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Coral Bleaching Situation and Influencing Factors in Recent Decade

Jiamei Zheng *

College of Life Sciences and Biopharmaceutical, Guangdong Pharmaceutical University, Guangzhou, Guangdong, China

* Corresponding Author Email: kirby-Zheng@hhu.edu.cn

Abstract. Coral bleaching is a very common but urgent problem that needs to be solved today. Coral bleaching due to global warming and other reasons is the greatest threat to the coral ecology system today. Coral reefs not only have great economic value but also have important ecological meaning. Protecting coral ecology is also one link to practicing global sustainable development. Research on bleaching events in recent years has shown that corals have different bleaching conditions under different environmental factors. Besides effects of exogenous factors such as the surrounding environment, there are also factors in coral itself, such as the different species of coral symbiotic. This is also a breakthrough in the battle against heat bleaching events, to give hope for the coral situation. In the future, gene editing and other technology can be used to breed corals which have more heat-resistant or more bleaching-resistant. The current study is mainly in terms of environmental protection and strengthening coral resistance to support coral ecology. For more challenges in the future, still needs deeper research in coral heat bleaching and recovery mechanisms area and interactions between coral and symbiotic mechanisms area. Understanding the key factors influencing coral bleaching will be a prerequisite for solving the problem in the future.

Keywords: Coral bleaching; Global warming; Ecology recovery; Coral reefs; Response mechanism.

1. Introduction

Corals are invertebrate species belonging to Cnidaria, typically classified as “hard coral” and “soft coral”, with hard coral also known as the reef-building coral. Coral reefs with carbonate structures formed by hard corals are one of the most important marine ecosystems, playing a crucial and irreplaceable role in both human society and nature. Currently, coral reefs, mangroves and seagrass beds are also known as the three typical marine ecosystems[1]. As one of them, coral reefs have the richest biodiversity and are important resources for thousands of species of animals and plants to survive. Coral reefs are also a valuable gene pool for marine creatures. The healthy coral reef system annual fishery production is up to 35t/km2. About 10% of global fishery production comes from coral reefs[2]. Meanwhile, coral reefs can prevent coastal erosion and absorb wave energy, also known as natural breakwater.

Coral reefs are scattered throughout the ocean, mainly growing in areas with clean and nutrient-deficient oceans, because excessively turbid water can suffocate corals. Temperate and tropical corals grow only in areas within 30 dimensions on either side of the equator. The hard coral prefers to grow at depths shallower than 30 meters and the temperature between 16-32 degrees centigrade. According to current statistics, total coral covers less than 0.015%of the ocean but inhabits more than a quarter of all marine creatures[3].

The main reason for coral bleaching is the color comes from a symbiotic species of zooxanthellae. When corals are exposed to external stimuli the symbiotic alga will leave, which can lead to coral bleaching. If the bleaching lasts a long time, it will eventually cause the death of coral. The main factors that cause coral bleaching are the change in temperature and salinity of the ocean, sea pollution, ultraviolet radiation, threats from other animals like starfish, etc [4]. The impact of global warming on the ecological environment is now an unavoidable fact. There were 3 global massive coral bleaching events in the last three decades[5]. From 1997 to 1998, heron et al used the data from

satellite remote sensing to statistic that almost 48% of corals were under bleaching. And the same proportion of bleaching coral from 2009 to 2010. During the period from 2014 to 2017, the closest bleaching event to us in three. Almost 32% of corals are bleaching, the Great Barrier Reef in Australia was the worst affected.

In recent years, because of the popularization of remote sensing technology, the research on coral bleaching is more detailed and comprehensive. The main content on hot spots is using satellite remote sensing technology to predict the abnormal SST, the changing of coral community and symbiotic algae and the gene regulation of coral under bleaching. For instance, in the remote sensing and SST area, the current study shows the main bleaching hot spot area in China is located in the northern part of the Spratly Islands and the southeastern central south peninsula[6]. For the coral community, by analyzing the bleaching situation of reef-building coral around Hainan Island and Xisha Island in the period between 2020 and 2021, people found that massive alga appeared in some reef areas after bleaching[7]. That would lead to a further decline in coral cover. The proportion of most of the coral community composition changed after bleaching events. The dominant species changed from branching staghorn coral to massive hammar coral. For gene regulation, Yu et al found Acropora pruinosa would regulate gene expression associated with the nitrogen cycle in laboratory simulation scenarios[8]. In the meantime, research shows that different coral species have discrepancies in sensitivity to bleaching. For example, it is widely accepted that hammar coral has more heat-tolerant ability than branching coral. There are also discrepancies in the coral bleaching threshold. Even the threshold of the same coral could change in different seasons[9]. It has been internationally recognized that the main reason causing global coral death is the bleaching caused by abnormal SST. But there are different views about future coral situations. Some people believe that coral will completely disappear in the near future. But others think that coral will change themselves to adapt to the high-temperature environment.

