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Anthropogenic Threats to Ecosystem Services of Maldivian Coral Reefs: Current Policies and Solutions

Ahil Sharma[1] and Nathalie Sommer[#]

[1]United World College of SouthEast
[#]Advisor

ABSTRACT

Healthy, biodiverse coral reefs provide many ecosystem services from both an ecological and socio-economic standpoint. Anthropogenic activity poses a threat to the capacity of coral reefs to provide ecosystem services. The vast, teeming coral reef system of the Maldives is under threat from overfishing, coral mining, destructive fishing methods, direct pollution and litter, and the unsustainable disposal of garbage in the country. The Maldivian government has implemented a number of policies to address these threats and protect local coral reef ecosystems from harm; however, these policies need to be expanded in order to more effectively and comprehensively protect local coral reefs. If the policies outlined in this paper are adopted, Maldivian coral reefs will be protected well into the future and the local population will benefit from their ecosystem services for generations to come.

Introduction

The ability of coral reefs to provide ecosystem services is rapidly declining on a global scale due to both global warming and local human pressures. (Eddy et al., 2021). Ecosystem services are the benefits humans derive from ecosystem state and function. The decline of ecosystem services is a pressing issue due to the high amount of people globally that depend on coral reefs for basic provisions, personal health, and economic stability.

Reliance on coral reefs is especially high in the island nation of the Maldives (Jaleel, 2013); 98% of the nation's GDP originates from coral reefs' biodiversity (IUCN, 2009). The reefs generate myriad ecosystem services including tourism, tsunami protection, fisheries, and pharmaceuticals (Jaleel, 2013).

However, an array of local anthropogenic threats including coral mining, destructive fishing, and water pollution, are endangering the reefs, and therefore jeopardizing the provisioning of ecosystem services from the Maldivian reefs. Following the 1998 and 2016 global warming driven mass coral bleaching events in the Maldives, local anthropogenic pressure has decreased the resilience of coral reefs and compromised the ability of reefs to recover from bleaching events (Montefalcone et al., 2020).

There are numerous policies in place in the Maldives to reduce local human-caused pressures on coral—including marine protected areas—but more still needs to be done to correct the persistent problems of garbage disposal, pollution, overfishing, and unsustainable fishing methods, especially considering the Maldives' economic dependence on the reefs (Jaleel, 2013). Policy implementation is required to reduce the impacts of anthropogenic activity on coral reefs and restore their ecosystem services in the Maldives.

This paper will provide a brief background about coral reefs and their ecosystem services, before exploring the current anthropogenic threats to Maldivian coral reef populations. The paper then proceeds to discuss the policies currently in place to protect Maldivian coral reefs and suggests new policies that should be implemented to bolster the reefs and secure their future for the Maldives.

Background

a) Ecology of coral reefs:

i. Biodiversity

Coral reefs are the most biodiverse ecosystem in the world (Cramer et al., 2021). They are home to over 25% of the world's fish species (NOAA, 2011). Reefs have high levels of biodiversity as a result of abundant nutrients, sunlight, microhabitats and their location in warmer water. Because of their high levels of biodiversity, reefs are ecosystems that are often more resilient to changing conditions and can withstand significant disturbances. This is in line with the diversity-stability theory which postulates that ecosystems with higher biodiversity and population are more likely to accumulate species that have traits allowing them to adapt to changing conditions (Cleland, 2011). This provides ideal conditions for many different species (small fish, crustaceans, sharks, etc) to thrive and for food chains to form. This is due to coral reefs being located in warmer, tropical waters which are known as high resource environments because of high nutrient levels in the water. This leads to coevolution, which is when species in an ecosystem evolve while interacting with each other (Langerhans, 2008). Coevolution results in high levels of specialization of different species in the ecosystem, where different species have narrow niches and carry out specific roles in the ecosystem. The coral themselves also provide habitat for marine species and act as a direct food source to coral feeders, such as parrotfish. All these factors lead to high levels of biodiversity in coral reefs and allow various species to thrive together in the given ecosystem.

ii. Zooxanthellae

Zooxanthellae are photosynthetic algae living in the tissues of coral. They form a symbiotic relationship with coral, as the coral provides algae with a protective environment and necessary components for photosynthesis, while algae produce oxygen and help the coral respire. This nutrient exchange between zooxanthellae and host coral is at the heart of coral reef growth and productivity. As much as 90% of organic material produced by zooxanthellae is utilized by the coral tissue (LaJeunesse, 2020), and without the photosynthetic algae, the coral would die from a lack of nutrition. When coral becomes physically stressed (e.g. from unusually high temperatures, water pollution, ocean acidification, etc), the coral polyps (living component of coral structures) expel the zooxanthellae and die soon after. This is known as bleaching, where the coral loses the color it was given by the photosynthetic algae and turns white.

