Anthropogenic stressors causing degradation of coral reefs on the Indian sub-continent?

Abstract

Coral reefs form a fragile ecosystem. They provide an essential food supply for local populations. They protect shores from waves, and they create opportunities for tourism. However, coral reefs are in decline. Anthropogenic stressors are a major cause in the change of ecosystems around the world, including coral reefs. This essay describes major anthropogenic stressors for coral reefs and tries to create an understanding of how these stressors play their part in the decay of coral reefs. Therefore, this essay focuses India as on the second largest nation in the world regarding population size. India is surrounded by four major coral reef areas. This thesis explains the present-day knowledge of the major anthropogenic stressors on coral reefs and compares how these stressors affect each of the four major reef locations of India. This is due to the variation among these coral reefs and the different anthropogenic factors threatening these locations.

Keywords: Coral reefs, Pollution, Overfishing

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Introduction

Coral reefs form an ecosystem that is found in tropical and sub-tropical waters where the minimum temperature is usually above 20 °C. This threshold temperature plays a large role in the distribution of coral reefs around the world. Coral reefs occupy a surface area of about 2.284.300 km^2. This is 0.09% of the total area of the world's oceans. They are only found in shallow waters between 25 °N and 25 °S. Most of these reefs can be found in the Indo-Pacific region, with Indonesia and Australia accounting for 35% of the total reef of the world (Majumdar et al., 2018).

Coral reefs serve many functions. They form a unique ecosystem with a high biodiversity. This biodiversity makes the ecosystem attractive for local fisheries and tourism. Most of the coastal fishing in the tropics for consumption is done in coral reefs. These fisheries yield 10% of the total fish catch in the world and yield 25% of the fish catch in developing countries (Majumdar et al., 2018). However, corals reefs are not only beneficial for humans as a source of food or a tourist attraction, but also function as shore protection (Saroj et al., 2016). The structures of the coral reefs reduce the erosion of the shoreline caused by wave actions. These functions make maintaining the coral reefs essential for the local ecosystems and for the humans making their livelihood of these reefs. Unfortunately, coral reefs are in decline. Natural phenomena can cause damage to vulnerable reefs. Hurricanes can destroy parts of reefs through the sheer force of the wind-generated waves passing the reefs. The phenomenon El Niño is a phase of increasing sea temperature over the eastern-Pacific Ocean that happens every few years, during which the water of the Pacific Ocean significantly increases (Sheppard et al., 2002). This increase in temperature causes coral bleaching. The coral has poor ability to adapt to these changes and rids itself of symbiont algae. This is coral bleaching and it could lead to coral mortality. These factors are outside of human control. However, these are not the only factors leading to the reduction of coral reefs around the world. Due to the rapid rise in populations across the world, we must strive to preserve nature from the increasing demand anthropogenic stressors create on nature. Anthropogenic stressors are changes of the organic world as a consequence of human activity. These anthropogenic stressors play a large role in the degradation of coral reefs. Understanding these anthropogenic stressors can be vital in the preservation of coral reefs

India is a country reliant on the wellbeing of the plethora of coral reefs surrounding the country. The country has four main coral reef regions (Figure 1). There is the Gulf of Mannar, which is located between the Indian province of Tamil Nadu and the island nation of Sri Lanka. There is the Lakshadweep Islands to the west of the Indian sub-continent. The Gulf of Kutch is located near the

border of Pakistan while the Andaman and Nicobar Islands are located north of the Indonesian island of Sumatra. These four coral reef areas contain four different kinds of reef structure (Saroj et al., 2016). The first of these structures is the fringing reef, which is a reef growing close to the shore. The Gulf of Mannar, the Gulf of Kutch and the Andaman and Nicobar Islands all have mostly fringing coral reefs. The second type of coral reef structure is the atoll. An atoll is a circular or oval coral reef in the ocean, which is surrounded by a lagoon. Indian atolls are mainly found in the Lakshadweep Islands. Thirdly, there is the barrier reef. Barrier reefs are reefs separated from the land by a wide expansion of water that follows the coastline. These barrier reefs in India are mainly found around the Andaman and Nicobar Islands. The last type of coral reef is called the platform reef. The platform reef is a nearly flat reef without any lagoon nearby. These reefs are mainly found in the Gulf of Kutch.

