



Exploring the Vital Role of Coral Disease in Coral Reef Sustainability: A Comprehensive Analysis

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ABSTRACT

Coral reefs are one of the most bio diverse ecosystems in the world. These are also regarded as one of the major productive ecosystem. The commonly reported threats to coral health include bleaching, over exploitation of fish stocks, destructive fishing and the rapid man-made development in the coastal areas. These environmental impacts have paved the way to the emergence of coral disease and are considered as the most serious issue of coral reefs deterioration. Globally, the major diseases affecting corals are Black band disease, White band disease, Aspergillois, Dark

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spot disease, Stony coral disease, Pink line syndrome, Yellow band disease, and Skeletal eroding diseases. In this paper, all the diseases affecting the corals are elaborately discussed.

Keywords: Coral reefs; scleractinians; zooxanthellae; mortality; causative organism.

1. INTRODUCTION

Coral reefs are one of the most productive ecosystems on earth. They constitute a diverse variety of marine organisms. They provide shelter, food, and spawning ground for a wide range of marine organisms [1]. Coral reefs also play an important role in the protection of shorelines, regulation of carbon dioxide, and support of local and global economies through activities including fishing, recreation, and tourism [2]. Coral reefs constitutes 0.1-0.5% of the ocean surface. In more than 100 countries the coral reefs are found in the coastal areas. They are mainly distributed in tropical regions. Most of the species were distributed in the area of South east Asia, Caribbean regions and Indo pacific regions. Some species are found in Arctic, the Antarctic and the deep-sea region. In India, totally 585 scleractinian coral species belonging to 108 genera and 23 families have been recorded, which includes 15 families and 60 genera [3]. Gulf of Kachchh, Lakshadweep, Andaman and Nicobar Islands, Palk Bay and Gulf of Mannar are the major reef areas of India. "Maximum species diversity was recorded in the Andaman and Nicobar Islands with 523 species belonging to 95 genera and 23 families, followed by Gulf of Mannar with 169 species of 46 genera and 16 families, Lakshwadeep Island with 165 species of 54 genera and 17 families, and Gulf of Kutch with 76 species of 30 genera and 11 families" [3]. Black band disease, brown band disease and skeleton eroding band are easily diagnosed diseases in the reefs of Indian region [4]. The documentation of the coral diseases in Indian coast are insufficient and minimal including the data about their prevalence, distribution, environmental interaction and the pathology. "Coral diseases in the Indian coastal region are poorly documented and very minimal data is available about the prevalence, distribution, environmental interaction and the pathology of these diseases. Till now, systematic investigations of coral diseases have been conducted. The diseases are being diagnosed in the field by easily observable pathogens and symptoms" [5]. Coral reef communities are stated as 'disturbance-adapted' ecosystems [6]. For the past 20 to 50

years, the coral reef population has been observed to be declining [7]. The major contributing factor to the decline of coral reefs mainly includes the coral diseases that have been reported recently at an alarming rate. Both the biotic and abiotic factors affect coral health [8]. The factors affecting coral health include water pollution, climate changes [9], and direct human-imposed stresses such as overfishing, the usage of destructive fishing methods and gears, and the proliferation of exotic species [10]. These factors lead to worsening the health of the corals. Fishing, a vital activity for millions worldwide, poses numerous threats to coral reef ecosystems, jeopardizing their health and biodiversity [11]. Coral reefs, often referred to as the "rainforests of the sea," provide habitat, food, and protection for a myriad of marine species [12]. However, various fishing practices disrupt these delicate environments in several detrimental ways. Non-target species, or bycatch, often get entangled in fishing gear, causing declines in populations of species that are vital to reef health. Lost or abandoned fishing gear, known as ghost fishing, continues to trap and kill marine life, further harming the reef ecosystem. Trawl fishing involves dragging a large net along the sea floor or through the water column to catch fish and other marine organisms [13]. Trawling is particularly destructive to coral reefs. The heavy nets and equipment dragged along the sea floor can cause extensive physical damage to the coral structures. This damage can include breaking coral branches, crushing coral colonies, and dislodging corals from the substrate. The sediment kicked up by trawling can also smother corals and reduce light penetration, affecting the photosynthesis of symbiotic algae (zooxanthellae) that corals rely on for energy [14]. Declining health results in disruption of the coral's normal microbial community or dysbiosis, allowing an increase in the number of primary and opportunistic pathogens [15]. These outbreaks will affect the coral abundance and diminish the reproductive potential. To date, only a few coral diseases have been characterized and reported in detail which includes white band, white plaque, white pox, patchy necrosis, black band, yellow spot, yellow band, brown band, porites ulcerative syndrome, white spot, red

