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Coral bleaching: Processes, extent and implications: A Review

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ABSTRACT - Coral reefs are threatened by several environmental factors including bleaching, where they lose their symbiotic zooxanthellae and this occurs in certain processes. It is very difficult to relate bleaching events to a single factor and such phenomena can cover wide geographical spots in the world's oceans and it will affect fisheries and tourism.

INTRODUCTION

Coral reefs are threatened by several environmental impacts around the globe that may seriously damage and degrade them. Among these impacts is coral bleaching; where the tissues of corals either lose their photosynthetic zooxanthellae (symbiotic *Symbiodinium* dinoflagellate algae) or loss of pigments from the zooxanthellae without being expelled due to many factors (or combination of factors) like pollution, anthropogenic stress, predation, erosion, sedimentation, salinity variation, bacterial infection, exposure at low tide, solar radiation (including ultraviolet radiation) or the elevation of sea surface temperature due to global climate change (such as El Niño and La Niña), which is the most important factor among all. For instance, a discharge of hot water from relatively calm lagoons can cause bleaching. Furthermore, cold water could also cause bleaching, such as that from precipitation, which shows the effect of temperature fluctuations too (Hoegh-Guldberg and Smith 1989; Szmant and Gassman 1990;Glynn, 1993; Fitt and Warner 1995; Goreau *et al.*, 2000; Loya *et al.*, 2001; Porter and Tougas, 2001; Andréfouët *et al.*, 2002; McClanahan, 2004; Coral Reef Impacts of the 2005 Caribbean Bleaching Event, 2009; McWilliams *et al.*, 2005; Fabricius 2005; Report on the mass coral bleaching event in Tobago, 2005; Trapido-Rosenthal *et al.*, 2005; Côté and Reynolds, 2006). Zooxanthellae are vital to the corals in which they provide them with photosynthetic derived nutrients along with the promotion of calcification and they are more sensitive to stress than corals (Douglas, 2003; Edmunds *et al.* 2003; Trapido-Rosenthal *et al.*, 2005) and they are of different clades and some of them can tolerate high temperature (clade D considered to be the most thermo-tolerant *Symbiodinium* dinoflagellate) but it also depends on the species of the coral in terms of temperature tolerance (Mise and Hidaka, 2003; Harithsa *et al.*, 2004; Obura, 2005). It is also possible that corals could exhibit new clades of symbionts after bleaching, from ones that are less thermo-tolerants to others which are more thermo-tolerant (Baker *et al.* 2004; Fabricius *et al.* 2004; Rowan 2004; van Oppen *et al.*, 2005). It is very difficult to relate bleaching events to a single factor of the ones mentioned since factors such as raise of water temperature is usually accompanied with high solar radiation (Report on the mass coral bleaching event in Tobago, 2005).

The earliest description for this event was performed by Boschma (1925, 1926), who concluded that this was a process where coral polyps digesting the symbiont algae at the mesenterial filaments where the zooxanthellae had aggregated. Followed by Yonge and Nicholls (1931a,b) who reinterpreted this process to be an active removal of zooxanthellae (or bleaching) of the coral that could occur in response to various types of stress including temperature as explained earlier. Moreover, coral bleaching was locally observed occasionally in the 1800s and mass coral bleaching events were unknown prior to 1982 (Williams and Bunckley-Williams, 1990; Glynn, 1996) but by the 1990s, coral bleaching was reported somewhere nearly every year (e.g. Hoegh-Guldberg, 1999).

Coral bleaching has been reported to be a major threat for corals and it is rapidly increasing since 1980’s (Coles and Brown, 2003; Douglas, 2003, McWilliams *et al.*, 2005; Trapido-Rosenthal *et al.*, 2005). Corals could die due to bleaching and could recover and survive (McClanahan, 2004; Côte and Reynolds, 2006). Corals suffer the decline in protein, lipids and carbohydrates due to bleaching. Furthermore, corals also suffer from a decline in skeletal growth, long-term fecundity (long after bleaching, reproductive failure or delay of spawning of one year and reduced ability to reach complete gametogenesis) in addition to tissue necrosis (Goreau and MacFarlane, 1990; Szmant and Gassman, 1990; Glynn, 1993; Coles and Brown, 2003; Mise and Hidaka, 2003). Macro-invertebrates and fish that are symbionts or directly consume living corals would be as diminished as their coral hosts and it is difficult to predict the total results of pervasive coral bleaching for the majority of reef organisms which are not directly linked to corals (Coles and Brown, 2003). Sometimes after bleaching, a shift of dominant feeding groups of fish assemblages occurs but no overall decrease in population (Wellington and Victor, 1985; Lindahl *et al.*, 2001; Coles and Brown, 2003). In some cases reported (e.g. Halford, 1997) macroalgae dominated corals in northwestern Australian Bay after bleaching, where large-scale mortality of corals and fish occurred due to hypoxia. This led to the dominance of herbivorous scarids. Furthermore, indistinguishable recruitment of fish in terms of number and diversity was noticed three years after a bleaching event at the Great Barrier Reef. At that time, a reduction of coral cover (>75%) occurred (Doherty *et al.*, 1997). Moreover, declination was observed in hepatocyte vacuolation (sublethal effect) in populations of *Chaetodon lunulatus* likely due to the decline in quantity and/or quality of coral prey (Pratchett *et al.*, 2004), since this species feeds selectively on living tissues of scleractinian and alcyonacean corals (Anderson *et al.*, 1981). In addition, Mass coral bleaching severely limits the ability of fish to locate alternative habitats (Wilson *et al.*, 2006). Furthermore, bleaching undermines the capacity of coral reefs to provide shelters for fish to breed and to protect other fragile marine ecosystems (Quarless, 2007).