Large-scale coral bleaching has serious impacts on the ecological environment. After large-scale coral bleaching events, the position of corals in the ecosystem may be replaced by macroalgae, which is known as the coral macroalgae institutional shift. In areas where bleaching lasts for a long time, large algae may permanently replace corals as a permanent ecological transformation. After large-scale bleaching events, the changes in fish population abundance and species richness lag behind. Many studies have found that after three years of severe coral bleaching, the abundance and species richness of fish will significantly decrease. But the number of herbivorous fish is increasing. Research has shown that herbivorous fish can slightly prevent the transformation of coral systems[10]. This speculation is because herbivorous fish can prevent coral from covering living corals. Wildlife data shows that coral reefs with a low proportion of herbivorous species are generally experiencing regime changes. Species with a higher proportion of herbivorous species have almost never undergone regime change.

By studying the changes in coral itself during bleaching and the factors that affect the degree of bleaching, people can better protect corals in the face of global warming and other extreme weather conditions. The importance of protecting coral reef ecology lies in the fact that coral reefs create enormous ecological wealth and serve as insurance for maintaining marine biodiversity. Secondly, by studying the differences in coral bleaching events faced by different coral communities, scientists have discovered hope for intervening in coral bleaching through gene editing technology. Finally, protecting corals during bleaching events is protecting the entire marine ecosystem and the global environment..

2. Case Description

In the summer of 2020, the northern part of the South China Sea suffered badly from the ocean heat wave and a large-scale coral heat bleaching event. Research shows that the numerical range of salinity, pH and dissolved oxygen concentration are suitable for coral growth [6]. However, the value of SST and nitrogen concentration are quite high in this area at that time. This research chose 4 coral reef

areas in the northern part of the South China Sea as observation subjects in total, each is Dayawan Bay, Weizhou Island, xuwen and the sanya luhuitou. The location of this observation subject is in the Figure 1. The seawater environment factor of coral reefs see table 1.

Figure 1. The location of 4 coral reefs area

Table 1. The seawater environment factor of coral reefs in northern part of South China Sea[6]

Coral reef area	SST/℃	Salinity/‰	pH	Oxygen/(mg·L-1)	nitrogen(μmol·L-1)
Dayawan Bay	28.9	33.5	8.08	7.71	1.25
Weizhou Island	31.3	32.0	8.14	6.97	4.75
xuwen	31.5	33.1	8.14	7.20	8.96
sanya luhuitou	30.1	33.4	8.15	6.87	9.9

The study's ecological surveys showed the proportions of thermally sensitive coral in Dayawan Bay and the Sanya luhuitou is close to 30%. The dominant species of coral in Weizhou island and xuwen each is thermotolerant and thermally moderately adapted, with a proportion is 81% and 68%. In this coral bleaching event, the coral community in Dayawan Bay at high latitudes and sanya luhuitou at low latitudes didn't experience coral bleaching phenomenon either. However, the coral community in weizhou island and xuwen at middle latitudes had serious bleaching events. The rates of coral bleaching and dying were the highest in xuwen, which was 84.78% and 10.68%. The rates of coral bleaching and dying in Weizhou island each is 65.52% and 0.70%. For the bleaching situation of the main dominant species in different coral communities, the dominant species bleaching rate in Weizhou island is 19.08%~89.83%, and the rate in Xuwen is 84.85%~98.47%. The bleaching rate of the dominant species of deep yellow coral is 93.04% in xuwen is higher than the rate in Weizhou Island which is 76.64%. In the dominant species of coral in Weizhou island and xuwen area, the bleaching rate of thermotolerant corals is lower than thermally moderately adapted corals.

This research uses Redundancy analysis(RDA) to analyze the relevance between coral heat bleaching and environmental factors. It found that the bleaching rate is positively correlated with SST, inorganic nitrogen and inorganic phosphate. Although the rates of coral heat bleaching are high in Xuwen and weizhou island, the rates of coral dying are low. The study conjectures it is related to the composition of the coral community. The other study shows that the appropriate water turbidity can reduce the radiation from the sun, which can also decrease the damage to the coral symbiotic algae. In this

research, both two areas have higher water turbidity, which might have some protection from the observation coral.