iii. Food webs

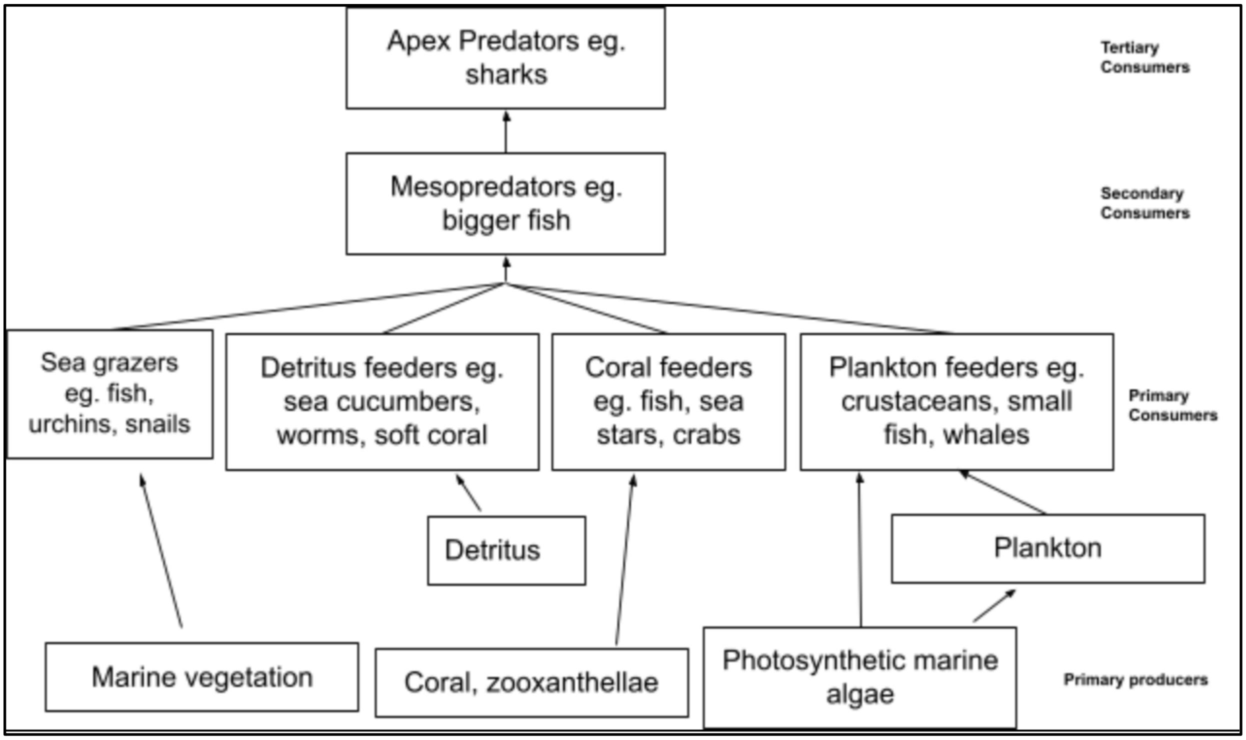

Figure 1- the food web of a typical coral reef ecosystem: (Adapted from Castro & Huber, 2016)

Coral reef food webs are the most intricate and expansive webs of any marine ecosystem. As in many ecosystems, primary producers form the basis of the food web; examples of primary producers include: blue-green algae, phytoplankton, zooxanthellae, seagrass, seaweed etc. Most of these are photosynthetic and all of them are autotrophs of various kinds. Autotrophs are organisms that generate their own energy and do not consume other organisms for nutrition. Detritus is also a source of energy in coral reef food webs. It is organic matter produced by the decomposition of marine organisms and is a byproduct of any organisms across the whole food web. Detritus is consumed by detritivores, which don't have a set trophic level but simply feed on the remains of dead organic matter created by organisms, or alternatively, dead organisms themselves if they haven't already been eaten. Primary consumers are one feeding-link above primary producers and detritus. Examples of primary consumers include: sea snails, sponges and sea urchins, herbivorous crabs, sea turtles, herbivorous fish, parrotfish, crown of thorn starfish etc. The secondary, tertiary, and quaternary consumers are larger, carnivorous fish (e.g. eels, seals, sharks, etc). All the trophic levels are interconnected and rely on each other for nutrients and survival. Any effect on one trophic level will affect the population levels and health of organisms in all other trophic levels.

iv. Ecosystem engineers

Ecosystem engineers are species that alter their habitat by restructuring the form and structure of a habitat's architecture (Coleman & Williams, 2002). Ecosystem engineers play a critical role in the health, productivity, and service provision of their ecosystem. Ecosystem engineers affect the biological (living, eg. fish) and structural (non-living, eg. rocks) components of an ecosystem Hence, a reduction in either the number of ecosystem engineers, or their ability to carry out their functions, can negatively affect the ecosystem as a whole. Coral themselves are ecosystem engineers as they create structures that help shelter species from predators and provide homes. Other examples of ecosystem engineers include tile-fish and grouper, which are both larger predatory fish. They are ecosystem engineers because they create burrows to live in and reproduce in. This contributes positively to the health and productivity of the ecosystem as it offers safe spaces for other fish to seek refuge from predators and reproduce, which increases the amount of fish in the ecosystem and the associated ecosystem services.

v) Formation of the Maldivian coral reefs

The Maldives are made up of around 1200 islands and small sandbanks (Morner et al., 2003). These islands are structured in 20 large circles with ocean in the middle, known as atolls. These atolls are bordered by fringing reefs, linear reef systems that almost directly border the coastline, and their formation is a result of several thousand years of geological processes. The atolls were originally fringing reefs around volcanoes (Darwin,1842), but as the sea level rose over time, the ocean level eventually passed the height of the volcanic islands that the coral reefs were surrounding. Because coral reefs require shallow water to survive, corals had to construct calcium carbonate encasements on top of one another at a rate fast enough to keep up with sea-level rise. The coral then continued rising upwards even after the submergence of the volcanic island (Fagerstrom, 1987). The islands of the Maldives are made up of rubble and sediment from dead coral and detritus from when the sea level rise occurred. The place of the submerged volcanic islands in the middle of the ring of islands in atolls has been taken by coral reefs fringing the islands, and an open ocean between the reefs. The nutrients derived from the old volcanic islands provided an extensive nutrient base for Maldivian marine ecosystems such as reefs to develop and thrive. The Maldivian reef system now provides livelihood and nutrition to most of the 540,542 people that call the islands home (World Bank, 2020).

B) Ecosystem Services Of Coral Reefs

Ecosystem services are the benefits humans derive from the function and existence of ecosystems (Stachowicz et al., 2002). Reefs provide their ecosystem services primarily through their high biodiversity. Reef-based fisheries provide high levels of food and income due to the high density of edible fish in reefs. Due to the high biodiversity, the beauty and wonder of all the wildlife attract reef-based recreation like diving and snorkeling. This provides income for local economies and leisure to millions. Also, the compounds isolated from organisms living on reefs hold vast medical potential.

i) Global services of coral reefs

Around three billion people around the world rely on coral reefs for income, nutrition, and other ecosystem services (Hilmi et al., 2019). Coral reefs are vital for coastal regions and low-lying island nation communities, especially for indigenous people in developing nations like the Maldives. Reefs provide services such as protection from coastal erosion and flooding as well as tsunamis. For example, in September 2009, reefs bordering Upolu island in Samoa in the Pacific Ocean reduced the impacts of a tsunami on the island (McAdoo et al., 2010), undoubtedly saving lives. Reefs also provide livelihood and income for many people as they attract tourists, providing employment opportunities for residents of coastal communities. Coral reefs also provide food to more than half a billion people (Hilmi et al., 2019) and the fisheries themselves can act as a source of income and industry for locals in the area. Reefs also provide recreation opportunities through snorkelling and diving. In addition, several medicinal components have been found in marine species that inhabit coral reefs as well as the coral themselves which can be used to treat diseases like Cancer, Alzheimer's disease and Heart disease (NOAA, 2021).

