**A review on coral reefs and their management**

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**Abstract**

 Coral reefs are one of the most ancient and dynamic ecosystems of India. One of India's oldest and most active ecosystems is the coral reef. Even though they only make up 0.2% of the whole seafloor in terms of area, coral reef ecosystems often referred to as the rainforests of the sea represent close to one-fourth of all marine species. Coral reefs serve a crucial function in preventing coastal erosion in addition to acting as a haven for a wide variety of marine species. India's 8,000 km of coastline is home to people who rely on coral reefs for their daily needs. India is located in the middle of the Indian Ocean's warm, tropical region, and its maritime areas are home to numerous coral reefs. Coral reefs are being harmed and destroyed because of anthropogenic and natural activity, despite the fact that they are extremely important. The Gulf of Mannar, Palk Bay, Gulf of Kutch, Andaman and Nicobar Islands, and the Lakshadweep Islands are the only places in India with significant reef formations. The other reefs are all fringing reefs, whereas the Lakshadweep reefs are atolls. The country's central west coast has patchy coral in the intertidal zones. The ecosystem of coral reefs is incredibly diverse and intricate. But because to several anthropogenic and natural disruptions, this tropical wonder is currently deteriorating at alarming rates and faces a significant risk of extinction. Despite the fact that India has extensive and complicated reef systems and benefits greatly from them, the country's management and conservation efforts seem inadequate. A review of the literature indicates that improved management, together with experienced marine biologists, contemporary infrastructure, and long-term funding, are necessary. This review also aims to highlight the current focus of bio-ecological research on Indian coral reefs and to discuss future research opportunities on some of the major global primary research areas. Moreover, there is a pressing need for effective communication between the scientific community and stakeholders for the strict implication of conservation practice to protect the spectacular coral reef ecosystem.

**Introduction**

 Because of their incredible diversity of life and amazing distinctiveness, coral reefs are frequently referred to as the "Tropical Rainforests of the Sea". Reefs are enormous biological treasure troves that also offer a wide range of economic and environmental services to millions of people worldwide. Corals are useful and beautiful things that are members of the phylum Anthozoa. The massive reefs that are only visible at low tides are built by hermatypic corals and their symbiotic zooxanthellae. Corals are only found in the ocean and, taxonomically speaking, are part of the scleratinia order.

 The solitary forms, known as ahermatypes, are both solitary and colonial and lack symbionts. Corals that form reefs are actively growing in the ocean's photic zone. Around the world, a belt of coral reefs can be seen in the tropical waters. Despite their enormous significance, coral reefs are currently deteriorating and disappearing at an alarming rate as a result of both natural and artificial factors. By 2030, 90% of the reefs will be in risk if current rates of degradation are permitted to continue. It is crucial to understand the current state of coral reefs and the growing threats to them. The goal of the paper is to shed light on the growing coral exploitation problem and examine management and conservation strategies. (Jhajhria 2021)

 The coral ecosystem is vital to the economies of many tropical and subtropical nations and offers a variety of benefits to millions of people worldwide. Reefs are a popular tourist destination around the world, but human and natural disturbances have an effect on these remarkable ecosystems alone or in combination (Ove 2011). It is concerning to see the general decline in coral reefs on a global scale. Coral growth rates are dramatically declining along with rising coral mortality rates, which is startling. According to Cantin et al. (2010), rising thermal stress has caused a 15%–30% decrease in the rate of calcification of corals since 1990, and predictions foresee future declines of up to 78% due to greenhouse gas concentrations expected for 2100 (Albright et al 2010). Although regulations are sufficient in principle to go for management and protection of the reefs in India, coral bleaching, ocean acidification, extreme natural events, coral diseases, unmanaged coral fishing, and anthropogenic activities have all put coral reefs in danger. These delicate eco-systems must still be protected because they are in danger. It can be accomplished by putting the laws into practise and launching research-focused initiatives. The study examines the factors and management strategies used to protect these biodiversity-rich places.

