2-2 Predation damage to corals

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1 Introduction

There are a broad range of organisms that prey on corals. In this chapter we will discuss crown-of-thorns starfish (*Acanthaster planci*), coral-eating gastropods, and the sponge *Terpios*. These organisms are major coral predators that are capable of causing significant disturbances to coral communities.

2 Crown-of-thorns starfish (*Acanthaster planci*)

This is a large starfish (up to ~80 cm diameter) with approximately 15 arms. It is widely distributed in coral reef areas in the tropics and subtropics throughout the Pacific Ocean, the Indian Ocean, and the Red Sea. Frequent increases in population numbers have caused extensive damage to coral communities at various locations in recent years; in fact, among the organisms that predate on corals, this species has had the biggest influence on coral communities (Birkeland and Lucas 1990; Photo. 1).

While some kinds of starfish reproduce asexually by autotomy, *A. planci* is known to proliferate only via sexual reproduction. One female may produce eggs to the number of several tens of millions during one season. Consequently, a very small increase in the survival rate of juvenile starfish can result in a large increase in the adult population; the species can therefore be said to have outbreak potential.

Spawning occurs during July around Okinawa Island and, about a month earlier (early June), around the Yaeyama Islands. The time of spawning is thought to be controlled by water temperature (Yamazato and Kiyan 1973; Yokochi and Ogura 1987); at both locations the water temperature is 27-28°C in June and July. It has been assumed that this water temperature is the most favorable for egg development and larval growth (Lucas 1973).

The life cycle of *A. planci* is described in Fig. 1. Fertilized eggs develop while drifting in plankton and before long hatch as swimming larvae. Larvae remain planktonic for several weeks, progressing through several stages of development, before swimming to the substrate and metamorphosing into a juvenile starfish. At this stage, *A. planci* has five arms (~0.5 mm diameter), like other starfish. Juveniles grow slowly at first, feeding on calcareous coralline algae. Similar to adult starfish, digestion occurs outside the body via a reversed gastric cavity, and

Photo. 1. *Acanthaster planci* (photo taken by K. Nomura).

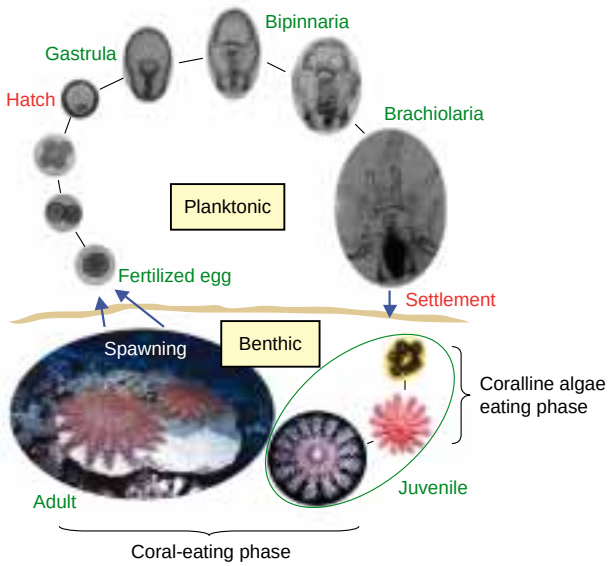

Fig. 1. Life cycle of *Acanthaster planci*.

round white feeding scars are left on the substrate. Around six months after spawning the starfish is ~10 mm in diameter and possesses its full complement of arms. At this stage it begins a gradual transition to feeding on corals, the body colour changes from pink to brown, and growth rapidly accelerates. Sexual maturity occurs at ~20 cm diameter, approximately two years after spawning, and most individuals will spawn within the next year (Yamaguchi 1973; 1974; Lucas 1984; Ueno and Yokochi 1990; Yokochi and Ueno 1990). At this stage coral consumption increases massively, and the starfish may be observed in groups on the reef. Although there are no data regarding natural longevity, one individual is known to have survived about eight years under breeding condition (Moran 1997).