This thesis tries to create an understanding of the anthropogenic factors influencing the major coral reefs of the Indian sub-continent, by answering the main question: ''What anthropogenic stressors could cause degradation coral reefs of the Indian sub-continent''. This essay tries to lay out the major anthropogenic stressors related to the loss of coral reefs and tries to connect these stressors with the four main coral reefs of India, in order to show the difference and similarities between the four coral reefs and their anthropogenic stressors.

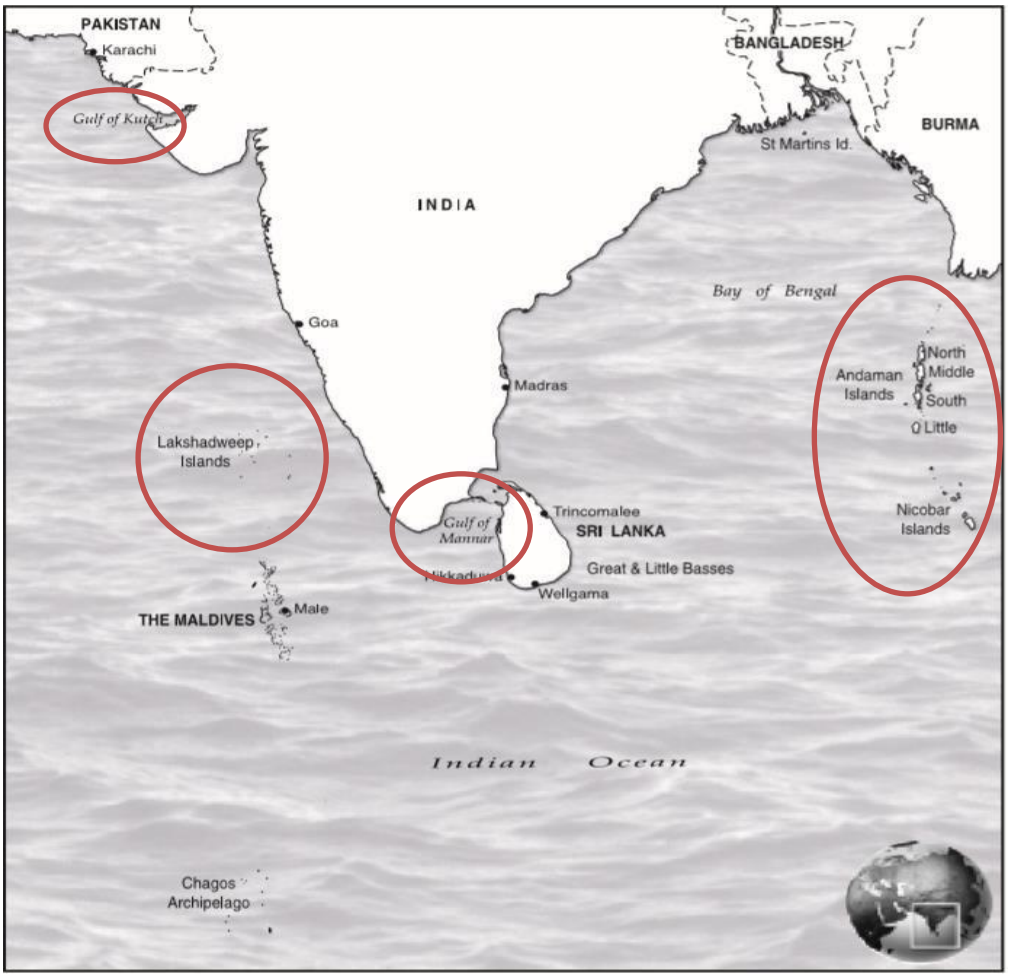

Figure 1: Map showing the Gulf of Kutch, Lakshadweep Islands, Gulf of Mannar and the Andaman and Nicobar Islands (after Rajasuriya et al., 2002)

