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Report on the
Acanthaster planci (*Alamea*) Studies on Tutuila, American Samoa

1979

Submitted to

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ABSTRACT

Outbreaks of adult *Acanthaster planci* have appeared at irregular intervals, arriving three years after extra heavy rains or after a record drought precedes a heavy rain near the beginning of the *Acanthaster* breeding season. *Acanthaster* outbreaks follow typhoons which bring heavy rains, but they do not follow "dry" typhoons of equivalent wind force. Outbreaks occur around the high islands in the Carolines, but not around the atolls at intermediate locations in the Carolines. Phytoplankton blooms appear at the beginning of the rainy season in bays with large watersheds off high islands and these are the initial sites of *Acanthaster* abundance on Guam. The breeding seasons of *Acanthaster* occur at the beginning of the rainy season on both sides of the equator, and the larvae of *Acanthaster* are adapted to salinities as low as 30°/oo. We present an hypothesis that on rare occasions, terrestrial runoff from heavy rains following the dry season may provide enough nutrients to stimulate an adequate phytoplankton bloom to produce enough food for *Acanthaster* larvae to result in an outbreak of adults three years later. The hypothesis predicts an outbreak at Saipan in 1981 and at Palau in 1982.

The place of *Acanthaster* in the cultures of some Micronesians, Melanesians, and Polynesians from high islands suggest that *Acanthaster* outbreaks are a natural phenomenon that recurs at irregular intervals. However, we have not yet found evidence that the coral communities ultimately depend on *Acanthaster* outbreaks and we have found no predator that is totally dependent on an abundance of *Acanthaster* for food.

E fofo e le alamea le alamea

Samoan proverb: "The cure for Acanthaster is Acanthaster"

INTRODUCTION

The crown-of-thorns starfish, *Acanthaster planci* or *alamea*, is a part of Samoan culture. *Alamea* is scarce and widely scattered in its distribution for decades at a time. Occasionally, however, there are abrupt increases in abundance. During these times of extreme abundance, fishermen are reluctant to go fishing on the reefs at night for fear of stepping on the *alamea* and being stung by the spines. If they step on *alamea*, they are advised by the Samoan proverb to turn over the *alamea* and step on the mouth and tube feet. The mouth and tube feet are reputed in the legend to suck out the spines or the toxin.

Despite the familiarity of the *alamea* in legend, which implies that *alamea* may have been prevalent at certain previous times (see also Appendix A), *Acanthaster* has rarely been seen for decades prior to 1977. Vaolui of Alofau has been a fishermen-farmer since 1958 and has been on the reef flat nearly everyday for 21 years. He didn't see a single *Acanthaster* until he found one in 1972. Never in his lifetime has he seen an outbreak of *Acanthaster* such as is occurring now. Leuila Alaimaleata has been a fisherman-farmer at Alofau all his life (68 years). He said that *Acanthaster* was abundant in both shallow (reef flat) and deep (reef front) water in 1916, but between 1916 and 1978 the *Acanthaster* were very scarce. Upuese Taifane of Poloa told us that *alamea* were abundant around 1932 but were scattered and scarce ever since. Chief Faiaipa'u of Onenoa said that before the present outbreak in 1978 they were never abundant in his lifetime, but he remembers from the talk of his elders that they were abundant many decades before. The familiarity of alamea in proverbs and legend is probably because of these past events, but adult Acanthaster may have been very scarce and scattered from at least 1938 until late 1977.

The increase in abundance of Acanthaster was very abrupt. In extensive diving around Tutuila (American Samoa) for 3 years prior to 1977, Dr. Richard C. Wass observed a total of no more than 6 Acanthaster. Then, in November of 1977, he found a large group on the north coast of Tutuila. In the next month, an aggregation of about 83,000 was surveyed on Taema Banks off the south coast of Tutuila (Appendix B). During the next year, 486,933 Acanthaster were removed from the ocean and buried on land (Table 1). Acanthaster were still abundant around Tutuila in April 1979.

At the suggestion of Patrick G. Bryan, Fisheries Officer, and the invitation of Henry Sesepasara, Director of the Office of Marine Resources, Government of American Samoa, we visited American Samoa to do a study on the Acanthaster infestation. In this report we will summarize the information available and state our conclusions concerning the possible causes of the Acanthaster infestations, the nature of the processes of coral reef recovery, and comment on the approaches to be taken in handling the problems.

TERRESTRIAL RUNOFF AS A CAUSE OF ACANTHASTER INFESTATIONS

Abrupt Nature of the Population Increase

Weber and Woodhead (1970) reported that no Acanthaster were found in American Samoa during 6 man-days of snorkeling and reef-walking in 1966, 1968 and 1969. Vine (1970) saw no Acanthaster at 3 locations and noted they were "scarce" (between 1 and 5 seen) at one location. R. C. Wass (pers. comm.) saw no more than 6 Acanthaster altogether during three years of extensive diving around American Samoa prior to November 1977. Samoan

Table 1. Totals of _Acanthaster planci_ removed from the ocean and buried on Tutuila during the bounty program, January 23 to October 25, 1978.

Location	Collection Dates	Number of _Acanthaster planci_ removed
Sa'ilele	July 11 - October 19	12,354
Aoa	May 26 - October 25	125,564
Onenoa	May 8 - October 25	258,913
Tula	June 5 - October 18	35,675
Amouli	February 9 - May 24	109
Pagai	June 21 - October 19	8,875
Faga'itua	June 12	41
Alega	January 26	1,437
Lauli'i	January 23 - June 7	21,690
Faga'alu	January 23 - March 31	478
Matu'u	January 27 - January 31	1,001
Faganeanea	January 27	200
Nu'uuli	January 26 - April 5	4,303
Fagamalo	June 27 - October 19	4,157
Aunu'u	April 26	296
Nafanua Banks	April 28 - May 24	3,757
Taema Banks	February 21 - April 24	8,083
Total removed		486,933
Total spent in bounty money ($.15 each)		$73,039.95

fishermen who were out on the reef nearly every day during the last few decades very rarely saw an alamea (cf. Introduction, this paper). Despite the frequent and widespread fishing, snorkeling or diving activities, Acanthaster was so scarce that it was seldom noticed for decades prior to late 1977.

The first group of Acanthaster (roughly 50 per half hour) were seen in November 1977 at Fagatuitui Cove, northeast of Fagasa Bay on the north coast of Tutuila. In the next month, an aggregation of about 83,000 Acanthaster was found moving as a front along Taema Banks (Sector IV, cf. Appendix B) off the south coast of Tutuila. A total of 486,933 Acanthaster were removed from the ocean and buried on land within less than a year from time the first group was observed (Table 1).

This sudden increase in numbers of Acanthaster implies that the population increase was the result of an especially heavy set of one year class and not the result of a gradual population buildup over several generations or years. The hundreds of thousands of Acanthaster in 1978 were of adult size, approximately 25 to 35 cm in diameter, which implies the larvae set about 3 years earlier (Lucas 1974, Yamaguchi 1974). The breeding season of Acanthaster in the South Pacific is in January or February (Lucas 1973). The population is most likely to have resulted from an especially successful year class that originated in January or February of 1975.

Widespread Nature of the Population Increase

In late 1977, large groups of Acanthaster were found moving inshore from deep water on both the north coast of Tutuila (Fagatuitui Cove) and off the south coast of Tutuila (Taema Banks). The largest group (384,477 +)

was first seen in May 1978, moving into Aoa and Onenoa Bays at the northeast tip of Tutuila. Alex Banse, a resident of Western Samoa, informed us that the first appearance of large numbers of *Acanthaster* occurred on Western Samoa also during 1977. This appearance of *Acanthaster* in large numbers at approximately the same time in such widely separated locations suggests that we should not expect to trace the origin of this population increase to a particular reef, river mouth or other specific location. It seems far more likely that the cause of the population exposion will be traced ultimately to some meteorological, hydrographic or other widespread environmental phenomenon (and the abruptness of this population increase of 3 year old adults suggests that this phenomenon took place about 3 years before 1977).

The widespread nature of origin of *Acanthaster* infestations also characterized the recent infestation in Palau. By following the changes in location of the centers of abundance of *Acanthaster* and the increases in extent of damage to *Acropora*, the infestations seem to have started at discrete locations, widely separated by Urukthapel (Ngeruktabel), a very long island (Birkeland 1979). Although *Acanthaster* outbreaks are concentrated on a geographic scale, occurring in some island groups and not in others, the outbreaks appear to start at several locations within these island groups subjected to similar climatic conditions.

Rainfall Records in Relation to *Acanthaster* Outbreaks

The breeding of the *Acanthaster* that produced larvae that eventually became the plague of 3 year old adults in 1977-1978 probably took place in December 1974-February 1975, the breeding season of *Acanthaster* 3 years earlier. This was at the beginning or early part of the rainy season south ble 3. Monthly and annual precipitation at Guam. Data taken from National Oceanic and Atmospheric Administration records.

ar	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annua
56										8.16	13.45	10.44	
57	5.51	3.77	3.00	3.13	1.83	3.46	4.74	13.77	14.79	20.59	18.14	2.96	95.69
58	7.91	2.23	1.70	2.44	3.87	11.53	12.89	11.22	14.43	12.12	5.80	4.62	90.76
59	3.45	2.27	2.08	3.22	0.90	2.27	6.15	11.56	18.39	10.76	11.71	6.31	79.07
60	2.71	0.67	1.73	1.44	5.69	7.54	7.93	14.82	9.35	11.78	11.30	6.23	81.19
61	7.66	2.74	4.85	4.28	5.37	5.90	8.10	16.61	15.40	19.17	5.31	4.35	99.74
62	2.24	9.17	1.66	8.66	6.68	7.97	14.98	14.12	21.86	14.95	13.09	13.08	128.46
63	9.33	9.47	2.46	19.55	12.56	7.11	11.25	11.85	13.47	18.06	6.88	16.19	138.18
64	1.99	4.11	4.44	7.48	20.69	7.49	7.67	8.92	19.30	14.62	6.05	6.92	109.68
65	10.29	1.02	0.59	0.50	1.69	5.35	15.67	3.87	22.27	6.89	6.97	3.13	78.24
66	2.13	1.69	1.71	1.31	2.51	5.72	6.74	11.39	22.28	6.96	7.26	4.76	74.46
67	5.26	4.45	11.28	8.97	3.76	8.37	12.62	23.07	20.28	14.20	11.75	2.51	126.52
68	5.75	8.48	3.71	1.69	3.16 **	6.17	12.36	14.61	11.82	13.31	11.92	3.36	96.34
69	2.79	1.12	0.97	1.36	2.72	1.52	13.83	9.30	6.79	25.32	10.10	10.11	85.93
70	11.93	3.60	2.68	1.22	2.96	5.60	8.99	10.42	13.70	11.65	9.77	5.71	88.23
71	5.25	5.78	16.94	5.74	22.68	5.06	16.06	20.92	12.21	8.63	6.75	3.14	129.16
72	4.86	6.40	11.29	3.35	3.02	7.95	20.00	18.09	16.09	7.09	4.83	6.35	109.32
73	2.10	2.94	1.57	1.90	3.01	4.85	9.55	6.65	9.05	17.82	2.08	5.35	66.87
74	4.27	3.13	12.25	14.83	12.00	10.46	9.32	25.66	9.96	10.00	8.03	6.20	126.11
75	9.68	1.15	2.25	3.67	1.33	2.46	11.13	22.54	8.86	10.68	12.35	6.42	92.52
76	20.39	13.56	9.04	4.37	40.13	6.40	13.38	24.40	10.79	6.63	7.91	8.91	165.91
77	3.12	3.01	4.98	2.29	6.88	5.10	7.25	6.09	17.32	16.67	12.38	2.22	87.31
78	2.44	4.99	0.85	2.65	3.48	7.89	8.91	19.63	10.01	10.49	14.10	4.80	90.24
79	5.60	1.85	4.20	1.89	**								