1. History and current state of outbreaks

The oldest written record of an outbreak of *A. planci* in Japan is believed to be in an article written by Shirai (1956) about his travels in Amami Oshima. A research report of the Nature Conservation Bureau, Environment Agency (1989) compiled information about historical outbreaks, including the period prior to the 1960s, using anecdotal reports from fishermen and others. Following the publication of this research report, more information was obtained from scientific studies and other sources, such as newspaper articles; these data are included in Fig. 2.

Based on this information, and although there are few written records, it appears that outbreaks of *A. planci* prior to 1960 were sporadic and short-lived. From 1969, however, a series of outbreaks began around Okinawa Island and then occurred simultaneously at various locations over a relatively long time period. Much more information is available about these outbreaks in the form of contemporary reports, research papers, and newspaper articles. The following sections use these materials to describe patterns of outbreaks since 1969 and the current situation in each main sea area.

a) Yaeyama Archipelago

Following a local outbreak around Hatoma Island in 1972, *A. planci* numbers started increasing gradually in the southeast of Sekisei Lagoon. The number of individuals increased explosively in the 1980s, and predation damage extended to the whole of Sekisei Lagoon (Fukuda and Miyawaki 1982). In the early 1980s the outbreak spread to surrounding islands and the sea area from the northern to the southern coasts of Iriomote Island, causing severe damage to these coral communities (Nature Conservation Bureau, Environment Agency 1984; Yokochi *et al.* 1991). Starfish numbers increased explosively around Hateruma Island in 1984, damaging major coral communities in sea areas stretching from the northern to the western coasts (Nomura and Kamesaki 1987). By the middle of the 1980s, all coral communities in the Yaeyama sea area (with some minor exceptions) had been catastrophically damaged by starfish predation. As the number of live corals decreased, the number of starfish dropped sharply, and the outbreak in this area terminated at the end of the 1980s (Fig. 3).

Subsequently, individual *A. planci* were seen sporadically, but their population density remained extremely low. Coral communities started to recover, and developed rapidly in the 1990s (Mori 1995). However, starfish numbers also began to increase, and by 2003 locally high densities were observed in some areas, including southern Sekisei Lagoon and Nagura Bay, Ishigaki Island (Nature Conservation Bureau, Ministry of the Environment 2003). Outbreak densities have not yet been reached in the district of Yaeyama, but the historical data indicate that this might be a possibility in the near future.

b) The islands of Okinawa

In 1969 an outbreak was first reported at Onna, on the western coast of Okinawa Island. A survey of the entire island in 1972 found the starfish at high densities off the coast at Onna and through the area around Motobu Peninsula to the western coast of the northern region (Nishihira and Yamazato 1974). Three years later, a dense distribution of the starfish was observed off the southern coast of the island, around to the central eastern coast (Okinawa Prefectural Tourism Development Bureau 1976). By the end of the 1970s, almost all of the corals on all the reefs off Okinawa Island were thought to have been eaten by the starfish. A 1984 survey found *A. planci* widely distributed, but at low densities, and many were seen in areas where coral coverage was high (Sakai *et al.* 1988). Coral coverage in 1984 was, on the whole, lower than in 1972, but in some sea areas it was higher than in 1976. This pattern has been interpreted as a small-scale recovery by coral communities from the 1976 outbreak, with ongoing starfish predation pressure inhibiting larger scale recovery in most areas (Sakai and Nishihira 1988; Fig. 4). This chronic outbreak around Okinawa Island, during which recovered coral communities were affected again and again, may have lasted for more than 20 years.