Fishing

The Gulf of Mannar is used extensively for commercial fishing (Kanaga et al., 2017). Lakshadweep, the Andaman and Nicobar Islands and the Gulf of Kutch mostly have local fishery. During the 1960s there was a rapid international demand for the fishing sector. The Indian government increased the fishing efforts as a response to the demand. This created the overfishing that is causing the imminent exhaustion of the coral reefs. A 2017 study concluded that the rise in fisher population and the overall fishing effort is now the leading cause for the overexploitation of the coral reefs in the Gulf of Mannar (Kanaga et al., 2017). This overfishing of coral reefs can lead to a plethora of direct and indirect consequences. The most direct consequence overfishing can cause is the local loss of species. In the Gulf of Mannar several species are under the threat of becoming extinct due to overfishing (Rajasuriya et al., 2002). These include seaweeds, sacred chanks, pipefishes, sea horses and sea cucumbers. This is partly due to the extensive use of fish traps made from bamboo. Populations of pearl oysters, acorn worms and gorgonians are severely reduced because of the constant over-harvesting. These species are not the only ones at risk of local extinction. About a thousand turtles per year are harvested and many more organisms such as dugongs, groupers, snappers and emperors are at risk due to their high demand. This loss of species could be the cause that led to the prevalence of the crown-of-thorns starfish (*Acanthaster* spp). This starfish eats corals on the reefs of the Gulf of Mannar. However, it has become quite a problem for the ecosystem. Its abundance in the Gulf of Mannar is so high that it consumes coral faster than it can regrow. The crown-of-thorns starfish also occurs on coral reefs of the Lakshadweep Islands. However, the Lakshadweep Islands do not have much commercial reef fishing practices. The local fishermen fish mostly outside the reefs (Rajasuriya et al., 2002). However, they use sprats (*Spratelloides sp.*) as bait. This is a fish native to the reef lagoons. Therefore, the local fishermen fish in the lagoons. This has become increasingly damaging to the reef over time and over time the yield has decreased. This could be due to bleaching events that took place, but another big factor is the increase of the Lakshadweep Islands human population, which has more than tripled in size between 1982 and 2002 (Rajasuriya et al., 2002). In the Gulf of Kutch fishermen are now fishing evermore close to the coral reef areas. Here they use fine meshed nets in order to catch fish at their breeding grounds. This bring unnecessary problems with it. The use of these nets could be harmful, not only to the target fish, but also to the brood. These nets have such a small mesh size, that commercially non-target fish, such as the young brood of target fish, are caught as bycatch.

Fishing in these regions can have devastating effects on the local ecosystems, especially when looking at destructive methods used to harvest fish. The most destructive method used is blast fishing or dynamite fishing (Rajasuriya et al., 2002). This is a form of fishing in which explosives are set off. These explosions create shock waves that knock out or kill the fish in the area, so that they can be harvested more easily. This form of fishing is highly destructive regarding the coral reefs for multiple reasons. The first reason being that this form of fishing can be destructive for the coral structures on the seabed (Hoon, V., 1997). Blast fishing is restricted to shallow waters where the impact of the blast can easily destroy the corals present. The second reason is because of how unselective this method of fishing is. The blast does not distinguish target fish from non-target fish. This causes unnecessary loss of fish. The Indian fishermen also use specific methods of catching lobster. This is done with trawl nets or gill nets (Hoon, V., 1997). Trawl nets are nets attached to one or more boats which are subsequently dragged behind the boat through the water. Gill nets are nets with weights added to them. These weights keep the net on the seabed. Both fishing methods can be destructive to the coral reef they are placed in. Trawl nets often drag low enough to the seabed to sweep corals with them, causing direct damage to the reef. Gill nets can also directly damage the coral reefs. When they are dropped in the water, they can damage corals with the weight. Corals can also become stuck in the net. This could cause coral to be taken out of the reef when the nets are reeled in.

