Coral bleaching, rise in sea temperature, and the population of *Acanthaster planci* in Okinawa

Yuji Arakaki and Kiyoshi Yamazato

ABSTRACT

Large scale coral bleaching in Japanese waters, extending from the Ryukyus to southern Kyushyu, occurred in 1998 owing to high seawater temperature. In this study, the authors show population fluctuations of *Acanthaster planci* before and after this bleaching event, and try to explain the reason for these fluctuations in relation to this event. *A. planci*, a strong coral predator, prefers to prey on acroporid corals. These corals are easily bleached, and most of them died from the bleaching during the last bleaching event. Thus, it is easy to believe that the decrease of *A. planci* in the year of coral bleaching is due to the lack of acroporid corals as food for this animal. The data of exterminations at Busena Cape, however, show decreases began in mid-June when seawater temperature began to rise, and about three months before the extensive death of acroporid corals. Adult *A. planci* have a very narrow tolerance range for temperature, and water temperature above 30℃ has a very big effect on its behavior. Therefore, one could consider the abnormally high seawater temperature starting in mid-June, 1998, as the immediate cause for the sudden decrease in the number of exterminations at Busena Cape in 1998, and the shortage of food for *A. planci*due to the subsequent death of coral from bleaching as a contributing cause.

【Key Words】 *Acanthaster planci*, Coral bleaching, Population fluctuations, Seawater temperature

INTRODUCTION

Some three decades have passed since global attention was concentrated on the outbreak of *A. planci*. The first out break of *A. planci* in Okinawa Island occurred in 1969 in the coast of Onna Village, a part of Okinawa Coastal Quasi-National Park (Yamazato, 1969). Extermination efforts funded by many sources after this initial outbreak were carried out, but the results were insufficient to protect the coral around Okinawa Island from predation by *A. planci* (Yamaguchi, 1986). The corals around Okinawa Island have been constantly exposed to *A. planci* predation.

In Onna Village, extermination efforts were carried out cooperatively by the Japanese government, the Okinawa prefectural government, the Onna Village office, and the local fishermen's association. Owing to these efforts, the condition of the coral in the area was improving by around 1995. However, a new outbreak occurring in the summer of 1996 devastated the coral community again in the area: The *A. planci* removed from the area by local fishermen, 210 persons in all in six work days, came to 81,000 individuals, or 28 tons

("Sukuramu", 1996). An aggregation of *A. planci* was found again in 1997 in an area neighboring site, and it was thought that the aggregation had moved there from the site of the outbreak of the previous year (Arakaki & Yamazato 1998; Arakaki et al., 2000).

The greatest coral bleaching occurred in the summer of 1998 (Hasegawa et al, 1999; Tsuchiya, 1999a; Tsuchiya, 1999b). The corals inhabiting not only the coast of Okinawa Island but also the coast of almost all islands of the Ryukyu Islands extending southward from Kyushyu caused serious damage (Nakano, 1998; Tsuchiya, 1999b; Yamazato, 1999).

Corals constitute the fundamental infrastructure in the food chain in the low nutrition environment of tropical and subtropical seas, and provide the most diverse eco-system on earth. Many species directly depend on corals. *A. planci* are one of such species. They prefer to prey on acroporid corals (Birkeland & Lucas, 1990; Nishihira & Yamazato, 1974). Therefore, the extensive death of corals would affect many organisms inhabiting coral reefs. The effects would be wide-spread, especially for species directly dependent on corals. In this research, the population of *A. planci* is documented before and after the coral bleaching event of 1998; and the causes of these changes are discussed.

MATERIALS AND METHODS

1. *Extermination of* A. planci

It is expected, if thorough extermination efforts of *A. planci* are made in a particular area, that the number of exterminated individuals reflect the magnitude of the population of that area. Thus, we considered the number of exterminations as an index of abundance of *A. planci*. Extermination data were obtained from the extermination project by Onna Village Municipal office and Onna Fishermen's Association conducted along the coast of Okinawa Coastol Quasi-National Park at Onna Village from 1987 to 1998, and another extermination project, conducted monthly by the Okinawa Convention and Visitors Bureau (OCVB), at Busena Cape from May, 1992 to May, 1998 (Fig. 1)

2. *Sea surface temperature*

Because temperature data were not taken in the two projects, Onna Village and Busena Cape; we used the temperature data of Sesoko Island, about 10 km north of Busena Cape, assuming the sea temperature would not be so much different from that of Busena Cape. Sea surface temperature data were obtained from the coastal observation record at Sesoko Station, Tropical Biosphere Research Center, University of the Ryukyus. The center takes temperature data three days a month (beginning, middle, and last) both in the morning and in the afternoon.

