Corals at the Edge: Potential Threats of Coastal Habitat Alteration on Coral Reef

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Background Nature itself may not be as fragile as we thought. Even if it was exposed to a drastic anthropogenic alteration, it can go through some kind of transitional phase, then reforms into another type of ecosystem that suits to the given condition. However, in a sense of 'ecosystem service' (that most of us are depending on), nature seems to be so fragile. We are now losing many of the great gifts that our ancestors had been received 'naturally'. Coral reef is not an exception. In coral reef, loss of the relatively fast-growing and visually-dominant branching corals is likely to have a noticeable impact on the aesthetics of many reefs, as well as altering the amount of available habitats for numerous reef-dependent species such as fishes and invertebrates. Such a drastic change leads to a significant shift in community structure of coral reefs to macro-algae dominated ecosystem. The ultimate outcome will affect the local economics and social systems in tropical islands where many fisheries, tourism, and domestic culture depend on the well-established coral reef ecosystem.

Coral reef is one of the most biologically diverse ecosystems on the globe in which reef-building corals play an important role as a trophic foundation of the ecosystem. In reef-building corals, obligatory mutualistic symbiosis with the photosynthesizing unicellular algae called zooxanthellae maintains the energy budget of the host animal. Under stress conditions, a paling phenomenon commonly referred to as coral bleaching occurs through the dissociation of zooxanthellae from the host or the loss of photosynthetic pigments from algal cells that remain within the host tissue. Mass-scale coral bleaching events have frequently been reported in the years with higher-than-usual water temperature. Due to deteriorative influences on the corals such as reduced growth, reduced reproductive capacity, increased susceptibility to diseases, and higher mortality rate, mass-scale bleaching events have been threatening coral reef ecosystem globally.

Management issue The need for management strategies against mass coral bleaching is now well recognized. The incidence and severity of mass coral bleaching events has increased continuously over the last two decades. As a result, almost every coral reef region in the world has now suffered extensive loss of live coral cover; coral reef ecosystems are in 'Crisis' situation. It has been suggested that the impacts of mass coral bleaching events will largely determine the condition of coral reefs in the next 50 years in combination with those from chronic local stressors. Because the major cause of mass scale bleaching is thermal stress that is related to the global warming trend, it is very much difficult to remove the major stressor. However, minimization of the combined effects of thermal stress and local stressors is more realistic for effective and practical coral reef management strategies.

Water flow as a potential mitigation factor Water motion in coral reef environment is diverse in both temporal and spatial scales produced by tidal currents, wind driven waves which are often magnified or reduced by surrounding topographic conditions. For example, a flow velocity measured in channel area often exceeds 30 cm s^{-1} and reaches up to 100 cm s^{-1} at its maximal velocity while the mean velocity in a typical sheltered habitat is usually below10 cm s^{-1}. These natural variations of water motion affect various biological aspects of coral reef organisms. Presenting our recent findings, we will discuss about potential threat of coastal habitat alteration such as land reclamation, dredging, port/marina developments that may affect local-scale movement of water mass. There are four potential processes that may determine the ultimate impacts of mass coral bleaching following a regional heat stress: 1) resistance to bleaching, 2) tolerance of corals, 3) coral colony recovery from bleaching and 4) recovery of live coral cover through new recruitment. Each process can be affected by the local-scale hydrodynamic conditions.

Water flow experiments Although the productivity of coral reefs is ultimately attributable to the photosynthetic activity of zooxanthellae, the algae become unable to process sun light without producing harmful radicals under the condition of increased temperature. When the radical production reaches its threshold level, coral-algae symbiosis is disrupted and the zooxanthellae either degenerate or released. Hence, corals appear to be 'bleached'. The amount of water exchange around a coral colony during thermal stress can be critical and has been hypothesized to influence the severity of bleaching. We hypothesized that an increased water flow enhances the flushing of toxins that are by-products of cellular processes in impaired photosynthesis. We tested the hypothesis by conducting an empirical experiment by comparing the bleaching-related mortality of a coral *Acropora digitifera* under both faster-flow (20 cm s^{-1}) and limited-flow (< 3 cm s^{-1}) conditions. Even when these two treatments were applied to corals grown under thermally stressful conditions (maximum daily water temperature of 33.6 ℃), there was 0 % mortality observed in faster-flow treatment whereas 100 % mortality were observed under the treatment of limited-water motion. A long term study (> 20 months) using two other branching coral species *Pocillopora damicornis* and *Stylophora pistillata* also showed less bleaching severity (or at least delay the onset of bleaching) under faster flow conditions (20 cm s^{-1}) in contrast to the limited flow conditions (< 3 cm s^{-1}) where greater mortality were observed. In addition to the mitigation of bleaching severity, the colony growth rates were doubled in both coral species with densely formed branches under faster flow conditions.