When looking at specifically the Gulf of Mannar regarding fishing activity, we must not only look at the actions taken by Indian fishermen, but also at the actions of Sri Lankan fishermen. The north- west of Sri Lanka is connected to the Gulf of Mannar and the Sri Lankan people too contribute to the

degradation of the coral reefs there. Sri Lankan fishermen too make use of unethical blast fishing methods and the use of gill nets

Coral mining

Besides fishing, there is another process which directly decreases the biodiversity of the all the four major coral reefs of India. This process is called coral mining. Coral is mined for several reasons (Hoon, 1997). The main reason to mine coral is for constructional purposes. The corals are mined to create limestone and other construction materials. Pieces of coral can also be used in the creation of bricks or roads. When mixed with sand, the coral limestone can also be turned in cement. Besides mining for construction, coral is also mined to create calcium supplements. Coral mining often takes place in similar ways as blast fishing. This method of mining brings its own set of consequences with it. Explosives are used to create a shockwave that breaks the coral in smaller pieces. These smaller pieces are then easily harvested. This causes loss of individual corals which can lead to an eventual decrease in biodiversity (Caras and Pasternak, 2009). However, this is not the only potential cause for a decrease in biodiversity. Due to the explosions, the seabed itself gets damaged. Rocks from the reef are destroyed and taken out with the coral. This is a direct reduction of substrate the coral could attach itself to. This in turn could lead to an increase in sedimentation. This sedimentation could block sunlight from reaching the corals on the seabed (Wear and Thurber, 2015). The reduction in sunlight on the seabed reduces the temperature on the seabed and the amount of photosynthesis in the corals. The sediment can also settle on the seabed and smother the corals. As much as 50% of the coral reefs of the Gulf of Kutch has been lost. The main cause for all of this, is the exploitation of coral and sand by the cement industry.

When parts of the coral reef are damaged or destroyed, they leave the coast more vulnerable to natural phenomena such as storms or hurricanes. The coral reefs form a defensive line which breaks waves about to crash on the shore. The loss of the coral reefs is a direct loss of a protective layer for the shore. This can have detrimental effects on the dense local populations near the Indian coral reefs.

Pollution

India is the second largest country in the world regarding total population size. The density of the population directly affects the nature surrounding the populations. This too is the case for coral reefs in direct and indirect ways. The coral reefs of the Gulf of Kutch have seen a large reduction in size, mostly as a result of the exploitation of the commercial industry (Hoon, 1997). Not only is this a result of direct harvesting of the coral and fish, but also because of another problem. This problem is pollution. The combination of industrial waste being dumped in the sea, together with human waste, poses an imminent threat to the preservation of coral reefs (Ramadas and Rajeswari, 2011). The dumping of sewage poses multiple threats for the Indian coral reefs (Table 1). The first major problem sewage brings with it, is the problem of adding freshwater to the coral reefs (Wear and Thurber, 2015). Freshwater can pose a great threat, as studies have shown prolonged exposure to fresh or brackish water to be fatal to most corals (Wear and Thurber, 2015). Limited field studies have also shown drops in salinity, when increased freshwater and runoff stormwater entered coral reefs. The second threat to coral reef due to input of sewage, is the increase of nutrients to the area. Sewage contains high concentrations of inorganic nutrients. These are nutrients such as ammonium, nitrite, nitrate and phosphate. The increase of these nutrients in the in the coral reef ecosystems causes eutrophication. This eutrophication causes an increase in algae growth (Bell, 1992). Corals thrive on the poor availability of nutrients in the reefs. This increase of nutrients in the coral reefs increases the capabilities for fast-growing alae to compete with the slower growing corals. This algae growth can lead to a higher mortality of corals in the reefs. The growth of algae in these coral reefs reduces the amount of sunlight reaching the

corals on the seabed. These corals can photosynthesise less as a result of the algae blocking in the incoming sunlight (Brown et al., 2019). Additionally, the temperature on the seabed also drops as less sunlight reaches the seabed. This can cause the water of the reefs to cool below the threshold for corals to survive. Both these factors can cause bleaching and death of the corals.

