Possible Measurement to Coral Bleaching from the Perspective of Climate Change——Taking South China Sea as an Example

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Abstract. The overall objective of this paper is to discuss possible solutions to the global coral bleaching events induced by climate change. To make detailed demonstration, this paper take South China Sea(SCS) area as an instance. Graphs and information are acquired by using Matlab based on data from NOAA-CRW program. The conclusion of this paper is to raise three measurements, which are on-time heat stress watching with quick action in small rage, directional evolution by genetic modification, and transplant of the coral-based ecosystem to Refuge.

1. Introduction
Coral reefs support one of the most diverse ecosystem. Since 1970s, with increasing CO2 and Sea Surface Temperature(SST), coral bleaching has become severer, appearing more frequently. The situation exacerbated in recent years. As coral reefs are treasure forecosystem and coastal economy, coral degradation has been the central issue in global coral study. This paper apply the satellite based heat stress product on South China Sea(SCS) areas, and brings up two possible counter-measurement, which are genetic modification and refugee. These in combination can prevent future deterioration of coral in SCS areas to some extent. These measurements can also serve for all coral bleaching events, thus provide methods to mitigate the deteriorated coral-based ecosystem.

2. Analysis of the cause of coral bleaching
2.1 Mechanisms of coral bleaching
In most coral species, polyps are transparent, and the colorful pigments are attribute to endosymbiotic algae(See figure1).
When photosynthesis of zooxanthellae is inhibited due to climate change, such as accumulated heat stress, polyps will expel the ‘nonfunctional’ zooxanthellae as well as the pigments\cite{1}. What deserves to be mentioned is that, bleaching is not equivalent to death. Corals can maintain their life through energy flow in food web. While this status is no more than a stopgap, finally bleached corals will perish, converting from white to withered yellow (See figure 2).

2.2 Climate factors
Corals are sensitive to energy flows. Several climate factors can attribute to bleaching.

2.2.1 Temperature. Abnormal sea surface temperature is the dominant factor. At relatively high temperature (above 30°C), the photoinhibition will appear in coral endosymbiotic algae\cite{2}, photosynthesis of zooxanthellae will be totally shut down at higher temperature (above 34°C). Warner and his fellows regard the damage of photosystem II (PS II) as the determinant factor of coral bleaching\cite{3}. Berkelmans and his fellows point out that 1-2 celsius degrees above coral tolerance can induce bleaching, and weeks of heat stress can result in massive coral bleaching events. After bleaching, further heating may contribute to death of coral reefs.

2.2.2 Carbon dioxide (CO2) level and ocean acidification. After Industrial Revolution, the CO2 concentration has risen from 280 ppm to 410.31 ppm, still increasing at a rate faster than any other time in the previous 650,000 years\cite{4}. Carbonate acid is the dissolved product of carbon dioxide.

\[
CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \tag{1}
\]

Acidic environment will inhibit enzymatic activity as well as Aragonite saturation\cite{5}, which are both essential to the coral growth. The data shows that saturation concentration level in the ocean has fallen form 4.6-4.0 over the past century, mostly due to acidification. It is estimated that CO2 levels will reach 450 ppm sometime in 2030-2040, when coral bleaching will occur rapidly and may become irreversible.
If CO$_2$ in the atmosphere reaches 600ppm, the surface ocean will be adversely undersaturated as PH fall by 0.3 unite from 8.2 at present to 7.9. At this level, very few spots on earth are still have the required aragonite saturation for coral growth. When CO$_2$ reaches 800ppm, the PH will decrease more than half unit, the total dissolved carbonate ion concentration will fall at least sixty percent. Certainly no corals can evade from erosional status\cite{6}.

3. Corals in South China Sea (SCS)
South China Sea (SCS) locates in E99°39′ ~ 121°11′, N2°45′ ~ 23°24′, south to China mainland and Taiwan province, west to Philippines island and east to Indo-China Peninsula. So environmental factors such as SST vary greatly here. There are more than 200 islands in SCS, including Pratas Islands, Paracel Islands, Spratly Islands and Zhongsha Islands.

Although the South China Sea (SCS) is adjacent to the Coral Triangle, there’s little attention paid to this area. However, there are 571 coral species found in SCS, with wide distribution in surrounded islands, which in total take up 5 percent of coral areas in the world\cite{7}.

Affected by climate change, SST in SCS increased at a pace of 0.038°C- 0.074°C/year, with PH decreased at 0.012-0.014unit/year. Under such rapid environmental conditions, it is reported that most coral species have undergone significantly reduced during the past decades. Thus it is of great significance to obtain more information, control bleaching situation and find solution about coral bleaching the South China Sea (SCS) area.

This paper uses the polygon middle point (16.4500N, 112.0250E) as the representative location of whole SCS areas, whose SST data is presented in NOAA-CRW website.