<u>Acanthaster</u> breeding season

-------- record drought

════ heavy rains

** outbreak of *Acanthaster*

end of Tumon Bay, one of us (CEB) saw 29 Acanthaster in about 30 minutes and Russ Clayshulte counted 30 Acanthaster along 50 m of reef front. Although this does not qualify as an "infestation" (> 50/10 minute swim or tow; Chesher 1969a, Pearson and Garrett 1978), there does seen to have been a recent increase in abundance.

There has been an infestation of Acanthaster in Palau in which the adults were first observed in 1977, implying that the breeding of the Acanthaster that produced the larvae for this infestation took place in 1974 (Birkeland 1979). The annual rainfall for 1974 (185 inches) was the highest on record (since 1947, cf. NOAA 1978a). May and June of 1974 has less rain than usual with more than average rain during the Acanthaster breeding season in July. This fits the same pattern of correlation of heavy rainfall with outbreaks that we found for Samoa, the Great Barrier Reef, and Guam. However, the average annual rainfall in Palau is 147 inches and there has never been an annual rainfall recorded in Palau less than 114 inches (NOAA 1978a). With heavy rainfall every year, the relationship between rainfall and Acanthaster outbreaks is not so striking on Palau as at the other places. The observations from Palau do not so strongly support this relationship, but they certainly do not refute it.

Heavy rain falls every year in Ponape. The average annual rainfall on Ponape is 192 inches, ranging from 159 to 236 inches per year (NOAA 1978b). There have been no droughts on Ponape since at least 1949 and perhaps never. The Acanthaster outbreak on Ponape was discovered when an extensive survey was made around Micronesia following the discovery of the outbreak on Guam (Chesher 1969b). The time of origin of the outbreak was not certain and the Micronesian commented that a previous infestation may have occurred just after World War II (Chesher 1969b). In any case, any outbreaks on Ponape are associated with heavy rain, but heavy rains also occur when there are no outbreaks.

It appears that there are always heavy rains three years prior to an infestation of adult Acanthaster. Heavy rain may be a necessary factor for an outbreak. However, rain is probably not sufficient to produce an outbreak; there are probably other factors involved. All outbreaks of adult Acanthaster are found three years after heavy rain, but all heavy rains do not necessarily result in an outbreak. As an analogy, light is a necessary factor for the growth of trees, but trees do not grow in all places in which there is light; other factors such as soil are also required.

We are attempting to obtain older weather records for Tutuila and also weather records for other locations of previous Acanthaster plagues, such as Okinawa. We have not yet received weather records for Okinawa old enough to assess the outbreak of Acanthaster. However, Nishihira and Yamazato (1974) noted that the density of Acanthaster was approximately proportional to the degree of siltation from terrestrial runoff. If we obtain more data we might find that both Acanthaster density and terrestrial runoff are correlated with intensity of rainfall.

Influence of Rainfall and Terrestrial Runoff on Coral Reef Systems

Marsh (1977:334) noted that phytoplankton "are usually associated with the beginning of the rainy season. It is probable that heavy rains coming after an extended dry season wash a pulse of nutrients, especially phosphorus, off the watershed and stimulate a bloom. Eventually, as the most easily available nutrients wash off the land, the runoff water becomes more dilute and the plankton bloom in the bay dies out. With the onset of the dry season, accumulation of easily leachable nutrients begins again on the watershed and the seasonal cycle is repeated." Marsh (1977) further noted that no phytoplankton blooms have been observed in Pago Bay which has a generally smaller watershed and a lower input of groundwater than Tumon Bay. Phytoplankton blooms have been recorded in Tumon Bay as far back as the earliest Spanish occupation of Guam. It is interesting to note that *Acanthaster* infestations have not been seen originating in Pago Bay, but the most abundant *Acanthaster* at this time are at the north end of Tumon Bay, near San Vitores cut, where Marsh did his study. *Acanthaster* infestations seem to have generally started around Agana and Tumon Bays, large bays with large watersheds.

Acanthaster Outbreaks Around High and Low Islands

Marsh (1977) found that phytoplankton blooms around Guam, a high island, were associated with availability of nitrate-nitrogen and reactive phosphorus. He also found that his values for nitrate-nitrogen levels around Guam, a high island, were over an order of magnitude higher than those found by Webb et al. (1975) around Enewetak, an atoll or low island. Further, he found slightly higher values of reactive phosphorus around Guam than Pilson and Betzer (1973) found around Enewetak. He went on to predict that reefs around high islands might generally be more heavily influenced by terrestrial runoff of nutrients than would low islands or atolls.

In the previous two sections, we have seen that *Acanthaster* outbreaks generally occur in bays with a large watershed and three years after periods of heavy rain, both characterized by terrestrial runoff. If terrestrial runoff of nitrate-nitrogen and reactive phosphorus is the factor which favors an *Acanthaster* outbreak, then we would predict that *Acanthaster* outbreaks would occur more frequently around high islands or continents than around atolls. Indeed, Tutuila, Western Samoa, Guam, Palau, Ponape and Okinawa are all high islands and the infestation of the Great Barrier Reef appeared to have begun near the continental coast of Queensland, Australia (ARC 1975). Infestations have been found around the high islands of Palau (Chesher 1969a, b; Marsh and Tsuda 1973; Birkeland 1979) but not around Kayangel, the atoll of Palau (Marsh and Tsuda 1973).

To statistically test the hypothesis of more frequent occurrence of *Acanthaster* outbreaks around high islands, we can subject the data of Table 1 in Marsh and Tsuda (1973) to a chi-square test. Marsh and Tsuda summarized findings of surveys and resurveys of various islands around Micronesia by University of Guam, Trust Territory, and Westinghouse teams. They categorized the islands as high islands or atolls and categorized the reef conditions on a scale from 1 to 6. Conditions 1 and 2 were essentially normal conditions, Conditions 3 to 5 designated large populations of *Acanthaster*, and Condition 6 indicated a hypothetical case which needed further documentation. Condition 6 was excluded from the analysis because of inadequate documentation. The tallies are presented in Table 4.

It is clear from Table 4 that *Acanthaster* outbreaks have a significant tendency to occur around high islands and almost never around atolls. As a matter of fact, the two instances of abundant *Acanthaster* on atolls tallied in Table 4 might be disregarded for two reasons. First, only one *Acanthaster* was actually seen on Kuop and only a few were seen on Ant (Marsh and Tsuda 1973). The atolls were categorized in Condition 5 because

Table 4. Results of *Acanthaster* surveys of 1969-1972 in Micronesia. The data were tallied from Table 1 in Marsh and Tsuda (1973).

	High Islands	Low Islands (Atolls)	
Conditions 1 and 2 (normal)	4	20	24
Conditions 3 to 6 (abundant *Acanthaster*)	19	2	21
	23	22	45

$X^2_{adj\,[1]} = 21.5$ $(p \ll .001)$

the "reefs appeared to have been substantially killed off at some time in the past" although there was "not convincing evidence that the kill was due to Acanthaster" (Marsh and Tsuda 1973). Second, both of the atolls were very near the outer reefs of high islands and the primary infestations could have occurred as a result of proximity to the high islands. Kuop is only 3 km from the outer reefs of Truk and Ant is only 10 km from Ponape.

The only real counterexample to the general trend of lack of infestation on atolls as far as we know, is the apparent damage of the coral communities by Acanthaster on Cocos-Keeling Atoll (Colin 1977). If the waters around this atoll do not receive an adequate input of nutrients to support a phytoplankton bloom, then the Acanthaster may have reached a large population level only by a gradual buildup in numbers over the years. Admittedly, Cocos-Keeling Atoll does not fit the story suggested by most other locations and, unfortunately, it is too isolated and rarely visited to provide enough observations to work with.

Despite the Cocos-Keeling counterexample, and perhaps eventually a few more special cases, there is still a significant tendency for outbreaks to occur around high islands rather than low islands or atolls. The terrestrial runoff hypothesis provides a plausible mechanism to explain why infestations might arise periodically, at irregular intervals, concurrently at high islands in the Carolines hundreds of kilometers apart, but not at intervening low islands or atolls.

Influence of Rainfall on Larval Biology of Acanthaster

The main breeding season of Acanthaster south of the equator is December-February (Lucas 1973). The main breeding season of Acanthaster north of the equator is June-July (Yamazato and Kiyan 1973). In both regions, these periods begin about a month after the beginning of the rainy season.

The larvae of <u>Acanthaster</u> appear to be adapted to surprisingly low salinity levels for an echinoderm. In fact, laboratory experiments by Lucas (1973) demonstrate that the survival of larvae increases as the salinity is lowered, at least to 30°/oo.

According to the Advisory Committee on Research (A.C.R.), Pearson and Lucas identified a mechanism for the outbreaks of <u>Acanthaster</u> by combining the breeding season of <u>Acanthaster</u> with the increased survival of larvae at lower salinity levels. "Thus, the right combination of heavy run-off (lowering salinity), light wind conditions (preventing mixing with more saline water) and an abundance of <u>A. planci</u> larvae could lead to a high survival rate in larvae and subsequent expansion of juvenile and adult populations" (A.C.R. 1975:16). Pearson and co-workers found optimum salinity levels as a result of runoff in reef waters near the coast of Queensland where infestations were common.