Added nutrients in the sea water can also have other effects on corals. Studies have shown that inorganic nitrogen is positively correlated with increased prevalence of diseases and even prevalence of coral bleaching. The increase in nutrient availability has a positive correlation with increasing disease progression rates of diseases such as yellow blotch and black band disease. These are progression rates such as the rate of movement of the disease over the surface of a coral. A study has also shown that after prolonged exposure to inorganic nitrogen and phosphorus, coral reefs have the ability to recover from the enrichment of the water and return to a state before the nutrient enrichment. An increase of freshwater and nutrients is not the only problem sewage disposal might have on the fitness of coral reefs. Sewage might be a source of pathogens able to infect coral species. A study conducted on Caribbean corals has shown that white pox disease caused a 70% die-off of corals in the Florida Keys at the time of the study (Wear and Thurber, 2015). In a subsequent outbreak, unique strains were isolated. These strains were compared to other strains found in reef water and nearby sewage sources. This study concludes that the sewage was the source of the disease. They even concluded that the of the pathogen was human. This was the first marking of a human pathogen being transmitted to a marine invertebrate.

In the sewage water is also a plethora of molecules, called endocrine disrupters (Wear and Thurber, 2015). These endocrine disrupters are chemicals that are able to disrupt hormone and endocrine systems in living organisms. These chemicals include for example: oestrogens, petrochemicals, microplastics and detergents. These chemicals, which are commonly found in sewage, can affect certain processes in animals. These processes include immune response, growth and reproduction. The most common way for the endocrine disrupters to enter the sewage is either through human excretion or through wastewater produced by households. A study has shown that addition of oestradiol can create a reduction of egg-sperm bundles in *Montipora* spp., and that the addition of estrone in *Porites* spp. can slow the growth rate of the coral (Wear and Thurber, 2015).

Suspended in the sewage are primarily organic solids. These solids dissolve poorly in the seawater and increase the turbidity of the water. This increase in turbidity blocks sunlight from reaching the corals, leading to reduced photosynthesis (Wear and Thurber, 2015). These solids can also sink to the seabed and land on the coral. Prolonged sedimentation of these solids can lead to the smothering of corals and the loss of reef area. As these suspended solids can originate from a variety of places. These can bring additional nutrients or toxic compounds with them. This can cause chemical stress for the corals.

Lastly, the sewage also commonly contains heavy metals. Metals such as mercury, lead, cobalt, zinc and iron are often present in sewage water (Jayaraju et al., 2009). This study has shown that accumulation of heavy metals in coral can result in higher mortality and bleaching, while reducing the success of fertilisation.

Alongside sewage, there is another great threat of pollution present. This threat is oil spillage. The effect of oil spillage can be devastating. A study conducted on the Gulf of Kutch predicts that the oil spillage of the local industry might be more damaging to coral reefs than a big disaster where lots of oil is spilled at once (Kankara and Subramanian, 2007). They concluded that the oil spillage will have devastating effects on the fitness of the shallow parts coral reefs when they oil reaches it. These are especially intertidal reefs. At low tide oil can easily come into contact with the coral reef, leading to bleaching and possible mortality. The subtidal reefs are more protected of such threats, as these reefs are exposed to high tidal currents. In 1986 a major oil spillage took place near the coast of Panama. A total of 8.000.000 litres of oil was spilled into the ocean. Research conducted showed that after the spillage coral coverage decreased (Guzmán et al., 1991). This study also showed that prolonged exposer to major oil spillage could lead to extensive damage from chronic exposure to major oil spills.

Table 1: Examples of coral reef (corals and associated organisms) responses to common stressors found in sewage (after Wear and Thurber, 2015)

Stressor	Response
Freshwater	Increased coral mortality (with lowered salinity for >24 h).
Dissolved inorganic nutrients (ammonium, nitrite + nitrate, and phosphate)	Increased coral bleaching, increased coral disease prevalence and severity, decreased coral fecundity, algal overgrowth, decreased coral skeletal integrity, decreased coral cover and biodiversity, and increased phytoplankton shading.
Endocrine disrupters (e.g., steroidal estrogens)	Reduction in coral egg–sperm bundles, slowed coral growth rates, coral tissue thickening.
Pathogens	Source of white pox disease pathogen for corals and associated mortality, and increased pathogenicity in corals.
Solids	Reduced photosynthesis of coral symbionts, coral species richness, coral growth rates, coral calcification, coral cover, and coral reef accretion rates, and increased coral mortality.
Heavy metals	Coral mortality, coral bleaching, reduction of basic functions such as respiration and fertilization success; Fe^{2+} may increase growth of coral disease.
Toxins	Lethal and sublethal effects on corals—highly variable and dependent on specific toxin. Reduced photosynthesis of coral symbionts, coral bleaching, coral mortality, reduced coral lipid storage, reduced coral fecundity, death of coral symbionts, and decreased coral growth.