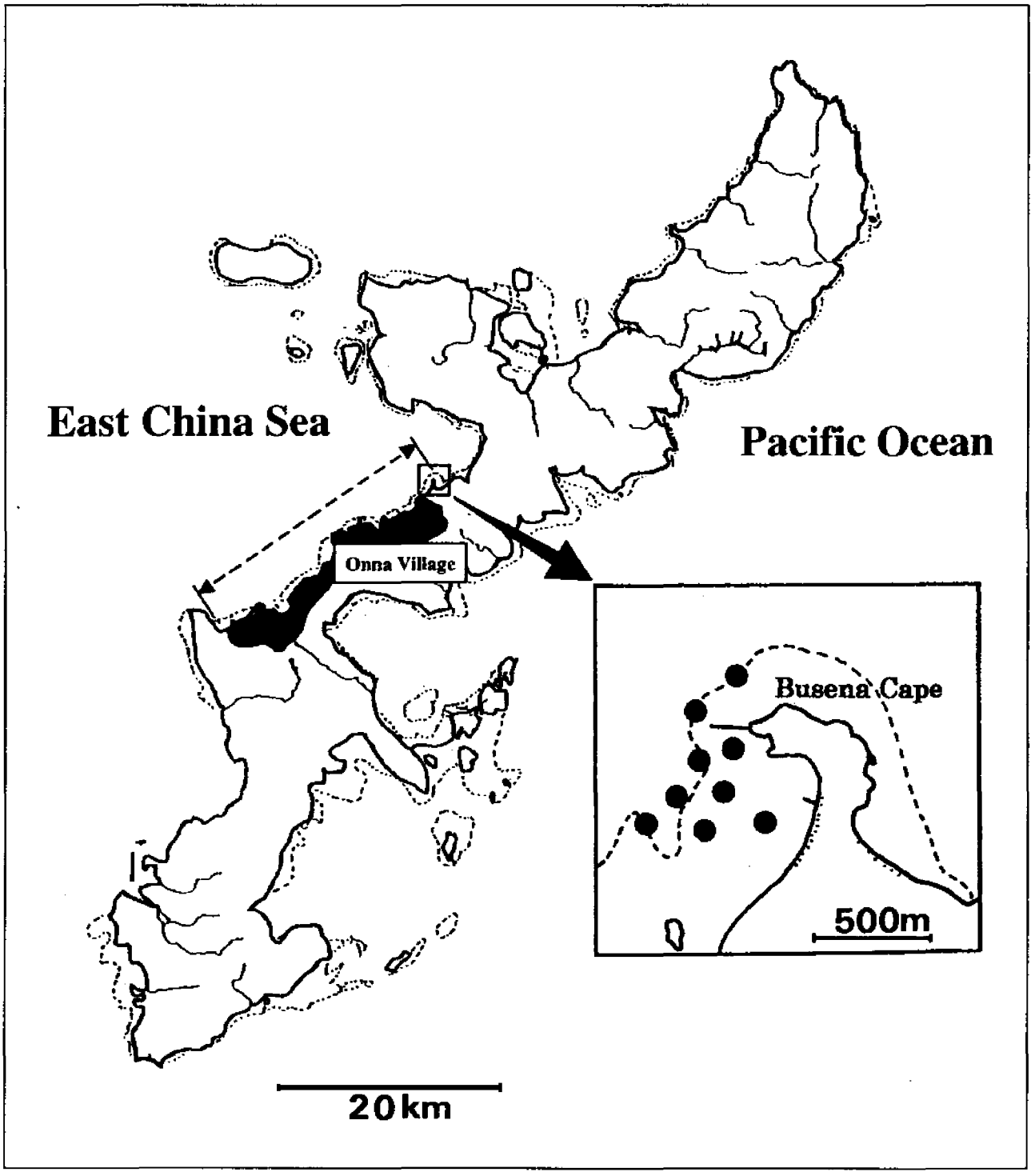

Fig. 1. A map of Okinawa Island with enlarged map of Busena Cape.
The Okinawa Coastal Quasi-National Park at Onna Village where *Acanthaster planci* was exterminated by local fishermen is indicated by arrow mark "←——→". The spots on the reefs of Busena Cape indicate approximate sites for extermination of *A. planci*.