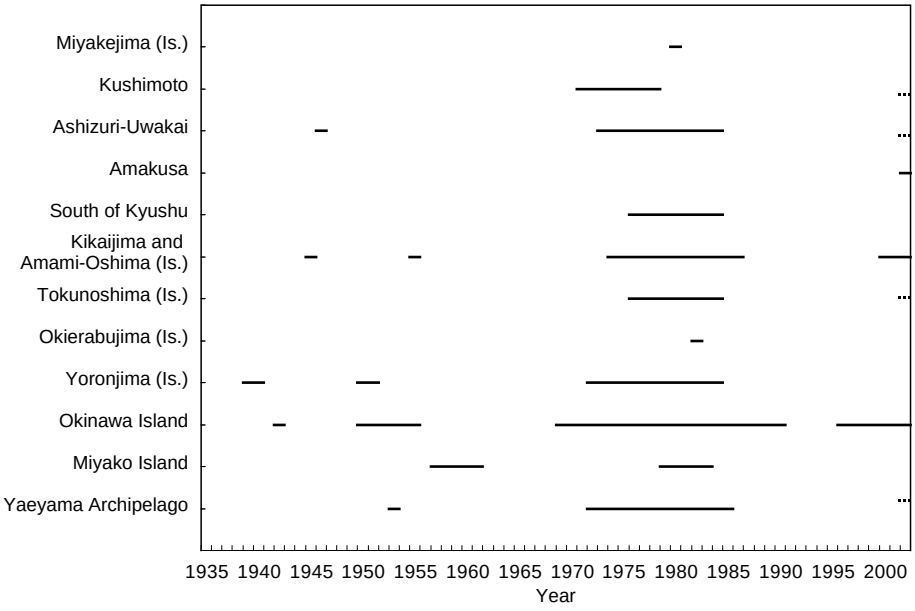

Fig. 2. History of *Acanthaster planci* outbreaks in Japan (modified from Nature Conservation Bureau, Environment Agency 1989).

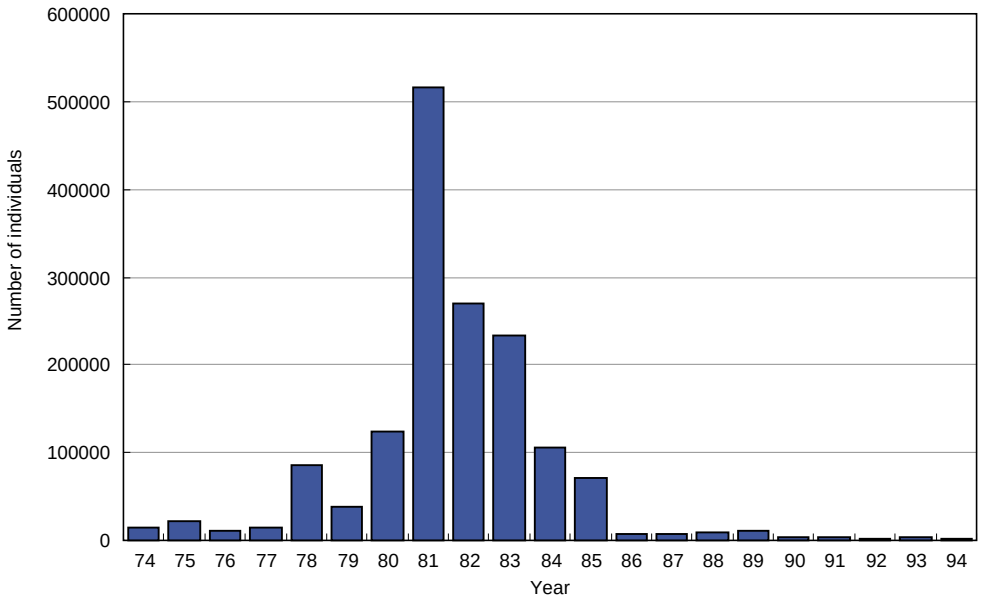

Fig. 3. Numbers of exterminated individuals of *Acanthaster planci* around Sekisei Lagoon (modified from Mori 1995).