The reasoning behind the importance of understanding the threat of pollution, regarding the coral reefs of India, is twofold. The first reason is the populations living alongside the shores near the coral reefs. Pollution already poses a threat to the fitness of coral reefs, but the increasing number of populations directly increases the amount of sewage produced. The population of the Lakshadweep Islands has more than tripled over the years and it is creating more strain on the local reefs. The Gulf of Mannar too sees an increase of sewage dumped in the reef, alongside the growing demand for fishery. On the Andaman and Nicobar Islands the pollution is partly caused by oil contamination created from fishing boats and other ships, especially around Port Blair. The reefs around Port Blair also appear to be contaminated with organochlorine pesticides (Majumdar, S. D., et al., 2018). Pesticides such as lindane and DDT are used in local agricultural practices. These compounds can prove dangerous to the coral reefs. The sewage problems on the Andaman and Nicobar Islands are not only linked to the local villagers, but they are also linked to the second reason as to why pollution is a threat to the Indian coral reefs.

Tourism

Tourism to the Indian coral reef is evermore increasing. Nearly 110.000 tourists visit the Andaman Islands each year. This tourism has caused severe damage to the coral reefs in multiple ways. The first harmful interaction is the direct harvesting of coral and fish with commercial intention. The commercial harvesting of corals and fish is not only done for constructional purposes, but also for the coral and fish to be sold. This could either be for the coral or fish placed in an aquarium, or for it to be turned into a souvenir. While blast fishing is more common practice for harvesting coral in India, the use of cyanide fishing is often used to catch fish alive in India. Cyanide fishing makes use of the chemical sodium cyanide. The chemical is sprayed on fish in order to stun them. However, the sodium

cyanide often comes into contact with the surroundings of the fish. When the sodium cyanide is absorbed by zooxanthellae, it can slow down photosynthesis. Zooxanthellae is a symbiont living in many different marine invertebrates found in coral reefs.

In the Andaman group of islands for example, tourism caused more problems. The increase of tourism to the island group requires more coastal development work (Hoon, 1997). This include the building of more facilities such as hotels and restaurants, but also the construction of piers and docks. These facilities are often made using limestone made from coral, as it is one of the cheapest options available. The piers and docks on the hand are built on top of existing coral reefs.

To increase the profit made from tourism, many activities take place in the coral reefs. Boat anchoring, snorkelling and diving activities often coincide with damage done to fragile branching corals and even causing lesions done to massive corals.

To accommodate not only tourism, but also industrial efforts, certain areas of especially the coral reefs of Lakshadweep and the Gulf of Mannar. are being dredged (Mallik, 1985; Mallik, 2017). Certain areas are being deepened, while the sediment is placed elsewhere. These efforts of dredging and repositioning the sediment are directly damaging the coral reefs, causing coral death through smothering.

Ocean acidification

The increasing human output of CO_2 is a global problem. Not only is this causing global warming, it is also causing another problem for reefs. Up to 30% of the total atmospheric CO_2 emitted by humans is taken up by the ocean (Majumdar et al., 2018). When this CO_2 comes into contact with water, it increases the concentration of hydrogen ions. This in turn decreases the amount of carbonate ion concentration. This change in ion concentrations decreases the pH of the ocean. The decrease of the pH globally has been 0.1 pH units over the duration of the last 150 years (Majumdar, S. D., et al., 2018). This is a 26% increase in the concentration of hydrogen ions. This increase can have the ability to prevent the accretion of calcium carbonate by corals and other organisms present in coral reefs.