3. Factors Causing Coral Bleaching

3.1. Exogenous Factors Causing Coral Bleaching

3.1.1. Temperature change

The temperature change includes temperature increase and decrease. In recent years, there has been an increase in the number of anomalous SST(sea surface temperature)events due to extreme weather such as El Niño[11]. Besides higher SST, sometimes a change in ocean currents can bring hot seawater. The warmer water can kill the zooxanthellae that live in symbiosis with corals. But low temperatures can cause the zooxanthellae to go into dormancy. The reef-building corals will not be able to build a hard skeleton when the environment temperature is lower than 18℃, and it will die at 13℃.

3.1.2. Nitrogen levels

Nitrogen is a basic element in the composition of marine life and a limiting factor of marine primary productivity. However, high nitrogen levels can directly affect the physiological functions of corals. And because the nitrogen cycle in the ocean is basically dominated by microorganisms, it is also indirectly influenced by the increasing sea temperatures. Nitrogen excess can bring many negative effects on the coral reef ecosystem, such as affecting coral growth and development, reducing the heat tolerance of corals, and aggravating coral bleaching[12].

3.1.3. Salinity change

The optimal salinity range of coral is 30% to 35%, which is a very small range. When the salinity is too low the coral will discharge symbiotic zooxanthellae from their bodies. When the salinity is too high the respiration rate of coral polyps will be higher than the rate of photosynthesis and it will cause coral death. In recent years due to marine pollution and changes in the global water cycle, the salinity has changed and beyond the optimal range in partial areas[13]. For example, untreated or substandard treated wastewater often contains a high concentration of salt ions. Secondly, the increase in the global water cycle has led to a salinity decrease of surface seawater in the tropical and subpolar sea area and a salinity increase in the subtropical sea area.

3.1.4. pH

The change in seawater pH is mainly due to ocean acidification[14]. The greenhouse effect is getting worse these days and the proportion of carbon dioxide in the atmosphere is increasing. So the proportion of carbon dioxide dissolved in the ocean is rising at the same time. This carbon dioxide turns into carbonic acid in the ocean and makes the pH of seawater drop. The reduction of pH can affect the chemical balance between different carbonates in the ocean. It can also decrease the rate of coral calcification slow down the growth speed of coral, and make the coral skeleton fragile which is easy to break in typhoons and other extreme weather.

3.1.5. Heavy metal ions and toxic compounds

The heavy metal ions have non-degradability and cumulative toxicity. The research shows that Zn, Pd, Cd, Cu, and other heavy metals can seriously affect coral growth[15]. The sewage discharge is the main cause. Sewage contains high levels of toxic heavy metals which can be a serious threat to corals and other sea creatures. One study shows that the level of heavy metal in surface water and sediment is highly consistent with the space distribution of busy shipping lines.

3.1.6. Coral diseases

There are lots of factors that can cause coral diseases, such as water eutrophication, frequent marine transportation, and leaking oil. The common types of coral diseases today are black spots, yellow

belts, stony coral tissue exfoliation, and so on. The study shows that corals will secrete large amounts of mucus which can make bacteria rapid reproduction when the concentration of organic matter such as crude oil is high[16]. Another study shows that marine plastic garbage also causes coral diseases. Except for corals that can uptake tiny plastic pellets during ingestion, the fishing nets and lines can wrap around the surface of coral which can lead to predation disorders and bacterial infections of corals.

3.1.7. Bioerosion

Corals have natural enemies, the most widely known is Crown of Thorns starfish(COTs). The crown of thorns starfish eat corals with an astonishing speed and they don't have predators in nature. According to statistics adult COTs can ruin about 400cm2 of coral reefs in one day[17]. The horrible thing about COTs is they usually appear in packs. Besides, ecological imbalances can cause the rapid growth of COTs. Without other sea creatures like fishes and shrimps that can hunt the COTs larvae, the density of the COTs has increased dramatically and also the hurt to corals.

3.1.8. Ultraviolet radiation

The ultraviolet radiation consists of three components, UVC(100-280 nm), UVB (290-320 nm) and UVA(320-400nm). the UVA can directly to the surface, the UVB and UVC are absorbed by the ozone layer. Because of the effect of freon, the ozone layer is reduced progressively year by year. It made lots of UVB also reach the surface. The ultraviolet radiation can easily pass through the surface seawater. The measurements show that the intensity of UV will be decreased by 50% at 3 meters deep and 75% at 10 meters deep[18]. It can also measure the UV at 25 meters deep. The ultraviolet radiation can break the DNA and protein, and even impact the photochemical pathways in the coral symbiotic zooxanthellae. In 1993, Gleason et. al. used ultraviolet light to illuminate the coral. They found only the coral group which under the UV light began to bleach in all the coral groups at the same deep. It proves that UV light can damage the coral. Besides, when the intensity of light is too strong, it will inhibit photosynthesis in coral symbiotic algae and lead the coral death. Also, the high radiation of the sun can make the SST increase.