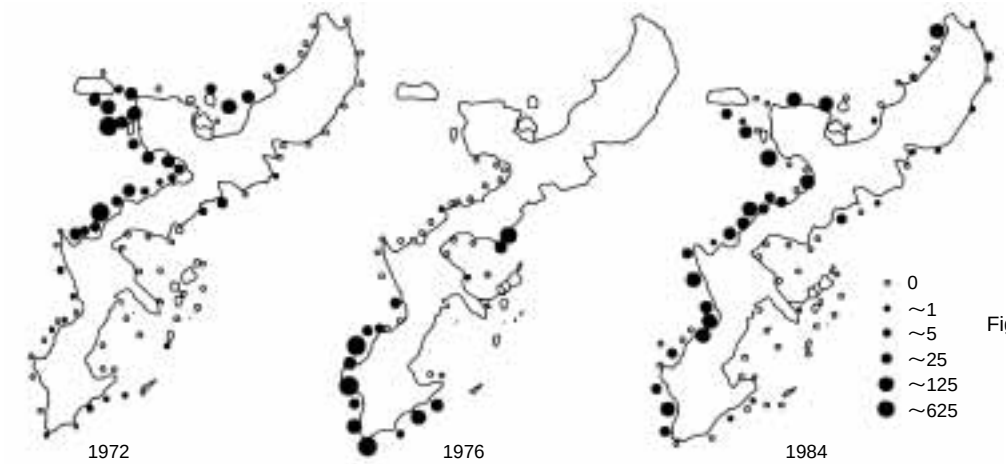

Fig. 4. Changes in observed numbers of *Acanthaster planci* around Okinawa Island, per 10-minute swim period (modified from Kato 1999).

After 1990, *A. planci* numbers remained low for a while. Coral communities showed recovery, and *Acropora* communities in comparatively healthy states were observed off some coasts of Okinawa Island and surrounding islands (Department of Planning and Development, Okinawa Prefecture 1993). However, in 1994 increased starfish numbers were reported off the coast at Onna, where outbreak populations had first been observed in 1969. The presence of a high-density cohort here was confirmed in 1996 (Arakaki and Yamazato 1998). Reefs at Chibishi near Naha City showed signs of damage by starfish in 1997, and this outbreak extended to surrounding islands such as Kerama, where starfish were observed in high density groups from around 2001. The outbreak continued to spread to various sea areas off Okinawa Island, reaching the east coast in 2002. By 2003, high-density groups of the starfish were rarely seen in the waters off Okinawa Island, except in some locations, and coral communities with a high coverage disappeared at the same time. However, outbreak populations were still active around surrounding islands (e.g., Maejima and Nagannujima of the Kerama Islands, and Tonaki Island), with coral coverage decreasing (material from Okinawa Prefecture Nature Conservation Division).

c) Amami Archipelago

Starfish extermination programs started in 1974 at Amami Oshima, and in 1976 at Tokunoshima. Based on the numbers of individuals exterminated, the worst outbreak in this area seems to have occurred at the beginning of the 1980s (Yamaguchi 1986c, 1987). Extermination rates subsequently decreased gradually at Amami Oshima, and remained low during the 1990s. However, rates increased rapidly in 2001, and this area is now considered to have outbreak status (Nature Conservation Bureau Ministry of the Environment 2003).

d) Kyushu, Shikoku, and the Kii Peninsula

Starfish extermination programs have been conducted in southern Kyushu since 1976. Numbers of exterminated starfish peaked at ~600 individuals in 1978 and subsequently decreased (Yamaguchi 1987). *A. planci* has rarely been observed around Amakusa in mid-west Kyushu, but starfish feeding scars were observed recently on local coral communities, and an extermination program was undertaken in 2002-2003 (Nature Conservation Bureau Ministry of the Environment 2003).