We agree that heavy runoff is favorable for the survival of <u>Acanthaster</u> larvae, but we think the main benefit of the runoff is not the lower salinity itself (a proximate adaptation), but that it ultimately provides more nutrients (nitrate-nitrogen and reactive phosphotes) which stimulate phytoplankton blooms which, in turn, provide food for <u>Acanthaster</u> larvae. The breeding season of <u>Acanthaster</u> coincides with the beginning of the rainy season and the larvae are adapted to relatively low salinities most likely as adaptations to place larvae in situations of maximum likelihood for ample nourishment.

Lucas (1974) determined the food requirements of Acanthaster larvae by raising larvae in aquaria with six different concentrations of a green falgellate and six concentrations of a diatom. The greatest percentage of larvae survived to late brachiolaria stage at 5,000 diatom cells/ml.

Lucas referred to Marshall (1933) as the only comprehensive study of phytoplankton on the Great Barrier Reef. Marshall sampled phytoplankton for almost a year and found most samples to contain phytoplankton at very low concentrations, about 2 cells/ml. In a few samples, at irregular intervals, phytoplankton reached maximum concentrations of about 170 cells/ml, and these were mainly diatoms. The maximum phytoplankton densities found in coral reef waters are a small fraction of the minimum densities required to support Acanthaster larvae. For this reason, we suggest that Acanthaster plagues are initiated when extra heavy rainfall occurs, especially when breaking an extensive drought. The heavy rains result in nutrients being washed into the sea, stimulating a relatively dense phytoplankton bloom. When this coincides with the breeding season of Acanthaster, an extraordinary proportion of the larvae may survive starvation, resulting in an infestation three years later.

Moore (1978) pointed out that Acanthaster planci is a long-lived species with a very high reproductive potential. The long life of adults allows the species to persist for long periods between times in which environmental conditions favor larval survival. When the conditions favoring larval survival occur, the high reproductive potential of adults produces a massive settlement and large fluctuations in local populations. We hypothesize that these conditions that favor larval survival include, in part, a large phytoplankton bloom resulting from extra heavy rainfall at the beginning of a rainy season. The breeding season of *Acanthaster* and the salinity tolerance of their larvae increase the chance of the larvae being present when the phytoplankton bloom occurs.

Other Marine Species that Correlate Abundance with Runoff

Sutcliffe (1972, 1973) showed that correlations exist between the amounts of land drainage or river discharges and fish and lobster catches. As with the 3-year lag between the terrestrial runoff that favors larval *Acanthaster* and the appearance of a plague of adult *Acanthaster*, the correlations of river discharges are found if lag periods are considered to account for age at maturity or age at commercially harvestable size. The timing of the runoff is important. He found that the runoff data to be analyzed for the correlation must be taken from early in the reproductive season for the species under consideration, just as we must remember that relevant rainfall data for the *Acanthaster* study are 6 months apart on the two sides of the equator in consideration of the different reproductive seasons in the two hemispheres. Sutcliffe (1973) found that the major effect of land drainage was in increased production of larval stages, probably through increased primary production. The degree of correlation was highest for the earliest larval stage and decreased with increasing larval stages.

Other Plagues Resulting from Changes in Rainfall and Added Nutrition for Larvae

White (1976) reviewed the literature on 7 species of locusts from around the world. As with *Acanthaster*, he found that very young locusts usually have an inadequate or too thinly dispersed food supply and most die off before reaching maturity. When there are periods of alternating unusually dry and wet seasons, the food supply becomes more favorable for the very young locusts. An increased survival of very young locusts later results in a plague. Parasites and predators have little influence on their abundance; the determining factor is added nutrition for early instars which results from extreme changes in rainfall patterns.

Fluctuating Densities of Marine Invertebrates with Planktotrophic Larvae

Although "plague" is a term reserved for invertebrates such as *Acanthaster* and locusts that are harmful to man economically, many marine invertebrates are characterized by irregular outbreaks or swarms (Coe 1956). Many marine invertebrates produce a tremendous "surplus" of larvae, the vast majority of which perish before metamorphosis. White (1976) hypothesized that the major influence on the abundance of herbivorous insects is a relative shortage of food for the very young; that food is usually too thinly dispersed. Both White (1976) and Wolda (1978a) present evidence that fluctuations in populations of tropical herbivorous insects are strongly affected by irregularities in rainfall. We suggest that this situation is generally the same for shallow-water marine invertebrates with planktotrophic larvae. Outbreaks occur when runoff of terrestrial nutrients coincide with the reproductive season of the marine invertebrates.

It is sometimes asserted that "pronounced short-term fluctuations in population densities are not features of the population ecology of specialized coral reef species and *A. planci* can be shown to be such a specialized coral reef species" (Endean 1977:188). The definition used for the term "specialized" (Endean 1974) is not definitive enough to clearly include or exclude most species, but if we consider tropical marine invertebrates with planktotrophic larvae, we find that most species are characterized by great year-to-year fluctuations in population densities. For example, while we were on Tutuila, we found concentrations (about 50 seen per half hour) of small (6 to 9 cm total diameter) Linckia laevigata at two locations: one at Austin Lambert's study site near the Governor's house on Coconut Point north of the airport and the other between the Rainmaker Hotel and the big square cement block due east on the reef flat. As Yamaguchi (1973) pointed out, Linckia laevigata is similar to Acanthaster in that it is long-lived and only large adults are usually found. Recruitment is very important, probably because of low survival of pelagic stages.

While on Tutuila, we noted an abundant recruitment of small (ca. 10 cm) Stichopus chloronotus on the reef flat at Masefau Bay. Barry Smith (pers. comm.) also noted an abundant recruitment of S. chloronotus on Guam at Shark's Hole. Marsh et al. (1977) noted that an extensive settlement of Diadema and Echinothrix occurred in 1973 and the abundant year class of 1973 was still prevalent in 1977 (and perhaps longer). The prevalence of these year classes is because of the irregularity of heavy recruitment. Peter Frank (1969) characterized tropical gastropods as being long-lived with irregular reproductive success.

We do not know of any tropical marine invertebrate with planktotrophic larvae that has regular and nonfluctuating patterns of recruitment. Endean (1977:188) argues that A. planci infestations are not periodic or cyclic because coral reef systems are regarded as having " a particularly stable or predictable organization because they are biologically accommodated." We suggest that coral reef systems might fluctuate as much as temporate marine systems, but the fluctuations of small motile invertebrates have been unnoticed and unstudied while the fluctuations in coral and sponge populations are on a long-term time scale because of the longevity of individuals.

Tropical insect populations were assumed to fluctuate less than temperate insect populations on the basis of the diversity-stability hypothesis. Once comparative data were obtained from the tropical rain forest (Wolda 1977, 1978b), it was found that there was no empirical basis for the theoretical assumption of less fluctuation of invertebrates in tropical rain forests. We predict that the same might hold for coral reef systems once data are obtained.

In summary, Acanthaster planci is typical of many large coral reef invertebrates with planktotrophic larvae in being long-lived with very irregular reproductive success. Many tropical marine invertebrates with planktotrophic larvae are also characterized by irregular outbreaks but their effects on the coral reef system go unnoticed by man. In this report, we hypothesize that the degree of larval survival depends mainly on the availability of sufficient phytoplankton of the proper quality and that this is correlated with amount of terrestrial runoff which is correlated with amount of rainfall at the breeding season.

Predictions to Test our Hypothesis

We might expect increases in abundances of Acanthaster planci at Saipan in 1981 and at Palau in 1982. In mid-August of 1978, over 45 inches of rain fell on Saipan within two days. The flooding was so bad that President Carter declared Saipan a national disaster area. Over 24 inches of rain fell on the Koror area of Palau in 24 hrs between 12 and 13 April 1979. Although these rains were not preceded by droughts, the rains might be intense enough to wash less readily available nutrients into the sea. The Palau rain was somewhat before, and the Saipan flood near the end of, the Acanthaster breeding season, but the phytoplankton blooms might be extensive enough to favor some of the Acanthaster larvae of their respective years.

We can also test our hypothesis with past events by examining the weather records. We expect that a drought followed by heavy rains or else extra heavy rains should precede an Acanthaster outbreak by three years. Factors other than nutrient runoff may be necessary for an outbreak of Acanthaster, so we would not expect all heavy rains to result in an outbreak. However, we would expect all outbreaks to be preceded by heavy rains three years earlier. For material with which to test our hypothesis, we have written to NOAA, to the military, and to other agencies for weather records.

CONSIDERATIONS OF ALTERNATIVE EXPLANATIONS FOR ACANTHASTER INFESTATIONS

Human Activities

Chesher (1969a, b) Randall (1972), Endean (1973, 1974, 1977) and Endean and Chesher (1973) all suggested various ways in which human activities might have triggered Acanthaster population explosions. The results of our studies on Tutuila gave no evidence in support of this contention. We believe the outbreaks of Acanthaster in American Samoa cannot be attributed to human activities because: outbreaks have occurred long ago, before human activities have been on an industrial scale; outbreaks have been of widespread occurrence in essentially uninhabited areas; and there is no evidence that the construction and industrial activities that have taken place on Tutuila have resulted in outbreaks of Acanthaster.

That outbreaks have occurred decades ago is stated in the testimony of native fishermen (cf. Introduction and Appendix A). Although Acanthaster is rarely seen, special words for Acanthaster are part of the vocabulary and cures for Acanthaster stings and other aspects of their biology are part of the folklore of native residents of some high islands (Appendix A). This suggests that they may have been more common at certain times in the past. Frankel (1977) presented information from sediment samples which suggest that Acanthaster planci has occurred in dense aggregations on the Great Barrier Reef many hundreds of year ago, long before the industrial revolution.

When the recent outbreak on Samoa occurred, Acanthaster appeared suddenly on the north coast of Tutuila where there are certainly no industries or commercial operations. At the same time it appeared on Taema Banks, well offshore of Tutuila. In Palau, Acanthaster apparently originated at three uninhabited locations (Birkeland 1979). One of the sites of origin, around Gaiangsu (Ngeangas) Island, south of Urukthapel Island, was certainly remote from any human dwellings or agricultural or industrial activity.

We list in Table 5 the major construction projects and industrial activities that have taken place on American Samoa. We could not find the date of the construction of the runway extension at the airport, but we were assured by several residents that it was at least 10 years ago. As was noted in the Introduction to this report, there were no outbreaks of Acanthaster noted until 1977. Therefore, we have no evidence that any of the construction or industrial activities prior to 1970 had any effect on the Acanthaster population. Since the road from Fagasa Pass to Mt. Alava was washed out by the heavy rains following the drought in 1974, any effect the road construction had on the recruitment of Acanthaster was probably brought about by the heavy rains. It was the rains, not road construction per se, that had the probable influence on Acanthaster recruitment. We certainly can find no

Table 5. Dates of major construction activities and initial dates of industrial processes in American Samoa.