plaque syndrome, pink line, pink spot, pink-blue disease. [5]. The environmental impacts on corals are also not well defined. Most of the studies have been carried out on the identification of causative agents and disease etiology and pathology. Reports on coral disease from an ecological point of view are also scanty.

2. TYPES OF DISEASES IN CORAL

2.1 Black Band Disease

Black band disease is the first reported disease in coral reefs. It was reported by Antonius (1973) in the corals of Belize, western Caribbean. Later, it was reported in gorgonians (soft corals) from the Indo-Pacific and now it is ecumenically distributed [16]. Globally, 42 species of corals were affected by the black band disease [17]. In particular, 19 species of scleractinians and 2 soft corals were affected along the Caribbean coral reefs [18]. Black band disease is a condition that causes recent tissue loss and leaves a defined strip of pigmented tissue next to the exposed skeleton. Black band moves across the surface of coral colonies, leaving behind exposed white skeleton. Entire colonies may be killed within months. They are primarily caused by the consortium of the micro-organisms dominated by Cyanobacteria (*Oscillatoria submembranacea* also called *Phormidium corallyticum*), Marine fungi, Sulfate-reducing bacteria (*Desulfo vibrio*) and Sulfide oxidizing bacteria (Beggiatoa) (as in Table 1) [19]. The affected corals show a dark black band with a thickness of 0.5-1.0 cm, present between the healthy coral tissue and exposed skeleton (in Fig. 1). Within the black band, sulfide accumulates up to 800µm due to the sulfidogenesis process in the anoxic microenvironment at the base of the band leading to the destruction of the coral tissue. The disease progression is at the rate of 0.3-1.0 cm per day and the whole colony can be killed in a span of months [19]. Increased seawater temperature, high solar irradiance, seawater depth, anthropogenic wastes, and elevated nutrient inflow create favorable conditions for the microbes to cause disease in the corals [18].

2.2 White Band Disease

“White-band disease (WBD) was first reported by Gladfelter in 1982 [20]. It is one of the coral diseases affecting primarily *Acropora cervicornis* and *Acropora palmata*” [20]. “It is a layer of diseased and necrotic tissue (in Fig. 1) that spreads rapidly from the base of the coral colony at a rate above 1cm per day” [21]. “Corals exhibit

loss of tissue, leaving the bare, white skeleton exposed. White band disease, occurs more frequently on branching corals, the syndrome has the existence of two forms, WBD type I and WBD type II. WBD type I occurs throughout the Caribbean and has an association with marine Rickettsia bacteria” [22], While WBD type II occurs predominantly in the Bahamas and putative pathogen *Vibrio charchari* (Table 1) has been identified as associates. Type I is widespread throughout reefs of the western Atlantic and type II has only been observed in the Bahamas. “Type I exhibits a disease line of active tissue necrosis in which coral tissue can be bleached but not necrotic, whereas type II has a variable zone between active tissue death and exposed coral skeleton” [23]. Lesions of type II WBD are more frequently found to start at the tips or middle of the branches. The comparison between Tetracycline and Ampicillin treatment suggests that WBD type I is likely by gram-positive bacteria and less likely by gram-negative bacteria. Gram-negative bacteria have been found within healthy and diseased tissue of both *A. cervicornis* and *A. palmata* colonies affected by WBD type I. WBD type II associated with an assortment of gram-negative bacteria always includes the bacterium *Vibrio charcharii*. Possible causal agents of WBD type I are identified using a range of molecular bacterial 16s rDNA techniques.