Several bleaching events occurred over the years and still occurring but the mass bleaching event that has occurred all over the oceans from mid-1997 to the last months of 1998, where corals in Atlantic Ocean, Caribbean Sea, Indian Ocean, Middle East, east and west Pacific Ocean, Southeast and East Asia experienced huge range of bleaching (Wilkinson, 1998). These bleaching events coincided with a large El Niño event, immediately switching over to a strong La Niña and it is considered to be the largest recorded bleaching event in all history.

Largest damage was observed throughout the Indian Ocean and the western Pacific. For instance, bleaching in some areas around Bahrain (shallow water area of the Arabian Gulf) was 100% with mortalities of 90-95%. Furthermore, bleaching occurred to corals down to 30 m depth in Puerto Rico, Caribbean Sea (Hoegh-Guldberg, 1999; Wilkinson *et al.*, 1999; Wilkinson, 2000; Rezai *et al.*, 2004). In Tobago 2005, bleaching was greater than 85% in 31 sites of the total 88 sites around the island (in some it was 100%) and the percentage of bleaching differs from species to species (Obura, 2005). Furthermore, 66% was the overall mean bleaching of hard coral cover, with a mean of 71% at the deep sites and at a mean of 63% in shallow sites (Report on the mass coral bleaching event in Tobago, 2005). Moreover, other extensive bleaching events have occurred in the Caribbean on the year 2005 at Belize, Jamaica, St. Lucia and the British Virgin Islands but with insignificant mortalities (Coral Reef Impacts of the 2005 Caribbean Bleaching Event, 2009).

Processes of bleaching variously reported including exocytosis, apoptosis, necrosis and coral detachment (Gates *et al.*, 1992; Brown *et al.*, 1995). In corals and other cnidarians, production of oxygen free radicals or other toxic forms of oxygen in the symbionts and coral's tissue precedes bleaching, subsequently causing cellular damage and expulsion of symbionts (Lesser *et al.*, 1990; Lesser, 1997). Furthermore, prior to the loss of zooxanthellae, great reduction of chloroplasts with an increase of vacuolation and presence of lipid vacuoles in a large proportion of the algal cells occurs. As a result, cell degradation increases along with coral bleaching (Salih *et al.*, 1998; Salih, 2001). Generally, processes of bleaching could be summarized into three general types with respect to high temperature; Physiological bleaching, algal-stress bleaching and animal-stress bleaching (Fitt *et al.*, 2001).

1. Physiological Bleaching:

The amount of temperature and/or solar radiation inversely correlated to the density of zooxanthellae present on corals. This shows that in order for the coral to have more symbionts, it should possess more tissue to contain them. Therefore, there is a seasonal variation regarding the amount of tissue and its associated zooxanthellae, where the maximum is generally during low temperature and low solar radiation times and the minimum during the highest level of temperature and solar radiation (Fitt *et al.*, 2001).

2. Algal-Stress Bleaching:

This type of stress is related to the raise in solar radiation and temperature levels previously described. Although normal diel changes in the routing of PAR (photosynthetically active radiation) photons occur at midday (probably to prevent damage to the photosynthetic pathway), excessively high levels of PAR are able to cause degradation in components of this photosynthetic pathway, which will result in the death of the affected algal symbionts.

3. Animal-Stress Bleaching:

Corals that are exposed to rapid and large changes in temperature may shed the gastrodermal tissue layer that contains the algal symbionts. Taking into account that symbionts in this case are victims of bleaching and not instigators (Gates *et al*., 1992). This extreme reaction is unlikely to occur in most sea conditions and the effect does not play a significant role in widespread bleaching events (Fitt *et al*., 2001).

In addition, high solar radiation and elevated temperature will lead to the expression of the cell cycle gene *p53*, a gatekeeper and modular of the cells damaged between DNA repair processes and pathways of apoptosis (Lesser and Farrell, 2004).

This phenomenon is expected to become more frequent (annual or biannual) and more severe in the upcoming decades (Hoegh-Guldberg, 1999; Sheppard , 2003; Donner *et al.*, 2005), in which an entire degradation could occur throughout the entire reef systems (Goreau *et al*., 2000). So we as humans must try to reduce global warming since bleaching could eliminate shallow water reefs in decades (Hallock, 2005) and anthropogenic inputs into the oceans so we can protect corals and their associated biota, mainly fish. Since when there is a combination of coral bleaching, storms, high fishing pressure and pollution, the recovery of reefs will be inhibited after disturbance, so coral reef communities might be suppressed in early stages of succession, which will result in keeping a low species richness (Hoegh-Guldberg, 1999; Wooldridge *et al*., 2005; Wilson *et al*., 2006; Mangi and Roberts, 2007).

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تبييض الجزر المرجانية: العمليات، المدى والتأثيرات
مراجعة عامة

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المستخلص الشعاب المرجانية مهددة بعدة أخطار منها التحول إلى اللون الأبيض بسبب خسارتها للعوالق النباتية التي تعيش عليها في علاقة تعايش بطرق محددة كما أنه من الصعوبة إرجاء هذه الحادثة لعامل واحد، ويجب الإشارة إلى أنه بإمكان هذه الظاهرة أن تغطي مساحات جغرافية واسعة من بحار العالم مسببة أضرارا جسيمة للبيئة والثروة السمكية والسياحة.