Healthy coral reefs also positively impact the global climate. The ocean is the world's largest carbon sink, helping to offset anthropogenically caused emissions and reduce global warming and climate change. Coral reefs are a carbon sink for 111 million tonnes C yr^{-1}, equivalent to around 2% of all human emissions (Kinsey & Hopley, 1990).

ii) Services of coral reefs specific to Maldives

The Maldives are low lying — less than 1 meter above sea level (Brown et al., 2019). The country boasts the 7th largest reef system in the world, which is home to over 1900 species of fish, 187 species of coral, and 350 species of crustaceans (World Bank, 2010). Maldivian people are very dependent on reefs for several reasons such as nutrition, economic benefits, and recreational value. The Maldives is also heavily reliant on reef tourism. In 2019, 66.1% of Maldives' GDP came from tourism (Knoema, 2019). Another ecosystem service provided by reefs in the Maldives is protection from coastal erosion. Reefs, especially fringing reefs which the Maldives is full of, can dissipate up to 97% of wave energy (USGS, 2021). Since the Maldives are low lying, coastal erosion is a persistent threat. The Maldives is also prone to tsunamis such as the Indian Ocean tsunami of December 2004 (Fernando & McCulley, 2005). Reefs can play a role in reducing destruction from such events. Coral reefs also provide extensive opportunities for fishing both for local peoples' nutrition and for industry.

Around 9500 households are directly involved in the fishing industry in the Maldives with many more reliant on reefs for food and fish as their main source of protein. Fisheries are vital to the Maldivian economy with the industry making up 23.9% of the country's GDP In 2019 (Knoema, 2019). Fishing and tourism together account for 75% of all jobs in the Maldives.

Threats to coral reefs in the Maldives:

A) Mass bleaching

In 1998 and 2016, the Maldives experienced mass coral bleaching events, with more than 60% of coral being bleached (The Guardian, 2016). Since then, local anthropogenic pressures, and not climate change, are mainly responsible for a decreased level of resilience in the population of coral in the Maldives (Montefalcone, 2016). The resilience of a population is the ability of the population and ecosystem to maintain its regular patterns of nutrient cycling and biomass production after experiencing damage caused by an ecological disturbance such as coral bleaching. The decreased level of resilience being caused anthropogenically in Maldivian coral is exemplified by the high mortality rate of atoll reefs in areas with greater human pressure, activity, and pollution during the 2016 bleaching event (Montefalcone, 2016). In addition, the recovery time for hard coral cover levels in the Maldives after a bleaching event was determined to be 16 years, a relatively long period of time, indicating low levels of resilience in the population (Montefalcone, 2016). Due to climate change and global warming, mass bleaching events are projected to become more frequent and severe (Hoegh-Guldberg, 1999), meaning it is critical for coral to be resilient. Therefore, human pressures in the Maldives must lessen so that reefs may be as resilient as possible. This is a challenging task as over 65% of the threat to Maldivian reefs is from human pressure (Montefalcone, 2016).

B) Overharvesting of the coral reef ecosystem

i) Coral mining

A major source of anthropogenic threat to coral reefs in the Maldives comes from coral mining. Coral mining is the mass harvesting of coral for their limestone and other materials which are used in bricks, construction, and road fill (Reefcause, 2021). Using current methods of overharvesting (Naseer, 1997) and at the current rate of mining, all coral in the North Male atoll (in which the capital Male is located) will be gone by 2039 (Brown & Dunne, 2009). Coral mining through the prying of large chunks of coral, as is done in the Maldives, can destroy reefs. Coral is extracted, removing the base of the reef. The organisms—mainly primary producers—that use coral structures as homes will leave the reef and therefore an entire trophic level of the food chain will disappear. This will cause a bottom-up trophic cascade, leaving higher trophic levels with no food, so they will either die out, leave along with their prey, or stay and adapt. Corals themselves are producers and provide nutrition to some organisms, so with the producers wiped out, consumers like coral feeders will not have access to the nutrition they gain from coral. So coral mining, whether it is a whole reef worth of corals extracted or just part of the reef, alters food chains, destroys habitats and changes the balance and biodiversity of ecosystems, completely wiping them out or leaving them deserted, less resilient and vulnerable. This results in a dysfunctional ecosystem, without the ability to provide services.

ii) Overfishing

Similarly, overfishing is a major threat to coral reef ecosystems. In the Maldives, fishing is the second largest industry (World Bank, 2020). The Maldives has an Exclusive Economic Zone (EEZ) spanning approximately 560,000 square miles, all of which Maldivian fishermen are allowed to fish (The Maldives Expert, 2018). A reduction in the population of species that are indigenous to local reefs can have drastic effects on Maldivian reef ecosystems. An example of one such species is Grouper, a keystone species, making up 80% of all fishing exports from the Maldives in 2012 (Blue Marine Foundation, 2020). If one trophic level is overfished and the population of this trophic level decreases, trophic cascades will occur and the food web and balance of the ecosystem will be disrupted. Additionally, the nutrient cycling in the ecosystem is reduced, affecting all organisms, even producers. If a keystone species is overfished, the absence or dwindling numbers of the species could create dramatically different or dysfunctional ecosystems. The ability of ecosystems to provide services without keystone species is greatly reduced.