4. Possible Measurement
Though there is no universal efficient method at present, several possible counter measures can be discussed.

4.1 Hotspot monitor mechanism
With the development of remote sensing and satellite data, it is practical and reliable to apply remote sensing technology in Sea Surface Temperature (SST) to monitor and forecast coral bleaching. With the product in NOAA-CRW program, several global massive bleaching events, such as in Great Barrier Reef and Caribbean Sea, were successfully monitored. So it’s practical to apply this product in SCS areas.

4.1.1 NOAA bleaching monitoring product. In 2000, the National Oceanic and Atmospheric Administration (NOAA) founded Coral Reef Watch (CRW) program. The remote sensing product of CRW include: SST Anomaly (SSTA), SST Bleaching Hotspot, Bleaching Degree Heating Weeks (DHW), bleaching alert zone\cite{8}.

4.1.2 Sea surface temperature anomaly (SSAT).
Sea Surface Temperature Anomaly (SSTA) directly shows global abnormal degree. SSTA is closely related to SST$_{climatology}$, which is the average SST in climatic scale (See figure 3).

\[
SST_{climatology}^{log, y} = \frac{D_{SST} - D_1}{D_2 - D_1} (SST_{c_{later}} - SST_{c_{early}}) + SST_{c_{early}}
\]  

(2)

In the equation, SST$_{c_{early}}$ represent the climatic temperature of the early month and SST$_{c_{later}}$ as that of the later month (current month). D$_1$ and D$_2$ are the date that SST$_{c_{early}}$ and SST$_{c_{later}}$ are released, and D$_{SST}$ is the date that SST is wanted.

SSTA is defined as the difference between daily SST and SST$_{climatology}$.

\[
SST_{anomaly} = SST - SST_{climatology}^{log, y}
\]  

(3)
4.1.3 Hotspot\textsuperscript{[9]}. Hotspot defines as the difference between SST and MMM\textsubscript{climatology}, which represent the extent that SST above the average temperature of the hottest month. MMM\textsubscript{climatology} is the maximum value of monthly-average SST\textsubscript{climatology}.

\[
\text{Hotspot} = \begin{cases} 
    \text{SST} - \text{MMM}_{\text{climatology}} & \text{SST} > \text{MMM}_{\text{climatology}} \\
    0 & \text{SST} \leq \text{MMM}_{\text{climatology}} \end{cases}
\] (4)

4.1.4 Degree Heating Weeks(DHW). To reflect the consecutively accumulated heat impact, DHW is defined as the accumulated Hotspot value that is greater than 1 in recent 12 weeks.

As 5km spatial resolution DHW data update everyday, there are 84 sets data in 12 weeks.

\[
\text{DHW} = \frac{1}{7} \sum_{i=1}^{84} \text{Hotspot}_i \quad \text{Hotspot}_i \geq 1
\] (5)
4.1.5 Bleaching Alert Area. With coral reef on-spot monitoring and satellite data, there will be bleaching to some extent if weekly DHW reaches 4 celsius degree, and massive bleaching appears if that exceeds 8 celsius degree a week.

4.1.6 Application in South China Sea (SCS)

- SST(3yr) Figure 5 is plotted with three-consecutive-year month average data in 2017-2019 (19th Aug). It is clear that there are five months (May & June & July & August & September) when Monthly Average SST are above the Averaged Maximum Monthly Mean (MMM), which indicates high possibility of coral bleaching events.

- SST(July 2019) Figure 6 plots the SST in July 2019. July is chosen as its Average Monthly SST is the highest. It is shown that SST of all the month, except the 31st July, is higher than the average maximum SST. This figure indicates significantly increase in SST in recently years, also lasting longer than before.

- Hotspot As what the six graphs below shows (Figure 7), the Hotspot reaches its maximum around 16th July and has a north tend movement.
Figure 7. Hotspot of 6 day in July(1 6 11 16 22 28)

The Hotspot trend in Parcel Island is shown in figure 8. Except for the last day, the whole July is featured by positive Hotspot. Though only five days above threshold, it is still not positive.

Figure 8. Maximum Hotspot in Parcel Island

· DHW The following four pictures(Figure 9) suggests that DHW value in SCS area is apparently higher than that in its adjacent area.
Figure 9. DHW in 4 weeks, represented by that of 4 choose date (1 11 22 28)

The DHW shows little change during the whole month, while all locate in bleaching interval. So the condition of corals are still not positive.

Figure 10. DHW in July, Parcel Island

- **Alert Area** Based on Maximum of bleaching Alert Area every seven day, the four-week Alert Area (Fig11) shows that most part of SCS is under bleaching threatened.
4.2 ‘Super Coral’
With long history of genetic enhancement on wild animals and plants, it’s possible to use genetic manipulation on coral conservation.