RESULTS

1. *Exterminations*

The number of exterminated *A. planci* in the Onna Village Project along the coast of the Okinawa Coastal Quasi-National Park ato Onna Village, about 3,000 ha., fluctuated approximately between 10,000 and 30,000 during the period from 1987 to 1995 (Fig. 2 and Table 1). However, it reached about 80,000 suddenly in 1996, and about 90,000 in 1997. The sudden increase in exterminations in 1996 reflected the outbreaks of *A. planci* population in this year (Arakaki & Yamazato, 1998; Arakaki et al., 2000). In 1998, the number of exterminated individuals abruptly decreased to 41,100, fewer than half that of 1997's extermination (Fig. 2 and Table 1). On the other hand, the number of exterminated individuals per day per person (Ext/Day/Person) fluctuated nearly in parallel with the number of total exterminations until 1995 (Table 1). The value of Ext/Day/Person for 1996 is more than four times greater than the average, 14.8, whereas values for 1997 and 1998 are much smaller. The value for 1998 is a little more than half that for 1997, paralleling the change in the total number of exterminations (Table 1).

Because the number of exterminated individuals per day per person is a better estimate for the population density of *A. planci* than the number of total exterminated individuals, the larger number of the total exterminated individuals for 1997 and 1998 indicate a bigger effort was exercised for the extermination project in these years. The actual population explosion took place only in 1996, and in 1997 and 1998, *A. planci* population remained at less than the level of normal years.

Table 1. Extermination data of *Acanthaster planci* in Okinawa Coastal Quasi-National Park at Onna Village. Data source: Onna Village Office and Onna Fishermen's Association.

	Number of			
Year	Exteminations (Ext)	Days	Persons	Ext/Day/Person
1987	29,240	14	378	5.5
1988	10,750	12	240	3.7
1989	29,010	8	200	18.1
1990	14,860	8	192	9.7
1991	15,725	8	208	9.5
1992	16,932	9	210	9.0
1993	16,980	8	214	10.0
1994	31,000	8	200	19.4
1995	20,900	6	196	17.8
1996	81,220	6	210	64.5
1997	88,080	28	481	6.5
1998	41,100	27	384	4.0
Average	32,983	11.8	259.4	14.8