An even worse impact of overfishing in the Maldives is one that doesn’t just compromise the health of local ecosystems but also places ecosystems in other locations at risk. The most fished species in the Maldives is tuna, making up 90% of fish caught in the region (The Maldives Expert, 2018). More specifically species like Skipjack tuna (72% of catch) and Yellowfin Tuna (25% of catch) (Miller et al., 2017). This has ramifications for tuna globally, as tuna are migratory species, only passing through the Maldives for part of the year. Migratory fish are important for all reefs and ecosystems they pass through in terms of the services they bring. These fish bring both ecological benefits to the habitats they pass through, and socio-economic benefits to fishermen along the migration route. This is especially true for areas where migratory fish mate and reproduce as they spend longer in these habitats, meaning the ecosystem of the area will have a higher reliance on the ecological services that the migratory fish species bring during mating season. The community of the area will be less healthy and less productive Migratory fish are involved in food chains of all areas they pass through. They bear ecological importance and socioeconomic value to the ecosystems and areas they interact with (Tamario et al., 2019). Hence, by the overexploitation of migratory tuna in the Maldives, local and global ecosystems can be compromised.

C) Methods of fishing

The method of fishing in the area can also threaten coral reef ecosystems. Maldivian fishermen mainly use the conventional pole and line fishing method (Figure 2).

Figure 2- a group of Maldivian fishermen using the pole-and-line fishing technique : (Greenpeace USA, undated)

Figure 3- two Olive Ridley Turtles in the Maldives found trapped in ghost net fishing gear: (IUCN, 2015)

One driver of unsustainable fishing in the Maldives is the prevalence of ghost nets (See figure 3). Ghost nets are fishing nets that have been carelessly discarded after use. From 2015 to 2020, the Olive Ridley Project, a local Maldives-based NGO removed 1340 ghost nets from local shorelines (IPNLF, 2020). Ghost nets are destructive as they can trap marine species, large and small and render them immobile while trapped in the net. In 2021, the Olive Ridley project rescued four Olive Ridley turtles and two sharks from just one length of the net (Olive Ridley Project, 2021). Trapped organisms may die or face serious injury unless rescued, and this can have drastic effects on local reef ecosystems if there is a large number of organisms trapped or if the organism plays an especially important role in the functioning of the ecosystem. Ghost nets can also encapture coral polyps and destroy them, possibly leading to death.

Another way ghost nets can contribute to the destruction of local ecosystems is through the transportation of invasive species. Ghost nets can travel for hundreds of miles and often end up in coral reefs, caught by a reef structure. Due to the high travel distance, ghost nets could potentially bring invasive species to the ecosystems where they are deposited. Invasive species can pose two threats by out-competing local species for space and resources (Stachowicz et al., 2002). They can wipe out a trophic level which can alter the food chain and destroy the ecosystem. An example of this is Crown-of-Thorns starfish which if brought to a coral reef, can wipe out all the coral. Invasive species can also wipe out a single species rather than an entire trophic level, taking the place of the species in the food web of an ecosystem. The invasive species will have different functional traits than the native species, so the cycling of nutrients and energy in the ecosystem is affected. Through all these processes, ghost nets have the potential to compromise the ability of Maldivian coral reef ecosystems to provide ecosystem services. Hence, the high prevalence of ghost nets in the Maldives needs to be addressed.

Fishing practices such as dredging, which is prevalent in the Maldives (National Geographic, 2022) can physically damage and destroy coral, as dredge nets are very heavy, so they scrape the sea floor and destroy coral reefs. This wipes out the ecosystem as a whole, as the ecosystem is completely based around coral and is heavily reliant on activity on the sea floor such as decomposition. Dredging also stirs up sediment from the seafloor which harms coral through siltation. This happens when excessive sediment loads in the water block light from penetrating through to coral which requires light for photosynthesis. Siltation also prevents coral from reproducing (Reefplan, 2019) and smothers the coral, which lack necessary mobility mechanisms to remove the sediment from its body. This also decreases the coral population and threatens the ecosystem.

Dynamite fishing, the use of explosives to stun or kill lots of fish, and its knock-on effects in the Maldives (National Geographic, 2022), can wipe out all life in the habitat which is affected by the blast. This negatively impacts the livelihood of other small-scale local fishermen who may rely on fish stocks. The destruction of coral reefs can decrease tourist numbers, further affecting the livelihoods of local communities. Once dynamite fishing occurs and creates a crater in the area, the local ecosystem is unlikely to ever recover (The New York Times, 2018). The rubble and debris from a local blast may land on nearby coral reef ecosystems causing negative effects there similar to those caused by siltation.

D) Garbage disposal and direct pollution

In the Maldives, all waste is transported to Thilafushi island, which is an open dump and the only waste disposal facility for the capital and surrounding islands (Biocycle, 2012). Every day, up to 1200 tonnes of waste is shipped to Thilafushi (CNA, 2022). Trucks load the garbage onto ferries which travel around four miles from Male to Thilafushi (Theworld, 2014). Unregulated and uncontrolled fires burn through the garbage that is deposited on the island.

The process of actually transporting the garbage is harmful to local coral populations. The ships cause pollution to local waters by releasing carbon dioxide which enters the water, acidifying it and contributing to coral bleaching. Moreover, carbon dioxide, when entering the water, reacts with calcium carbonate to release carbonic acid and hydrogen ions. These hydrogen ions are responsible for ocean acidification. Calcium carbonate is used by calcifying organisms, such as coral, to create their outer shell. The reduction of calcium carbonate as a result of its reaction with carbon dioxide results in lower calcium carbonate concentrations in local waters, so coral cannot fully form and create their outer shell (Zhang and Cao, 2016). This harms local ecosystems and coral reef populations. Ships may also carry invasive species to new waters through ballast water. This is seawater held in the cargo hold of ships to provide stability, and can bring invasive species to a new area if the ballast water is dumped. The trucks that transport rubbish may also emit greenhouse gasses contributing to global-scale coral bleaching and ocean acidification.