2.3 Aspergillosis

Aspergillosis is one of the best-characterized coral diseases, identified on the sea fans (gorgonians) of Caribbean and Florida Keys [24]. Nearly 10 species of octacorals were found to be affected by aspergillosis [25] especially mass mortalities have been observed in the two species of gorgonians such as *Gorgonia ventalina* and *Gorgonia flabellum* [26]. Aspergillosis is an infectious disease, that can be transmitted by physical contact between the healthy and infected colonies or by the water-borne infection of the hyphae or spores of the fungus from the infected corals [24]. Lesion progression shows Tissue loss patches devoid of coral polyps and less density of zooxanthellae, tissue necrosis, gall-like structures, (due to the encapsulation of fungus in the cortex of the axial skeleton of the coral), and irregular outgrowths (in Fig. 1) are the symptoms of this disease [27]. The disease was named after the saprophytic terrestrial fungal pathogen *Aspergillus sydowii*, (as in Table 1) which emerged as the sea fungus

as a result of the wind transport of dust from the African Sahara desert across the Atlantic or the terrestrial runoff. The deposited organic materials reducing the coral immunity, high quantum of nutrients and elevated temperature became favorable for the pathogens sequelling in increased incidence of the disease in Caribbean reefs [16]. The impact of this disease on the Gorgonians includes partial to complete mortality of the colony and near-complete reproductive failure. The disease progress may stop for some period, when the condition becomes favorable it re-emerges establishing a deep infection within the skeleton [16].

2.4 Dark Spot Disease (DSD)

The Purple or brown lesions are defining features of the non-lethal, slowly developing condition known as "dark spots disease." It was first reported in Colombian reefs during the early 1990s. DSD affects numerous coral species and

has been observed mainly on the massive corals *Siderastrea siderea*, *Montastraea annularis*, and *Stephanocoenia interrepta* [27]. It has been described as small, round, dark spots that grow in size overtime (in Fig. 1). These spots are typically dark purple, gray or brown in color and irregular in shape. "Some can be associated with a depression of the coral surface and others expand into a ring surrounding dead coral. Dark spot disease is most commonly observed on massive corals. This disease might decrease the capability of corals spread. In fact, lesions as small as 1cm² showed no regeneration of tissue during a period of several months. The spreading rate of the disease was prolonged. The average loss of tissue due to the action of DSD was 0.51cm² per month for *S. siderea* and 1.33cm² per month for *M. Annularis*" [28]. It is not clear if disease signs are present in all species or the result of the same pathogen or whether different disease exhibits similar sign in different coral species.

