2-3 Coral diseases

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1 Introduction

Many of the coral communities around the world may disappear within a few decades as a result of influences such as global warming (Hughes *et al*. 2003). In Japan, elevated seawater temperatures during the 1997/1998 El Niño-Southern Oscillation (ENSO) event caused the most severe coral bleaching and mortality ever observed. This phenomenon has continued to occur intermittently during subsequent years. In addition to bleaching, corals have been threatened with predation by the crown-of-thorns starfish (*Acanthaster planci*), smothering by terrigenous sediments, and poisoning by agricultural chemicals in runoff. Since the 1970s, there have been reports of bacterial diseases among hard corals (scleractinians), and the number of such reports increased throughout the 1990s. In some locations, the damage caused by coral disease has been catastrophic. Coral disease is now considered a significant new threat to coral reefs, and this section will further examine the crisis. This paper is a modification of a manuscript that was submitted to the Journal of Fossil Research (Yamashiro 2003), with the addition of new information.

2 Malignant coral diseases

Coral disease transmission processes are poorly understood. They can be caused by infection with pathogenic bacteria, viruses, fungi, or protozoans, as well as by helminthes and arthropods. Coral diseases can also be triggered by abiotic factors such as temperature, soil particles, ultraviolet rays, heavy metals, and agricultural chemicals. However, in reality, both biotic and abiotic factors are likely to be intricately intertwined in many cases, and specifying a single causative factor is not easy.

Many coral diseases have been recognized, but comparatively little is known about the causative agents (Richardson 1998). Research is further complicated by the assignment of more than one descriptive name to a single disease. Thus, there are still many unsolved problems in the study of coral diseases. Some diseases can be fatal to a colony, while others are less harmful and may result in minor skeletal anomalies. The list of coral diseases presented in Table 1 is not exhaustive, and, in addition to the traditional published scientific literature, further information on coral diseases is available on a range of websites*[1]. The large impacts of coral diseases on coral reefs and the diseases for which causes have been identified are included in this section.

Table 1. Coral diseases with known causes (excluding tumors).

Disease name	Causal bacteria	Coral species	Location	Remarks	Reference
White Pox	*Serratia marcescens*	*Acropora palmata*	St. Croix, Belize, Jamaica, Florida, Bahamas	From 1996. Active in summer.	Patterson *et al*. (2002)
Black Band Disease	*Phormidium corallyticum*, etc.	various species	GBR, Fiji, Red Sea, Philippines, Bermuda, etc.	Hypoxia death brought by hydrogen sulfide. Active in summer.	Garrett and Ducklow (1975), etc.
Bacterial Bleaching	*Vibrio* AK-1	*Oculina patagonica*	Mediterranean coast of Israel	Active in high temperature	Kushmaro *et al*. (1996)
Plague type II	*Sphingomonas*	*Diploria*, *Dichocoenia*, etc.	Florida, Bahamas, etc.	From 1996. Necrosis occur at a speed of 2 cm/day	Richardson *et al*. (1997)
Aspergillosis	*Aspergillus sydowii*	*Gorgonia ventalina* (soft coral)	Caribbean Sea	Octocorallia was damaged	Geiser *et al*. (1998)

Coral diseases came under the spotlight in the 1970s, when black band disease (BBD) was discovered in the Caribbean Sea and, subsequently, in the Indian and Pacific oceans. It became apparent that BBD had infected not just Hexacorallia but multiple species of coral, including Octocorallia and Stylasterina. The causal agent of BBD is a consortium of microbes, composed of a filamentous cyanobacterium (*Phormidium* spp.) together with sulfate-reducing bacteria and/or sulfate-oxidizing bacteria that create a microbial mat structure. When these bacteria are introduced and propagate inside coral tissues, a black mat is formed, which makes the diseased coral easily distinguishable from healthy, live coral. Tissue necrosis, caused by oxygen depletion and the release of hydrogen sulfide from the bacteria, occurs at a rate of several millimeters per day (Richardson *et al.* 1997). The dying coral tissue becomes a source of nutrients for the bacteria.