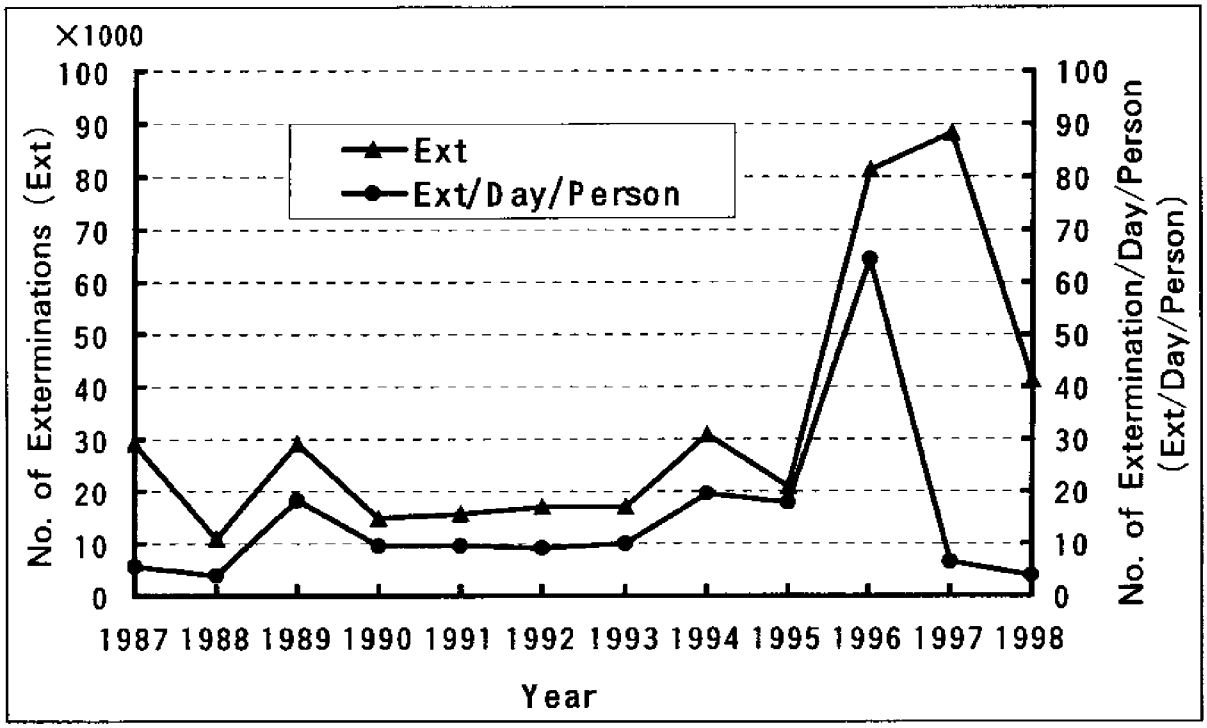

Fig. 2. Fluctuation in the number of exterminated *Acanthaster planci* in Okinawa Coastal Quasi-National Park at Onna Village. The labels "Ext" and "Ext/Day/Person" indicate the total number of exterminated individuals and the number of exterminated individuals per number of days per number of persons, respectively. Data source: Onna Village Office and Onna Fishermen's Association.

The number of exterminated individuals at Busena Cape (i.e., OCVB project), from April of 1992 to the end of 1995, fluctuated on a comparatively small scale, fewer than 300, and suddenly increased in 1996 reaching approximately 1,300, and in April, 1997 reaching a maximum extermination, approximately 1,400 (Fig. 3). In May, 1997, the exterminated individuals suddenly decreased to fewer than half, about 500, of those in April of 1997 and slowly decreased until April of 1998 (Fig. 3). These fluctuations in extermination are similar to the inclination of exterminations in Onna Village (Fig. 2 and Fig. 3). In May of 1998, however, the exterminated individuals suddenly increased again to 635, almost double those in April, and then suddenly decreased in June and steadily decreased until May, 1999 (Fig. 3).

The decrease in extermination at Busena Cape, from May of 1997 to April of 1998, is considered to be due to the extermination conducted in Coastal Quasi-National Park in Onna Village, from June to the end of 1997, since Busena Cape was included in the extermination area.

Because about similar effort was exercised in every monthly extermination program, monthly trend in the number of exterminated individuals roughly indicate a constantly decreasing trend in the population size of *A. planci* at Busena Cape since the middle of 1997.-

