The impact of higher temperature in climate change on coral reef bleaching

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Abstract: Today, with global warming, more animals and plants are suffering from the negative effects of temperature rise. As an important part of marine ecosystem, coral plays a vital role in maintaining the marine ecological balance and biodiversity of the ocean. Therefore, when a large number of corals keep disappearing during the climate change, we should be alerted that it is time for us to find out the relationship between climate change and coral bleaching, so as to find out the methods to overcome coral bleaching. In this paper, our team consulted a large number of documents to prove the relationship between coral bleaching and temperature, and what great impact of such changes on nature and human civilization. It is hoped that this article can provide the specific relationship between coral bleaching and temperature trend, and provide a way to find a method to alleviate the impact of coral bleaching to the nature and human life in the future.

1. Introduction

The coral reef system is the most diverse ecosystem in the global ecosystem. They are an important part of the marine material cycle and an important source of primary producers such as oxygen. At least 25% of marine species live in coral reef systems, such as mollusks, worms, fish, crustaceans, etc. The Great Barrier Reef in Australia is the largest coral reef system in the world. Because of the important position of coral reefs, the study of the coral reef system is of far-reaching significance when human beings understand and explore Geosciences, and its commercial values such as tourism and fishery also have a deep attraction for human beings to explore their living conditions and environment. According to statistics, coral reefs provide more than 500 million people around the world with opportunities for survival, work, and leisure every year, and provide more than 375 billion US dollars in economic benefits. If the research on it is slow and ignores the serious current situation it faces, leading to its extinction, countless marine organisms and related industries that depend on it will face a serious blow and produce a huge butterfly effect.

At present, it is found that due to global warming and rising water temperature, symbiotic algae and other organisms in coral reefs will be discharged, resulting in coral bleaching. The too high temperature will accelerate this phenomenon. The 21st century faces several threats associated with climate change, including global warming and the associated rise in sea surface temperatures (SSTs). The leading cause of coral bleaching is water temperatures about one °C (or two °F) above average. Rising sea surface temperatures are expected to cause frequent coral bleaching in the coming decades and threaten the long-term viability of coral reef ecosystems worldwide. According to incomplete statistics, due to the intensification of the global climate, the bleaching risk increases at a rate of 4% per year. For example, in the 1980s, about 8% of coral reefs were affected every year, and by 2016, the figure was 31%. According to the data of the national ocean and Atmospheric Association of the United States, in the four years from 14 to 17 years, the bleaching of global coral reefs caused by

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severe heat stress has continued to increase, and about 75% of tropical coral reefs have been affected, resulting in the disappearance of about 30% of coral in the world.

In this paper, the relationship between global coral bleaching trends and temperature is discussed and summarized in detail, and the effects of temperature on coral bleaching and coral bleaching on the coral reef ecosystem are discussed in detail. Globally trends of coral bleaching with temperature. By analyzing early warnings of coral bleaching as ocean temperatures warm, coral reef managers are reminded to prepare and raise awareness of future coral bleaching events.

2. Global trends of coral bleaching in relation to temperature

2.1. Effect of global temperature trend to coral reef bleaching

There are over 60,000 reef pixel sites in the world and 97% of them show a positive trend in SST, which usually predicts global ocean warming. Of these 97% pixels which show a positive trend in SST, 60% of them have a significant warming record, implying that most of the coral reef distribution areas are suffering from increased ocean temperatures [1]. As temperatures increase, the winter cold period becomes shorter, meaning that reefs in warmer areas will suffer longer summer heat waves each year, with little time to recover from bleaching. Longer warming periods may not only cause massive coral bleaching or even death, but also lead to serious infectious diseases in the reefs. In addition to the above observations, another observed feature is that there are differences in SSTs between different seas, i.e., different temperature changes in different seas. For example, the Indian Ocean is warmer than the Pacific Ocean, which in turn is warmer than the Atlantic Ocean [1]. And coral reef bleaching is more in the Indian Ocean and Australia and less in the Middle East and the Pacific, which is consistent with previous observations. It is of interest that the trend of temperature increase in the Middle East and the Pacific is as fast as in the Indian Ocean. In addition to increased seawater temperatures causing coral reef bleaching, increased cold winter fronts from North America also cause coral bleaching, suggesting that not only hotter SSTs cause bleaching, but colder SSTs also cause reef bleaching [1].