White pox is a widespread disease that has killed about 90% of the branching *Acropora palmata* in Caribbean coral reefs, resulting in this species being classified as an endangered species. It has been reported that corals are being killed at the rate of 10 cm^2 per day. The causal bacterium is *Serratia marcescens* (Patterson *et al.* 2002). *Serratia* bacteria are better known as enteric bacteria; these bacteria are implicated in human infection and have become a problem in hospitals. A vibrio virus (*Vibrio* AK-1) has also been found that rapidly kills the tissue of *Oculina patagonica* at the rate of several centimeters per day (Kushmaro *et al.* 1996). In addition, the cause of a mass die-off of Octocorallia (*Gorgonia ventalina*) in the Caribbean was attributed to the universal soil fungus *Aspergillus sydowii* (Geiser *et al.* 1998).

Recently, a new disease called Porites ulcerative white spot disease (PUWS) has been identified on *Porites* species in the Indian and Pacific oceans (Raymundo *et al.* 2003). From an initial colony 3–5 mm in diameter, the disease can spread and lead to the death of an entire colony. Although the cause is still uncertain, precautions should be taken.

The mass die-offs of coral caused by pathogenic bacteria have been reported only relatively recently, indicating that most of these diseases have developed since the 1990s. This implicates the deterioration of the marine environment and an accompanying decrease in the strength of corals' immune systems in the development and spread of the coral diseases that are caused by pathogenic bacteria.

3 Coral diseases associated with tumors

Some researchers do not consider overgrowth (i.e., hyperplasia, a state in which the polyps become huge) and tumors (e.g., neoplasm, mutation) as symptomatic of disease in corals. For example, Loya *et al.* (1984) suggested that overgrown polyps of massive corals, such as *Platygyra* on the Great Barrier Reef, are normal. Thus, an abnormal external morphology may not directly signify a diseased state in corals. Tumors have been observed growing on a variety of coral species worldwide (e.g., Cheney 1975; Bak 1983; Loya *et al.* 1984; Peters *et al.* 1986; Coles and Seapy 1998; Yamashiro *et al.* 2000; Gateno *et al.* 2003), but the causes have not been clarified.

Tumors on corals generally appear as hemispheric lumps with a lower zooxanthellae density than that of the surrounding colony. The tumor growth includes the skeletal structure of the coral and does not kill the colony; therefore, it is usually thought of as a so-called benign structure. However, at the site of the tumor, there is a decrease in polyp number and in fecundity, indicating that it is more appropriate to consider the tumor to be a diseased condition. Corals with tumors are easily recognized in the field by their lower polyp number and the whitish appearance that results from a reduced number of zooxanthellae.

Coral colonies display a multiplicity of morphologies,

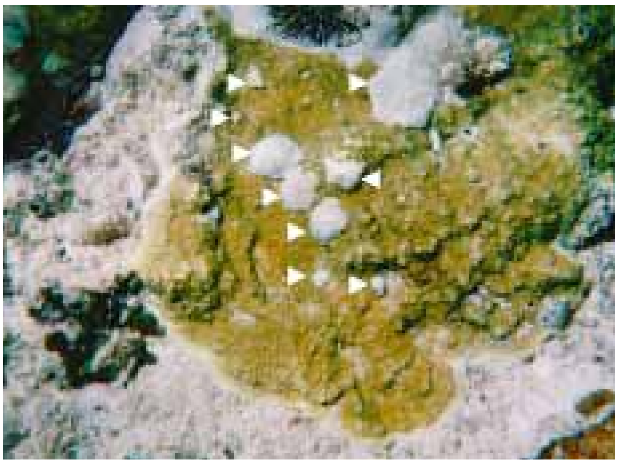

Photo. 1. Tumor on encrusting *Montipora informis* on Sesoko Island, Okinawa. Usually, the hemispheric portion swallows the neighboring tissues, zooxanthellae density and polyp density decrease, and the tentacles disappear. In the end, the characteristic morphology of this species is lost at tumor sites.

which are determined by species, growth stage, and habitat; for example, corals can be branching, tabulate, massive, or encrusting. On the other hand, the primary characteristic of tumors is a lack of individualized forms. In other words, the characteristic skeletal construction of each coral species will disappear as the tumor becomes a hemispheric lump that is surprisingly similar regardless of the species or the original colony shape. For instance, the characteristic denticles of *Montipora informis* are completely absent at a tumor site (Photo. 2).