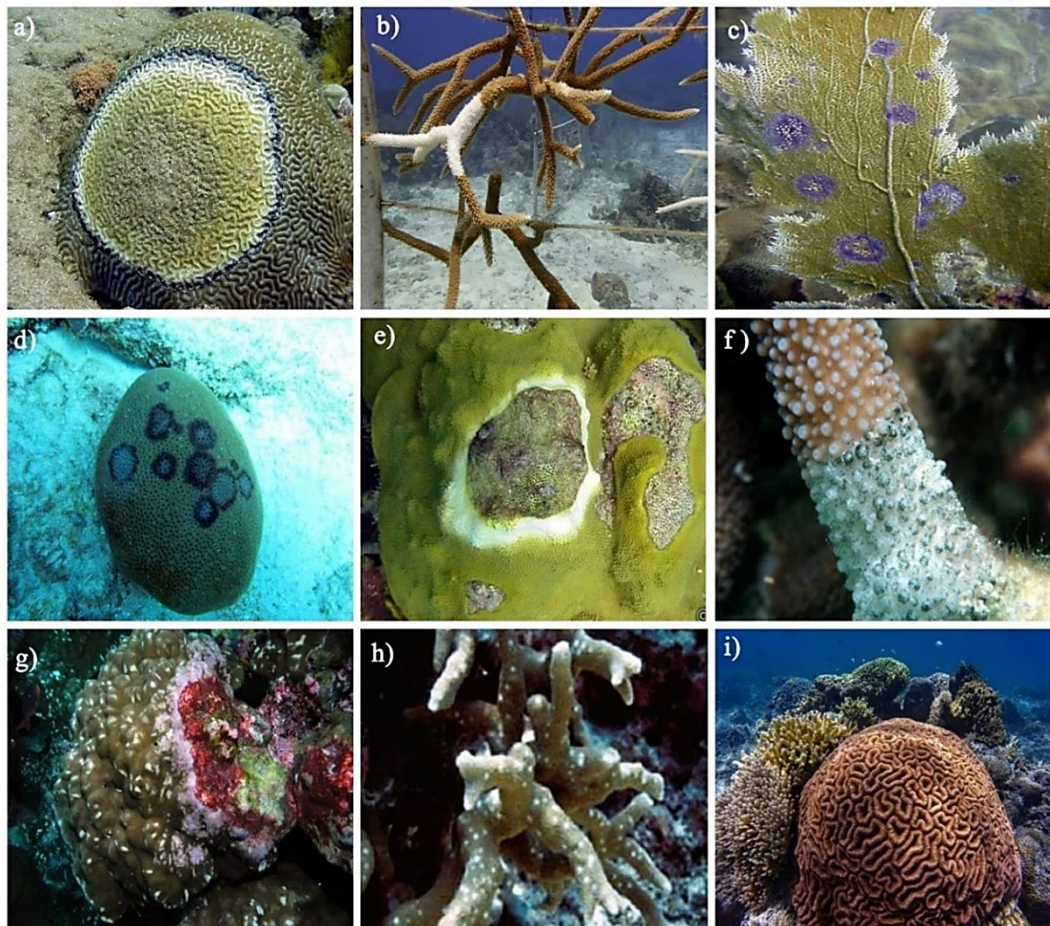


Fig. 1. Common coral reef diseases. a) Black band disease; b) White band disease; c) Aspergillosis; d) Dark spot disease; e) Yellow band disease; f) Skeleton eroding band; g) Pink line syndrome; h) Porites ulcerative white spot; i) Stony coral tissue loss disease

(Source: NOAA's National Ocean Service.gov)

Table 1. List of coral diseases, distribution and distinguishing feature [5]

Disease name	First characterized	Distribution	Pathogen and causation	Distinguishing features	Affects which species?
Black Disease Band	1973	Western Caribbean	Cyanobacteria (<i>Oscillatoria submembranaceae</i>), Marine fungus, Sulfate reducing bacteria (<i>Desulfo vibrio</i>) and Sulfide oxidizing bacteria (Beggiatoa)	causes recent tissue loss and leaves a defined strip of pigmented tissue next to the exposed skeleton	Sclerectinian
White Disease Band	1982	Caribbean	<i>Rickettsia</i> bacteria, <i>Vibrio charcharii</i>	Type I exhibits a disease line of active tissue necrosis in which coral tissue can be bleached but Not necrotic. Type II has a variable zone between active tissue death and exposed coral skeleton	<i>Acropora Cervicornis</i> And <i>Acropora Palmate</i>
Aspergillosis	1995	Caribbean and Florida	Fungal pathogen <i>Aspergillosis sydowii</i> ,	Lesion progression showing Tissue loss patches on the blades surrounded by purple band devoid of coral polyps, polyps and less density of zooxanthellae, tissue necrosis, gall like structures	<i>Gorgonia ventalina</i> and <i>Gorgonia flabellum</i>
Dark Spot Disease (Dsd)	Early 1990	Colombia		Small, round, dark spots that apparently grow in size overtime.	<i>Siderastrea siderea</i> , <i>Montastraea Annularis</i> and <i>Stephanocoenia interrepta</i>
Yellow Band Disease	1994	Florida	<i>Vibrio</i> sp.	It first affects the tissue at centre of the blotch, became darker yellow or brown eventually died, with remaining affected tissue forming a characteristics circular band of pale yellow tissue 1 to 3cm wide.	<i>Montastraea annularis</i> , <i>M. franksi</i>
Skeleton Eroding Band	1988	Motupore Island, Papua New Guinea	<i>Halofolliculina coralasia</i> ,	Exposed skeleton is dotted with empty lorica giving a dirty appearance on the surface	Millepora, Pocilloporidae and Acrporidae
Pink Line Syndrome	1996	Papua New Guinea region and Indian Ocean	Fungi, <i>Curvularia lunata</i> and bacterial mat of cyanobacteria, <i>Phormidium valderianum</i>	The pink band of 3-10 mm appears between the healthy and dead tissues on the polyp	<i>Porites lutea</i> and <i>Porites compressa</i>
Porites Ulcerative White Spot	1996	Indo-pacific region	<i>Vibrio</i> spp	Small bleaching lesions affecting a few polyps and these lesions may result in the mortality	<i>P.australiensis</i> , <i>P.lobata</i> , <i>P. lutea</i> and <i>P. solida</i>
Stony Coral Tissue Loss Disease	2014	USA (Florida) Caribbean	Flavobacteriales, Rhodobacterales and Rhizobiales	Acute, Sub-Acute, or Chronic tissue loss lesions that spread rapidly throughout the colony, leaves skeleton exposed.	Scleractinian corals.