**Distribution of coral reefs in India**

 In India, the reefs are distributed along the east and west coasts at restricted places, with platform reefs in the Gulf of Mannar and Palk Bay, patchy reefs near Ratnagiri and Malvan coasts, and fringing and barrier reefs in the Gulf of Kutch, Gulf of Mannar, Lakshadweep, and Andaman and Nicobar Islands. India has a coast line of nearly 8129 km, but the reef formation is restricted to four major centres. The total area of coral reefs in India is estimated to be 2,375 sq. km (DOD and SAC, 1997).

Coral reefs are restricted mainly in seven regions of India, such as:

1.Coral reefs in Gulf of Mannar

2.Coral reefs in Palk Bay

3.Coral reefs in Gulf of Kutch,

4.Coral reefs in Andaman and Nicobar Islands

5.Coral reefs in Lakshadweep Islands

6.Coral reefs in West Coast of India

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**Figure 1. Major coral reef areas in India** (Jhajhria, 2021)

**1) Gulf of Mannar**

 On the other side, the Gulf of Mannar reefs are built around a network of 21 islands that run over 140 km between Tuticorin and Rameswaram (Krishnamurthy, 1987). On the southeast coast of India, these islands are situated between latitudes 8°47' N and 9°15' N and 78°12' E and 79°14' E. An average distance of 8 km separates the 21 islands that run parallel to the shoreline. In the Gulf of Mannar, many reef morphologies, including shore platforms, patches, coral pinnacles, and atoll types, can also be seen. Patch reefs and bordering coral reefs surround the islands. The majority of the time, narrow bordering reefs are found 50 to 100 metres away from the islands.

**2)Palk Bay**

 On the coast of Tamil Nadu, coral reefs may be seen in the Gulf of Mannar and Palk Bay near Rameswaram. Rameswaram Island and the Mandapam peninsula divide the Gulf of Manner from Palk Bay. Centred at 9°17'N and 79°15', the reef. In the Palk bay, which extends east-west along the mainland from the Pamban channel at the Pamban end of the bridge to Rameswaram Island, there is only one fringing reef. This reef has a length of 25 to 30 km and a typical width of less than 200 m. The north east monsoon has a negative impact on visibility and makes it only around 1 metre wide. The reef flat is relatively broad from Pamban channel to the southern end near Ramnad and narrow from Pamban to south of Rameswaram.

**3)Gulf of Kutch**

 One of the depressions on the northern side of the Saurashtra Peninsula is the Gulf of Kutch, which is situated between 22°15' and 23°40' N Latitude and 68°20' and 70°40' E Longitude. With sporadic massive sandstone formations, the beaches are often muddy or sandy. There are roughly 40 islands with sporadic coral formations, with Pirotan Island being the largest. Patches of coral can be seen on the substrate of sandstone. In comparison to other regions of India, the coral fauna in the Gulf of Kutch is relatively less diverse (Pillai, 1996). According to and Radhakrishnan (2014), there are around 352.5 square kilometres of reefs in the Gulf of Kutch.

**4)Andaman and Nicobar Islands**

 Between 6° and 14° N latitude and 91° and 94° E longitude, in the SE of the Bay of Bengal, lie the Andaman and Nicobar group of Islands. There are 350 islands in all. Nearly every island in the Andaman and Nicobar group has surrounding reefs that are narrow, linear, and extensively well-developed (Vineeta Hoon, 1997). Andaman and Nicobar have a combined 135 species spread across 59 taxa (Pillai 1983). 1021.46 sq. km is the entire area that the reef occupies (SAC, 2010). To accurately depict the reefs' current state, there isn't enough recent data about the reefs near the North Andaman and Nicobar Islands.

**5)The Lakshadweep Islands**

 The Lakshadweep islands are dispersed over the Arabian Sea, 225 to 450 km off the coast of Kerala. Geographically, the islands are located between latitudes 8°N and 12°3'N and longitudes 71°E and 74°E. The Laccadive-Chagos undersea ridge rises rapidly from a depth of about 1500 m to 4000 m off the west coast of India, and the islands are made up of coral formations that have been built up on it. A continuous submarine bank that spans more than 2000 km is made up of an interrupted network of coral atolls and reefs that includes the Union Territory of Lakshadweep, the Maldives, and the Chagos Archipelagoes. The islands are thought to be the remains of the submerged mountain cliffs, and this ridge is thought to be a continuation of the Arravali Mountains (James et al. 1986). There are 36 tiny islands, 12 atolls, 3 reefs and 5 submerged banks, covering an area of 32 km2 with lagoons occupying about 4200 km2.