Event	Year
Van Camp took over Pago Pago fish factory and began operation	1954
Star Kist began operation	1963
Aerial tramway from Solo Hill to Mt. Alava and educational T.V. station KVZK transmitter on Mt. Alava were constructed	1964
Rainmaker Hotel was constructed	1961-1966
Rainmaker Hotel was opened for business	1966
Typhoon (February)	1966
Road linking Fagasa Pass to television transmitter on Mt. Alava was constructed	1974

evidence that commercial enterprises, heavy construction, or pollution could explain any of the several apparent sites of origin on either Samoa or Palau.

Predators

Endean (1977) suggested that the collecting of shells by tourists, shell collectors or shell vendors may have reduced the populations of *Charonia tritonis* and released *Acanthaster* from predation pressure to the extent that there was a population explosion. There had not been a great amount of collecting of *Charonia* in American Samoa, at least in recent years. Richard Wass is an avid shell collector and has been looking for shells regularly all around Tutuila, with scuba and by snorkeling, for the last 5 years. He has found only a couple of *Charonia* shells occupied by hermit crabs. A friend of his found two live *Charonia*. Chuck Brugman, manager of Samoa Sunshine tourist store, said the four *Charonia* shells he had for sale were collected from Tonga. He had been talking to local shell-collecting divers who told him they were not getting any. It seems that *Charonia tritonis* has been scarce on Tutuila for a long time. This may indeed reduce the predation pressure on *Acanthaster*, but this pressure has probably been off *Acanthaster* for a number of years and does not explain the sudden infestation observed in 1977 that probably originated from a set in 1974.

A few puffers and numerous balistids were observed, but we never saw one attacking an *Acanthaster*. As White (1976) pointed out, plagues of invertebrates are unlikely to start by reduced predation pressure on adults. They are probably initiated when larval stages are given an adequate food supply, an unusual event.

Typhoons

Dana et al. (1972) suggested that *Acanthaster* aggregations resulted from food limitation caused by typhoon damage to coral communities. However, typhoons on Guam do not kill many of the coral colonies (Randall and Eldredge 1977, Ogg and Koslaw 1978), they just break off and scatter some of the branches. Typhoon Karen (in 1962) and Typhoon Pamela (in 1976) were two extremely strong typhoons with sustained winds of 220 to 270 km/hr. Typhoon Pamela brought 33 inches of rain (27 inches in 24 hours) in 1976 and was followed by an increase in abundance of Acanthaster. Typhoon Karen was a "dry" typhoon of equal wind intensity, but was not followed by an increase in abundance of Acanthaster.

The only typhoon in recent years on Tutuila was a "dry" typhoon in February 1966. Note in Table 2 that the total monthly rain for February 1966 (5.91 inches) was the least rain for the 18 months on record. Therefore, it was a "dry" typhoon with no Acanthaster resulting from it. A "wet" typhoon like Pamela, with 27 inches in 24 hours, results in an increase in abundance of Acanthaster.

The 1959 typhoon near Townsville was accompanied by heavy rains (Maxwell 1968:89) and was followed by the first publicized Acanthaster outbreak. The 1968 outbreak at Guam and the 1977 outbreak at Samoa followed heavy rains, but not strong winds. The pattern that seems to be emerging is that Acanthaster outbreaks follow heavy rains. They follow typhoons that that are accompanied by heavy rains but they do not follow "dry" typhoons with equally intense winds.

Behavioral Aggregations

Dana et al. (1972) suggest that Acanthaster infestations do not actually result from increases in abundance but instead result from behavioral aggregations. They state that "Field evidence is lacking to support the idea of increased larval settlement or increased survivorship at any life stage"

(Dana et al. 1972). They presented the hypothesis that large aggregations of _Acanthaster_ are the results of behavior, that they are redistributions of populations that were already there. We agree that _Acanthaster_ has a strong tendency to aggregate (cf. Birkeland 1979:13) and we agree that some of the small aggregations found on atolls appear to be behavioral phenomena. An example of this might be the observation of a group of about 100 _Acanthaster_ on a small patch reef in Enewetak Atoll (J. A. Marsh, pers. comm.). There were no other groups of _Acanthaster_ in the area and no extensive damage to the coral community was observed. Groups of _Acanthaster_ on atolls appear to be behavioral aggregations; true infestations may not occur on atolls.

However, it is very difficult for us to conceive of true infestations as behavioral aggregations without increased numbers from larval settlement. Certainly well over a half a million _Acanthaster_ appeared abruptly on all sides of Tutuila (and at Western Samoa) and began devastating the reefs. If they suddenly appeared from all sides at once, where were they hiding during previous years? If they have been around, but more scattered in distribution, how did this keep the same total number of predators from eating a noticeable amount of corals here and there? The only typhoon on American Samoa in recent years was in early (February) 1966. If _Acanthaster_ aggregates because of food shortage caused by typhoon damage to the reefs, why were the half million _Acanthaster_ unseen until late 1977? Where have they been hiding for almost 12 years?

PATTERN OF DESTRUCTION BY _ACANTHASTER_

When first moving into an area, _Acanthaster planci_ feeds mainly on the tabular (flat-topped corymbose) _Acropora_ (e.g., _A. hyacinthus_ and _A._

reticulata). When the tabular Acropora become relatively scarce, most of the Acanthaster are then found feeding on the branching (arborescent) Acropora (e.g., A. acuminata and A. abrotanoides), the encrusting Montipora, and the fungiids. For example, during our stay on Tutuila, Acanthaster were moving into Masefau Bay and eating coral, but had not yet devastated the coral community. We took surface cover measurements and found that the tabular Acropora was being eaten First (Table 6). Most of the Acanthaster were found eating tabular Acropora (Table 7).

After the acroporids and fungiids are eaten, the Acanthaster generally turn to feeding on faviids, agariciids, and mussids, although large pieces of Diploastrea (a faviid) are often left uneaten. The last scleractinians to be eaten are usually the poritids (Goniopora, Porites and Porites (Synaraea), the siderastreids (Coscinaraea) and the dendrophylliids (Turbinaria and Dendrophyllia). Many corals of these latter families are often left uneaten when Acanthaster moves out of an area.

If Acanthaster finishes the scleractinians and Millepora, then it will feed on the soft corals (alcyonaceans) and Palythoa (zoanthids), but it is doubtful that Acanthaster ever remains in an area long enough to eliminate alayonaceans or zoanthids, unless they were scarce to begin with.

The degree of destruction of the coral community depends on how many Acanthaster are in the group and how long they stay before moving out of the area. Sometimes only the Acropora are eaten and Turbinaria, Porites, Dendrophyllia and Millepora are left alive. At Onenoa, Acanthaster was very abundant and only a few Millepora, alcyonaceans, and zoanthids were left.

Table 6. The relative surface cover (number of random quadrat points) on living and apparently recently killed tabular (flat-topped corymbose) and branching (arborescent) *Acropora*. A greater proportion of tabular *Acropora* was being eaten by *Acanthaster*.

Acropora group	Number of random points contacting living	dead	
tabular (mostly *A. hyacinthus*)	169	170	339
arborescent (mostly *A. acuminata*)	639	90	729
	808	260	1068

$X^2_{[1]} = 179.5$ $p << .001$

Table 7. The relative proportions of living tabular and branching *Acropora* available (from Table 6) and the proportion of *Acanthaster* counted on these two groups of *Acropora*. *Acanthaster* tended to aggregate on living tabular *Acropora*.

	tabular *Acropora* (mostly *A. hyacinthus*)	arborescent *Acropora* (mostly *A. acuminata*)	
proportion of surface cover of living *Acropora*	169	639	808
number of *Acanthaster* counted on the coral	60	4	64
	229	643	872

$X^2_{[1]} = 162.5$ $p << .001$

In sheltered bays, the coral community can be devastated up to the low tide level. On the open coast, however, the corals in the shallow water, to a depth of 3 or 4 meters usually have a refuge from *Acanthaster* in the surf zone. *Acanthaster* avoids shallow areas of heavy wave assault. One of us (R.H.R.) noted that when an *Acanthaster* was pulled loose and being tossed by the surge, damselfishes would peck at or bite off some of the tube feet.

A healthy stand of *Acropora* usually extended to a depth of 2 or 3 meters at open coast areas such as Alofau and Fagasa where the *Acanthaster* had devastated the corals at greater depth. Surface cover data for 1 to 3 meters and for 6 to 8 meters depth are given for Siufaga Point in Table 8. The crustose coralline algae and filamentous algal turf included in Table 8 covered the skeletons of dead tabular and branching *Acropora*. According to Mab'bu Vae, a Matai of Fagasa, the *Acropora* below the refuge in the surf zone was killed by *Acanthaster* in late 1977.

MECHANISM OF CORAL COMMUNITY RECOVERY

While *Acropora* was almost totally devastated below the surge zone (Table 8), we would generally see a few loose branches or fallen tabular sections of living *Acropora* scattered about the devastated areas. The aspect of these "survivors" that was most striking was that they were loose pieces usually laying on top of or wedged into the skeletons of dead corals that were overgrown with algal turf. Considering the preference of *Acanthaster* for acroporids, the degree of devastation of the coral community, the fact that the living acroporids were all loose pieces, and that there was an abundance of living acroporids above in the surge zone refuge, we hypothesize that these pieces had fallen down and become wedged into the

Table 8. Relative surface cover (percent of random quadrat points) in the shallow surge zone (a refuge from *Acanthaster*, 1 to 3 m depth) and in the deeper devastated zone (6 to 8 m depth) at Siufaga Point. The crustose coralline algae and filamentous algal turf were mainly contacted on dead *Acropora*.

Depth Number of quadrats Number of random points	1 to 3 m 17 612	6 to 8 m 102 3672
	Percent cover	
crustose coralline algae and filamentous algal turf	3.8	90.2
Acropora hyacinthus (tabular)	77.8	1.8
Acropora acuminatus (arborescent)	16.9	3.8
other *Acropora* spp.		.7
Montipora spp.		.8
Pocillopora spp.	1.5	2.2
faviids		.2
Goniopora sp.		.08
Pavona sp.		.08
Galaxaea sp.		.05
Dysidea herbacea (grey encrusting sponge)		.14

devastated areas after the *Acanthaster* had moved away. Arborescent *Acropora* often spread by the reattachment of broken branches. The widely spaced and lengthy branches readily wedge into crevices in the reef framework or between the branches of other arborescent, cespitose, or foliaceous corals. They have two mechanisms for reattachment. The *Acropora* recements itself by growing onto the barren substratum from one end of the branch or, if it has fallen onto a living coral, the coral into which it is wedged grows up onto the branch of the *Acropora* and cements the two corals together.