2.5 Yellow Band Disease

Yellow band disease (YBD), commonly referred to as yellow blotch disease, is one of the most prevalent diseases in the Caribbean. YBD was first noted off the coast of the Florida Keys in 1994 and has since been reported for the *Orbicella annularis* species (in Table 1) [29]. It first affects the tissue at the centre of the blotch, becomes darker yellow or brown, and eventually dies, with the remaining affected tissue forming a characteristic circular band of pale yellow tissue 1 to 3cm wide (in Fig. 1). Disease severity increased over time, due to the appearance of multiple lesions and individual colonies that coalesced with other lesions progressively radiated outward. YBD is characterized by a 1-5cm wide, yellow to white, circular band that radiates outwards. The band has been recorded to spread out 0.6cm per month. Blotches progressively increased in diameter from a few cm up to 15cm. Corvine et al (2004) identified four *Vibrio* sp. "As the putative causative agents for YBD using traditional isolation and culturing techniques" [30]. *Vibrio*-induced diseases such as YBD-infected corals, result in destruction of the symbiotic algae in the animal gastroderm but thermal bleaching where symbiotic algae are released from the tissues of the corals during stress. In the case of vibrio- induced bleaching of *Oculina patagonica*, a prolins-rich P toxin is released by increasing sea water temperature, leading to Zooxanthella lysis and death. *Montastraea annularis* colonies are infected more frequently, fewest infections observed in *M. franksi*. Mostly this disease is prevalent in remote locations with a low degree of nutrient pollution, including offshore locations with high clarity and areas removed from the human population [31]. It is commonly confused with thermal bleaching owing to the paling and coloration changes. Yellow-band disease (similar to Yellow Blotch disease) is a coral disease that attacks colonies of coral at a time when coral is already under stress from pollution, overfishing, and climate change.

2.6 Skeleton Eroding Band

Majority of the coral diseases appeared to be caused by bacterial pathogens but skeleton eroding band disease is the first reported eukaryotic protozoan disease. Skeletal eroding band (SEB) is a disease of corals that appears as a black or dark gray band that slowly advances over corals, leaving a spotted region of dead coral in its wake. It is the most common

disease of corals in the Indian and Pacific Oceans, and is also found in the Red Sea. For the first time, it was noted on the coral reefs around Motupore Island, Papua New Guinea in 1988 [32] and later it was reported from the Red Sea, Gulf of Aqaba, Great Barrier Reef, Mauritius, and Sinai, and also the Caribbean reefs and now it shows a global distribution. It was recorded in 82 species of scleractinian corals representing 22 genera and 12 families as well as the hydrozoan genus. *Millepora*, *Pocilloporidae*, and *Acrporidae* are the most commonly affected scleractinian corals [33]. *Halofolliculina coralasia*, (mentioned in Table 1) a species of folliculinid, heterotrich ciliate is reported to be the responsible pathogen [32]. These sessile folliculinid protists secrete a bottle-like housing called lorica (black test), with two ciliated pericytosomal lobules that help to feed by extending out, in most cases, the neck of the lorica rises above the surface of the corals. The lorica is found to be embedded in the trabecular limestone skeleton of the corals and break it into splinters by the ciliates. A maximum of 417 individuals of ciliates have been reported [33]. Cell division in the ciliates gives rise to larvae secreting new lorica, the dense aggregation of the lorica resulting in the appearance of a black band separating the diseased tissue (in Fig. 1) from a healthy tissue. The organic acid of the new lorica in combination with the rapid spinning of the larvae totally destroys the outer layer of the coral exposing the skeleton [33]. The black band appears to be similar to the band caused by the black band disease. The difference is that the exposed skeleton is dotted with empty lorica giving a dirty appearance on the surface. The growth of the band is at the rate of 1mm per week to 1mm per day [33].