**6)West Coast of India**

 According to Nair and Qasim (1978), there are submerged banks with lone coral formations along the west coast of India between Bombay and Goa. Coral patches have been observed in the Gaveshani Bank, 100 kilometres west of Mangalore (Nair and Qasim, 1978), and in the intertidal areas of Ratnagiri, Malvan, and Redi, south of Bombay (Qasim and Wafer, 1979). There have been reports of ponies, coscinarares, turbinaria, some favids, and pseudosiderastrea. Hermatypic corals have been found along the shoreline between Quilon in Kerala and Enayam in Tamil Nadu in the south. In this region, Pocilipora spp. is the most prevalent genus. Three species of Accropora are present there.

**Table 1:** Status of coral reefs in India (Jhajhria, 2021)

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| --- | --- | --- | --- | --- |
| Particulars | Geographical location | Area of the reef (in Sq. Km) | Destruction during bleaching | Potential for recovery |
| Gulf of Mannar | 21 islands, South East Coast of India 140 km, between Tuticorin and Rameswaram |   94.3 | 60-80 percent loss of live cover. Only 25 percent live corals remaining | Medium Low |
| Gulf of Kutch | 40 islands, Northern side of Saurashtra peninsula |   325.5 |  50-70 percent | Medium Low |
| Andaman and Nicobar Islands |  530 islands |   1021.46 |  15-20 percent |  Good |
| Lakshadweep Islands | Uninterrupted chain of coral atolls-stretch of 2000 km |   933.7 |  70-90 percent  |  Good |

 **Types of coral reefs**

There are mainly four types of coral reefs found in India (Saroj et al 2016).

**1. Platform Reefs:** These are almost flat reefs without any lagoon. They rest on the shallower part of the continental shelves and they may present associated with atolls and also between a coast and a barrier reef. These types of reefs are mainly found in Gulf of Kutch of India.

**2. Fringing Reefs:** These types of reefs are directly attached to a shore, or borders it with an

intervening shallow channel or lagoon. Fringing reefs are found in Gulf of Manner, Palk bay

and in Andaman & Nicobar Islands of India.

**3. Barrier Reefs:** These reefs are separated from a mainland or island shore by a deep channel or lagoon. Barrier reefs are mainly found in Andaman & Ni cobar Islands of India. Outside India the Great Barrier Reef is located in Australia. Barrier reefs separated from the land by wide expanses of water and follow the coastline.

**4. Atolls:** These are more or less circular or continuous barrier reef extends all the way around a lagoon without a central island. Atolls in India are mainly found in Lakshadweep islands: a roughly circular ring of reefs surrounding a lagoon, a low lying island, common in the Indian and South pacific oceans.

**Threats to coral reefs**

1. **Coral Disease**

 Numerous bacterial and fungal infections can also harm corals. Three different disease kinds, including bacterial/fungal infections, black band diseases, and white band diseases, have recently been reported in the Gulf of Mann and Lakshadweep. Several institutions are investigating the precise reason of this Corals die as a result of asfixia on polyps caused by silt and sedimentation. Construction projects, deforestation, reef dredging, and sea erosion all churn up silt and sediment. Coral deaths can also a result of pests and predators. The most harmful predator is the echinoderm *Acanthaster planci*. (Pillai 2010)

 Lakshadweep and the Andaman Islands have reported this. Lakshadweep's starfish population is typical and poses little threat. The Andaman Islands saw a significant surge in starfish, but the damage was minimal. The coral polyps that the star fish consume turn the skeleton white. Polychaetes and echiuroid are the main bioeroding agents on a reef, and bio-closion and reef-building molluscs go hand in hand. Reefs are destroyed by human activity such as reef blasting. The arrival of mechanised fishing vessels in the years following independence led to the blasting of the reefs to deepen the boat passage in Lakshadweep Construction activities in the Gulf of Mannar and the quarrying of corals for various industrial uses led to the complete destruction of bordering reefs on certain islands. The Lakshadweep atoll reefs were damaged by lagoon dredging for navigational purposes. Only a small portion of the Nicobor Islands and Andamans have unaltered reefs. (Pillai 2010)

