Characteristics of coral reef islands and impacts of agriculture on coral reefs

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ABSTRACT

Most islands in the Tropics and Subtropics are surrounded by coral reefs that are inhabited by many kinds of organisms. However, the environmental conditions to which coral reefs around the world are exposed have been declining in recent decades. Coral reefs are utilized not only as tourism resources, but also as fishing grounds. The conservation of coral reefs is now an urgent issue. Coral reef ecosystems have been damaged by numerous factors, such as unusually high temperatures, outbreaks of corallivore organisms, sedimentation, eutrophication, and pollution. The latter 3 factors have a strong correlation with tropical agriculture. In this paper, case studies of the effects of agriculture on coral reefs are introduced, and countermeasures to reduce the impact of agriculture on the coral ecosystem are discussed.

Introduction

Islands in tropical and subtropical regions are generally surrounded by shallow coral reefs. A coral reef is a rigid limestone structure that has been shaped over thousands of years by calcareous organisms, mainly stony corals. The scale of coral reefs is extremely large, sometimes over 1300 m thick from the surface down to its base on volcanic rock (Enewetak Atoll), or over 2000 km long (Great Barrier Reef) (Birkeland, C. 1997). In principle, coral reefs are topographically classified into three categories: 'fringing reefs', 'barrier reefs' and 'atolls' (Veron J.E.N., 2000); however, fringing reefs are the most common in tropical and subtropical islands. Fringing reefs extend up to a few kilometers from the coastline out to the sea, and protect the coast from wave erosion. A coral reef is a natural breakwater.

One of the characteristics of coral reef ecosystems is their extremely high biodiversity, comparable to that of rainforests. Stony corals (hereinafter referred to as corals) are major constituents in coral reef ecosystems. Corals belong to the phylum Coelenterate, which contains hydras, jellyfish and sea anemones. Most corals possess symbiotic unicellular algae called zooxanthellae. Zooxanthellae give photosynthetic products to the host coral; hence, corals play the role of primary producer (as do plants in terrestrial ecosystems) in the coral reef community, in spite of being animals. Mucus and living tissue of corals are important energy sources for other animals, including fish. Colonies of corals occur in a great variety of shapes and sizes, and create shelter for other vulnerable species. Corals are, as just described, indispensable in coral reef communities.

Many kinds of organisms inhabit coral reefs, some of which (fish, shells, squids, turtles and seaweeds) are harvested as fisheries resources. Coral reefs are, in fact, important areas for fisheries in tropical and subtropical regions. In particular, people in developing areas depend for a large proportion of their food on products from coral reefs. Conservation of coral reefs is thus very important not only for protecting the

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natural environment, but also for sustaining fisheries resources.

Threats to coral communities

Coral reefs worldwide are now facing an environmental crisis due to several factors. Unusually high temperature is one of the factors degrading coral reefs. Over the past one hundred years, the temperature of sea water in many tropical areas has been rising because of global warming. Corals are very sensitive to high temperature. At above a threshold temperature of 30–32 °C, corals release the zooxanthellae from the body and their color gradually turns white; this process is called "bleaching". The bleached coral eventually die unless the temperature returns to below the threshold. The worst bleaching event occurred in 1988, and coral communities worldwide suffered severely damage (Aronson R.B. *et al.*, 2000; Berkelmans R. & Oliver J.K., 1999; Fujioka Y., 1999; McClanahan T. *et al.*, 2002; Pillay R.M. *et al.*, 2002; Spalding M.D. & Jarvis G.E., 2002).

Population explosions of corallivore species are also having a major impact on coral communities. In particular, outbreaks of the crown-of-thorns starfish (*Acanthaster planci*) have frequently occurred and devastated coral communities throughout the Indo-Pacific (Moran P. J., 1986; Nishida M. & Lucas J. S., 1988; Yamaguchi M., 1986). The starfish have remarkably high reproductive abilities. A single female can produce up to 60 million eggs in a breeding season, allowing populations to grow rapidly under favorable conditions. The mechanism of the outbreak is unknown yet; however, eutrophication (sometimes related to agriculture) is suspected as a cause.