The easily broken, easily wedged, and reattached branches of arborescent *Acropora* may allow these species to gain a refuge in size when invading an area and to bypass some of the main problems of coral recruitment by planulation. Planulae have a very difficult time recruiting into an algal turf because until the small coral reaches a refuge in size, it can easily be smothered by algae or by the sediment traps created by the filamentous algae (Birkeland 1977). Planulae also have a difficult time settling on another coral or onto an extensive patch of living corals because the coral could eat the planulae and because a planula probably cannot attach to living tissue. *Acropora* branches can invade these areas because they have a refuge in size from the sediment, the algae and other corals. Although the lower surfaces or the parts of the branches that are wedged into the substrata die, the exposed surfaces live and continue to grow.

In cases where there is enough surge to provide a zone of refuge from *Acanthaster*, the *Acropora* appears to be the coral most rapid in reinvading the area if the surge zone refuge exists. Of course there is no reason to interpret this as an adaptation by *Acropora* to *Acanthaster*. *Acanthaster* outbreaks are irregular and *Acanthaster* is generally scarce. The problems planulae have with the algal turf, sediment and living corals are ubiquitous and the tendencies of Acropora to fragment and reattach are most likely to be adaptations to these factors.

The pocilloporids, poritids, and agariciids generally spread by planulation as evidenced by themoften showing up on settling plates. When branches or nubbins of Pocillopora damicornis are attached to terra cotta bricks and transplanted to areas where the species is not normally found, planulae settle and groups of new colonies start on the sides of the bricks. One hundred forty nine P. damicornis colonies started on the side of ten small (22 x 10 x 6 cm) terra cotta bricks in Ylig Bay on Guam. P. damicornis nubbins were attached to the upper surfaces of these bricks, but the species was absent or very scarce in the surrounding environment. The relevance of this example is that very small surviving colonies are probably important as "seed" colonies.

Other than the Acropora branches, which probably fell from the surge zone after the Acanthaster left, less than 5% of the substratum was occupied by living coral colonies. Most of these survivors were in crevices, at the tips of otherwise dead arborescent colonies, or on vertical surfaces. We are not sure whether the importance of these "seed" colonies is in producing larvae, in attracting larvae of their own species from the plankton, or both, but the importance of these small survivors is probably disproportionate to their prevalence.

In order to test the importance of "seed" populations and Acropora branches for the speed of recovery of the coral communities, we transplanted branches of Pocillopora and Acropora into devastated areas. The rate of colonization of corals in the immediate area of transplants can then be compared with the rate of colonization into other nearly areas. We might expect more Pocillopora planulae to settle in the immediate area of the transplanted Pocillopora branches. We expect the Acropora to reattach and grow.

It might be important whether the corymbose Acropora land right side up or upside down so we transplanted some of them right side up and others upside down to see if this affects their survival and reattachment.

Transplant experiments were set up at Siufaga Point, at Alofau, and about halfway between Aualili Point and Leutu Point. These sites are labeled "A", "B", and "C", respectively, in Figure 1 in Appendix C. At Siufaga Point, we transplanted 32 branches of Acropora acuminata, 11 pieces of A. hyacinthus right side up and 4 A. hyacinthus upside down. At Alofau, we transplanted 38 branches of A. acuminata, 4 A. abrotanoides, 11 A. hyacinthus right side up, 4 A. hyacinthus upside down and 7 Pocillopora. Between Aualili Point and Leutu Point, we transplanted 32 A. acuminata, 5 A. abrotanoides, 12 A. hyacinthus right side up, 6 A. hyacinthus upside down and 6 Pocillopora.

Unfortunately, a few Acanthaster could move through any of these sites again and wipe out the transplant experiments, so transplant experiments have been set up on Guam where they are relatively free of Acanthaster and can be kept under surveilance. Transplant experiments have also been set up at three sites on Palau (Birkeland 1979).

ARE THERE ADAPTATIONS TO *ACANTHASTER* INFESTATIONS?

Although *Acropora* is the preferred prey of *Acanthaster*, it reinvades a devastated area more rapidly than other corals if it has a refuge in the surge zone. However, we wish to stress that we do not claim that this refuge or manner of reinvasion is an adaptation to *Acanthaster* infestations. The invasion of areas below the surge zone by the breaking and reattaching of branches is probably an adaptation for invading an algal turf or a stand of other corals. The algae and corals are a perpetual problem for planulae, and *Acanthaster* infestations are a very irregular and rare event that occurs mainly on high islands rather than atolls. *Acanthaster* may be too rare or irregular to be a strong selective force. The adaptations for invading an algal turf may provide a preadaptation for *Acanthaster* infestations.

Whether some species are adapted to *Acanthaster* to the extent that *Acanthaster* is depended upon for their survival is relevant to the question of whether we should let *Acanthaster* infestations run their course. *Acanthaster* has many predators, but it is not the preferred prey for any of them. *Charonia tritonis* prefers several other asteroids. *Cassis cornuta* usually feeds on irregular urchins. *Cymatorium lotorium* and *Murex* sp. will probably take other small echinoderms or molluscs if *Acanthaster* are scarce. *Bursa rubeta* will probably take other small echinoderms or polychaetes if *Acanthaster* are scarce. *Hymenocera picta* prefers smaller asteroids (Glynn 1977), especially ophidiasterids. *Dromidiopsis dormia* can most likely survive on other small echinoderm prey. Xanthid crabs and *Dardanus* sp. are usually omnivorous. The grouper *Pomicrops lanceolatus* will probably take small fish and crustaceans if *Acanthaster* are scarce. Although *Balistoides viridescens* and *Arothron hispidus* were observed near *Acanthaster* in Samoa, we never saw one attack an Acanthaster. Ormond and Campbell (1974) document the predation of Arothron hispidus, Balistoides viridescens, and Psendobalistes flavimarginatus on Acanthaster, but according to the information from Hiatt and Strasburg (1960), each of these predators can take other invertebrates. Cheilinus undulatus will feed on crustaceans, molluscs, and other echinoderms as well as Acanthaster (Randall et al. 1978). In summary, we do not know of any predator that depends on Acanthaster and, in fact, we do not know of any predator for which Acanthaster is the preferred prey.

Including predators, parasites and commensals, about 34 associates have been listed for Acanthaster planci (Eldredge, in Tsuda 1972:15-17; Cannon 1972). Most of these are associates of other species as well, but there are protozoa (Cannon 1972), a copepod (Humes 1970), and a parasitic flatworm (Cannon 1974) that may be restricted to Acanthaster planci. These associates still may not require an abundance of Acanthaster for survival.

It might be suggested that since Acropora, the preferred food of Acanthaster, is the fastest growing coral, disruption of growth of Acropora patches by Acanthaster infestations might ultimately result in greater coral diversity. Coral communities on atolls tend to be of lower diversity, larger monotypic patches, and more distinctly zoned than coral communities around high islands, and Acropora spp. tend to be predominant on atolls. Since Acanthaster infestations are more common around high islands, we might conclude the differences between high islands and atoll reef communities to be a result of previous infestations. We doubt that this conclusion will hold up to further study. Acropora is often predominant around high islands such as Tutuila, Palau and many others and the greater diversity of coral communities may just as likely be the result of more variable habitats, coastlines, nutrient flow patterns, and other features of the physical environment of high islands. Furthermore, atolls in the Marshalls tend to be further from the center of coral dispersion than high islands in Carolines and Melanesia. Outlying high islands, such as the Marquesas, are relatively depauperate in corals (Chevalier 1978).

A lot of research should be undertaken to examine and explain differences in reef communities on high and low islands, but to date we have no convincing evidence that anything is dependent upon or adapted to *Acanthaster* infestations. Lucas and Jones (1976) argue that *Acanthaster planci* is a relatively recently evolved species. Our observations cannot refute this claim. However, the lack of adaptations to *Acanthaster* may be because of its recent arrival on the scene or, instead, because of the irregularity of its abundance. (There are probably very few organisms adapted to 17-year locusts for this latter reason.)

Walsh et al. (1971) suggest that because *Acanthaster planci* infestations are probably a natural phenomenon, then infestations might be an essential part of the system and, in the long run, contribute to the growth of the reef. Therefore, they conclude, it might be best to let nature take its course and leave the infestations alone. However, James A. Marsh (pers. comm.) commented that much of the nutrients in a coral reef system are bound up in the corals and recycled. If coral communities are devastated beyond a certain point, much of what had accumulated over years might be lost from the system, and recovery might be relatively slow. We all agree that we need to learn more about the role of *Acanthaster* in the system. It is possible that *Acanthaster* infestations are beneficial to coral reef communities through increasing the rate of turnover, but we are inclined to question this hypothesis until more studies have been obtained because we can find no evidence of adaptations to Acanthaster infestations.

From the above considerations, we can see no reason why we should necessarily be required to let nature take its course if we have our own aethetic or economic reasons to reduce the abundance of Acanthaster in certain areas. Studies on these matters should be undertaken, but as advised by Johannes (1975:42), until we know more about this matter, interim decisions should be based on what we know, rather than on how much we do not know.

RECOMMENDATIONS

The main conclusion of our study was that Acanthaster infestations are a natural phenomenon that recur suddenly at irregular intervals. Extra heavy rains or strong rains following a drought are one of the major factors leading to the infestation. We could consider ways to prevent future outbreaks if human activities were a major factor, but we cannot control the weather. The known predators of Acanthaster all prefer other prey, so their introduction might do more harm than good. Until we learn more about the system, we are limited to two courses of action, either manually reduce the size of the Acanthaster population or let nature take its course.

To decide which alternative to take is a very difficult decision that must be made by the local people or administration because they must weight the necessity of the task against the cost. The task of significantly reducing the numbers of Acanthaster is usually overwhelming and expensive, yet if nature takes its course, there might be a relatively long wait for the coral reef community to return to its previous state or it might return to an alternate state.

Extensive efforts have previously been made to attempt to control the numbers of *Acanthaster* in Micronesia, but there is some doubt that these control measures had any significant effect. When the *Acanthaster* left, they appeared to leave on their own. For example, Richard C. Wass (in Tsuda 1972:25) testified that 68,793 *Acanthaster* were killed in Ponape but a subsequent survey found "that the density and locations of major concentrations have remained virtually unchanged". James A. Marsh (In Tsuda 1972:24) reported that *Acanthaster* infestations had been apparently continuous in the Seventy Islands area of Palau to that time, despite long-term control efforts. Although the total infestation of the greater Koror area of Palau in 1979 was estimated to consist of about 50,000 *Acanthaster* (Birkeland 1979), 57,000 were removed from one small area around the mouth of Malakal Channel (W. M. Hamner, pers. comm.). The population was still there and the bounty money ran out. The bounty system in American Samoa removed 486,933 *Acanthaster* but many thousand still remained during our visit.