 The reef sustains significant damage as a result of the outbreak of various epidemic diseases, including the White plague, White pox, White band, and Black ban. Indian Reefs have recently been observed to have high rates of coralline fatal orange disease (CLOD), pink line, pink spot, yellow band, fungal blotch, black band and white band. (Carpenter et al 2008, Fridman et al 2015, Guldberg et al 2007, Rowden et al 2019 and Jhajhria 2021)

**2. Ocean acidification**

 The amount of carbon dioxide (CO2) in the atmosphere has increased due to human activity by 36%, and the pH of ocean surface waters has already decreased. Ocean acidification is a set of chemical alterations brought on by the ocean's uptake of CO2 that lowers pH and carbonate ion concentration. Increased CO2 has a negative impact on coral calcification rates. (Ardron et al 2014 , Barnett et al 2015, Jones et al 2018, and Ravindran et al 2012).

**3. Reef fishing**

 Illegal and destructive fishing practices are also responsible for such type of damage. Many banned malpractices like blast fishing are still going on. Overfishing causes the removal of herbivorous fishes that encourages excessive algal growth in the absence of these grazers. In such a way coral reef ecosystem is shifted to algal dominated barren without any fish and corals. Bio-invasion of macroalgae *Kappaphycus alvarezii* (Fig 2) and snowflake *octocoral Carijoa riisei* (Fig 3) have caused detrimental impact on reef corals(Fridman et al 2015)**.**

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| Fig 2: *Kappaphycus alvarezii*  |  Fig 3:*Carijoa riisei* |

**4. Pest, predator, and competitor**

 Outbreak of coral eating Crown of Thorns Starfish *Acanthaster plansi* and overgrowth of bio eroding coral boring sponges have been reported from the Indian corals (Hughes et al 2017 and Rajan et al 2015).

**5. Extreme natural events**

 There is a range of natural calamities causing the immense destruction of corals includes cyclone, local tectonic upheavals, tsunami.

**6. Reef tourism**

 Uncontrolled tourism may cause major problem responsible for degradation of Indian reefs by causing significant damage to shallow water corals by unintentionally or intentionally trampling and breaking coral fragments.

**7. Anthropogenic activities**

 The illegal collection of shells for souvenir hunting, uncontrolled harvesting, smuggling various exotic marine organisms and products derived from the reef is still major problem for Indian reefs.

**8. Coral Bleaching**

 When sea surface temperatures (SST) rise above a certain threshold, coral reefs experience "bleaching events" (loss of symbiotic algae) because they are so sensitive and vulnerable to thermal stress. Because to the partial or complete eradication of the zooxanthellae symbiotic algae population, coral bleaching is the "whiting of coral tissue"60. Bleaching can be caused by a variety of stressors, including increasing sea surface temperatures, higher irradiance, lower salinity, metal pollution, etc. However, the elevated sea surface temperatures brought on by increased global warming are the primary worry. (Venkataraman et al 2017)

**Ecological services**

 Coral reefs are frequently referred to as the sea's "medicine chests." Life-threatening illnesses like heart disease, ulcers, leukaemia, lymphoma, and skin cancer could be cured by coral reefs. Additionally, the most cutting-edge bone-grafting materials have been created using the unique skeletal structure of corals. Limestone, which is abundant in coral reefs and is frequently utilised as a cement alternative in the building sector. The calcium-rich coral sand is also a potential raw material for the cement industry on an industrial scale. ( Thinesh et al 2015, Venkataraman et al 2003]. ( Jhajhria 2021)

 **Food resources**

 Fish, molluscs (clams, scallops, octopi, oysters), crustaceans (crabs, lobsters, prawns), turtles (adults and eggs), and algae are only a few of the many things that humans consume from coral reefs (UNEP/IUCN). Coral reefs provide between 10 and 12% of the canned fish harvested in tropical nations and up to 25% in developing nations (Wilkinson 1993; Gomez 1997). Since many fish are taken by subsistence fishers but never reported, these estimates should be seen as being at the low end of the spectrum. In addition, 9 million metric tonnes of shellfish and molluscs are harvested annually from coral reefs [Jameson et al 1995].