2.7 Pink Line Syndrome

Pink line syndrome (PLS) is one of the most commonly reported coral diseases in the Papua New Guinea region and the Indian Ocean. It is mainly reported in the two corals species namely, *Porites lutea* and *Porites compressa* [16]. The pink-line syndrome is also called a "pigmentation response" and "hyper-pigmented irritations" [34]. Pink-line syndrome (PLS) was first observed in 1996, affecting the hard coral, *Porites lutea* at Lakshadweep Islands in the Arabian Sea and it was first characterized in 2014 [35]. PLS is a band of pink pigmented tissue separating skeleton of recently killed coral and normal tissue; it may begin as a small ring and progress outward. The affected corals are characterized

grossly by the pink band of 3-10 mm appearing between the healthy and dead tissues (in Fig. 1) on the polyp [16]. It leads to the weakening of the coral skeleton and they become fragile [25]. Around the dead patches of corals, fungi, *Curvularia lunata*, and bacterial mat of cyanobacteria, *Phormidium valderianum* could be seen [36] and they release toxins and lead to competition for dissolved oxygen, ultimately resulting in the expulsion of zooxanthellae (as in Table 1) [36]. This cyanobacterium is a common blue-green alga in seawaters, backwaters, and salt pans. It is reported that the prevalence of this disease is higher in the summer than the post-monsoon which indicates that the rise in seawater temperature may facilitate the disease occurrence [36]. The water temperature plays a crucial role in the occurrence of this disease. So, PLS-associated coral tissue lysis is aided by both the cyanobacteria and environmental stressors. The presence of cyanobacteria is the trigger of this disease [16]. Cyanobacterial mats act as a poison for scleractinian corals and deemed to have the probability of killing live coral tissue. Corals can't easily recover from infection with cyanobacteria. It was concluded that the PLS type of disease need not have to be caused by specific pathogens. Any opportunistic cyanobacteria or other agents have the potential to interfere with the host.

2.8 Porites Ulcerative White Spot

Porites ulcerative white spot (PUWS) is one of the common coral reef diseases in Indo-Pacific region and it is mainly reported in *Porites* spp. Most commonly species like *P. australiensis*, *P. lobata*, *P. lutea*, and *P. solida* were highly susceptible to this disease. This disease was first reported in 1996 in the Philippines [16]. The main features that is used to identify PUWS are discrete, bleached, round foci, which may either reduce or spreads to full tissue ulceration (in Fig. 1) and finally result in mortality of the colony [37]. The affected coral appears as small bleaching lesions affecting a few polyps and these lesions may result in mortality. *Vibrio* spp. is the main causative agent in PUWS and *vibrio* spp have predominant occurrence in seawater laden with high organic load [38]. The specific species and strain of *Vibrio* that cause this coral disease are still left unknown. Also, the surrounding environmental factors greatly influence the spreading of this disease. Research is being continued to identify the causative species.

2.9 Stony Coral Tissue Loss Disease

Stony coral tissue loss disease (SCTLD) is the atypical white plague that infect the coral reefs throughout the world. It spreads rapidly and cause mortality in the corals. Rapid spreading and high mortality rate have led to significant decreases in overall coral population, coral and its biodiversity. SCTLD represents the most lethal coral disease that increase and worsens the white disease outbreaks [39]. It was first documented in the USA (Florida) Caribbean in 2014 [2]. It is mainly reported in large groups of scleractinian corals. SCTLD- affected corals rendering the appearance as Acute, Sub-Acute, or Chronic tissue loss lesions (in Fig. 1) that spread rapidly throughout the colony, and leave the skeleton exposed. Some species also have bleached tissues [32]. The causative agent responsible is still unknown. Recent findings reports that bacterial species of Flavobacteriales, Rhodobacterales, and Rhizobiales (mentioned in Table 1) play a vital role in SCTLD [40]. The factors that lead to increases in coral disease outbreaks include increasing thermal stress and frequency of warm temperature. SCTLD spread through direct contact, vector-borne, and through water column [41]. Till date, there are no diagnostic tools to identify SCTLD making it difficult to determine if all impacted species are suffering [42].