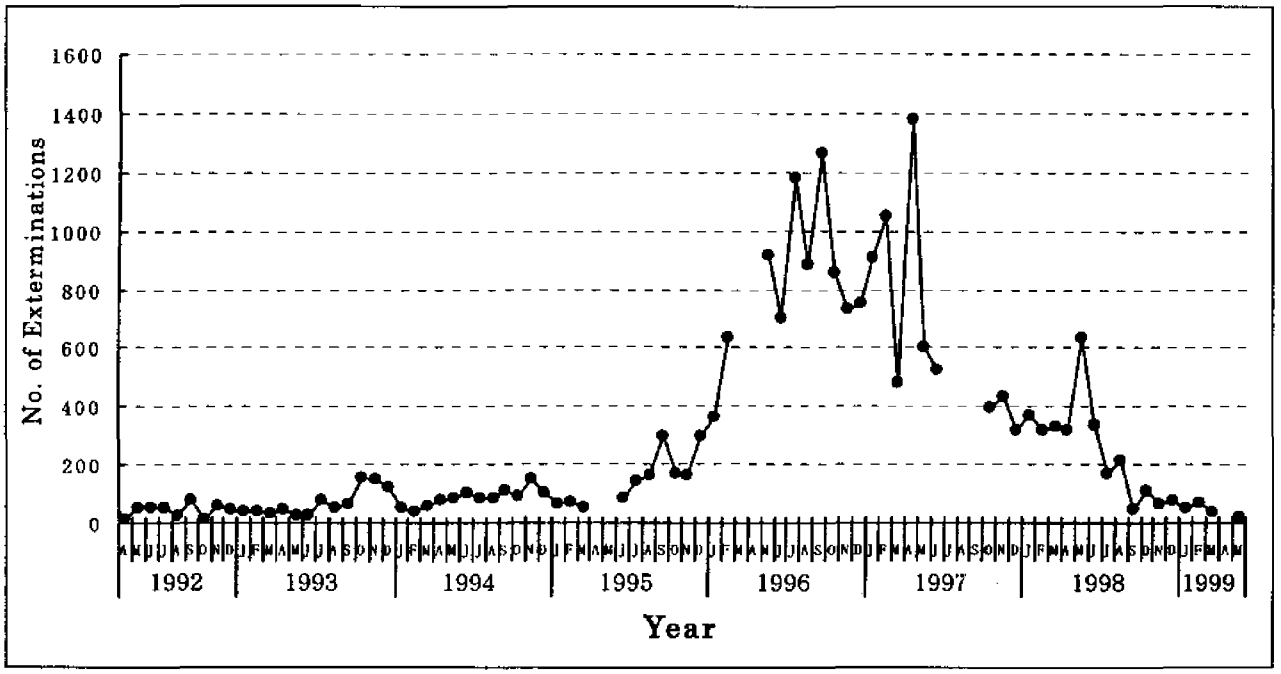

Fig. 3. Fluctuation in the total number of exterminated *Acanthaster planci* at Busena Cape's nine extermination sites. Data source: Okinawa Convention and Visitors Bureau, and Okinawa Diving Information Center.

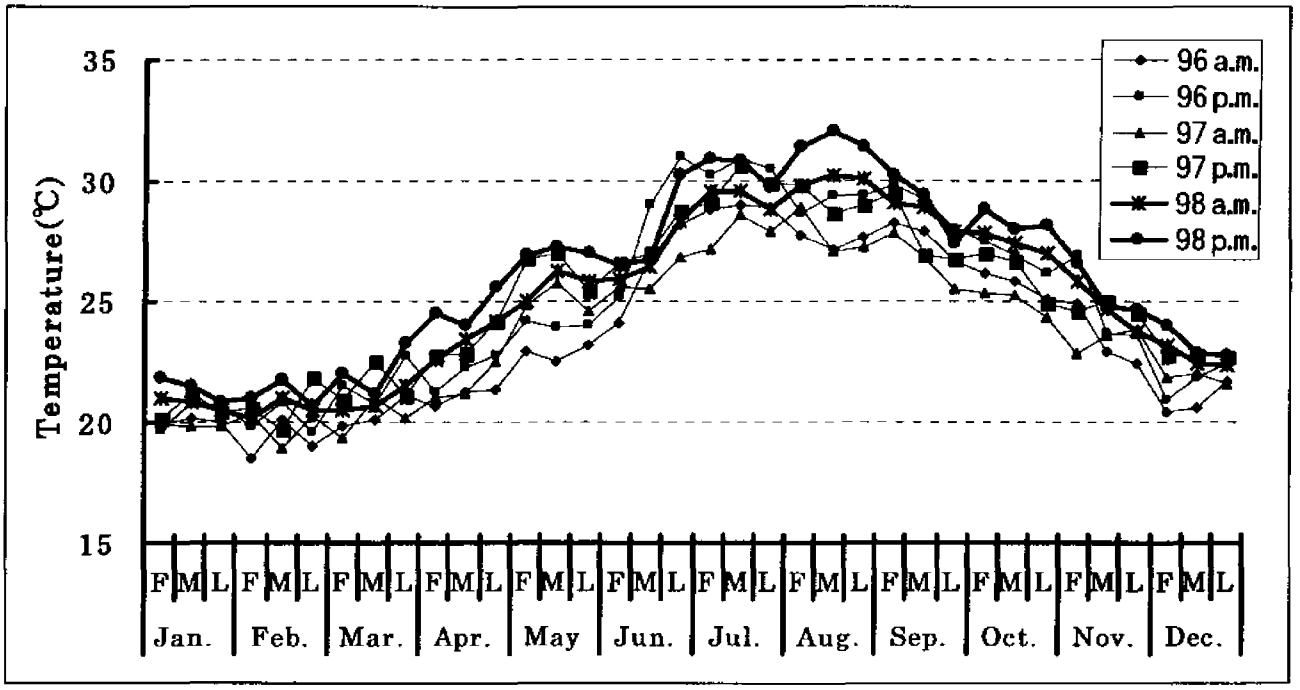

Fig. 4. Fluctuation in sea surface temperature during the year at Sesoko Island.
Sea surface temperature was recorded twice a day, in the morning (a.m.) and in the afternoon (p.m.), three days a month, in the first (F), middle (M), and last (L) 10 days. The lines connect either the morning or afternoon temperature readings, recorded every ten days The numerals in the box indicate the year of the temperature data. Data source: The Sesoko Station, Tropical Biosphere Research Center, University of the Ryukyus.