Another problem with Maldive's garbage disposal system is what happens when ashes and garbage residue from the burnt garbage leach into the ocean. This sediment can harm local organisms, and, through siltation, harm coral. A small percentage of waste on Thilafushi is composed of toxic heavy metals and chemicals from things like batteries which can also leach out into the sea and endanger local wildlife and ecosystems. These are especially harmful, potent, and toxic and have more immediate impacts in killing wildlife and contaminating habitats. This is exacerbated by how the Maldives has no mechanism in place to get rid of hazardous waste, and this may well end up in the ocean (ADB, 2017)

In 2011, Thilafushi was overwhelmed with garbage (BBC, 2011). This resulted in no space left for disposal on the island and boat captains became impatient in queues up to 7 hours long. As a result, waste was dumped into the lagoon of Thilafushi. Also, leachates and unconsolidated waste is known to enter the oceans from sites where informal garbage disposal and combustion happen in residential areas far away from Thilafushi (ADB, 2017). The trash in the ocean can suffocate and entangle species and ocean organisms may eat the garbage. All of this results in the death of species which has drastic impacts on local biodiversity, food chains and ecosystems, not to mention the ability of reefs to provide ecosystem services.

Most of the Maldives does not have a recycling or composting system. It is reported that some resorts in the Maldives that are far away from Male and Thilafushi don't have regulated waste management systems and resort to burning it themselves or worse, dumping it into the ocean (Biocycle, 2012). If waste is not recycled or put in the dump, it could end up as litter in the ocean. The worst types of litter in the ocean are non-biodegradable materials such as plastics which can take up to 1000 years to fully decompose (Narayan and Balakrishnan, 2009). Plastics and other garbage may float for a long time in the ocean, far away from their source. Currents may carry garbage for up to five years before it reaches a gyre and stays in the same place in the ocean (Nagle and Cooke, 2017). This garbage may be carrying invasive species which can wipe out or change the food webs and reduce ecosystem service providing abilities of habitats by outcompeting local biodiversity.

Moreover, over the years, plastics photodegrade (Chamas et al., 2020). This means they break up into smaller and smaller particles and eventually into microscopic microplastics which tend to float near the surface of the ocean. Microplastics are a global issue to which the Maldives is a large contributor. In the Maldives, the microplastic concentration is extremely high, with an average of 197-822 microplastics per kilogram of water found in the reefs of various inhabited and uninhabited islands (Patti et al., 2020)

Many species of coral that make up reefs are filter feeders. These are marine organisms that feed by straining suspended nutritious matter, or organisms from water, typically by passing the water over a specialized filtering structure (Bullivant, 1968). Filter feeding coral normally feeds on organisms, such as plankton, which are the same size as microplastics. Hence, filter-feeding coral species may ingest microplastics unintentionally, and die from a lack of nutrition. In a study conducted in the remote Faafu atoll in the Maldives, scleractinian coral, a filter-feeding species was found to have dangerously high amounts of microplastics (Saliu et al., 2019). More worryingly, the highest concentration of microplastics was found within coral nearest to the most highly inhabited island in the atoll, indicating that anthropogenic activity is a probable cause of microplastic pollution and coral reef ecosystem harm. The pathway is most likely through littering and incorrect garbage disposal in the area.

Existing policies to tackle threats to coral reefs in the Maldives:

a) Marine Protected Area

In 2010, more than 190 countries participated in the UN Convention On Biological Diversity where the 2020 Aichi biodiversity targets were created (Nature Journal, 2020) in order to try and protect and conserve the biodiversity that underpins global food health, food security and access to clean water (Mongabay, 2021). The Maldives' efforts needed to be heavily focused on the oceans and coral reefs because that is what the country primarily relies on for economic, environmental, and social welfare. The Maldives achieved numerous goals and targets and a major method that resulted in their success was the creation of protected areas. The Maldivian government created 44 protected areas with marine areas accounting for 428,569 hectares (CBD, 2022). These areas are protected under the Environment Protection and Preservation Act 4/93 created in 1998. The law states that waste, oil, poisonous substances, and hazardous toxic/nuclear waste shall not be disposed of in protected areas (UNESCO, 1998). The law provides basic protection from over-fishing, coral mining, anchor damage, and garbage dumping (Jaleel, 2013) The penalty for a minor violation of the law is a fine of between 5-500 Maldivian Rufiyaa ($0.32-$32.37 USD). The fine will not exceed 10,000,000 Rufiyaa (USD $64749.33)

Another list has been established as well which identifies 387 areas in the Maldives that are rich in biodiversity as "sensitive areas" (CBD,2022). These include possible fish breeding areas, micro atoll reefs, islands, mangroves, and other important marine areas.

The Maldivian government also implemented legal protection measures that target specific species. There is a moratorium on turtle harvest and rare species that are likely to be threatened or endangered are banned from being exploited and exported (CBD, 2022). In ten areas where sea turtles are under the greatest threat, there is a ban on harvesting sea turtle eggs. The punishment for breaking the laws is a fine under law 4/93 section A (UNESCO, 2020). In 2009, a major area for whale shark aggregation, the Hanifaru region, was declared a marine protected area, and a management plan for whale sharks followed in 2013. There has also been a ban on shark fishing in the Maldives since 2010. Overall, 103 species of birds, 14 marine species, and black turtles are the wildlife that has been granted protected status in the Maldives. Yet a very low proportion of the country's wildlife is currently protected.

Environmental protection also makes up a very low proportion of the government and overseas investment budget. There is a need to create a variety of financing mechanisms to fund the complete protection of Maldivian oceans and the life within, as monitoring and enforcing protective legislation can be expensive.

In 2021, a new regulation was published by the Maldives Ministry of Environment in the Government gazette. The aims of the new regulation—-"Regulation On Protecting Living Organism In Its Natural Or Original Form"—include: the creation and implementation of a management plan to protect and conserve marine life and habitats, compilation of a list of endangered species, registration of centers to look after protected species and the conduction of research on the same (Gazette, 2021). The regulation means the Ministry of Environment has to set out a plan to manage the protection and conservation of endangered species in the country within the span of a year.

B) Overfishing and Coral Mining

The Ministry Of Fisheries and Agriculture (MOFA) in the Maldives regulates fishing through the fisheries act 5/87 (Jaleel, 2013). This law applies to the main areas used by Maldivian fishermen, which includes waters up to 75 miles away from the nearest outer atoll coral reef (MOFA, 1987). The law states that any commercial fishing activities taking place in the EEZ by Maldivians or foreigners requires permission from the ministry. Commercial fishing needs licensing and baitfish should be caught using sustainable, traditional methods. If any species is under threat or if there is the need for conservation of certain species or marine areas, MOFA has the right to prohibit the exploitation of said species or areas. Punishment for breaching laws in the legislation includes larger fines and/or imprisonment.