Killing 486,933 *Acanthaster* at American Samoa and 57,000 in Palau in 1979 might have relieved some of the predation pressure from corals. There was a general decline in *Acanthaster* populations in Micronesica between 1969 and 1972 and Marsh and Tsuda (1973) attributed this in part to control efforts;approximately 280,000 *Acanthaster* were killed by control teams. However, *Acanthaster* also disappeared about as rapidly from areas in which no control efforts were ever carried out. For example, no control efforts were made on Aguijan, yet the survey of August 1970 counted 3753 *Acanthaster* and the resurvey of October 1971 counted only a single starfish (Marsh and Tsuda 1973). The control efforts at Ponape and at the Seventy Islands of Palau had little apparent effect, but the *Acanthaster* eventually left.

From these considerations, we would conclude that attempts to significantly reduce infestations of Acanthaster around an island by either control teams or a bounty system would be very expensive and the Acanthaster would probably eventually leave on their own after devastating the coral communities. On the other hand, a devastated coral community will take several years to return to a similar state or it may develop into an alternate state. The basic question here is whether the original coral community is worth the expense and effort to protect. If a large hotel catered to spearfishermen, sport divers or underwater photographers, it would undoubtedly find it worth the expense to keep the main aggregations of Acanthaster away from its immediate area or preferred tourist diving or fishing sites. For this reason, one of us recommended the bounty system for a recent outbreak in Palau (Birkeland 1979).

We must now bring up a delicate point that we cannot ignore. The Samoans and Micronesians we have spoken with were mainly concerned with the bounty money rather than the state of the natural reef community. Acanthaster outbreaks have occurred in the past, and the system eventually recovered. A Palauan fisherman questioned the value of removing Acanthaster and described the value of the after-effects of the infestation (cf. Appendix A). The Samoans we talked to were mainly concerned with territorial rights of families and villages in harvesting the Acanthaster for bounty. Robert Owen, Chief Conservationist of Palau, described (pers. comm.) how Palauans raised coconut rhinoceras beetles for bounty when the bounty system was initiated to protect the Palauan's coconut plantations. One of us (C.E.B.) is concerned with the amount of time it takes for the coral community to recover (discussed in the paragraph below) and is convinced that reducing the abundance of Acanthaster will not harm the system (cf. preceding section of this report), but we acknowledge that an adequate control system would be expensive, and the effects of Acanthaster on the coral communities does not appear to be of concern to the residents of Samoa or Micronesia.

Since it appears that Acanthaster infestations are a recurring natural phenomenon, then we might predict that the coral communities will recover as they have in the past. This may take a number of years and this delay may be economically harmful if a resort or hotel were involved. On the other hand, if general environmental conditions have changed since the previous outbreak and recovery, the system may develop to an alternative stable community (Holling 1973, Sutherland 1974). For example, if a change in runoff patterns favors an increased productivity of algae, this could inhibit recolonization by corals (Hedley 1925, Moorehouse 1936, Dawson 1959, Nishihira and Yamazato 1974, Johannes 1975). After devastation of coral communities by Acanthaster predation, the devastated area is often replaced by algal communities. Sometimes these alternative communities may dominate the area for considerable time, perhaps indefinitely (Nishihira and Yamazato 1974). Only time will tell. Examples of coral communities replaced by algal communities because of environmental changes are given by Dawson (1959) and Johannes (1975). Examples are given by Johannes (1975) and Endean (1976) of reefs that showed little or no recovery of coral communities after 30 and 35 years.

Goreau (1969) hypothesized that the patchy distribution of reef communities may be a result of problems of recruitment. The chance location of a reef may result when the coral community reaches a "critical mass", after which the community could perpetute itself until it developed into a reef. Those communities not reaching the "critical mass" soon enough might be set back or "damped out" by random events. Reef recovery may not be such a problem on Samoa because the exposed fringing reefs have refuges for "seed populations" of corals from Acanthaster in the surge zone (cf. discussion in the section of this report on reef recovery).

If a control system is to be initiated, there are two methods that could be used: a bounty system or a control team. With both methods, there has always been a problem with poor handling of daily kill records (Tsuda 1972). In most bounty programs, there seems to have been a problem with inflated kill records. As a typical example, we quote (from Tsuda 1972:33) Dr. Gerald R. Allen from his written summary of the bounty program on Truk:

> "I counted a total of 39 killed by a man I accompanied on one dive. Upon surfacing this person reported a kill of 76 starfish. The numbers that are turned in on the reports are probably indicative to a certain extent of the actual population, but may be inflated by as much as 20-50%."

Tsuda (1971) points out many inconsistencies in kill records. This is a chronic problem. We strongly recommend that if a bounty system is initiated, then the starfish killed for the bounty must always be counted by a fisheries officer or scientist.

If a control team is used, it should be remembered that enthusiasm for the project can wear off. A responsible person must be in charge of control teams. As an example, a Palauan control team spent about a month supposedly killing starfish on the small atoll of Kayangel. An examination of kill records indicated that no starfish were ever killed there and the University of Guam survey team previously determined that Acanthaster was absent from that atoll to begin with (Tsuda 1972:32).

However, if the above problems can be controlled with reasonable management procedures and if the island residents and administration consider the protection of their reef communities desirable enough to warrant the expense and effort, then the bounty system has a number of merits. It is a self-regulating method of harvesting. At $0.15 per alamea, control will be most intense when alamea are abundant. When or where the Acanthaster are scarce, searching for them would become impractical at that price. Acanthaster are harmful only when they are abundant enough to be aggregated and exposed to view during the daytime, making collection by bounty hunters efficient. When Acanthaster are aggregated, they more thoroughly devastate the reef, leaving larger patches in the community which take longer to recover. Even small aggregations increase the probability of successful spawning by Acanthaster. Most control effort could concentrate on aggregations and the bounty system promotes this approach. Control teams lose interest and are expensive to maintain. The bounty system only has a cost when expense is justified. Another good aspect of the bounty system is that the money goes to interested local residents.

An alternative approach to the Acanthaster problem might be to let the Acanthaster go away on their own, then transplant seed populations of corals. Whether this might be an effective method of increasing the speed of recovery might be indicated by the results of the transplant experiments described in a previous section of this report.

In summary, Acanthaster infestations are a naturally recurring phenomenon brought about in part by weather conditions that are indirectly favorable to Acanthaster larvae. Controlling infestation of adult

Acanthaster is a very expensive and almost overwhelming project to attempt. If managed reasonably carefully and if local residents and the administration consider the protection of their reef communities important enough to justify the expense and effort, then we would recommend the bounty system. At $0.15 per alamea, the bounty system would only be effective where Acanthaster are abundant enough to be a problem.

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APPENDIX A

Acanthaster in the Cultures of High Islands

Although *Acanthaster* is usually very rare, some residents of high islands in Micronesia, Melanesia and Polynesia have their own special names for *Acanthaster*, have advice on curing the sting of the spines, and claim that *Acanthaster* has been abundant at certain times in the past. We believe that this familiarity of *Acanthaster* in some high island cultures implies that outbreaks are a naturally recurring phenomenon.

In Palau (Micronesia), the *Acanthaster* is called *rrusech*. At Fiji (Melanesia), *Acanthaster* is called *bula* (a homonym of "hello") while the general terms for "starfish" are *gasagasan* or *basage* (Atelaite "Laite" Smalley, pers. comm.).

In contrast, the languages from atolls might not contain terms for *Acanthaster*. The Gibert Islands (Kiribati), the Ellice Islands (Tuvalu) and Fanning Island are all atolls. Lobel (1978) presented a list of 407 names of fishes and 95 names of marine invertebrates used by Gilbertese and Ellice Islanders on Fanning Island. These inhabitants of atolls had their own specific names for many species of fishes, molluscs and crustaceans and even distinguished between three groups of holothurians, but all sea-stars came under one name. *Acanthaster* may have never been abundant on these atolls.

The cure for *Acanthaster* is claimed by several cultures to be their own discovery. When one of us (C.E.B.) was studying an *Acanthaster* outbreak in Palau, he accidentally jabbed his knee strongly against an *Acanthaster* and came to the boat with a lot of blood dripping out of six holes in his knee. The boatman, Ngirbauliad ("Yahd") Mineich, advised him to take one of the Acanthaster and place it mouth down on the bloody knee. (This was tried, but was not found to be of great help.) When asked if he heard of this cure from a Samoan, Yahd said it has always been common knowledge in Palau. Ramon Rechebei, another Palauan, said that he knew of this cure since he was a boy.

Laite Smalley told us that when fishermen step on bula on the reef flat, they turn over the same bula and put their foot against the mouth so that the bula will suck out the poison. She said this was generally known by Fijian fishermen and there is no reason to believe it was learned from the Palauans or Samoans. Maybe the cure was discovered in Fiji.

The years in which some previous outbreaks in Samoa have occurred, as cited by Samoans, are given in the Introduction of this report. Vine (1970) reported that fishermen in the Soloman Islands (Melanesia) remembered large concentrations of Acanthaster about 1930, forty years previous to 1970. Chesher (1969b) reported that Micronesians remember an outbreak on Ponape just after World War II.

Michael Parke talked to an old Palauan fisherman who described an extensive infestation that took place just prior to World War II. According to this fisherman, the Acanthaster soon disappeared, leaving algae in the place of coral. Then urchins became abundant during the early years of World War II. The fisherman felt that Acanthaster were transitory and no real problem. The abundance of urchins that resulted were a benefit. Old people could easily collect them for food within wading depth on the reef flat. I have not heard of other cases of an abundance of urchins following

Acanthaster. It will be interesting to see if herbivorous urchins become common following the present devastation in Palau. Except for areas around artificial sea walls, break waters and ramps, regular urchins are remarkably scarce in Palau at the time of this writing.

APPENDIX B

RESULTS OF AN *ACANTHASTER PLANCI* (CROWN-OF-THORNS) SURVEY AROUND TUTUILA ISLAND, AMERICAN SAMOA

by

Richard C. Wass

1977

OMWR#2

INTRODUCTION

Late in 1977 fishery biologists working for the Office of Marine Resources in American Samoa, reported that the "Crown-of-Thorns starfish" (Acanthaster planci (L.)) has caused severe damage to some local reefs around Tutuila Island. This coral-eating starfish, known locally as "alalamea", was responsible for extensive coral kills on many reefs in the late nineteen-sixties throughout the tropical Pacific Ocean, and now appears to constitute a threat to the entire reef system of American Samoa.