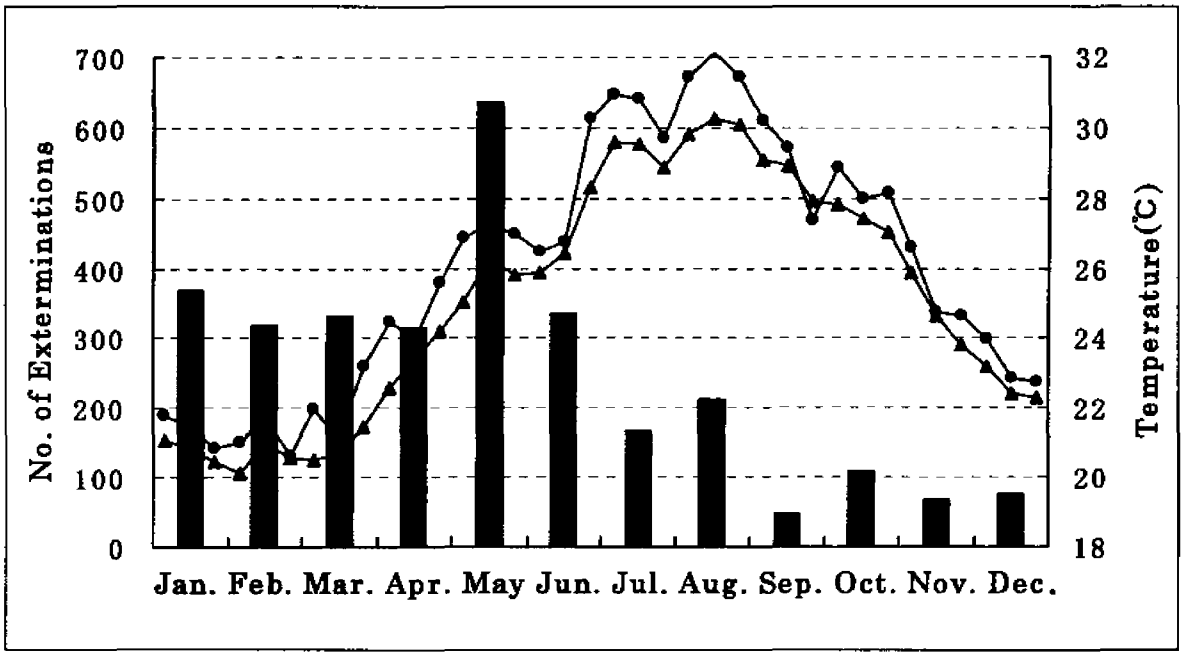

Fig. 5. The number of exterminated *Acanthaster planci* and sea surface temperature changes. Black bars indicate the number of exterminated *A. planci* at Busena Cape in 1998, and lines indicate sea surface temperature changes at Sesoko Island in 1998. The symbols ▲ and ● indicate temperature in the morning and in the afternoon, respectively. Data on *A. planci* were obtained from the Okinawa Convention and Visitors Bureau, and those on temperature from the Sesoko Station. Tropical Biosphere Research Center, University of the Ryukyus.

2. *Sea surface temperature changes and the number of exterminations*

Sea surface temperature around Sesoko Island was higher in 1998 than in the previous two years (Fig. 4). The temperature in the afternoon rose abruptly in mid June and reached to higher than 30℃ in late June, 1998. Then it dropped to a little lower than 30℃ in late July but rose again soon, and in mid August it reached a maximum temperature of 32.1℃ for the year, and never dropped lower than 30℃ until the beginning of September (Fig. 4). The drastic decrease in extermination in 1998 at Busena Cape started in June. It was the middle of the same month that the sea surface temperature at Sesoko Island rose abruptly in 1998 (Fig. 5).