In addition to an abnormality of the skeletal frame (osteoporosis), metabolic disorders, such as changes in lipid metabolism, can be caused by tumors (Peters *et al.* 1986; Yamashiro *et al.* 2001). It is often thought that tumors are merely lumps that do not affect coral health, but this may not be the case. We noted the occurrence of abundant tumors on encrusting *Montipora informis* found on Sesoko Island, and we consequently began measuring and analyzing these corals in spring 1998. The data on

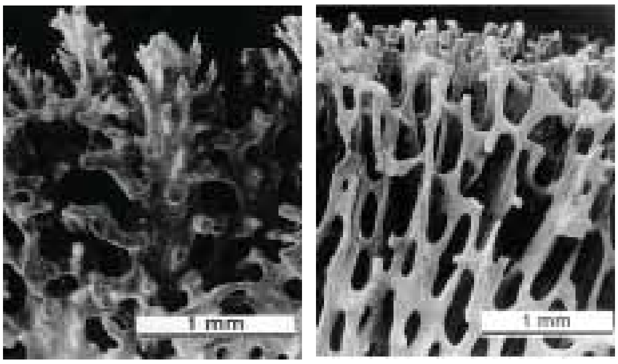

Photo. 2. Scanning electron micrographs of normal (left) and tumored skeleton (right) in *Montipora informis*.

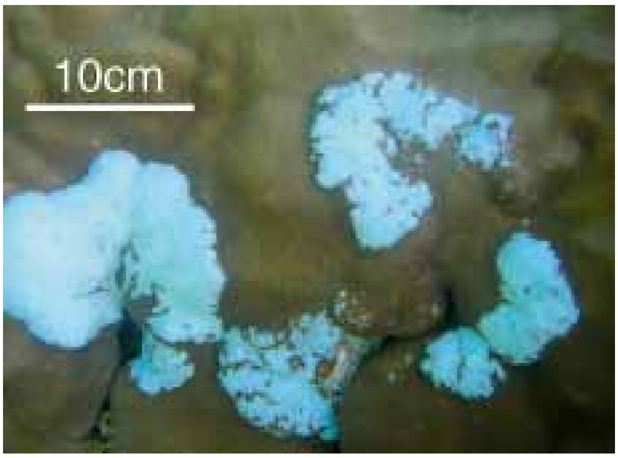

Photo. 3. Whitish and pale brown tumor seen on a massive *Porites lutea* colony on Okinawa Island. The boundary is indistinct, and emboli of the normal tissue can be seen on the whitish tumor.

growth rates could not be collected, however, owing to a mass bleaching event in the summer of 1998, when the 20 colonies that had been marked for measurement all died. It was apparent that the high temperature stresses caused tumors to die earlier than healthy coral (Yamashiro *et al.* 2000). Therefore, it appears that tumors are more sensitive to adverse environmental changes. Although, polyp density decreases on tumors, the polyp itself does not exhibit any apparent external changes. However, stereo and optical microscopic observations have revealed that polyps at the tumor site do not undergo oogenesis. Thus, tumor growth reduces the overall reproductive capacity of a coral colony.

Living things generally store food energy in the form of fats and sugars, but corals store their metabolic energy as lipids (Yamashiro *et al.* 1999). Studies by Yamashiro *et al.* (2001) revealed that the lipid content (i.e., the weight of extracted lipids per dry-weight of tissue expressed as a percentage) was 32.2% in normal tissue and 10.6% in tumor tissue. Additionally, wax and triacylglycerol amounts were markedly lower in tumor tissue. A decrease of lipid content supports the observation of suppressed oogenesis, as oogenesis requires a large amount of lipid. The increased susceptibility of some tumors to high water temperatures might be closely related to the lower capability for lipid storage in tumor tissue. Similarly, the lipid content in normal but bleached coral colonies of several species also decreased (Yamashiro *et al.* in preparation), signifying the importance of lipids in coral metabolism. Whether a coral will survive the ‘war of attrition’ will likely depend on its ability to effectively mobilize stored lipid as an energy source during periods of stress.

At present, the mechanisms underlying tumor development are uncertain. However, it seems more than coincidental that tumors, as well as other diseases, are becoming more common in corals at the same time as global environmental deterioration continues to degrade marine conditions.