4.2.1 Corals Evolutionary Potential[9]
(i) Reproduce in both sexual and asexual approach which attribute to the high potential for trans-generational acclimation.
(ii) Lack of segregation of the germ cell from the somatic cell line
(iii) Naturally high levels of genetic diversity with interspecific hybridization possibility.
(iv) The existence of endosymbiosis which play an important role in resilience.

4.2.2 State of coral reef restoration[10]. Nowadays coral reef restoration approaches are mostly based on the asexually reproduction with coral fragments. These fragments, also named as “corals of opportunity”, are obtained from corals that have less degradation trend than others in disturbed areas. These fragments are directly explanted into another disturbed reef environment, expected to replace original damaged or degraded ones. This “coral nurseries” process has been proven a practical tools in coral reefs restoration, with more than 90 coral species successfully explanted around the world.

However, this approach can only be applied in areas where environmental conditions change in a relatively slow rate.

4.2.3 Assisted evolution approaches to enhance corals resilience. There are four approaches the accelerate the natural evolutionary process, which are incremental in the level of human intervention.
  · Acclimatization Stress exposure of natural stock to induce preconditioning acclimatization and transgenerational acclimatization through epigenetic mechanisms sense stricto.
Expose coral to nonlethal light or heat, which may lead to enhanced trans-generation tolerance to thermal stress. (e.g. Acanthochromis polyanthus have the second generation descendants with completely restoration in aerobic activity if parents are raised within high temperature.)

· **Symbiodinium introduction** The manipulation in composition of coral-associated microbes (eukaryotic and prokaryotic). Introduction of Symbiodinium is more efficient. Symbiodinium is the genes of the endosymbiosis dinoflagellates, divided into nine groups (A-I) with diverse genetic types. More than one Symbiodinium type exist in host coral at the same time, which attribute to numberless combination with different thermal tolerance limits. Though there is no compelling evidence in wild, we can be confident about as the ‘vacuum stage’ after birth is a perfect timing to translocate new Symbiodinium.

· **Prokaryotic community manipulation** There are thousand of prokaryotic communities per colony, serving in nitrogen fixation, sulfur metabolism and immunity against pathogen virulence. So the manipulation on community may also change coral’s heat resistance ability.

· **'Super Coral'** The instance of hybrid corals observed in Caribbean show similar, and sometimes higher, fitness with less decline facing climate change, suggesting that hybridization may be another approach to produce “super coral”. What is more, the fittest individuals can be subsequently served as the parent group for further breeding. However, it may lead to reduction in gene pools, making corals more vulnerable to other intervention.

### 4.2.4 Possible side-backs

There are reasons that why human directed genetically modified organisms are generally banned and criticized in wild. As the manipulation will generally endorse the organisms with competitive advantages, they are very likely to be invasive. Even for those non-modified species introduction in Africa, there are 37 of 44 are considered to be invasive.

### 4.3 Refugia

#### 4.3.1 Possible refuge location

It is estimated that SST will increase by 3°C this century which can lead to severe coral mortality and decrease in diversity. However, there are subtropical places where is exactly 3°C lower than that in SCS areas, such as Daya Bay of HongKong, which can be the the future refuge for coral.

![Figure 12: The SST trend in Parcel Island and HongKong](image)
It is predicted that the SST in Parcel Island (Xisha) will increase by 2.7°C at the end of 21 century. However, the SST in Hong Kong will increase to that in Parcel Island for now, which is around 28°C. Thus Hong Kong can be a possible refuge for the corals in SCS area.

What’s more, SST in Sanya has lower SST at present with lower growth rate, which can be the second group refuge in about 150 years when Hong Kong also is overheated.

4.3.2 Challenges.
- pH
As SST is not the only factor of coral bleaching, conditions such as PH should also taken into consideration. Based on gran titration method, pH decrease at a rate of 0.0142/year in Hong Kong water area, which greatly exceed the IPCC scenario rate of 0.003/year[14]. By the way, the pH decrease in Sanya is 0.012/year, which is not accepted either.
- 'immigration'
Future studies on how to migrate the whole coral-based ecosystem and whether the immigration will affect local natural balance need to be conducted.

5. Conclusion
As the result of global warming, coral bleaching has been the general problem for all coral reefs on earth. If no effective measures done quickly, the bleaching process will become irreversible in decades. There are methods to mitigate the heat stress effect on coral. With the product from NOAA-CRW and satellite SST data, we can predict heat stress thus take instant action on the first place of coral bleaching. The application of the system in SCS implies great possibility of bleaching events. What is more, human-directed acclimatization and genetic modification increase coral heat tolerance. Ecosystem migration to higher latitude can also avoid coral bleaching. However, all the aforementioned methods are no more than temporary measures. The fundamental way to eradicate coral bleaching is to stop global warming and atmospheric carbon dioxide concentration.

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