In conclusion, erratic and persistent changes in SST can lead to bleaching of coral reefs, thereby increasing reef mortality, regardless of whether such changes in temperature are increasing or decreasing.

2.2. Reaction to Temperature Raising of Typical Coral Reef Area

Since coral reefs in the Middle East and the Pacific are more exposed to such frequent and severe thermal effects than other regions, this means that it is urgent to study the negative damage to coral reefs in this region due to seawater warming. In order to fully understand the warming crisis faced by coral reefs, we selected reefs located in places that are subject to higher SST changes such as the Rhea Sea and the Great Barrier Reef as subjects for study [1].

2.2.1. Red Sea

The Red Sea is a region with the most bleaching stress in the world, and has a special figure related to the ocean temperature [2]. The bleaching pressure on coral reefs in the Red Sea is among the top in the world-wide seas, as the local reef ecosystem is almost destroyed, relying only on a few genotypes with high phenotypes, plasticity and temperature tolerance to try to maintain the biodiversity of this prefetch. To study the risk of bleaching in Red Sea coral reefs, three indicators, namely nutrient levels, light intensity and mucus secretion, were chosen to be measured in this study. Amazingly, a diverse coral reef system exists in the Gulf of Aqaba, where coral reefs do not show signs of bleaching even at temperatures 1-2°C above their long-term summer maximum (equivalent to a warming week of 11 degrees) and a pH of 7.8 for 1.5 months [3]. These reefs have evolved thermotolerance by migrating through the warm Southern Red Sea after the last ice age [3]. Moreover, coral reefs throughout the northern Real Sea, not only Stylophorum pistil Lata, are better adapted to higher temperatures. In contrast, in the central and southern Red Sea, coral reefs have a limited ability to sustain at higher temperatures.

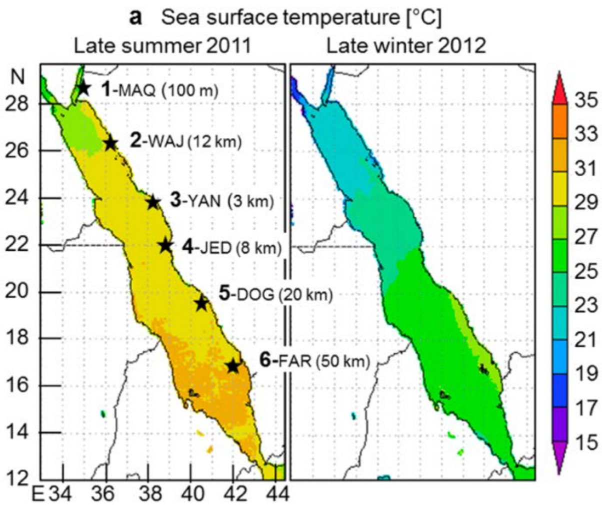

Fig. 1 Map with study sites and environmental conditions [2].

In summary, coral reef communities in the northern Red Sea appear to have better thermal resilience than those in the central and southern parts of the Sea, a possible explanation for which is that coral reef ecosystems in this region have evolved a higher degree of temperature adaptation.