The third factor is sedimentation. In tropical and subtropical regions, it often rains very heavily. Heavy rain removes soil from farmland or bare ground, and the eroded soil is carried by rivers into the coral reef. The soil is deposited on corals and impedes their respiration. It also causes a reduction in underwater visibility, interfering with the photosynthesis of zooxanthellae.

The fourth is eutrophication. Eutrophication is often associated with sedimentation. The nutrition levels of water columns in coral reefs are basically very low, and this is the reason for the low density of plankton and extremely high underwater visibility. Terrestrial run-off that includes large quantities of nutrients causes an imbalance in the coral reef ecosystem, since it stimulates the growth of phytoplankton and algae. Increased phytoplankton leads to reduced water visibility and may result in an outbreak of the crown-of-thorns starfish. (The planktonic larvae of starfish feed on phytoplankton.) There is a competitive relationship between corals and algae in occupying coral reef grounds. Increased algal growth caused by eutrophication thus leads to reduction of coral cover.

The fifth item is water pollution. Various contaminants such as detergents, heavy metals and agricultural chemicals flow into coral reefs and cause serious problems. These contaminants directly affect the physiology of corals. Among the factors above, sedimentation, eutrophication and pollution are strongly related to agriculture in tropical and subtropical islands.

Effects of agriculture on coral reefs

I review here some case studies regarding the effects of agriculture on coral reefs in Australia and Japan. Australia is a leading country in coral reef science, and enormous volumes of data regarding coral reef ecology, hydrology and land use have been published. In Japan, attention has been focused on soil erosion from reclaimed land, including farmland. These kinds of data are sparse in other regions where coral reef diversity is extremely high, such as Indonesia, the Philippines and other developing countries.

1) Australia

The Great Barrier Reef (GBR), the world's largest coral reef, is located off the coast of Queensland in north-east Australia. The GBR stretches to over 2000 km in length, and is comprised of about 3000 reefs and

900 islands. In 1981, UNESCO inscribed the GBR as a World Heritage Site.

Prior to the European settlement of Australia (mid-1800s), a mix of forest and woodland vegetation covered 96% of the GBR catchment. During the last 150 years, however, the areas covered by native forests and woodlands have decreased to 80% of the GBR catchment, due to land clearing or vegetation thinning for cropping and grazing (Furnas, M., 2003). Removal of vegetation directly reduces the retention capacity of soils, leading to soil erosion and increased sedimentation that directly affect coral reefs. It is sugarcane that is predominantly cultivated in the GBR catchment. Much of the sugarcane fields are restricted to a coastal strip between the World Heritage rainforest and reef areas. Sugarcane cultivation is supported by extensive use of fertilizers. The application of fertilizers to the GBR catchment has increased over the last 50 years, since both the harvested area and the rates of fertilizer use in sugarcane cultivation have continued to increase (CRC Reef Research Centre, 2003). For these reasons, agriculture is regarded as being the primary source of sediments and nutrients in coral reefs (Haynes D. & Michalek-Wagner K., 2000). Fabricius *et al.* (2005) surveyed marine biota along the water quality gradient in two regions (Queensland) with contrasting agricultural land use. They found that macroalgae increased with rising nutrient levels, while the abundance of corals decreased. (Brodie J. *et al.*, 2005) reviewed past studies regarding the crown-of-thorns starfish, and stated that frequent outbreaks of the starfish on the GBR were strongly linked to increased nutrient levels.