A new type of tumor was identified on *Porites lutea* colonies in the moat off Okinawa Island in September 2002 (Nakano *et al.* unpublished data); subsequently, it was also found in several areas in Okinawa Prefecture. This tumor is distinctive, in that it usually swells, making it quite noticeable, and the number of zooxanthellae is extremely reduced (Photo. 3). The growth rate of this tumor seems to be very slow. Moreover, unlike other tumors discovered previously, this tumor has an indistinct boundary, with emboli present on the surrounding tissue (Photo. 3).

Investigations of how tumor tissue is maintained are in progress. At present, two possibilities are being considered: the tumor tissue obtains food from outside the colony, or nutrients are supplied to the tumor from neighboring tissue inside the colony (Yasuda *et al*. unpublished data).

4 Coral diseases caused by helminthes

A helminth that clings to *Porites* colonies has been identified as the cause of another emerging coral disease called Porites pink block disease (PPBD), which is easily recognized because the surface of the colony turns pink. According to research conducted in Hawaii, the Trematoda *Podocotyloides* parasitizes coral polyps. The first host for this helminth is a bivalve; the second is the coral; and the last is a fish, such as a butterfly fish (*Chaetodon*) (Aeby 2003). Although quantitative data have not been collected, this disease is expanding rapidly around the Ryukyu Archipelago. Although the portion of a *Porites* colony affected appears to be small, having a diameter of only a few millimeters, this disease has been reported to cause a 50% decrease in the growth rate of the colony (Aeby 1992). A decrease in zooxanthellae density also occurs in the infected portions. However, because *Porites* is not a favored prey of the crown-of-thorns starfish and is comparatively more resistant to high water temperatures than many other species, the impact of the disease may be tolerable.

5 Conclusion

In 2003, a large number and variety of tumors were reported in the coral reefs off the southern part of Yonaguni Island (broadcast from NHK Okinawa on 19 February 2003). The investigation showed that the tumors had developed primarily on *Montipora informis*. Similar outbreaks might also be occurring elsewhere but be as yet undocumented. In addition, a large coral community with tumors was found around the Kerama Islands in an area with healthy, mature communities and high water transparency, in April 2003 (Irikawa and Yamashiro unpublished data) (Photo. 4). Two causal mechanisms may explain this phenomenon: a genetic abnormality associated with the age of the colony may have occurred, or a bacterial infection might have taken advantage of the suppressed immune system of coral exposed to adverse environmental conditions. We cannot be complacent about the impact of tumors on coral structure and function, particularly fecundity. If coral diseases are closely associated with the deterioration of their environment then we must be aware of the increasing risk and take precautions to prevent diseases that are capable of causing catastrophic damage to corals from spreading widely in the future.

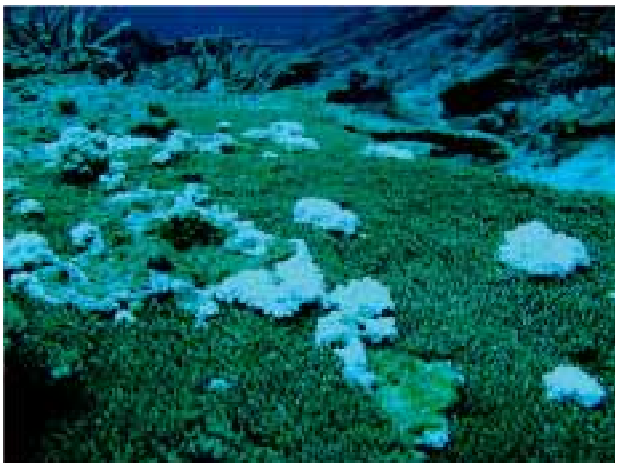
Photo. 4. Tumors on tabulate *Acropora* sp. on Kerama Island, Okinawa. (photo by A. Irikawa)

Recently, coral cultivation and/or transplantation techniques aimed at coral reef restoration have been studied in many institutions. When transplanting corals to other regions, we need to carefully consider not only the possibility of so-called genetic disturbance but also the threat of disease expansion.

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Cited websites:

*1: WWW pages related to diseases of hermatypic corals:
http://www.sbg.ac.at/ipk/avstudio/pierofun/aqaba/disease1.htm
http://www.nmfs.noaa.gov/prot_res/PR/coraldiseases.html
http://www.wcmc.org.uk/marine/coraldis/home.htm