Biological Impacts of Global Warming on Coral Reefs: Lessons from Coral Bleaching Studies

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ABSTRACT

Most ecosystems on the earth, except deep-sea hydrothermal vent environments [1], are sustained by solar energy from the sun. The primary producers including plants and algae utilize solar energy to produce carbohydrates through photosynthetic activity. Since plant growth and development are highly affected by ambient temperature, temperature beyond the growth optimum, either higher or lower, potentially harms plants by acting as environmental stressors.

In certain plants and also in coral-algal symbiotic systems, only a few degrees increase in temperature causes growth inhibition and sometimes it is lethal. However, its fundamental mechanism for the action of heat stress on plants and algae remains yet obscure. In the context of global warming, the issue has become more important than before because many endemic species may go extinction due to elevated ambient temperature. Coral bleaching phenomenon, which can be ascribed to disruption of the symbiotic photosynthesis due to an increase in sea surface temperature (SST), is well known as an impact of global warming.

Many studies have suggested that high SST is a major cause for mass-scale bleaching events and it leads to a degradation of coral-reef ecosystems via mass mortality of reef-building corals. A recent model predicts more than a 1 °C increase in SST during the next half century, a situation that may result in disastrous coral bleaching on a regional as well as global scale. A heat-sensitive coral species that may be close to local extinction would be placed under greater threat by global climate change. Until recently, however, there have been a limited number of reports available on interspecies difference in bleaching tolerance. The absence of measurable indicators for the bleaching tolerance was a difficulty in research.

To explore species-difference in bleaching tolerance, simple and reliable measures are needed for comparisons. Applying PAM chlorophyll *a* fluorescence technique, we have demonstrated that recovery potential of photosystem II (PSII) in photosynthesis is an important determinant for bleaching tolerance in corals. Figure 1 shows a comparison of the recovery rates of three coral species under different temperatures. Although little effect on recovery is observed among them up to 28°C, species-specific differences become evident above 30°C [2]. This new parameter shows a good agreement with ecological observations.

It has been suggested that *Pocillopora damicornis* and *Stylophora pistillata* are typical bleaching-susceptible species that show high mortality under high SST conditions. Investigating a large number of corals, McClanahan et al. (2004) reported a clear species-dependence in bleaching-susceptibility and mortality in GBR and Kenyan reefs. These reports have provided the essential information on inter-species difference in bleaching tolerance but did not account for intra-species differences that have sometimes been observed in the field. Thus, exploration of such intra-species differences is also required to find out a practical way for preventing local extinctions of bleaching-susceptible species. We have shown substantial evidence that water-flow facilitates the survival of bleaching-susceptible

corals under high SST conditions and reduces photodamage of photosynthesis under strong light conditions, observations implying the involvement of water-flow effects in the intra-species as well as the inter-species difference of bleaching tolerance [3, 4].

In this talk I will present an overview of coral bleaching studies on a mechanistic aspect. Based on recent findings [5-7], some implications that should be taken into the consideration for the conservation of coral reefs will be discussed.

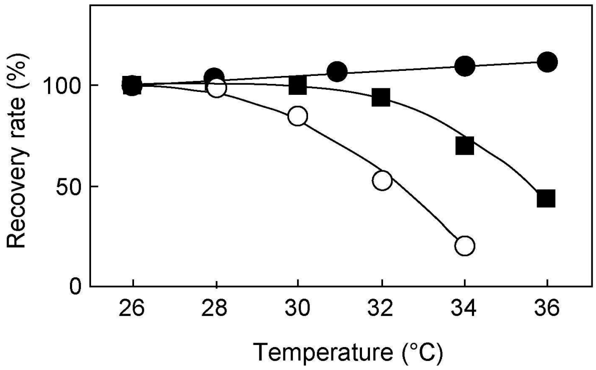

Figure 1. Temperature dependence of the recovery of damaged photosystem II (PSII) in coral species. Open circle, *Acropora digitifera*; closed circle, *Pavona decussata*; closed square, *Stylophora pistillata*. Redrawn from [2].
珊瑚在不同溫度下所吸收的受損光合系體（photosystem II, PSII）。空心圓圈：指形鹿角珊瑚；實心園圈：板葉雀屏珊瑚；實心方塊：萼柱珊瑚。摘自[2]。

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全球暖化對於珊瑚礁帶來的生物衝擊：珊瑚白化研究

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摘 要

除了深海熱泉生態圈[1]外，地球上絕大部份的生態系統都是藉由太陽供給熱能維持運作。植物及藻類等初級生產者則透過光合作用製造碳水化合物。既然周遭的溫度對於植物的生長及發育都有著很大的影響，那麼無論是造成高於或低於最適成長溫度的環境刺激，都有可能傷害到植物。

對某些植物還有珊瑚海藻共生的生態系統而言，溫度上升個幾度就會抑制其生長，有時甚至造成其死亡。不過目前關於熱刺激之於植物還有藻類等的作用機制仍究不得而知。這問題隨著全球溫度上升而有加遽的現象，因為許多瀕臨絕種的物種可能會隨著周遭溫度的上升而走向滅絕。全球暖化最著名的衝擊之一就是珊瑚白化現象，造成珊瑚白化的原因可歸咎於海平面溫度(Sea Surface Temperature, SST)上升，造成共生圈的崩解而無法行光合作用。

許多的研究結果都將造成大規模白化的元兇指向海平面高溫；珊瑚群的大規模死亡就是所謂的珊瑚白化現象，也是引起珊瑚礁生態系統的崩坍的主因。最近的暖化研究推估接下來 50 年內海平面溫度將再升高攝氏 1 度以上，如此一來將會引發區域性或是全球性的珊瑚白化災害。對溫度敏感度很高的瀕臨絕種珊瑚而言，全球氣候變遷將是很可怕的威脅。不過時至今日針對跨物種間抗白化差異程度的研究仍為數不多。在現階段未有有效測量白化程度的尺標造成研究實驗上的困難。

為了能夠更進一步探討不同物種間抗白化的差異程度，還是必須透過比較來找出簡單又可靠的測量方法。透過葉綠素光合測定法(PAM chlorophyll a fluorescence technique)，我們發現珊瑚在光合作用下吸收潛在的光合體系 II(photosystem II)正是抗白化的一項重要指標。三個不同的珊瑚物種在不同溫度下的吸收率比較如下圖一所示。雖在攝氏 28 度左右時差異不大，但到了物種差異性在攝氏 30 度以上時[2]就非常明顯。此一新的指標能夠與我們在生態觀察時的需求吻合。

細枝鹿角珊瑚(Pocillopora damicornis)及萼柱珊瑚(Stylophora pistillata)是典型易白化物種，也就是在海平面溫度較高的情況下其死亡率較其它珊瑚為高。McClanahan 等人(2004)在澳洲大堡礁及肯亞珊瑚礁發現了易白化以及死亡率好發率是跟珊瑚物種息息相關。那些報告為跨物種間的抗白化差異性提供了重要的資訊，卻沒有將常見的同種內差異列入考量。所以我們須要更進一步探討同種內的差異性，才可以更實際的預防易白化物種發生本土性區域性滅絕。我們有充份的證據顯示流水裝置有助易白化珊瑚在海平面高溫的狀況下存活，並且能夠在強光的情形下減少光合作用帶來的光害。同時我們也觀察跨物種以及同物種內在有流水裝置的情況下抗白化差異程度。

我的報告中將會以機能的觀點切入關於珊瑚白化研究。其中也將根據一些近來的研究結果[5-7]，深入探討珊瑚礁保育的重點。