Agricultural chemicals, as well as sediments and nutrients, are suspected to be involved with coral reef degradation. In particular, diuron, a phenylurea herbicide, used extensively in sugarcane cultivation for pre-emergence weed control, has come into the spotlight (Bengtson Nash, S.M. *et al.*, 2005; Duke N.C. *et al.*, 2005; Haynes D. *et al.*, 2000a; Haynes D. *et al.*, 2000b; Jones R.J. & Kerswell, A.P., 2003; Jones R.J. *et al.*, 2003; Negri A. *et al.*, 2005). Diuron targets the photoreduction site of photosystem II in the chloroplasts of plants and algae. Corals are damaged by diuron, since corals are strongly dependent on the photosynthetic products of zooxanthellae. Diuron can inhibit the photosynthesis of zooxanthellae isolated from corals at 0.25 μg/l (Jones R.J. *et al.*, 2003) and zooxanthellae within the coral tissue at 0.3 μg/l (Jones R.J. & Kerswell A. P., 2003). On the other hand, fertilization of coral oocytes and metamorphosis of coral larvae were not inhibited at diuron concentrations of up to 1000 and 100 μg/l, respectively (Negri A. *et al.*, 2005). These results indicate that diuron damages the photosynthesis of zooxanthellae in spite of its effect on coral itself being minimal. In addition to zooxanthellae in corals, herbicides are also harmful to seagrasses and mangroves. Extensive losses of seagrass beds have occurred in Australia (Walker D.I. & McComb A.J., 1992). Diuron can inhibit the photosynthesis of the seagrass *Halophila ovalis* at 0.1 μg/l (Haynes D. *et al.*, 2000b). Northern Queensland nearshore sediments are contaminated with a range of herbicides (Haynes D. *et al.*, 2000a), and in particular, the marine sediment concentration of diuron is high enough to inhibit the photosynthesis of seagrasses (Haynes D. *et al.*, 2000a; Haynes D. *et al.*, 2000b). Large areas of mangrove trees have also died within several estuaries in the Mackay region of Queensland (Duke N.C. *et al.*, 2003). Diuron concentration in sediments was negatively correlated with mangrove health, suggesting that diuron was the major cause of the severe mangrove dieback in the region (Duke N.C. *et al.*, 2005).

2) Japan

Okinawa Prefecture is the most southwestern part of Japan, and consists of hundreds of small islands, most of which are surrounded by shallow coral reefs 1–2 km wide, called fringing reefs. The population density of Okinawa is extremely high. In 2005, 1.36 million people were living there, at a population density of 580/km^2. That of Queensland is only 2 /km^2.

Okinawa was under US administration for 27 years following the end of World War II, and was restored to Japan in 1972. The Japanese Government then embarked on a large-scale investment program to stimulate the Okinawan economy. Deforestation and development for urbanization and agriculture have since been actively conducted. Most the Okinawan islands are covered with red soil, which consists mainly of fine particles (clay) which is easily dispersed due to a lack of organic matter (Matsuzaka Y. *et al.*, 1971; Omija

T., 2003). Okinawa often experiences downpours. Every time it rains heavily, huge amounts of red soil are eroded from both reclaimed land and farmland. This is a major cause of the severe degradation of coral reef communities observed throughout Okinawa since the restoration (Nishihira M., 1987; Yamazato K., 1987).

In 1995, Okinawa Prefecture implemented a red soil prevention ordinance for construction projects of area greater than 1000 m^2, which compels developers to reduce the suspended solids (SS) discharged from the ground to 200 mg/l or less. If land reclamation is conducted in red soil areas without any countermeasures, SS levels can reach 10 g/l. The ordinance therefore demands that developers cut 98% of their soil run-off (Omija T., 2004). The Okinawa Prefectural Institute of Health and Environment has measured SPSS (content of Suspended Particles in Sea Sediment) in inshore coral reefs throughout Okinawa since 1983. Omija *et al.* (2002) compared the SPSS data before and after the enforcement of the ordinance, and concluded that red soil discharged from construction projects had been significantly reduced, while that from farmland had not. This is because the ordination targets construction projects, not agriculture.