 The existence of the people who live in the coastal areas of poor countries depends on the coral reefs that line many of the world's coastlines (Wilkinson et al. 1994; McManus JW. 1197). According to Linden O. (1990), 1 billion people in Asia alone rely on fisheries from shallow coastal waters dominated by coral reefs, so the destruction of these reefs would undoubtedly result in a significant decrease in the amount of animal protein available for consumption by the local populations of the coastal nations.

**Tourism**

 The intrinsic beauty of coral reefs, which annually draws millions of tourists to marvel at their splendour, accounts for a significant portion of their economic value. Tourism is crucial to the economies of many countries across the world, especially those with small islands like the Maldives, Mauritius, the Solomon Islands, Fiji, and those in the Caribbean. In Florida, close-by coral reefs are anticipated to generate $1.6 billion USD to the local economy each year, and tourism is the single largest foreign exchange earner in the Seychelles (Birkeland 1997). According to Caesar (1992), tourism accounts for 45% of the Maldives' GNP and up to 50% in other Caribbean nations. 350 000 persons were employed by the Caribbean tourism industry in 1990, which brought in $8.9 billion USD.

**Coastal protection**

 Around small islands and along continental edges are where you'll find many of the world's coral reefs. As a result, they play a crucial part in preventing erosion of the shoreline caused by ocean swells and tropical storms (Berg et al. 1998; Hinrichsen 1998). Coral reefs' protection enables productive mangrove and wetland ecosystems to flourish in protected regions and serve as crucial fish nurseries for young fish, many of whom live on coral reefs as adults. A big draw for thousands of tourists each year is the accumulation of white coral sand along coastlines protected by coral reefs.

**Biodiversity**

 Coral reefs are second only to tropical rainforests as the most diverse ecosystem in the world. Only one of the 33 phyla that exist on this planet does not occur on coral reefs and 15 occur nowhere else. Recently, (Malak et al 1997) estimated that coral reefs support between 1 and 9 million species. Of these, only approximately 4000 species of fish and 800 species of coral have been described (Pauly 1997).

**Medicines**

 Pharmaceutical companies are paying closer attention to coral reef dwellers as they look for potential new therapeutic targets. Many bacteria that were once killed by conventional antibiotics like penicillin have developed resistance as a result of their ongoing misuse. As a result, researchers are looking for novel medication sources to combat sickness (Bryant et al. 1998). They provide excellent research subjects since many coral reef inhabitants manufacture bioactive chemicals to protect themselves from competition, predators, and the environment (Shic et al. 1996). In fact, active substances originating from marine species are the focus of 50% of all cancer research (Fenical et al. 1996; Maragos et al. 1996), and coral calcium carbonate skeletons are already employed for human bone grafts**.**

**Management measures**

 Certain maritime species are protected by the Wild Life Protection Act of 1972. Corals are being included in this act through various means. In 1991, the Indian government published a Coastal Regulation Zone notification, which was later amended. Except for specific institutes' scientific studies, it is legally forbidden to harvest corals, either dead or alive. From July 2001, all scleractinians and gorgonids are covered under the Wild Life Protection Act of 1972. (Pillai 2010)

**Legislation**

 The Indian government has published a number of laws pertaining to the preservation of coral reefs. Since July 2001, the Scleractinians and Gorgonids are covered by the Wild Life Protection Act of 1972. Coral reefs in India are legally protected under the Coastal Regulation Zone (CRZ) Notification, 2011, and the Marine Fishing Regulation Act (MFRA), both of which were passed in 2000. In India, there are a total of 31 marine protected areas (MPAs), five of which have been surveyed and designated as needing protection. (Jhajhria 2021)