2.2.2. Great Barrier Reef

Over the past 30 years, the Great Barrier Reef has shown a declining trend in the number of reefs and their recovery rate has decreased by 84%. The weakened recovery of coral reefs is attributed to the cumulative effects of chronic stresses, including global warming and water quality, sub-lethal effects of acute disturbances, and other causes [4]. Coral reef mortality and bleaching rates vary with depth, with 60-90% bleaching and 8-12% mortality at 5-25 m depth and 40% bleaching and 6% mortality at 40 m depth [5]. Although numerically, increased depth reduces the rate of bleaching and mortality of coral reefs, this is not the truth. Firstly, much of the reduction in bleaching rates and mortality of coral reefs due to increased depth is caused by the thermocline caused by the South Equatorial Current flowing westward through the Coral Sea and striking the Australian continental shelf, which can enhance the survival of coral reefs. In summer, the influx of cold water can provide thermal relief for Mesozoic reefs. However, this capacity is seasonally limited when hot temperatures continue into winter [5]. As a result, deeper reefs may experience more severe temperature increases after seasonal protection from water flow ends, resulting in massive bleaching. Temporary protection does not prevent the eventual occurrence of reef bleaching, which may become more severe at depth after the end of the protection period. In addition, coral reefs are more sensitive to the environment in their early survival stages than adult reefs, so they are more likely to die in an ocean with dramatic climate change, which makes the recovery of coral reefs in the region slower than before [6]. If there are no more new reefs to maintain the surface morphology of the reef, it will take on the ancient white bone structure after all the colorful reefs lose their algae and become transparent.

In conclusion, reef bleaching in GBR is strongly associated with long periods of thermal stress and reduced survival of individuals, and even reefs in deeper waters are not immune.

3. The Effect of Temperature on Coral Bleaching

3.1. Effects of temperature on coral function

The influence of temperature on coral function mainly depends on the thermal influence on coral reef-related microflora. Coral-related microorganisms play a vital role in the adaptation and survival of their hosts. After reading a lot of literature, the heat tolerance of coral symbiotic bacteria is closely related to its species type/richness. Through the study of the distribution of coral symbiotic bacteria and the heat-resistance pattern, it is found that the use of full-length 16S rRNA and its (internal transcriptional spacer when Pac bio cycle is consistent) can clearly indicate that the coral symbiotic bacteria's porous growth bacteria will experience fine bacteria and fungi. The specific dynamic changes of the community in the natural bleaching cycle [7]. This finding proves that under high temperature stress, the internal community composition and surface structure of the coral microbial community will change significantly. Studying the changes of related community structure is of great significance for understanding the natural bleaching phenomenon of coral symbiotic bacteria under heat stress. For example, after natural bleaching under high temperature stress, the dominant bacteria of coral microorganisms transform γ-proteobacteria into α-proteobacteria and interact with β-proteobacteria. But overall, the composition and diversity of its internal symbiosis group remain unchanged, which means that it will neither appear out of thin air, nor will it disappear out of thin air. Therefore, the mechanism of coral symbiotic bacteria type conversion is different from the response mechanism of yellow whitefly to the increase of sea temperature. Therefore, temperature will become a basic tool for studying the microbiota of coral reefs.

3.1.1. Effects of Temperature on Nutrient Cycling in Corals

In the ocean, most inorganic nutrients are transported by upwelling, and coral reef systems are no exception. Upwelling is also of great significance in the cycle of basic nutrients in the coral reef system. In terms of horizontal gradient characteristics, the most typical one is the concentration of inorganic nutrients in the equatorial upwelling zone of the Southern Line Islands across the Central Pacific. In 2020, Professor Maggie D Johnson and others used this gradient to construct an experimental model to verify the hypothesis that nutrient-rich coral reefs will enhance the ecological physiology of benthic autotrophs, and how they are used by primary producers of coral reef systems. Inorganic components have made more progress. Taking chlorophyll as an example, as shown in Fig. 2, the average surface ocean chlorophyll concentration increases from south to north, which is a research summary of more than four months. The surface Chla (MG-3) is the spatial resolution product of the medium resolution imaging spectroradiometer. This indicates that the concentration of Chlamydia is higher near the equator and lower away from the equator. It is through the concentration change of specific nutrient elements to study the effect of temperature on coral reef nutrients. They verified the metabolism and photophysiology of primary producers in coral reef communities by collecting common benthic communities such as algae, algae prolation, avrainville. And Halimeda, as well as corals Pocillopora and Montipora.Professor Maggie D Johnson et al. found that temperature (27.2-28.7°C) was inversely related to dissolved inorganic nitrogen (0.46-4.63 μM) and surface chlorophyll-a concentrations (0.108-0.147 mg m-3), which increased near the equator. Contrary to that prediction, ecophysiology did not consistently track these patterns in all taxes [8].