There is also more specific protection of reef ecosystems, for example reef fishing is banned in all resorts (Naseer, 1997). The Maldives Fisheries Act allows sustainable methods of fishing for several species such as skipjack tuna pole and line fishing, yellowfin tuna handline fishery, grouper fishery, reef fishery and many more under (section 17 (A)) (Fisheries Act Of The Maldives, 2019). There are yet to be any management plans developed for managing the total removal of fish by fisheries at one time, or the specific targets of fisheries, or catch limits imposed on vessels (IALA, 2021).

In 1992, the Maldivian government directly intervened by introducing a set of bans on coral mining, including a ban on mining in island house reefs, a ban on mining in common bait fishing reefs, and a ban on mining in atoll rim reefs. They also established regulations on permission from atoll offices and island offices to mine coral and required every island to keep a logbook of coral mined (Naseer, 1996). In 1995, Male, the island with the highest amount of construction and use of coral for anthropogenic development, stopped using coral in construction, raising awareness in all Maldivian communities that a switch to other materials is required (Jaleel, 2013).

C) unsustainable fishing methods

In section 27 of the Maldives fisheries act, unsustainable fishing methods such as purse seine, gillnet fishing, trawl net fishing, fishing using a net (excludes bait fishing and fishing for personal consumption), fishing using explosives, fishing using poison, cyanide or other chemicals are banned (IALA, 2021). In 2020, the Maldives implemented a new monitoring system (VMS) to control fishing vessel operation in its waters, with the VMS being installed on 732 vessels active in the Maldives EEZ. In 2017 there were an estimated 1066 vessels engaged in fishing per month (Statistics Maldives, 2018). The main methods of fishing in the Maldives in light of the restrictions include pole and line, handline, and longline fishing. It is extremely hard to monitor whether fishermen discard used nets into the water to become ghost nets and even the VMS cannot detect this. In 2020, the IPNLF has launched a new initiative in partnership with *The Olive Ridley Project* called "The Ghost Net Retrieval Project", which incentivizes Maldivian fishermen to collect and retrieve ghost nets they may find during their fishing operations (IPNLF, 2020).

D) Waste disposal and direct pollution

Most Maldivian islands are far away from Thilafushi and there is a lack of options to transport waste, so in these islands, waste is deposited on unmanaged areas of the shoreline (Jaleel, 2013). During high tide and strong swell, garbage may float out into the ocean or be deposited near coral reefs. The management systems and policies on this front are outdated, because up until the mid-80's most household waste in the Maldives was organic and would decompose easily and relatively quickly (IUCN, 2018). Due to globalisation and economic developments, products packaged in materials that don't biodegrade, such as plastics, have been major parts of household waste on residential islands. There have been relatively weak efforts, such as that from the Hoandedhoo Island Development Society (HIDS) NGO which spreads awareness about waste management issues and developed a fully functioning sustainable waste management system on the islands of Nadella and Hoandedhoo. This initiative is small in scale and therefore relatively low impact. Its efficacy is also low as residents preferred to dispose of trash in an unregulated fashion for reasons of convenience. In 2017, the World Bank approved $17.5 million in financing in efforts to improve waste management systems in 9 selected zones (The World Bank, 2017). The project, known as the "Maldives Clean Environment Project" aims to support the government's efforts to address current challenges faced in waste management. The project also aims to fully operationalize the Regional Waste Management Centers (RWMC) and build RMWC's in 3 zones of the country. The project supports the government in developing individual island facilities for managing collection, segregation, treatment, and storage of waste until final transfer to a common facility. The Maldivian Ministry of Environment and Energy's (MEE's) capacity for the implementation of projects through the establishment of a Project Management Unit (PMU) to manage project activities has been increased, and infrastructure for an immediate response to emergencies is planned to be constructed.

The main mode of transport in the Maldives is by boat. There are no provisions for the oily byproducts of boat operation. To this day, they are commonly discarded overboard, mainly while en route, but sometimes in lagoons and coral reef areas (Jaleel, 2008). This demonstrates the inadequate measures to address liquid waste from local and foreign vessels in the Maldives. The oily waste from the numerous large maritime operations in the Maldives is likely vastly underestimated. Even though the 4/93 legislation doesn't allow the dumping of waste overboard, this is still common practice and needs to be seriously addressed (Jaleel, 2013).

Potential policies to better address threats to coral reefs in the Maldives:

A) Marine protected areas

The Exclusive Economic Zone of the Maldives extends nearly one million km^2 (Adam, 2004). This means that roughly 916,453 km^2 of the EEZ is not part of a marine protected area. Of existing protected areas, the Act 4/93 legislation still allows fishing. The main reason for the lack of a marine protected area and the allowance of fishing in marine protected areas is the reliance of the country on the fishing industry. A fishing quota (See Figure 4) would solve the issue of overfishing. The 4/93 legislation for MPAs already provides basic protection from coral mining, anchor damage, and garbage dumping (Jaleel, 2013). If the Maldives were to extend the protection of existing MPAs, all marine habitat areas could be protected from these threats, while still supporting the fishing industry. The 387 "sensitive areas" that the government recently identified as important for biodiversity (UN, 2022), should also be fully converted into protected areas and regulated by the 4/93 act.

Environmental protection currently makes up a very low proportion of the government and overseas investment budget (CBD, 2022). The monitoring of Marine Protected Areas and marine species requires extensive funding as human labor and manufactured equipment (eg. vessel monitoring systems) need to be employed for the protection and monitoring of these areas and species. Hence, the government needs to create a variety of financing mechanisms to fund the complete protection of their local biodiversity. There are a few ways to do this without eating into the government budget. The government could set an indirect tax, a government levy on the production and consumption of goods (Blink and Dorton, 2020) on the fishing industry. This means a tax is paid to the government by the fishery for a certain amount of fish produced (eg. $1000 for 100 tonnes of fish). This tax is paid by the fishery but the cost will be passed, at least in part, to the consumer. Fish in the Maldives are a commodity and staple food, meaning the demand for fish is inelastic in nature. This means an increase in the price of fish is not likely to decrease consumption much, so an indirect tax on the fishing industry will not harm the industry to a great extent. The government can then generate revenue from the taxes set on the fishing industry which they can use to fund the protection of MPAs and species. This also makes the industry less comfortable and profitable to be in for fisheries, who will be discouraged to catch more fish. Adopting this approach would ensure the longevity of the industry.