Freshly killed corals and numerous Acanthaster planci starfish were first noticed in American Samoa during September 1977 on fringing reefs along the north coast at Fagatuitui Cove. About 50 A. planci, ranging in size from 30-35 cm in diameter, were counted in November 1977 during a half-hour dive on the reef at this initial infestation site. Severe damage to corals attributable to A. planci was next seen in December 1977 on the offshore Taema Bank along the southeast coast. At this time, similar coral banks between Taema Bank and Anuu Island were reported to be free of A. planci infestation, although increased numbers of the starfish were being reported from the inshore fringing reefs along the south coast between Nuuuli and Aumi Villages. These initial observations along with increasing reports of other reefs infested by A. planci prompted the Office of Marine Resources, Government of American Samoa, to conduct a field survey of reef areas to determine the distribution and abundance of the starfish and to assess the extent of the resulting coral damage around Tutuila Island and offshore coral banks.

METHODS

The principal field surveys used in this report were performed during a year-long period between January 1978 and January 1979. The surveys were for the most part conducted by Dr. Richard C. Wass and Mr. Jan Swan of the Office of Marine Resources. Dr. Frederic Martini, Director of Research Programs of Marine Environmental Research, Inc., also accompanied the survey party in the field on two occasions.

During January and February of 1978 the following reef areas were surveyed: 1) reef-flat platforms at Afao, Leone, Nuuuli, Faganeanea, Matuu, Lauliituai and Auasi Villages; 2) reef front and seaward slope zones at Fagatele Bay, Steps Point, and Fagaalv Cove; Aua, Auasi, and Tula Villages and the entire coast between Breakers Point and Sinatau Point; and 3) offshore coral banks and patch reefs between Tafuna Airport and Aunuu Island. Several reef front zones along the north coast were also investigated during November and December, prior to the initial survey. Reefs on the eastern tip of Taema Bank, Nafanua Bank, and several other patch reefs situated between those two regions were resurveyed on April 18, 1978. On May 5, 1978 the reef front zone of fringing reefs along Tutuila's south coast near Faganeanea and Fatumfuti Villages were surveyed and reefs at Alega and Lauliituai Villages that were previously investigated during the first of the year were resurveyed. On June 1, 1978 the reef front and seaward slope zones of fringing reefs along the eastern end of the island were surveyed at places between Auasi Village on the south coast to Puputagi Point on the north coast. On June 6, 1978 the reef front and seaward slope zones of fringing reefs were surveyed along the north-central coast between Masefau and Fagasa Villages. On June 7, 1978 the reef front and seaward slope zones of fringing reefs were surveyed along the northwest coast from Cape Larsen on the west side of Fagasa Bay to Luania Rocks at Cape Taputapu. Fagatele Bay was resurveyed in November 1978 and during the first week of January 1979 Cape Larsen on the north coast was resurveyed. Reef and lagoon areas around Tafuna Airport were also surveyed during the first week of January 1979. The above survey locations are shown in Figure 1.

Three methods were used to estimate distribution and abundance of A. planci and to determine the extent of the corals killed by them. Reef-flat platforms were surveyed by making 100 meter walks across the surface during low tides. During these reef walks A. planci were counted within a corridor four meters wide (two meters on each side of the observer) and the percentage of coral coverage recently killed (white bleached color) by the starfish was estimated. Extensive areas of the deeper forereef zones of fringing reefs and offshore coral banks were surveyed from depths of 2-20 meters by snorkelers towed on the surface behind a boat. When possible, A. planci and their feeding sites were enumerated and the percentage of coral recently killed by them were estimated during these tow observations. In reef areas deeper than 20 meters scuba divers counted all A. planci observed within a certain period of time and estimated the resulting coral damage.

Because of the large population of A. planci observed at Taema Bank, a more intensive survey was conducted there to measure starfish density so that an estimate of the total population of the entire bank could be made. The bank was divided into four sectors (I-IV) from west to east (Fig. 1). The bank in each sector was divided into three zones consisting of the backreef slope facing the island, the relatively flat upper surface, and the forereef slope facing the sea. Two to three transects were run simultaneously across Taema Bank from its shoreward to seaward edge in each of the Sectors I-III. In Sector IV, a number of rectangular quadrats 2.15 meters wide by 10.75 meters long were used instead of transects to measure A. planci densities because of a very high population concentrated in a narrow band along its backreef slope. The transects in Sectors I-III were established by scuba divers swimming along the bank surface with a fishing spear 2.15 meters long held at right angles to their direction of movement. Transect lengths were calculated from navigation charts by taking bearings on various landmarks on Tutuila Island at the shoreward and seaward ends of the sector transects. Average A. planci densities for each sector were calculated by counting all the starfish within each of the 2.15 meter wide transect bands in Sectors I-III and within the quadrats in Sector IV. The percentage of corals killed by A. planci were estimated for each bank sector from observations made while making the transect and quadrat starfish counts. Total A. planci populations for the bank sectors were calculated from the area of each respective sector and its average starfish density. The area for each of the Taema Bank sectors was calculated from navigation charts of the Pago Pago Harbor area.

RESULTS

Taema Bank Survey

Sector I

Sector I of Taema Bank was surveyed on January 18, 1978. The transects across this sector of the bank were run on a bearing in lime with Fatu Rock and the television towers located on Alava Mountain. Relatively few A. planci were observed in the westernmost Sector I of Taema Bank, however, about 95 percent of the reef corals were dead in many places indicating that large numbers of starfish had already passed through the area.

In a seaward direction along this transect the backreef slope shoals from 28 to 15 meters. Over 90 percent of the reef corals were dead and only three A. planci were observed. Scattered Pocillopora colonies and a few arborescent patches of Acropora make up most of few remaining living reef corals. Tabletop Acropora species were once common, but none were found alive. The upper surface of the bank is relatively flat, averaging about 15 meters in depth. No A. planci were observed and about 20 percent of the coral coverage was still alive. Originally the reef community in this zone was composed mostly of Pocillopora and some arborescent Acropora species. The forereef slope dips downward from 15 to 34 meters. Rubble covers most of the slope and apparently there was little coral previously growing in this zone. About 50 percent of the scattered corals on the slope are still alive and ten A. planci were seen at 31 meter depth feeding on a single unidentified coral species with large conspicious calices.

Based upon average starfish densities the current A. planci population for Sector I was estimated at about 5000.

Sector II

Sector II was surveyed on the same date as Sector I by running three parallel transects, 405 meters long, across Taema Bank on a bearing in line with the Pago Pago Harbor rangemarkers.

Thirteen A. planci were observed on the backreef slope which shoals from a depth of 31 to 12 meters. About 10 percent of the corals were still alive along its length. Greatest starfish density in Sector II was found on the upper bank surface where a total 74 were observed. Water depth on the low undulating upper bank surface averages about 12 meters and only about 10 percent of the corals were still alive. The forereef slope dips downward from 12 to 34 meters and has a rubbly/surface, similar to that observed on the Sector I transects. Judging from the few living and dead corals, it is doubtful that much coral was previously growing on the rubbly forereef slope. Only four A. planci were observed in this zone.

A total of 91 A. planci were observed along the entire length of the three transects across Sector II. This total gives an average starfish density of 1/28.7 m^2 for the three transects and on overall population for Sector II at 13000.

Sector III

Sector III was surveyed on January 24, 1978 by running two parallel transects, 476 meters long, across Taema Bank on a bearing in line with Lepua Church and Breakers Point.

Corals on the backreef slope were mostly dead with less than 5 percent of them still living. All the tabletop Acropora species, most of the arborescent Acropora patches, and all but a few scattered Pocillopora colonies were dead. Only 27 A. planci were observed in this mostly dead coral zone. Numbers of starfish increased dramatically on the shallower upper bank surface where 182 were counted along the two transects. The starfish were especially abundant along the seaward edge of the upper bank surface but upon reaching the forereef slope they were conspicously absent where a rubble substrate was encountered with few living or dead corals present.

A total of 209 A. planci were counted along the two transects of Sector III giving it an average starfish density of $1/9.8\ m^2$ and on overall population of 68000.

Sector IV

Sector IV was surveyed on the same date as Sector III. A very large concentration of A. planci was found on the forereef slope of this sector. The starfish were aggregated along the slope, parallel to the main axis of the bank reef, into a narrow band about 5-8 meters wide and 800 meters long similar to the classic "fronts" discribed by Chesher (1971). Because of the concentration of starfish into a band, a quadrat method of measuring starfish density was used. The starfish front extended from the eastern end of Taema Bank to a point in line with bearings between the television tower on Alava Mountain and the western tip of Breakers Point. By plotting those bearings on a navigation chart the starfish front was estimated to be about 800 meters long.

The first quadrat survey was conducted on January 24, 1978 at a location along the starfish front in line with a bearing between the television tower on Alava Mountain and the navigation light on Breakers Point. Two quadrats at this location averaged 400 starfish each. On February 1, 1978 the starfish front was surveyed again at two more locations. Two quadrats at the first of these two survey sites, located on a bearing in line with the television tower on Alava Mountain and the top-most peak at Breakers Point, averaged 364 starfish inch. At the second survey site, located on a bearing in line with the television tower on Alava Mountain and the middle part of Breakers Point, two quadrats averaged 340 starfish each. Based upon densities from these three survey sites the average starfish density along the front was estimated at 15.9/m². Using this average density value and on area 800 meters long by 6.5 meters wide, the total starfish front population was calculated to be about 8~~0~~3,000.

The *A. planci* front appeared to be moving up the reef slope and across the upper bank surface at Sector IV in a seaward to landward direction. The white skeletons of the recently-eaten corals were obvious immediately behind the front. The white coloration of the coral skeletons graded into yellow-green and finally brown-green as one proceeded seaward indicating increased algal growth and an increasing period of time since the starfish had passed. Immediately landward of the front the corals were mostly living and free of starfish. As the starfish front moved across the bank only about 80 percent of the corals were eaten, however, large numbers trailing behind were eating the remaining corals. About 48,000 starfish were estimated to be trailing behind the actual front itself, which gives Sector IV a total population of 128,000.

At the time of the sector surveys the total *A. planci* population of Taema Bank was estimated to be about 212,000 with an estimated 80 to 90 percent of all the corals killed.

A resurvey of the eatern tip of Taema Bank (Sector IV) on April 18, 1978 revealed that the well established starfish front observed earlier in the year had broken up. The breakup of the front was probably very recent as observers from Marine Environmental Research, Inc., reported numerous starfish there just three weeks earlier.