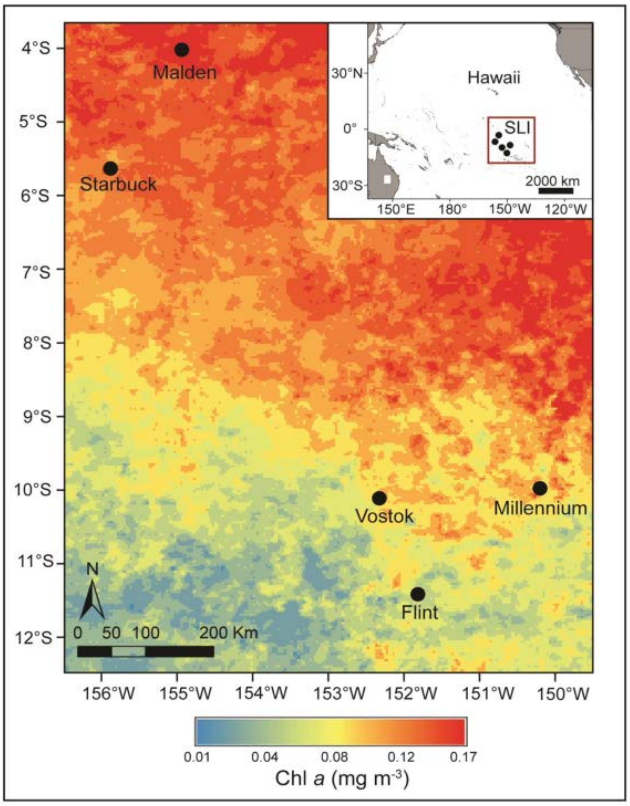

Fig. 2 Surface-ocean chi a during cruise [9].

As we all know, human activities are rapidly changing our environment. It is expected that the temperature will rise by 1-5 ℃ in the next century, and the input of nitrogen and phosphorus in the aquatic ecosystem will also increase. In the upper layer of the coral reef ecosystem, sleeping aquatic plants have a resource competition relationship with phytoplankton, which will improve the transparency of water, provide habitat as a food source for other organisms and provide their habitat. Carbon: nutrient stoichiometry of submerged aquatic plants is affected by changes in temperature and nutrient availability. According to Professor Mandy's research results, higher temperature leads to a higher carbon nutrient ratio by improving nutrient use efficiency. On the contrary, the addition of nutrients leads to a lower carbon nutrient ratio through the excessive absorption of nutrients. In the study of freshwater plants, Elodea nuttily grew on sediments composed of 100, 50, 25, and 12.5% pond soil/sand mixture at 10, 15, 20, and 25 ° C. To address the effects of climate warming and nutrient addition on carbon: nutrient stoichiometry of submerged freshwater and marine plants, a meta-analysis was also conducted on experimental studies of increasing temperature and/or adding nutrients (nitrogen and phosphorus). The C: N ratio of Elodea decreases with the increase of temperature, and this effect is most obvious at medium nutrient availability [8]. Therefore, due to the change of temperature caused by climate impact, the inorganic components in the aquatic ecosystem will fluctuate. Therefore, the increase in temperature will significantly change the proportion of nutrient elements in the coral reef system.

3.2. Effects of temperature on the mucous layer of coral surface

The change in temperature is different from the change in the coral mucus layer. In Professor Sonny t m Lee’s paper, we found that coral mucus may contain symbiotic bacteria that inhibit the growth of pathogens. Therefore, it is necessary to understand the dynamics of bacterial communities between coral mucus and tissues. Specifically, by sequencing the 16S rRNA gene amplicon, the top spore nucleus of the mouse was placed in a water temperature of 26°C-33°C, and the bacterial diversity in coral mucus and tissues was explored at the same time. The mucus and tissues of Paecilomyces maculatus are mainly composed of gamma-proteobacteria, but under heat stress, warts and alpha-proteobacteria are transferred to the bacteria. The members of cyanobacteria, Flavobacterium, and sphingosine bacteria also become more prominent at higher temperatures. The research results of Professor Johnson, M. show that at different temperatures, the dominant bacteria in the mucosal layer of the bacterial surface are very different. In addition, during the bleaching process, as the mucus increases each other, the relative abundance of endophytic algae in the tissue decreased [9].