In the Ashizuri-Uwakai Sea in Shikoku, extermination programs have been conducted since 1973. The number of exterminated individuals peaked at ~15,000 in 1977 and subsequently decreased; the outbreak ended in the early 1980s. In subsequent years, several hundreds of individuals were exterminated annually in the area of Okinoshima. Although *A. planci* mostly disappeared from the Tatsukushi sea area after ~1990; since 2000, populations have tended to increase once again (Nature Conservation Bureau, Ministry of the Environment 2003), and the possibility of a future outbreak cannot be ignored.

A. planci were first observed around the Kii Peninsula in the 1970s, and 1,385 individuals were exterminated between 1972 and 1980, peaking in the mid-1970s. The starfish disappeared in the early 1980s and were not observed again for some time afterwards. However, numbers have started to increase again recently, and there is concern that this may signal an impending outbreak (Nature Conservation Bureau Ministry of the Environment 2003).

e) Miyakejima Island

The presence of *A. planci* was confirmed for the first time in 1977 at Miyakejima in the Izu Islands. Some 3,500 individuals were exterminated in 1980. Following this extermination program, the population was almost extinct; the few survivors were probably killed by unusually low water temperatures during the following winter (Yamaguchi 1986c).

2. Countermeasures

Despite immense budget funding for *A. planci* extermination programs, the countermeasures generally ended in failure; most coral communities sustained devastating damage from starfish predation during outbreaks. Probable reasons for this failure include the possibility that countermeasures commenced too late (extermination programs were set in motion only after outbreaks became obvious), sea areas targeted for protection were too vast, and the purchasing method tended to disperse extermination effort, thereby preventing thorough extermination (Yamaguchi 1986a). Nonetheless, a partial success was achieved at one location. Vast areas of Sekisei Lagoon have been monitored in annual surveys of corals and *A. planci* by the Yaeyama Laboratory of the Marine Parks Center of Japan since 1983. At the start of this survey program, starfish damage was already such that most of the coral reefs in Sekisei Lagoon had been destroyed. The laboratory recommended, therefore, that the Yaeyama Fishery Cooperative concentrate their extermination efforts on those small areas where live coral cover-

age was still apparent (Kamesaki *et al*. 1987). As a result, the corals in these areas were able to survive the outbreak, just barely escaping starfish damage.

In terms of controlling outbreaking starfish populations, the lessons of these experiences are clear. The protection area must be limited, so that effort can be concentrated. Adequate monitoring is essential to provide warning of an imminent outbreak. Rapid response to warnings is also necessary, and repeated, thorough exterminations must be carried out in the area that is to be protected. These points are now commonly recognized among researchers.

Although countermeasures may have been delayed and inadequate during the current Okinawa outbreak, efforts to learn from past lessons and develop alternatives are being made. A survey conducted by Okinawa Prefecture's Emergency Coral Reef Conservation Project, in 2002, aimed to describe the current status of Okinawa's reefs and to identify priority areas for protection in the event of an outbreak. As a result, concentrated monitoring and extermination programs are being conducted at the five most important conservation areas in the Zamami and Tokashiki island districts of the Kerama Islands. The Ministry of the Environment and the Nature Conservation Bureau of Okinawa Prefecture, in cooperation with fishermen and diving businesses, are collaborating to strengthen monitoring, select protected areas to prioritize, and conduct preventative extermination programs in the Yaeyama Islands, where an imminent outbreak is possible. Similar systems are being organized for Miyako Island. In cooperation with these measures, the Research Institute for Subtropics is attempting to verify whether outbreaks can be predicted by monitoring young starfish feeding on coralline algae (Yokochi 1998).

It has been suggested that the chronic nature of the previous outbreak in Okinawa was fostered by half-hearted extermination programs, which increased the relative food available per starfish, thereby improving conditions for the remaining individuals (Sano 1985; Yamaguchi 1986a). However, extermination programs were conducted in a similar manner in the Miyako and Yaeyama archipelagoes, and the starfish infestation did not become chronic in these locations (*A. planci* almost disappeared at the same time as the corals were devastated); the reason for this difference remains unclear. Anthropogenic eutrophication of the seas around Okinawa Island may have contributed to the chronic outbreak populations of *A. planci*; however, if this was the case, the mechanism is unknown.