3. SEASONAL CHANGES THAT LEADS TO THE EMERGENCE OF DISEASE IN CORALS

Nearly one-third of reef-building corals have been facing rapid extinction risk from climate change and other impacts [43]. The most important environmental factor that have a greater impact on declining coral health include: increasing ocean temperature [9], nutrient pollution [44], and over-fishing [10]. All the environmental factors that changes seasonally will affect the coral health that increase the chances of disease emergence in the reef ecosystem.

3.1 Water Temperature and Salinity

“When the temperatures rises in the ocean (increased up to ~30–32 °C), zooxanthella often get detached from corals due to thermal stress caused leading to coral bleaching. Coral bleaching even happens when reactive oxygen species rise due to environmental stress, which

ultimately leads to coral death” [45]. “A most widespread threat to reef ecosystem is coral bleaching. Some other studies also covered how water temperature can affect coral metabolism. Exposure of corals to high temperature (30 °C) and low salinity (20 psu) leads to stress response, resulting in the bleaching and even death [46]. Corals are narrow salt tolerant organism, so change in salinity will adversely affect their health and immunity that pave ways for the emergence of diseases” [47].

3.2 Water Depth

“Depth is one of the determining factors for coral diseases. In case of Black Band disease, it is caused by a microbial consortium that uses light” [48], so that the disease is most common in shallow waters [21]. In the White Plague also the correlation between disease prevalence and water depth has been reported. So water depth is also one of the environment for that affects the coral reefs.

3.3 Rainfall and Runoffs

“Declining water quality combined with the effects of climate change are rapidly increasing coral diseases on reefs worldwide. Rainfall and associated runoff increases the chances seasonal disease outbreaks, by reducing host fitness or by increasing pathogen virulence due to higher availability of nutrients and organic matter. Rainfall and seawater temperatures are increasing due to climate change which lead to decreased health of corals” [49].

3.4 Changing Ocean Chemistry

“A more dangerous and destructive consequence of increasing greenhouse gases for corals is ocean acidification. Absorption of CO₂ lowers the pH and decreases the availability of carbonate ions, lowers the saturation state of the major shell and skeleton forming carbonate minerals. It is observed that ability of corals to form their skeletal structures reduces in more acidic waters results in weaker coral reefs that are vulnerable to erosion and lower growth rate” [50].

3.5 Sea Level

“Global average sea level has risen by about 20 cm over the past century mainly due to thermal expansion of the oceans, melting of land and sea ice. Continuous rising of sea levels have greater impact mainly on densely populated, low-lying

tropical communities adjacent to coral reefs. Rising sea level may drown some deeper reefs, increase shallow areas available to others, and wash away low lying reef islands and cays. Likely to increase destruction associated with more intense tropical cyclones due to higher storm surges and intensified coastal erosion” [50].

3.6 Cyclones and El Nino

“High intense tropical cyclones increases incidence of localized reef destruction. Changes to ENSO activity are likely to continue as source of significant interannual climate variability with El Niño events increasing probability of warmer waters throughout most of tropics and, therefore, conditions conducive to coral bleaching and coral diseases superimposed on warmer baseline water temperatures” [50].

