organisms to become more resistant to the harsh conditions that they are placed in which would increase their survivability in the wild. Their resistant traits would pass on to their offspring which would create a generation that is more adapted to the harsh environment and more likely to survive. When it comes to corals, preconditioning would focus on their resistance to increasing ocean temperatures (Ibid). This means that corals would be put in conditions with increased temperatures which will help

build their tolerance to higher temperatures. Corals would then develop genes that are more tolerant to heat stress (Ibid). This will increase the survivability of corals as future generations will become more resistant to increasing temperatures that would normally cause the corals to bleach.

D) Crown-of-thorns Starfish Control

Methods of reducing Crown-of-thorns starfish outbreaks and keeping their populations at safe levels is crucial for the restoration of the Great Barrier Reef. The methods that could be used include culling starfish populations to sustainable levels and and long-term monitoring of the starfish populations. The direct control of the Crown-of-thorns starfish populations by culling their populations is crucial for the protection of the reef. Culling keeps the starfish populations from completely overwhelming and decimating reefs (Australia Government, 2019). Divers kill the Crown-of-thorns starfish by injecting them with bile salts or vinegar (AIMS, 2023).

Monitoring the Crown-of-thorns starfish populations and the reefs is another method of controlling their population and protecting the Great Barrier Reef. The Crown-of-Thorns Starfish Control Program has shown that monitoring the starfish populations has allowed for action to be taken quickly when outbreaks occur (Australia Government, 2019). The quick responses to outbreaks minimize the damage caused to corals. The monitoring and culling of the crown-of-thorns starfish not only help with suppressing their current populations from increasing too much, but also helps with reducing the number of larvae that are produced. The larvae can be distributed by ocean currents to other reefs (Ibid). This is another problem that can also be mitigated through these control practices because culling reduces the number of adult crown-of-thorns starfish that are able to reproduce. The opportunity of outbreaks occurring in neighboring

coral reefs will therefore be reduced. This creates better conditions for restoration projects to occur in coral reefs as there will be less of a worry of starfish overtaking the reef.

E) Land-based Run-off Management

Managing land-based run-off that flows into the Great Barrier Reef is another crucial method of protecting it. Reducing the run-off that flows into the reef can be done by implementing sustainable farming practices, using low-impact developments, and reducing impervious surfaces. Agriculture is one of the main contributors of the run-off that ends up in the Great Barrier Reef. As such, implementing sustainable practices such as planting cover crops and planting field buffers. Planting cover crops is helpful in reducing run-off because it reduces bare ground on farms (US EPA, 2022a). Reducing the bare ground reduces the opportunity for the nutrients in the soil to be lost to erosion or caught by water thereby reducing the amount of excess nutrients that end up in waterways. Planting field buffers (trees or shrubs along the edges of fields) also helps reduce run-off because they can absorb some of the excess nutrients used on the field (Ibid). This therefore reduces the amount of nutrients that can end up going into the rivers or streams that flow into the ocean and negatively impact the reef.

The next method to reduce run-off that ends up in the Great Barrier Reef is by reducing the amount of run-off coming from urban areas. Implementing low impact developments (LIDs) and reducing impervious surfaces are a few ways of reducing urban run-off. LIDs are sustainable practices that are designed to protect water quality and help with storm water management (State Water Resources Control Board, 2017). There are various kinds of LIDs including rain gardens and rooftop gardens (Ibid). These different LIDs reduce the amount of water that flows straight into stormwater management systems by using plants that increase water infiltration into the ground. For example, rain gardens, such as the one shown in ***Figure* 4**, containing grasses and

perennial plants are placed in low lying areas in the landscape to collect any excess water and help filtrate pollutants (US EPA, 2018). LIDs therefore are a form of run-off filtration systems which help reduce the run-off that could flow into the Great Barrier Reef and harm it.