In Japan's temperate zones, *A. planci* numbers are affected by fluctuations in low water temperatures in winter following a seasonal shift in the location of the Kuroshio Current, which carries larval starfish from the south (Yamaguchi 1987). As average seawater temperatures have risen in recent years, there have been corresponding reports of northern range extensions for marine organisms along various coasts of southern Japan. Now or in the near future, coral communities in temperate zones may be being damaged by *A. planci,* and appropriate monitoring programs should be developed with this in mind.

3 Coral-eating gastropods

Coral-eating gastropods of the muricid family, particularly *Drupella* spp., sometimes develop into outbreak populations and damage coral communities (Turner 1994). Although damage by the closely related species *Habromorula spinosa* has been reported from Amakusa in Kyushu, in all other areas a *Drupella* species has been responsible, in many cases *Drupella fragum* (Photo. 2). Both gastropods are small (40 mm or less in husk length) and widely distributed in live coral areas south of central Honshu (mainland Japan). They use a grater-like feeding organ called a radula to scrape soft coral tissues away from the hard skeleton.

In Japan, outbreak populations of coral-eating gastropods have caused damage to coral communities at Miyakejima (Moyer *et al*. 1982), off the Nichinan coast of Miyazaki

Photo. 2. *Drupella fragum* preying on *Acropora hyacinthus* at Komeotoura, Miyazaki. (photo by H. Yokochi)

Prefecture, the Ashizuri-Uwakai Sea (Nature Conservation Bureau, Environment Agency 1991), and Amakusa (Nature Conservation Bureau, Environment Agency 1994a).

At Miyakejima, the outbreak began simultaneously with that of *A. planci* in 1976, and together these two coral predators caused the destruction of many coral communities. In some places it appeared that the gastropods damaged corals as much as, or more than, *A. planci* (Moyer *et al*. 1982).

Off the Nichinan coast, an outbreak of coral-eating gastropods occurred in 1987, and extermination programs commenced the following year. Despite countermeasures, *Acropora* communities were catastrophically damaged in places such as Komeotoura Bay, around the boundary between the town of Nango and the city of Kushima in Miyazaki Prefecture (Takayama and Shirasaki 1990; Nature Conservation Bureau, Environment Agency 1991).

In 1989 an outbreak was identified at Shirigai, Otsuki, in the Ashizuri-Uwakai Sea. The town of Otsuki immediately put together an emergency budget and began extermination programs (Tominaga 1998). An emergency ecological survey by the Environment Agency in 1991 led to a policy of intensified extermination within a prioritized protected area. Monitoring programs record the health of the coral communities during extermination programs. Administrative agents, citizens, and volunteer organizations cooperate in these operations, and are actively engaged in the extermination effort. As a result, coral communities within the protected area have escaped catastrophic damage and are in a relatively healthy state (Nomura and Tominaga 2001).

Habromorula spinosa caused damage to corals in Amakusa in 1992. Following surveys of the gastropod population and rates of predation damage, two areas were selected: one to be protected through extermination programs, the other to act as an unprotected control site (Nature Conservation Bureau, Environment Agency 1994a). Comparison of results showed that gastropod numbers remained low at the protected site, and that coral damage was minimal; however, at the unprotected control site, coral coverage declined sharply, although the damage was not catastrophic.

Occasional coral damage by high-density populations of gastropods has been reported from various locations in the Ryukyu Islands (e.g., Fujioka and Yamazato 1983; Fujioka 1984; Habe 1989; Shimoike 1995), but there have been no examples of wide-ranging community devastation. Fujioka (1984) reported that outbreak populations of *D. fragum* were causing considerable damage to coral reefs off Chinen, southern Okinawa Island, in 1981-82, but no further details are known. Outbreak populations of coral-eating gastropods have also been known to affect coral communities in non-reefal areas.