3.3. Effects of Temperature on Intraspecific Competition in Corals

Take the Solomon Islands. The Solomon Islands, located at the southwestern boundary of the coral delta, are the center of global coral diversity in the Indian and Pacific Oceans. He is representative of the world's relatively healthy coral reef ecosystem. However, the report on the state of Solomon Islands coral reefs is based on monitoring conducted at five monitoring stations in 2003-2004 and 2006-2007. There is no information on how corals in the area are coping with recent global warming, bleaching and other local pressures. According to the research report of Danielle Daniele, Anna Metaxas, Robert Scheduling et al., there is a significant interspecific difference in hard corals in Solomon Islands reefs from 2016 to 2018 [10].

It is well known that the temperature of sea water increases with the global climate. Mass bleaching events will lead to mass coral loss across the tropics, and their frequency and severity are expected to increase. By the end of the century, 90% of the world's coral reefs will be gone. Professor Andre Aglotto's team in the Caribbean wondered if coral reefs could adapt to bleaching events that have occurred repeatedly over the years. Currently, no team can say how coral reefs adapt to coral bleaching each year. Here, they demonstrate for the first time that annual coral bleaching can significantly alter the heat tolerance of Gallebi corals. The high coral energy reserve and the changes in the type of symbiotic bacteria (symbiotic bacteria) in the dominant algae promoted the rapid adaptation of porous bacteria in the meristem.

In contrast, low energy reserve and lack of phenotypic plasticity of algae significantly increased the sensitivity of porous bacteria to the second-year bleaching. The phenotypic plasticity of dominant endosymbiotic Chlorophyta prevents repeated bleaching but may contribute to rapid recovery [11]. Therefore, years of bleaching events will change the coral population that is most suitable for the current environment, and this change often occurs.

4. Effects of coral reef bleaching on natural ecology and socioeconomics

4.1. Natural ecological effects of coral reef bleaching

4.1.1. Immediate effects on coral associates

Bleaching can weaken corals and, together with other secondary stressors, may lead to a range of problems resulting in an overall decline in coral health, including an increased incidence of disease [12]. Coral disease has been observed to be associated with bleaching and/or thermal stress, with bacteria increasing virulence and antibiotic resistance when corals experience thermal stress [13]. Although coral mortality varies widely due to different weather conditions and taxa affected, generally, most corals recover from bleaching events. However, severe bleaching events can lead to the extinction of some taxa and cause minor extinction of others. For example, overall coral mortality reached 90% on Cocos Island and 97% on the Galapagos Islands during the 1982-1983 El Niño bleaching event [14].

The implications of reef bleaching on diverse species can be catastrophic, even resulting in the obliteration of coral's critical organs. Many of these include the crustacean symbionts of coral. Coral host colonies assessed during the 1982-83 Panama bleaching event showed a dramatic decline in mucus production and the disappearance of crustacean symbionts as their condition deteriorated The feeding behaviors of Trapezia crabs also changed from collecting mucus from healthy corals to feeding in suspension on bleached corals [15]. When a coral dies, many of its partners die as they migrate from its host colony. This causes an increased risk of predation for the surviving coral species.

4.1.2. Longer term effects on micro-ecology

The recovery of coral with no mortality following bleaching can nonetheless lead to significant long-term sublethal effects. The coral bleaching process is characterized by a patchy appearance, and it may affect the entire colony or only certain areas like flanks, apexes, or terminal branches. It has been proven in a broad range of research investigations that a discontinuous distribution and/or spinning of founder organisms between certain corollaceous taxa may emerge from interconnections among environmental pressures. Environmental stress produces diverse reactions from various types of symbionts. Coral symbiont diversity may explicitly or implicitly impact bleaching patterns and coral community changes after bleaching events due to its distribution throughout colonies and species.