3.2. Endogenous Factors Causing Coral Bleaching

3.2.1. The heat tolerance of corals

In all the species of corals, there are classified as different degrees of heat-tolerant such as thermotolerant, thermally moderately adapted, thermally sensitive, etc. For instance, Acropora pruinosa and Pocillopora damicornis are known as thermally sensitive. But Pavona decussata is thermally moderately adapted. Research shows that a reef-building coral can increase their heat-tolerant by modulating the transcriptomic response of the host and symbiotic algae[19].

3.2.2. Diversity of coral communities

A study shows that the coral community has higher diversity and will have higher heat tolerance[20]. Having more coral species in one coral community can improve the resistance to bleaching. It is because a variety of species have a variety of symbiotic and also a greater density of symbiotic alga. It will help corals within a community to regulate and adapt to bleaching.

3.2.3. Difference in symbiotic alga communities

The current hypothesis of coral adaptation to bleaching indicates that coral can achieve the purpose ofhigh-temperature adaptation by regulating the community composition of self-symbiotic algae[21]. corals can reacquire symbiotic algae from the outside to adapt to high-temperature after they lose their original symbiotic algae which is bleaching. In the research of Baker et. al., they found the bleaching rate would increase in the short term after transplanting the deep water coral to shallow water. But the symbiotic community would change at the same time and improve the long-term survival rate of corals. This also confirms that corals themselves can adapt to the risky environment by regulating the composition of their symbiotic algae communities.

3.2.4. Reactive oxygen species（ROS）

Currently some studies suggest that the level of reactive oxygen has a significant influence on coral bleaching[22]. The high temperature and intense light could lead to more energy uptake by chloroplasts within the symbiotic algae. That would result in an excessive accumulation of electrons and produce more oxygen. This overwhelming oxygen would become reactive oxygen species and spread into a coral cell. The coral mitochondria also produce reactive oxygen species so these ROS would cause damage in coral cells. In the end, it would promote coral bleaching.

4. Suggestion

The cause of most coral bleaching is because of intensive human activities. Whether the situation is directly caused by human activity such as busy shipping lanes, sewage disposal and plastic garbage or indirectly caused by humans such as the green-house effect and ozone hole, it can be showing that the main offender of coral bleaching is human beings. To change the current situation of coral, we should unite the efforts of all mankind, not to mention the extreme weather and abnormal SST that are difficult to change. Even if carbon dioxide emissions were banned from now on, the current carbon emissions will continue to exacerbate the greenhouse effect in the coming years. However, it is essential to take necessary protective measures. Firstly, it is necessary to establish coral conservation areas to control human activities in the vicinity. For example, reducing fishing aims to increase biodiversity in the region and thus suppress starfish populations. At the same time, it can also reduce the amount of plastic waste, especially homemade torpedoes used for illegal fishing, allowing divers to regularly protect corals and clean up some starfish, fishing nets, and other plastic waste. It also can know the coral condition in this area better. If some corals are infected disease divers can give them medicine immediately. It is also possible to plan routes that do not pass through coral reef areas or restrict the flow of shipping routes to reduce the occurrence of oil spills. Secondly, activities related to artificial coral cultivation will be carried out. Coral planting plan is also called by “marine tree planting program”, and many volunteers are doing this now. Planting fast-growing corals or breeding more heat-resistant corals can help stabilize coral reef ecosystems. Not only has it increased the biodiversity of coral communities, but it has also expanded the area of coral reefs. The third is to adopt ocean remote sensing system monitoring technology. If some SST of the area increases abnormally, it can be detected earlier. Since 2002, national oceanic and atmospheric administration(NOAA) has been use ORSS to protect coral. The fourth is gene editing technology. The different heat-tolerant between different corals provide a chance for them to adapt the future climate conditions. Research shows that corals have higher densities of symbiotic zooxanthellae and are less likely to be affected by bleaching. Sequence analysis shows that coral genes resistant to bleaching are mainly associated with maintaining coral and symbiotic and immune defense.

5. Conclusion

For the past few years, because of global warming and other factors, worldwide coral reef systems have been eroded in varying degrees and showing bleaching frequently. From studies on coral bleaching, it could be found that not only exogenous but also endogenous factors affect coral bleaching. Among these, the study of endogenous factors will help scientists find the direction of solving the bleaching problem. Corals are heat-tolerant in terms of genetics, symbiotic algae and community structure, but they still need some time to adapt. The current speed of weather changes is too fast for corals to react immediately. If remote sensing technology can be used for early warning and combined with human intervention, more corals can be saved in bleaching events. Using gene editing to create more heat-resistant corals is a better solution, as more corals will survive in current extreme environments by using genetically modified corals.

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