Another way the government could help enforce their marine protected area legislation is through support from NGOs. This could potentially raise a lot of money if larger international NGOs such as the World Wildlife Fund are involved. NGOs like Sea Shepherd may also actively involve themselves in the enforcement of sustainable practices meaning the government does not have to employ resources to do this and the reputation of the government may be more positive than if they were directly enforcing this.

The government could also use tourism to its advantage by employing a scheme similar to the guide scheme used in the Galapagos Islands. This is a sustainable tourism scheme where it is compulsory for each tourist to pay for a local tour guide to take them to see coral reefs and go diving or snorkeling. This raises revenue for the government to monitor MPAs and species but also brings social and economic benefits through local employment.

b) overfishing and coral mining

Despite some more threatened species being given protected status in the Maldives, very little of the country's wildlife is currently protected. There are 1899 marine species in the Maldives, not including planktonic species (UN, 2022). Excluding coral, there are 32 marine species in the Maldives that are either vulnerable, near threatened, endangered, or critically endangered (WWF, 2022), but only 15 have been granted protected status. This is likely due to the heavy reliance of the Maldives on fishing. If species are protected, the fishing of these species will not be allowed, harming the industry. Regardless, many species that are not commonly fished are still unprotected. There is also potential legislation that can protect commonly fished species while still allowing them to be fished by permitted fishermen. Corals and all other marine species that are under threat should be granted protected status.

Fishing is a large industry in the Maldives that contributes greatly to the economy and offers employment and livelihood to many. With this in mind, a non-fishery species could be granted protected status as this still allows industrial fishing to take place.

With regards to overfished species that are targeted by fisheries, such as skipjack tuna, and the need for their conservation to maintain ecosystem services in local ecosystems, a balance needs to be struck between the socio-economic and environmental benefits of exploiting these species. If these species are overharvested rapidly, this will affect the health of ecosystems and potentially decrease their ability to provide ecosystem services which will greatly negatively harm local populations in the long run. For example, if the population of skipjack tuna is reduced, an apex predator is lost and a top-down trophic cascade will occur, with the population of tuna's prey increasing and the biomass and nutrient cycling balance of the ecosystem altered. If the overfishing of these species is done so quickly and to such a great extent, it could mean their populations in the local area cannot sustain themselves and will go extinct. This also means drastic negative consequences for locals in the long run. With this in mind, a potential policy that accounts for the socioeconomic benefits of harvesting these species in the short run, but also the environmental sustainability of the species and the ecosystem, is a local, catch-based fishing quota. This is a limit set on the amount (in kg or tonnes) of a fish species or fish stock that can be caught by a fishery or fishing vessel during one fishing season which normally lasts a calendar year (afma, undated). For example, the Ministry of Fisheries and Agriculture in the Maldives could state that in one calendar year, each tuna fishery can only catch 1000 tonnes of skipjack tuna. A potential legal instrument to monitor this could be modelled after the statutory fishing rights system used by the Australian fisheries management authority, where legal action is taken against any fishery that does not cooperate. However, an ideal option for the Maldives would be to make the fishing quotas untradable, meaning that the limit on fish catch cannot be transferred to another fishery if not used up. This is because each fishery would operate in a specific region and therefore a specific habitat and ecosystem. If one fishery in one area transfers an extra quota to another fishery, that fishery may overfish the species in the area which defeats the purpose of the quota. This quota could also be imposed on specific vessels rather than fisheries as a whole, which would also address the loophole in section (17(A)) of the Fisheries Act where there are no catch limits imposed on vessels.

In addition to the first quota, another quota or limit could also be set on the amount of fish that fisheries remove at any one time from an area. If a large number of one species are removed from one habitat at one time, it makes it very difficult for the species to sustain itself in the long run with so many individuals gone and a lower rate of reproduction. This has knock-on effects that harm the whole ecosystem. This second quota would address the loophole in section (17(A)) of the fisheries act whereby there is no limit on the total removal of fish by fisheries at one time.

The section 4/93 legislation provides protection from coral mining in Marine Protected Areas. To further protect coral from being mined, more of the Maldivian EEZ should be converted into MPA's, especially areas of high coral density. These areas should also be monitored and protected to a greater extent.

C) unsustainable fishing methods

The incorrect disposal of fishing gear is the Maldivian fishing industry's main threat to the local marine ecosystems. When used fishing nets and lines are deposited in the ocean they are known as ghost nets. Direct retrieval of fishing nets from the ocean is not an ideal solution that the government could use to solve this problem. It would be very costly, inefficient, lengthy and ultimately be a waste of resources. The government would need to rely on NGOs to carry out such an effort, the likes of which are not happening on a large or substantial scale currently. However, there are several other ways to solve this problem.

One simple and easy solution is to establish waste fishing gear deposit stations at local docks so when fishermen get off their boats they can safely and conveniently dispose of their fishing gear. There are some drawbacks to this issue though. The waste disposal system in the Maldives has several flaws and there is no recycling system in place. The waste fishing nets would most likely end up in landfills like Thilafushi and be burnt. There is also a chance that on a coastal landfill the ghost fishing gear leaches into the ocean again. Though, the disposal of fishing nets into designated deposit areas is still better than them ending up in the sea.

There are several ways to recycle ghost fishing nets. For example in Australia, a non-profit called "Ghost Nets Australia" is collecting ghost nets and providing them to local communities who make art pieces out of the discarded fishing gear (LeRoux, 2016). Another example of such a company is "Fourth Element", a company that makes swimwear out of ghost net gear (fourthelement, 2022).

Another solution to the issue of ghost nets in the Maldives is to launch education programs that reach out to local fishermen and communities and inform them about the dangers and harm to the environment that discarding fishing gear directly into the ocean can bring.