4. CORAL DISEASES IN INDIAN REEF ECOSYSTEM

Coral reefs are one of the important ecosystem in Indian waters. The total area of reefs in India is 2,375 km² [51]. “In Indian waters, the coral reef populations are restrictedly distributed in regions of Gulf of Kutch, Lakshwadeep, Gulf of Mannar and Andaman and Nicobar” [5]. The most commonly found coral species in Indian reefs are Porites sp. and Acropora sp [52]. These species of corals are severely affected by various diseases. On overall, 14 different coral diseases have been reported from the Indian coral reefs most of the diseases were common to all regions [5]. These includes white band disease, white plague, white pox, patchy necrosis, black band disease, yellow spot or blotch, yellow band disease, brown band disease, porites ulcerative syndrome, white spot disease, red plaque syndrome, pink line syndrome, pink spot disease, pink blue disease [5]. In Gulf of Mannar, about 11 coral diseases have been reported [53]. The major drawback is that the coral diseases of the Indian coastal regions are poorly documented and there are no sufficient investigational studies about prevalence, distribution, environmental interaction and the pathology of these diseases. The environmental stress factors such as water pollution [54], (Szmant, 2002), warming temperature, decrease in salinity, sea level rise, subsequent changes in ocean circulation [9], (Bruno et al., 2007) and over-fishing are responsible for the increase in prevalence of coral disease along with the natural processes including siltation, soil erosion, quarrying corals from the shore and reefs, and sponge attack are

factors that leads to increasing susceptibility of corals to pathogens. In recent years, "Corals in the Lakshadweep coast on the Arabian Sea as well as those along the eastern coast of India on the Bay of Bengal are experiencing bleaching [55,56]. Till to date Lakshadweep islands are the only one reporting widespread bleaching especially in three locations of the Kavaratti island and neighbouring atolls. The bleaching is very higher than that of 2015-2016. The shallow lagoons of these regions often host monospecific stands of certain species like *Acropora muricata* and *Porites cylindrical* that are temperature sensitive and also facing lots of bleaching problem. The bleaching has been extended to the hard corals as well as the soft corals. Also the more stress-tolerant species, such as *Porites lutea* and *Pavona varians* have also begun to bleach. The ongoing bleaching has been declared as the fourth global mass coral bleaching experienced by the world. Global mass coral bleaching events have been reported in 1998, 2010, 2014 and 2017, according to the United States National Oceanic and Atmospheric Administration. Since 2023, mass bleaching in coral reefs have been reported in more than 50 areas of the world. However, the high ocean temperatures and El Nino since April 15, 2024 had increased the coral bleaching area and threatening the corals. The current El Nino event is one of the primary contributors to the increased sea surface temperatures, that triggers coral bleaching [57,58]. The high temperatures of water disturb the symbiosis between corals and zooxanthellae. The algae, once separated, make the corals look pale. The corals will never recover from bleaching but long-term bleaching can lead to mass mortality, making them unable to recover" (Szmant, 2002).

5. CONCLUSION

Coral diseases have become the major serious threats challenging the coral reef ecosystem's resilience. Around half of the world's reefs are likely degraded from climate change, pollution and overfishing. Almost three-fourths, or 72.1 per cent, of the world's coral reefs have experienced bleaching-level heat stress, the highest recorded to date (NOAA). Hard coral cover has declined significantly in some regions, and there has been a clear change in coral community structure, with loss of susceptible coral species and loss of diversity. As a summary of what is currently known about coral diseases, changing environmental factors and prevailing anthropogenic activities have a greater impact on

the outbreak of diseases in corals, resulting in the declining coral reef population. Also, very little data about these diseases and their ecological impact have been reported. There is a necessity to conduct more studies and research to know about their impacts. Also measures to conserve these declining corals and coral restoration should be carried out actively to protect this coral ecosystem. Also the pollution causes decline in the coral population. So proper management action should be taken to reduce the pollution and to protect the coral population. Avoiding active fishing gears usage, destructive fishing in the coral stretches is one of the effective measures to sustain and restore the coral reefs. Also the better management includes the inclusion of coral reef areas in the marine protected areas or fishing restricted areas. Also satellite signals can also be used to analyze the growth and distribution of coral reefs. A advanced approach to eliminating the draw back in data processing for coral reef monitoring is artificial intelligence (AI) and its application through machine learning. AI tools like surf perch AI, coRail AI, Reef cloud AI are emerging in the field for coral monitoring. Biosensors are also being used for the coral monitoring and assessment of the population.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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