While damage by high-density populations of gastropods has often been observed on Japanese coral reefs, the impact has generally not been devastating. However, the influence of these gastropods cannot be ignored in places where coral coverage has already decreased because of other causes, like *A. planci*. In these situations the gastropods may cause further devastation and delay recovery.

4 *Terpios*

Terpios hoshinota (Photo. 3) is a sponge that lives symbiotically with a photosynthetic cyanobacterium (Rützler and Muzik 1993). This species is widely distributed in coral reefs of the western Pacific Ocean; the thin ash-black layer of symbiotic tissue sometimes covers and kills corals over a wide range (Bryan 1973; Yamaguchi 1986b; Plucer-Rosario 1987).

The first Japanese outbreak of *Terpios* occurred in Tokunoshima around 1985. Survey teams from the Environment Agency found large patches of *Terpios* (ca. 200 × 500 m) off the coast of Yonama, Amagi, in the northwestern part of the island (Nature Conservation Bureau, Environment

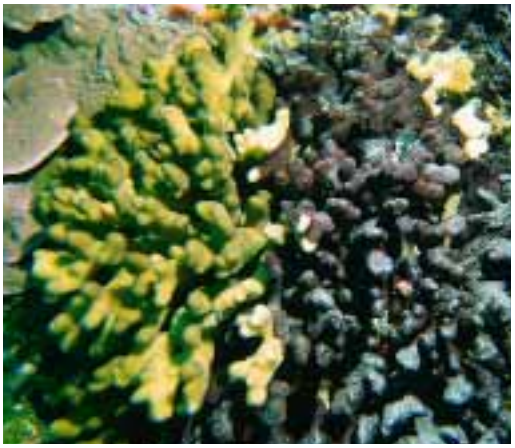

Photo. 3. *Terpios hoshinota* overgrowing *Stylophora pistillata* at Iriomote Island, Okinawa. (photo taken by H. Yokochi)

Agency 1986). At Boma, Tokunoshima, off the central area of the eastern coast, a few small patches were found, but the outbreak seemed to have faded. The Tokunoshima outbreak is assumed to have been temporary, and ended without human interference*1.

Terpios is widely distributed in the Ryukyu Islands (Nature Conservation Bureau, Environment Agency 1986; Rützler and Muzik 1993), but further details are not known. *Terpios* was not mentioned in a coral reef survey report covering almost the entire area of Okinawa Prefecture in 1993-94 (Department of Planning and Development, Okinawa Prefecture 1993, 1994). A 2003 nationwide survey report of *A. planci* distribution in marine park zones did not mention *Terpios* either, although coral-eating gastropods were discussed (Nature Conservation Bureau, Ministry of the Environment 2003). *Terpios* outbreaks may not become a particular problem in these areas.

5 Summary

The causes of outbreaks, with respect to any of the above mentioned species, are not clearly understood. While relationships with the terrestrial outflow of soils and nutrients, etc., have been suggested, verification is difficult and no convincing proof has yet been presented. Clearly, further research is necessary, but the immediate problem of reef destruction requires immediate, effective action. It has been recognized that unthinking, unfocussed extermination programs have solved none of the problems described above, and may even have prolonged the damage in some cases. Furthermore, it should be kept in mind that extermination of the predator species is not the objective of extermination programs; their aim is to conserve coral communities.

Even when devastated by disturbances such as those described above, coral communities can recover, as long as the disturbance is temporary. What is of the utmost importance in this respect is the preservation of an environment that facilitates the recovery of damaged coral communities; this can be achieved through conservation (or improvement) programs that monitor and regulate the quality of the sea areas, as well as the adjacent land areas, where coral reefs found.

Cited website:

*1: http://www.cc.u-ryukyu.ac.jp/~coral/Terpios.htm