Discussion

There are four main coral reef regions around India. They make up but a fraction of the total area of coral reefs. Each of these regions has different anthropogenic stressor that threaten the decay of the reefs. However, they do share one thing, namely that they are all in decline as a result the destructive practices conducted by the local populations. In all the four regions there is a massive threat of blast fishing in the coral reefs. Blast fishing practices are not only used to harvest fish, the use of blast fishing also proves detrimental for the coral mining industry. The growing population of India demands resources. Resources such as food and coral to turn into limestone and cement.

The effects of pollution might be some of the most important factors regarding the loss of coral reefs in India. The constantly growing populations of India could be the undoing of the coral reefs. Freshwater entering the coral reefs could lead to mortality of corals unable to live in fresh or brackish water. The inorganic nutrients present in the sewage could have several effects on the fitness of the corals. The nutrients can bring pathogens for the corals with them. They also could create a competitional disadvantage against fast-growing algae. Endocrine disrupters present in the sewage could cause behavioural changes in the coral, such as slowing down growth or the reduction of egg-sperm bundles. The suspended solids of the sewage could smother or intoxicate the coral, while heavy metals can increase mortality or reduce the success change of fertilisation, when accumulating inside the cells of corals. Lastly, the effect of oil spillage could prove devastating for the Indian coral reefs. This is especially true for intertidal reefs where the oil can easily cover the corals at low tide.

Tourism creates a set of problems regarding the fitness of coral reefs. The increase in tourism promotes the mining of corals. This is both to be sold as souvenirs, as well as to create more building materials. That is due to the demand for facilities such as hotels and restaurants for these tourists. Besides these facilities, the locals also build docks and piers over the coral reefs to accommodate tourists. Tourism also promotes other dangerous methods of fishing, such as cyanide fishing. These methods are used to catch fish from the reef alive, so they can be sold to the tourists. Lastly, tourist activities, such as diving activities, can cause direct harm to the corals they are interacting with.

Of the four main coral reef areas of India, the Gulf of Kutch is most plagued by the dangers the local industry might have on the coral reefs. The fishing practices are not commercial and the biggest threats in this region are those created by pollution. The effect sewage has on this region is massive. As much as 50% of the coral reefs here is already lost and the imminent danger of oil spillage and the increase in sewage material create the threat of losing more of the coral reefs in this region.

The coral reefs of Lakshadweep are prone to a lot of threats. The crown-of-thorns star fish has become a plague, as it eats coral faster than it can grow. The human population has exploded in size. This increases the need for constructional material. This also increases the sewage output, thus the effect of pollution. To sustain their fishing efforts, sprats are being overfished in the lagoons. Dredging efforts are part of the sedimentation that is smothering the reefs. Coral mining efforts relate to all of these stressors.

The Gulf of Mannar is intensively mined for shells and corals. The coral reefs suffer a lot from coastal erosion, dredging and the subsequent sedimentation, which is killing the coral. Pollution from industry and boats, paired with the discharge of sewage into the Gulf, create a harsh landscape for coral to survive in. Rapid algae growth chokes coral polyps and creates a barrier against light and oxygen.

The Andaman and Nicobar Islands have fallen prey to the destructive capacity of tourism. While pesticides used by farmers end up in the reefs of Port Blair and the use of blast and cyanide fishing destroys corals, the amount of tourism is doing just as much, if not more harm. The growing need for building materials and the growing influx of tourism cause more harm to the coral reefs. Resulting in sedimentation and the subsequent infestation of the crown-of-thorns starfish.

These four coral reef areas all share the same fate. They are being exploited by humans until they are exhausted. To prevent these reefs from disappearing, actions need to be taken to reduce the amount of stress, we, as humans, put on this delicate and valuable ecosystem. These anthropogenic stressors are largely driven by local demand for the recourses these coral reefs bring. This growing demand is the result of the growing population of the coastal areas. In order to preserve the Indian coral reefs, the Indian government should implement measures to combat the destructive fishing methods, to decrease the demand for coral to be used for constructional and recreational purposes and to prevent sewage from overflowing into the coral reefs.

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