***Figure* 4** shows a rain garden. Rain gardens are one type of LID that is used to help stormwater management systems by absorbing excess water and filtrating run-off. https://extension.umn.edu/landscape-design/rain-gardens

Reducing impervious surfaces also reduces urban run-off that could end up in the reef. Impervious surfaces can include cement driveways and streets (King County, 2023). These surfaces do not allow water to infiltrate into the ground. This means that the water is led into drainage systems that could directly lead to the reef. Implementing pervious paving or increasing vegetated areas would help with the filtration of water and run-off (Ibid). Therefore, replacing impervious surfaces with pervious surfaces helps reduce the amount nutrients or fertilizers that go into drainage systems and into the reef. The run-off would now be absorbed into the ground and pose less of a threat to the Great Barrier Reef.

Policies and Regulations

There are some factors that need to be considered before implementing any coral reef restoration effort. Firstly, regulations, policies, and enforcement of reef protection need to be set before beginning the restoration process. The regulations set in place will also help set restoration standards that organizations will need to follow, help organize the participation by communities and organizations, help create incentives for action to be taken and help with the tracking of the restoration effort and its success (Fidelman et al., 2019). This means that regulations will help create opportunities for organizations to benefit and work together to develop restoration research and practices. It is also important that the regulations that are set in place are clear to avoid confusion and to properly track the success of the reef restoration efforts put in place.

The financial resources spent on the effort must be managed and put to the right use for the restoration effort to work effectively. Individuals or organizations need to make sure that they understand how their financial resources will be put in place and the key parties involved with the process and restoration efforts (Fidelman et al., 2019). This is so that the process of working towards implementing the restoration efforts is as efficient as possible without any setbacks that could hinder the research and process, which could then lead to a larger sum of financial resources being spent.

It is important that the potential negative impacts of each type of restoration method on the coral reef ecosystem are considered. Different reef interventions or restoration efforts have different risks associated with them (Fidelman et al., 2019). There are interventions in the low risk level, medium risk level, and high-risk level. This means that organizations involved will need to balance the “risks vs the rewards” and consider which restoration method will be most beneficial as well as safe to use depending on the reef they are working with. This is so that the

organization or party involved minimizes any other potentially detrimental impacts to the coral reef ecosystem while also maximizing the improvement of the overall ecosystem.

The Australian government has enforced various legislations and policies to protect and manage the Great Barrier Reef. The primary legislation protecting the reef is the Great Barrier Reef Marine Park Act 1975 (Australian Government, 2022). This act establishes the Great Barrier Reef Marine Park, provides a planning and management framework for it, and takes enforcement actions (Ibid). Planning and managing the reef is important for its protection because it allows for consistent monitoring and updating of the reef. This means that scientists and researchers can study what impacts are occurring to the reef to act quickly and stop problems that occur or enforce policies that would reduce any damage caused. Enforcement mechanisms for action to be taken against criminals or penalties as well as having administrative action is also important for the protection of the reef because it deters individuals from using practices that could harm the reef. In the case that the reef is negatively impacted by others, legal enforcement can be taken, and punishments will be given to those that break the rules.

Another piece of legislation that helps protect the Great Barrier Reef is the Great Barrier Reef Marine Park Regulations 2019. This piece of legislation sets the Marine Park rules, manages permissions in the Marine Park, regulates the operations of vessels and discharge of sewage in the park, and requires the reporting on the condition of the Great Barrier Reef (Australian Government, 2022). This helps protect the reef because it helps manage issues such as discharge that could potentially bring excess nutrients into the reef. With the help of this piece of legislation, regulations can be set to reduce the discharge of sewage that can get released into reef. Any issues that come up in the reef are also reported, which also helps with the management and protection of the reef.

Conclusion

The Great Barrier Reef is a worldwide treasure and is beloved by many around the world. Its enormous ecological importance cannot be overlooked. The reef's economic and cultural value cannot be underestimated either. Although the Great Barrier Reef is being negatively impacted by various issues including ocean acidification, coral bleaching, crown-of-thorns starfish outbreaks, harmful fishing practices, and land-based run-off, there is still hope. The creation and implementation of different restoration methods and policies may be complex, take a long time to implement, and seem overwhelming, but it is most definitely possible. If countries, researchers, scientists, and natives work together to come up with ways to mitigate impacts, restore the reef, manage and monitor the state of the reef, the Great Barrier Reef holds a chance at adapting and fighting against its looming threats.

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