DISCUSSION

Large scale coral bleaching occurred owing to abnormally high seawater temperature in 1998 (Fujioka, 1999; Kayanne et al., 1999; Tsuchiya, 1999b, 1999c). Japanese waters affected by the coral bleaching extended from the Ryukyu archipelago to the south of Kyushyu (Nakano, 1998; Tsuchiya, 1999b; Yamazato, 1999). About 90% of hard corals were dead around Sesoko Island due to the effects of bleaching (Yamazato, 1999). The increase in sea

surface temperature began to be noted at Sesoko Island in mid-June of 1998 with some corals being bleached in the beginning of July and most corals being bleached by late July (Nakano, 1998). Almost all acroporidae corals died by late September (Nakano, 1998). In the shallow moat of the southern part of Okinawa Island, corals bleached in late August, 1998, and most of these corals died in late October, 1998 (Tuschiya, 1999c).

A. planci prefer acroporid corals (Nisihira & Yamazato, 1974). During the coral bleaching of 1998, acroporid corals were seriously affected (Taniguchi et al., 1999; Kayanne et al., 1999; Yamazato, 1999; Sugihara et al., 1999; Shibuno et al., 1999; Fujioka, 1999), and the rate of mortality of acroporid corals due to bleaching is relatively high (Kayanne et al., 1999; Yamazato, 1999; Sugihara et al., 1999; Shibuno et al., 1999; Fujioka, 1999; Hasegawa et al., 1999). The decrease in exterminations of *A. planci* both in Onna Village and at Busena Cape in 1998 is suspected to be due to starvation of the species owing to the dying out of corals which had undergone bleaching. However, a drastic decrease in exterminations at Busena Cape occurred in June of 1998, which was more than one month before the coral bleaching and, moreover, more than three months before the extensive death of corals. Therefore, the immediate cause for the decreased number of exterminations is probably not due to the starvation of *A. planci* owing to the death of corals.

The range of temperature tolerance for *A. planci* depends on their stage of development (Habe et al., 1989). The range of tolerance for 50% survival was reported to be 10.5℃ to 34℃ for larvae, 10.4℃ to 34.5℃ for juveniles, and 12.5℃ to 32.5℃ for adults. The feeding ratio of the species reaches a peak at 31℃ for juveniles and at 30℃ for adults, and it decreases drastically at temperatures higher than these (Habe et al., 1989). Since the temperature tolerance of *A. planci* is narrowly limited, the rise in water temperature should have adversely affected the behavior of *A. planci*. Therefore, presumably the sudden increase of seawater temperature starting in mid-June, 1998 caused the decrease in the *A. planci* population and, hence, the decrease in the number of exterminated individuals at Busena Cape, which started in June, 1998.

Yet it is not clear that abnormally high temperature and starvation due to the death of corals in 1998 actually caused a sudden decrease in the *A. planci* population size. Since there were not any eyewitness reports of *A. planci* being washed ashore or being found dead in the water in 1998, there is still the possibility that *A. planci* evaded the high water temperature by removing themselves to deeper waters. Besides, *A. planci* can survive without food for months (Pearson & Endean, 1969), or for at least half a year (Nakano, personal communication). It is better to regard *A. planci* as still being alive around Okinawa Island, and there is a possibility that they will return to the coral reefs as the corals around Okinawa Island recover.

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サンゴ白化がオニヒトデに与えた影響

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1998年には、高水温が原因であると思われる大規模なサンゴの白化が起こり、日本での白化の規模は琉球列島から九州南部まで及んでいる。本研究では、サンゴ白化の前後でオニヒトデ個体数の変動を示し、この変動の原因を白化との関連で説明して行くことを試みる。ミドリイシ類を好んで捕食す

るオニヒトデは最も強力なサンゴ捕食者の一種である。ミドリイシ類は白化し易いサンゴ類であり、その殆どは白化により死滅している。これらより、オニヒトデが餌としているミドリイシ類が白化により殆ど死滅することにより、オニヒトデの餌がなくなりオニヒトデが減少したと考えることができる。しかし、部瀬名岬におけるオニヒトデ駆除の記録では、オニヒトデ駆除数の減少はミドリイシ類の大規模な斃死の約3ヶ月前で、水温の上昇し始めた6月中旬であることを示している。成体のオニヒトデは温度耐性が極めて狭く、約30℃でオニヒトデの行動に大きな影響を与える事がわかっている。これより、部瀬名岬で行なわれたオニヒトデ駆除数の急激な減少の第一の要因は1988年6月中旬に始まった異常高水温であり、サンゴの白化後の餌不足が第二の要因であると考察される。