In Okinawa, farmland occupies 18% of total land area, and 53% of farmland is used for sugarcane cultivation. Sugarcane growers in Okinawa also use fertilizers and herbicides (including diuron), as in Australia. Unfortunately, little data is available regarding eutrophication or pollution in Okinawan coral reefs caused by agriculture. In addition to red soil, these kinds of data should be tracked to monitor the effects of agriculture on coral reefs.

Compulsory measures to conserve coral reefs environments

A comparison of case studies in Australia and Japan shows that coral reefs in both countries have been degraded in a similar manner. Soil, nutrients and chemicals included in run-off are major agricultural causes of coral reef disturbance. Large quantities of nutrients and agricultural chemicals are also attached to fine sediment particles (CRC Reef Research Centre, 2003). Therefore, prevention of soil erosion is the primary requirement. Techniques for achieving this objective have been developed, such as cultivation of green manure crops, crop rotation (minimizing the duration of non-use), and surrounding fields by green belts. A willingness on the part of the growers to adopt these techniques is also important. Financial support by administrative agencies would be effective if these techniques were to incur costs or hours of labor. The appropriate usage of fertilizers and agricultural chemicals is another important factor in reducing the impact of agriculture on nearby ecosystems.

Agriculture is not automatically a bad thing for coral reef ecosystems. Under appropriate management, simultaneous pursuit of agriculture and coral reef conservation is possible. Degradation of coral reefs is now in progress throughout the world, and collaboration among growers, researchers and public administration is needed to improve the balance between profitable agriculture and preserving coral reefs.

References

Aronson, R.B., Precht, W.F., Macintyre, I.G., Murdoch, T.J.T. 2000. "Coral bleach-out in Belize." Nature 405: 36.

Bengtson Nash, S.M., McMahon, K., Eaglesham, G., Mueller, J.F. 2005. "Application of a novel phytotoxicity assay for the detection of herbicides in Hervey Bay and the Great Sandy Straits." Mar. Pollut. Bull. 51: 351-360.

Berkelmans, R., Oliver, J.K. 1999. "Large-scale bleaching of corals on the Great Barrier Reef." Coral Reefs 18: 55-60.

Birkeland, C. 1997 "Introduction." *In*: Life and death of coral reefs, (Ed.) Birkeland, C. New York: Chapman & Hall.

Brodie, J., Fabricius, K., De'ath, G., Okaji, K. 2005. "Are increased nutrient inputs responsible for more outbreaks of crown-of-thorns starfish? An appraisal of the evidence." Mar. Pollut. Bull. 51: 266-278.

CRC Reef Research Centre, 2003. Land use and the Great Barrier Reef, Current state of knowledge, pp. 6.

Duke, N.C., Bell, A.M., Pederson, D.K., Roelfsema, C.M., Nash, S.B. 2005. "Herbicide implicated as the cause of severe mangrove dieback in the Mackay region, NE Australia: consequences for marine plant habitats of the GBR World Heritage Area."

Mar. Pollut. Bull. 51: 308-324.

Duke, N.C., Bell, A.M., Pederson, D.K., Roelfsema, C.M., Godson, L.M., Zahmel, K.N., MacKenzie, J., Bengtson-Nash, S., 2003. Mackey mangrove dieback. Investigations in 2002 with recommendations for further research, monitoring and management, Report to Queensland Department of Primary Industries, Northern Fisheries Centre and the Community of Mackey., pp. 177.

Fabricius, K., De'ath, G., McCook, L., Turak, E., Williams, D.M.B. 2005. "Changes in algal, coral and fish assemblages along water quality gradients on the inshore Great Barrier Reef." Mar. Pollut. Bull. 51: 384-398.

Fujioka, Y. 1999. "Mass destruction of the hermatypic corals during a bleaching event in Ishigaki Island, southwestern Japan." Galaxea 1: 41-50.

Furnas, M. 2003. Catchments and corals : terrestrial runoff to the Great Barrier Reef. Townsville: Australian Institute of Marine Science.