Coral leaching does readily not cause mortality, and if stress subsides before the host mortality occurs, zooxanthellae can repopulate. However, oftentimes, the post bleaching impacts are harsh. Since a faster water motion around a coral colony promotes a greater molecular exchange through reducing the diffusion barrier between coral and surrounding water mass, it was hypothesized that a reduced water flow limits the nutrient uptake that is necessary for zooxanthellae repopulation process. Our experimental study conducted on artificially bleached colonies of *S. pistillata* have confirmed that repopulation of zooxanthellae from bleached conditions was slower under a limited-flow treatment (34% of non-bleached colonies in 7 weeks) compared with a faster flow treatment (70% of non-bleached colonies in 7 weeks). Corals that showed less bleaching and shorter period of bleaching duration would be less affected from post-bleaching impacts. Hence it is expectable that higher water-flow keeps coral reef resiliency.

Photo-physiological effects In order to provide logical supports for these water-flow effects on corals, we are now investigating photo-physiological responses of coral-symbionts using PAM chlorophyll fluorometer, a non-destructive method for monitoring photosynthesis of zooxanthellae. As we mentioned the above, the disruption of symbiont photosynthesis by excessive light energy, termed as photoinhibition, is a key process of coral bleaching phenomenon. Therefore, we have investigated photo-physiological stress responses of various coral species against high water temperature, strong irradiance and limited water-flow conditions. In *A. digitifera*, a bleaching susceptible branching coral species, flow-mediated mitigation of photo-physiological stress in zooxanthellae was highly effective during the period of strong irradiance and high water temperature. In addition, comparative studies are undertaken using several coral species with various stress tolerances to strong light or high water temperature conditions. Our results indicates that there are highly bleaching susceptible coral species that depend on water-flow-mediated stress mitigation. We suggest that the present pattern of water circulation acts on many bleaching susceptible coral species as potential mitigation factor against thermally-induced-bleaching. In another word, if perturbation in local scale water flow pattern occurs, it is likely that the amount of damage from a single thermal stress event could become worse in a negatively affected area.

What we should consider Concept and theory for the design and application of terrestrial reserves is based on our understanding of environmental, ecological, and evolutionary processes responsible for biological diversity and sustainability of terrestrial ecosystems as well as on knowing how humans have influenced these processes. How well this terrestrial-based theory can be applied toward the design and application of the coastal marine reserve depends on the degree of similarity between these systems.

There exist several marked differences in ecological processes between marine and terrestrial ecosystems. These differences are rooted in as ramifications of fundamental differences in their physical environments (i.e., relative density, heat conductance, prevalence of air and water) and contemporary patterns of human impacts. Most notably, the extent and rate of dispersal of nutrients, materials, planktons, and reproductive propagules of benthic organisms expands to the scales of regional connectivity among near-shore communities and ecosystems. Such differences appear to be particularly significant for the groups of organisms that have been most exploited (damaged) and targeted for protection in coastal marine ecosystems (fishes and macroinvertebrates including reef-building corals). These differences between marine and terrestrial ecosystem may imply the necessity of well-considered application of reserves in the marine environment.

Prospects The role of water flow in mitigating the impacts of thermal stress on corals is under investigation. However, the practicality as a strategy for management intervention needs to be assessed. Although this presentation does not aim to offer immediate 'cure' for bleaching, it would provide a potential clue to prevent a greater loss of live corals by supporting and enhancing the natural ability of reef-building corals to survive, or to recover from bleaching events. Environmental issue tends to misunderstood as a issue of biology, chemistry, or ecology. However, because they are involved in the maintenance processes of marine ecosystems, especially a coral reef ecosystem, there are many issues that cannot be understood or solved without a detailed understanding of physics of seawater or atmospheric dynamics. In order to establish a more effective and reliable management strategy under increasing potential threats from global change, we will have to integrate our knowledge from a molecule to the globe.