4.2. Socioeconomic effects of coral reef bleaching

In tropical coastal nations, coral reefs provide an array of ecosystem services that benefit the people and economies. Coral reefs produce food, money, and employment for millions of people; they provide major export and tourist earnings for economic development, and they fulfill critical tasks such as defending shorelines and assisting in the creation of beaches. Reefs are culturally valuable to coastal communities. Reef ecosystem systems are crucial to many countries' employment, nutrition security, and well-being. As a result, threats to coral reefs jeopardize ecosystems and species, posing direct threats to the communities around the globe that rely on them.

4.2.1. Reef-associated population

The coral reef ecosystem provides ecosystem services to around 850 million people worldwide, who are likely to benefit from them. Most of the inhabited coral reef countries and territories are developing nations [16]. Among them, 19 countries are considered least-developed (LDCs) due to their low incomes, limited resources, and vulnerable economies. Forty-nine reef nations are small-island developing states, where vulnerability is often compounded by high population densities, limited natural resources, geographic isolation, fragile economies, and susceptibility to environmental hazards such as hurricanes, tsunamis, and sea-level rise [17]. As a direct consequence, despite the lesser number of reef-associated populations, the proportional consequences of reef destruction might be significant.

4.2.2. Reef-associated fisheries

The fishing sector is amongst the most direct benefactors of coral reefs, relying on them for food, cash, and jobs. They also contribute significantly to poverty reduction. Coral reef fisheries are mainly small-scale artisanal fisheries, many of which are open systems with relatively low entry costs, making them particularly attractive to the poor and migrants [16]. Even with no fishing gear, some reefs are accessible, and gleaning (artisanal harvesting) is a popular activity carried out mostly by women and children. While most reef nations' statistics tend to understate the significance of reef fishing, employment numbers on the reef fishing industry have become more readily accessible as a result of recent large-scale socioeconomic research of tropical coastal regions.

4.2.3. Reef-associated tourism

Reef tourism supports 96 countries and territories in certain forms, and reef tourism contributes to at least 15% of the national GDP in 23 nations worldwide. Diver and snorkeler spending supports diving stores, accommodations, restaurants, and transportation, and in certain regions of the globe, tourist fees directly fund the maintenance of marine protected areas. In addition to recreational fishers (such as those in Australia, the Bahamas, and Cuba) and beachgoers, reefs in nearby regions also provide sand to beachgoers.

5. Conclusion

In this paper, methods of data collection and literature search is adopted to study coral bleaching. The main conclusions can be summarized as follows: (1)Coral bleaching is caused by repeated and long-term increases or decreases in sea surface temperature that shorten the function of coral reefs. Similarly, rapidly changing temperatures tend to cause higher mortality rates. (2)Reefs are limited to maintain in higher temperature and the old coral reefs ecosystem has changed to a new one with warmer temperature adoption ability, though they still have the limitation of much higher degrees. The northern coral reef groups seem to have better anti-thermal ability than the middle and southern groups.(3)Coral reef bleaching in GBR is significantly related to the temperature change from climate change and happens even in the deeper water, which is the result of long-period thermal pressure and fewer individuals' survival rate. (4)In conclusion, coral reef bleaching in GBR is significantly related to the temperature change from climate change and happens even in the deeper water, which is the result of long-period thermal pressure and fewer individuals' survival rate. (5)Due to the change of temperature caused by climate impact, the inorganic components in the aquatic ecosystem will fluctuate. Therefore, the increase in temperature will significantly change the proportion of nutrient elements in the coral reef system. (6)There are great differences in the dominant bacteria in the mucosal layer of the bacterial surface at different temperatures. In addition, during bleaching, with the mutual increase of mucus, the relative abundance of endophytic algae in tissues decreased. (7)Annual coral bleaching can dramatically alter thermal tolerance in Caribbean corals. Years of bleaching events will change the coral population that is most suitable for the current environment. (8)Coral reefs have a direct and long-term impact on coral associates and microecology. (9)Coral reefs are closely linked to socio-economic benefits, tourism and fishing. Declining coral reef populations can have negative effects. In terms of the future work, awareness of the location and severity of coral reef risks should be raised. The results can also facilitate changes in policies and practices to protect coral reefs and thereby improve the ecosystem or environment for the benefit of future generations and contribute to socio-economic development.

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