Offshore Patch Reefs and Nafanua Bank Surveys

Offshore Patch Reefs A-D

On February 6, 1978, four patch reefs (A-D) situated between the eastern end of Taema Bank and the western end of Nafanua Bank (Fig. 1) were surveyed.

Patch Reef A is located a few hundred meters inshore from the eastern tip of Taema Bank. It is surrounded by water at least 80 meters in depth and rises to within 20 meters of the surface at places. Seventy-nine *A. planci* were counted during a fifteen minute scuba dive at about 15 meters depth on the upper patch reef surface. A second member of the survey party saw five *A. planci* during a three minute observation period on the patch reef slopes below 35 meters in depth. Most of the tabletop *Acropora* species were dead, but more than half of the arborescent *Acropora* and other coral species were still alive.

Divers were towed across the seaward and landward edges of Patch Reef A and along the seaward edge of Patch Reef C. Both patch reefs were heavily infested by *A. planci*. The starfish were not banded into a distinct front, but appeared to be scattered with denser concentrations occurring in areas of richest coral growth. Tabletop *Acropora* species, which are the prefered corals of *A. planci*, were mostly dead on Patch Reef B and about half dead on Patch Reef C. Other reef corals were eaten to a lesser extent.

A tow survey along the entire length of Patch Reef D revealed numerous scattered starfish. About half of the tabletop *Acropora* species encountered were dead, but little of the arborescent *Acropora* species had been killed.

On April 18, 1978 a short resurvey of Patch Reefs C and D was made. On Patch Reef C two five minute scuba dives revealed only 17 A. planci, but about 90 percent of the reef corals were dead. Evidently most of the starfish had left the patch reef after killing most of the available coral. Two similar five-minute scuba dives made on Patch Reef D revealed a total count of 47 starfish. Most of the corals on the deeper parts of this patch reef were dead with few starfish observed, but the shallower areas had considerable numbers present that were feeding on more abundant living corals.

Nafanua Bank Surveys

On February 6, 1978 divers were towed along the entire forereef slope of Nafanua Bank. Most corals, including tabletop Acropora species, were alive. Few A. planci were observed, but those that were seen were small, ranging in diameter from 6.7 to 9 cm. Feeding scars observed were also small and the starfish secretive. In contrast to the forereef slope, the upper surface of the bank was free of A. planci with no evidence of feeding scars.

On April 17, 1978 Nafanua Bank was resurveyed. Deeper parts of bank at this time were mostly dead, but regions shallower than 15 to 20 meters were still living and free of A. planci. Starfish density on the forereef slopes appear to be greater on Nafanua Bank, at its time, than anyplace else on the banks and patch reefs off the south coast of Tutuila Island. The small A. planci (6.7-9 cm dia.) previously observed on the forereef slopes were absent, as all the starfish observed during the resurvey were relatively large. It is unlikely that the present abundant and large sized starfish are the same population as the smaller ones observed earlier, but instead represent an eastern movement of the previous large populations observed on

Taema Bank and patch reefs to the west. On April 20, 1978, 74 A. planci were counted along a 100 meter transect across the forereef slope. The deeper end of this transect crossed a region of corals recently killed and algal-covered with few starfish observed. The algal-covered zone graded into freshly killed corals and a somewhat loosely aggregated front of starfish along the shallower end of the transect. The front was not as well defined as the one observed earlier on Taema Bank, but it was definitely moving up the reef slope as evidenced by the deeper recently algal-covered corals.

Tutuila Island Surveys

Reef Flat Surveys Along the Southeast Coast

Reef flat surveys along the southeast coast were conducted during the first five weeks of 1978. Most of the reef-flat platforms between Nuuuli and Fatumafuti Villages to the west of Pago Pago Harbor and the reef flat east of the harbor mouth at Lauliituai Village were found to be heavily infested with A. planci. A few A. planci were observed on the forereef slopes seaward of the infested reef-flat platforms, but most of the corals were alive. With the exception of a concentration of very large A. planci found on the north coast near Fagatutui Cove in September 1977, and those infesting the reef-flat platforms adjacent to the Pago Pago Harbor area, the remaining fringing reefs surveyed around Tutuila appeared to be largely free of A. planci at the present time.

Forereef Slope Surveys Along the Southern Coast

During January and February 1978 the forereef slopes at Fagatele Bay, Steps Point, and Fagalua Cove; Aua, Auasi, and Tula Villages; and the entire coast between Breakers Point and Sinatau Point were surveyed. All were found to be free of A. planci except at Alega Village and Sinatau Point where one and six starfish were seen respectively during towing surveys.

On May 5, 1978 the forereef slopes near Alega and Lauliituai Villages were resurveyed by two divers by making five minute scuba dives in opposite directions. At Alega Village no _A. planci_ were observed, but one fresh and one old feeding scar, possibly attributable to starfish feeding, were seen. At Lauliituai Village ten _A. planci_ were counted (4 by one diver and 6 by the other) and considerable coral damage was observed at 20 to 26 meter depth.

Forereef slopes west of Pago Pago Harbor entrance near Faganeanea Village (Sweets Rock) and Fatamafuti Village were also surveyed on May 5, 1978 by making five minute scuba dives in opposite directions. At Faganeanea Village site 14 _A. planci_ were counted (4 by one diver and 10 by the other) and numerous feeding scars observed at 13 to 20 meter depths. Most of the deeper corals appeared to have been killed some time ago. Four starfish were also observed at this site at a depth of 32 meters moving across a sand covered terrace some distance seaward of the reef itself. Possibly these starfish were migrating away from offshore bank and patch reefs that were previously infested by large numbers of _A. planci_. At Fatamafuti Village no _A. planci_ were observed, but numerous feeding scars were observed at 20 to 23 meters depth.

Forereef Slope Surveys Along the Eastern Coasts

Forereef slopes were surveyed on June 1, 1978 by making ten minute tows with a single diver at Auasi and Tula Villages and along the entire coast from Nuutele Rocks to Puputagi Point.

No _A. planci_ were observed along the Auasi and Tula Village tows. Earlier surveys at these two villages produced similar results during the first five weeks of 1978.

Between Nuutele Rocks and Papaloa Point 71 A. planci were counted along three fronts which appeared to be moving parallel to the shore. Between these starfish fronts abundant live corals was observed.

From the relatively short distance between Papalao Point and Ogefao Village 1080 A. planci were counted. Even so, the distribution of the starfish were rather patchy. Corals in particular, at the basal periphery of large mounds were being eaten, but the upper shallower surfaces were relatively free of starfish. Starfish were found in all sizes ranging from 6.8 to 40.5 cm in diameter, although most were in the 18 to 22.5 cm range.. Depth distribution was also variable, with some observed as shallow as 1.7 meters, but most were found between 6 to 9 meters depth. Although the starfish apparently moved into the present shallow infested regions from deeper water, the percentage of living corals in the latter(about 70%)were greater than that found in the shallow reef areas.

Between Ogefao Village and Solo Point 270 A. planci were counted on the forereef slopes. About 90 percent of the corals on the outer part of the reef-flat platform were alive with relatively few starfish observed. Along the remaining tow sectors surveyed along this coastline the numbers of starfish counted steadily decreased from 200 between Solo and Motusaga Points, 17 between Motusaga Point and Taligai Cove, and 4 between Taligai Cove and Puputagi Point.

From the above survey it appears that a fairly large population of A. planci is located along the northeast coast between Motusaga Point and Nuutele Rocks. The large size range of the starfish suggests that the population is composed of individuals from several larval recruitment periods.

Forereef Slope Surveys Along the North-Central Coast

The reefs along this north-central part of Tutuila Island were surveyed at twelve sectors between Tiapea Point and Fagasa Bay on June 6, 1978. Acanthaster planci counts and condition of the reef corals were made by towing a diver for ten minutes on the surface behind a boat in each sector.

Within each of the sectors the following numbers of starfish were observed: none between Tiapea Point and Masefau Reef Flat, 212 between Nuusetoga Island and Lepua Point where they were more or less restricted to projecting points of land; none between Tapisi Point and Oa Village, Vainuu Point and Anapeapea Cove, Craggy Point and Amalau, Vatia Village school and Pola Island, and along the reefs within Vaaogeoge Cove; 51 between Manofa Rock and Puaneva Point where they were mostly restricted to a point of land at Manofa Rock; and 11, 13, 12, and 0 along four contignous sectors between Mulivaisigano Point and the back side of Fagasa Bay. Along the latter four sectors some reefs were undamaged while others appeared to have been dead six months to a year. Starfish distribution must have been patchy as there were numerous living reef areas intersperced among the dead regions.

Forereef Slopes Surveyed Along the Northwestern Coast

On January 7, 1978 reefs along the northwestern coast of Tutuila Island were surveyed along twelve sectors between Cape Taputapu and Cape Larsen. Acanthaster planci counts and the condition of the reef corals were made by towing a single diver at the surface behind a boat for ten minutes.

Within each of the sectors the following numbers of A. planci were observed: 27 between Luania Rocks and Tiaoalii Rock, 10 between Tiaoalii Rock and Leopard Point, 112 between Faiaiulu and Faga Points, 236 between Faga Point and Maloata Bay, 30 between Fagamalo Village and Paapala Cove, 39 between Pa Cove and around Square Head, 6 between Tolotolooteoti and Matautuele Points, none between Aoloau Bay and a prominent point to the east, 3 in the vicinity of Nuutavana Rock where considerable dead corals were found, none between Siliage Point and Asau Village, none between Fagatiale and Ogegasa Points, and none between Agalua Rock and Cape Larsen. With the exception of the sector in the vicinity of Nuutavana Rock and the last two sectors surveyed, there was no reef damage whatsoever along this section of the coast. On the last two sectors surveyed no starfish were observed, but many dead reef corals were seen.

Survey at Fagatele Bay Along the Southwest Coast

In November 1978 Fagatele Bay along the southwest coast was resurveyed. Earlier in February 1978 this bay was free of A. planci, but now was found to have very little live coral down to depths of 45 or more meters. The shallow forereef slopes still had considerable amounts of live coral present, but numerous starfish were observed to be moving into this remaining live coral zone.

Other Surveys

During the first week of January 1979 numerous A. planci were found on a reef opposite the east end of the runway at Tufuna Airport. The starfish here were very numerous, but scattered, in water ranging from 3 to 6 meters deep. Many dead corals were observed, but some living reef areas were intersperced amoung the starfish patches. Numerous starfish were also observed in front of the Vortoc Station, but not as abundant as at the end of the runway.