Haynes, D., Michalek-Wagner, K. 2000. "Water quality in the Great Barrier Reef World Heritage Area: past perspectives, current issues and new research directions." Mar. Pollut. Bull. 41: 428-434.

Haynes, D., Mueller, J., Carter, S. 2000a. "Pesticide and herbicide residues in sediments and seagrasses from the Great Barrier Reef World Heritage Area and Queensland coast." Mar. Pollut. Bull. 41: 279-287.

Haynes, D., Ralph, P., Prange, J., Dennison, B. 2000b. "The impact of the herbicide diuron on photosynthesis in three species of tropical seagrass." Mar. Pollut. Bull. 41: 288-293.

Jones, R.J., Kerswell, A.P. 2003. "Phytotoxicity of Photosystem II (PSII) herbicides to coral." Mar. Ecol. Prog. Ser. 261: 149-159.

Jones, R.J., Muller, J., Haynes, D., Schreiber, U. 2003. "Effects of herbicides diuron and atrazine on corals of the Great Barrier Reef, Australia." Mar. Ecol. Prog. Ser. 251: 153-167.

Matsuzaka, Y., Otowa, M., Yamada, Y., Hamazaki, T. 1971. "Soils of Okinawa and Kume Islands (in Japanese with English summary)." Bulletin of the National Institute of Agricultural Sciences, Series B (Soils and Fertilizers) 22: 305-404.

McClanahan, T., Maina, J., Pet-Soede, L. 2002. "Effects of the 1998 coral mortality event on Kenyan coral reefs and fisheries." Ambio 31: 543-550.

Moran, P.J. 1986. "The *Acanthaster* phonomenon." Oceanogr. Mar. Biol. Annu. Rev. 24: 379-480.

Negri, A., Volhardt, C., Humphrey, C., Heyward, A., Jones, R., Eaglesham, G., Fabricius, K. 2005. "Effects of the herbicide diuron on the early life history stages of coral." Mar. Pollut. Bull. 51: 370-383.

Nishida, M., Lucas, J.S. 1988. "Genetic differences between geographic populations of the Crown-of-thorns starfish throughout the Pacific region." Mar. Biol. 98: 359-368.

Nishihira, M. 1987. "Natural and human interference with the coral reef and coastal environments in Okinawa." Galaxea 6: 311-321.

Omija, T. 2003. "Water pollution in coral reefs caused by soil run-off." Bulletin on Coastal Oceanography 40: 141-148.

Omija, T. 2004 "Terrestrial inflow of soils and nutrients." *In*: Coral Reefs of Japan, (Ed.) The Japanese Coral Reef Society and Ministry of the Environment. Tokyo: Ministry of the Environment.

Omija, T., Higa, E., Nakasone, K., Mitsumoto, H. 2002. "Comparison of the accumulated soil in Okinawa coastal sea before and after the Enforcement of Red Soil Erosion Prevention Ordinance (in Japanese)." Annual Report of Okinawa Prefectural Institute of Health and Environment 36: 77-84.

Pillay, R.M., Terashima, H., Kawasaki, H. 2002. "The extent and intensity of the 1998 mass bleaching event on the reefs of Mauritius, Indian Ocean." Galaxea 4: 43-52.

Spalding, M.D., Jarvis, G.E. 2002. "The impact of the 1998 coral mortality on reef fish communities in the Seychelles." Mar. Pollut. Bull. 44: 309-321.

Veron, J.E.N. 2000. Corals of the world. Townsville: Australian Institute of Marine Science.

Walker, D.I., McComb, A.J. 1992. "Seagrass degradation in Australian coastal waters." Mar. Pollut. Bull. 25: 191-195.

Yamaguchi, M. 1986. "*Acanthaster planci* infestations of reefs and coral assemblages in Japan: a retrospective analysis of control efforts." Coral Reefs 5: 23-30.

Yamazato, K. 1987. "Effects of deposition and suspension of inorganic particulate matter on the reef building corals in Okinawa, Japan." Galaxea 6: 289-309.