There could also be legislation specifically against discarding ghost nets. The section 4/93 act technically bans this in MPAs, but most of the fishing occurs in the 916,453 km2 of unprotected marine areas. The government could either impose more Marine Protected Areas or create a new legislation banning the disposal of fishing gear in the ocean. This would be hard to monitor though, and additional funding may be needed which could potentially come from a fishing quota (as suggested previously).

D) Waste disposal and direct pollution

Thilafushi is the only island of its kind in the Maldives. To prevent the casual and unregulated dumping or burning of garbage on random beaches on islands far away from Thilafushi, more islands that specifically function as garbage dumps could be created. However, this is not an ideal solution because the designation of an island as a specific dumping and burning site is in itself unsustainable and causes environmental harm. It would also mean an island needs to be repurposed and it would be unsightly, which could deter tourists from nearby areas and be unpleasant for locals.

The aforementioned "Maldives Clean Environment Project" which aims to support the government in developing individual island facilities for managing collection, segregation, treatment, and storage of waste until final transfer to the common facility (World bank, 2017), is an ideal solution as it treats waste before facilitating transfer to a main facility. This solution hasn't become fully operational yet because of insufficient funding. To make the project truly successful, a lot of funding is needed to build many garbage processing centres so all islands in the Maldives can have a nearby facility. An issue with this is the land on which the facility would be built. A solution to this issue could be to build islands out of garbage, like was done with Thilafushi.

Due to the remote nature of the Maldives, the garbage disposal system needs to be specialised and has potential to be more refined than simply dumping garbage on a large island. The government could implement a waste management system similar to that of Singapore. Singapore's non-recyclable trash is incinerated (burnt) in large incineration towers (SSG, undated). The ash and non-incinerable waste are sent to Pulau Semakau, an island built completely out of trash like Thilafushi, but is now a major site for tourism and leisure with a vibrant coral ecosystem. Thilafushi could follow the same model. The garbage and ash that make up Semekau are sealed off by a clay sealing from the ocean which prevents leaching of substances into the surrounding waters. On Thilafushi, the trash should be cleaned up and added to the island to expand it. The island should then be developed on and made into a site of leisure or tourist destination. There could be several islands developed in the Maldives which follow the same model of being an island made of waste, and are completely sustainable and don't harm the surrounding environment. With regards to incineration, it would be feasible for the Maldives to install incineration plants of the same style as those on those on Semekau. The incineration does not harm the environment because the flue gas that is created from combustion is passed through a catalytic converter system and precipitator which removes dust, neutralises acid, and breaks down dioxins into harmless gasses before releasing into the atmosphere (Gov.sg, 2022). The solution of designing a whole new waste management system requires a lot of funding though. However, this would be a worthwhile investment to maintain the longevity of Maldives' coral reef ecosystems and ensure the sustainability of the services the provide eg. tourism

The issue of dumping of oily wastes off the sides of boats also needs to be addressed. Firstly, expanding marine protected areas would mean that this is illegal in many more areas. Additional monitoring of vessels could also be employed but this would require lots of funding. Another way to reduce dumping of liquid waste would be education programs which inform boat captains about the harm to the environment that dumping liquid waste does. Overall, additional monitoring and education programmes are called for in reducing the impact of boat traffic on Maldivian reef ecosystems.

Figure 4- Table showing the main anthropogenic threats to coral reefs in the Maldives, the current policies in place to tackle them, and proposed policies to further support coral ecosystems detailed in this paper

Threat	Overharvesting of reef ecosystems- Overfishing and coral mining	Methods of fishing/harvesting	Garbage disposal and direct pollution
Current policies (to be kept)	1. Marine protected areas (MPA's), species protection status - Environment Protection and Preservation Act 4/93 2. Fisheries act 2019 section (17(A)) 3. Fisheries act 5/87 4. Ban on coral mining	1. "The Ghost Net Retrieval Project"- Olive Ridley Project and IPNLF 2. Vessel monitoring systems (VMS) 3. Fisheries act 2019 - section 27	1. Hoandedhoo Island Development Society (HIDS) NGO 2. "Maldives Clean Environment Project" - The World Bank and the Ministry of Environment and Energy
Proposed policies (to be implemented)	1. Protected status for all threatened marine species 2. Expand MPA's so more areas are protected under act 4/93 3. funding for monitoring MPA's through indirect tax, NGO's or sustainable tourism guide scheme 4. Fishing quotas	1. Ghost net deposit system at docks and subsequent recycling 2. Education programs 3. Expand MPA's so more areas are protected under act 4/93	1. Incineration plants and islands made of garbage system 2. Education programs

Conclusion

Global warming leading to ice melt is causing global sea levels to rise rapidly. For a low-lying island nation like the Maldives, this could be a death sentence to land-based life. With this in mind, the conservation and preservation of the teeming reef ecosystems that lie within the Maldives are highly important because after the islands are submerged, all that will remain is one of the world's largest reef systems. The Maldives is a global player in the worldwide ocean ecosystem. Contributing greatly to factors like carbon capture and harboring migratory fishes. Such a large reef system and how relatively well it had been preserved so far mean the Maldivan reef system is a great indicator of the health of coral reefs and oceans globally.

The reef system of the Maldives is mainly under threat from anthropogenic, local factors that **can be controlled.** The population of the Maldives relies heavily on the coral reefs, and so a human-caused reduction in the ecosystem services provided by the reefs affects the livelihoods of thousands of local people. A balance needs to be struck between conserving the reefs and protecting the livelihoods of locals, and exploiting and damaging the reefs for short term economic gain.

The Maldives has implemented a number of policies in the past 30-40 years, including expanding Marine Protected Areas and heavily regulating fishery activity. This paper proposes several additional policies which, if implemented, would bolster the long-term sustainability of Maldivian coral reefs and the ecosystem services they provide.

Recently, global awareness and action against the devastating effects of climate change have skyrocketed. With climate pacts like the Paris Agreement and global United Nations goals like the Sustainable Development Goals, the decisions of the Maldivian government in the preservation of its rich environment will receive greater global support. With a few key changes and sufficient funding, the Maldivian coral reef system will continue to thrive and maintain its reputation as one of the most beautiful ecosystems on our planet.

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