Under the Wildlife Protection Act of 1972, the Environmental Protection Act of 1986, and the Coastal Regulation Zone Notification (CRZN) of 1991 that fall under it, the protection of coral reefs has been emphasised. The conservation of India's coral reefs is also somewhat helped by other laws including the Indian Forests Act of 1927, the Forest Conservation Act of 1980, and the Indian Fisheries Act. However, even under the Wildlife Protection Act, coral conservation does not have a separate legal position. In India, state-level agencies like the State Forest Department, Fisheries Departments, and most recently the State Coastal Management Authority are taking on the duties of coral reef conservation. The Wildlife Protection Act includes the protection of significant ecosystems; coral reef conservation is not specifically emphasised.

 Therefore, the suggestion for legal change and policy making for coral reef conservation and management in the nation essentially entails amending the Wildlife (Protection) Act 1972 to include species of coral in the schedules and explicitly state that the extraction of coral is forbidden under the provisions of Chapter VA of WPA. The CRZ notification also primarily protects coastal regions 500 metres from the High tide line and the land between the Low and High tide lines on the landward side; however, it does not extend to coral and coral reefs on the seaward side. Under the EPA 1986, the main coral reef areas might be designated as ecologically sensitive, and hazardous businesses could be subject to stringent regulation **(**Saroj et al 2016).

 The Department of Forests and Wildlife is responsible for overseeing, managing, and conserving India's coral reefs, which are delicate eco-systems (Saxena, 2015). The Ministry of Environment and Forests is competent to produce recommendations for the sustainable exploitation of coral reefs and to create a positive action plan to manage the reef resources. The National Conservation Strategy and Environment Action Plan of India (UNDP, 1997) also supports the management of coral reef ecosystems.

 In India, there is now hardly any legislation or policy governing coral reefs (Panini, 1997). The Environment (Protection) Act of 1986 and the Wildlife Protection Act (WPA), both of which were passed in 1972, are two laws that can be used to safeguard coral reef regions. Coral reef regions do not, however, have a separate legal standing even under the WPA (Saroj et al., 2016). The only reefs that are off limits for development are those in protected areas. The Indian Forest Act (1927), the Forest Conservation Act (1980), and the venerable Indian Fisheries Act are the other legislation that might have an impact on coral reef regions. The Coastal Regulation Zone (CRZ) Notification (1991) offers the only legal protection to all the coral reefs in India and under these coral reef areas come under the CRZ1 category (Panini, 1997).(Baswapoor et al 2017)

**Conclusion**

 The coral reef ecosystem is under extreme risk of being destroyed by several stresses, hence intensive research on its ecology is urgently needed. To address the difficulties of protecting the Indian coral reefs in an eco-sustainable manner, future orientations should be put up appropriately. Indian study on coral reefs is still in its early stages. There is a plenty of information about coral reefs. However, there is relatively little knowledge about the relationship between coral population density and abundance in respect to species found on reefs. On the coral reef ecosystem and its natural resources, little information is accessible. This makes it particularly challenging to design practical management strategies for coral reef regions that involve local community involvement. The primary issue is that each institute has a distinct research programme and area of emphasis. In almost all of these institutes, coral reef research has been more of an accidental than a main stream programme. If we are serious about creating management plans for conserving and managing our coral reef heritage, this must change.

 In-depth research on the ecology of the Indian coral reef is urgently needed in order to prevent the interesting ecosystem from being destroyed by a variety of stresses as well as to maintain the intended economic growth of the millions of people and companies that depend on it. Although there are numerous obstacles, overcoming them will require the cooperation of the central government organisation, state departments, NGOs, scientists, and educators as well as political support and scientific understanding. It is hoped that the encouragement provided over the past few years by various Indian government agencies in the form of research funding, as well as the intense interest shown by students and the scientific community, will shed some light on coral reef research. Despite all the challenges, there has been a tremendous surge in coral reef research in India during the past three decades. To tackle these issues, future paths should be put up appropriately. under order to give young and eager researchers a platform to study and manage this crucial natural resource, the National Coral Reef Research Institute under the A&N should be revived, as should a dedicated national "Coral Reef Research" programme with a well-thought-out purpose.

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