Report on the

Acanthaster planci (Alames) Studies on Tutuila,

American Samoa

1979

Submitted to

Henry Sesepasara, Director
Office of Marine Resources
Government of American Samoa
Pago Pago, American Samoa 96799

By

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TABLE OF CONTENTS

INTRODUCTION 1

TERRESTRIAL RUNOFF AS A CAUSE OF ACANTHASTER INFESTATIONS 2
- Abrupt Nature of the Population Increase 2
- Widespread Nature of the Population Increase 4
- Rainfall Records in Relation to Acanthaster Outbreaks 5
- Influence of Rainfall and Terrestrial Runoff on Coral Reef Systems 11
- Acanthaster Outbreaks Around High and Low Islands 12
- Influence of Rainfall on Larval Biology of Acanthaster 15
- Other Marine Species that Correlate Abundance with runoff 18
- Other Plagues Resulting from Changes in Rainfall and Added Nutrition for Larvae 18
- Fluctuating Densities of Marine Invertebrates with Planktrophic Larvae 19
- Predictions to Test our Hypothesis 21

CONSIDERATIONS OF ALTERNATIVE EXPLANATIONS FOR ACANTHASTER INFESTATIONS 22
- Human Activities 22
- Predators 25
- Typhoons 25
- Behavioral Aggregations 26

PATTERN OF DESTRUCTION BY ACANTHASTER 27

MECHANISM OF CORAL COMMUNITY RECOVERY 31

ARE THERE ADAPTATIONS TO ACANTHASTER INFESTATIONS? 36

RECOMMENDATIONS 39

ACKNOWLEDGMENTS 45

REFERENCES CITED 46

APPENDIX A
- Acanthaster in the cultures of high islands 51

APPENDIX B (by Richard C. Mass)
- Results of an Acanthaster planci (crown-of-thorns) survey around Tutuila Island, American Samoa 56

APPENDIX C
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‰. 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.
F 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 fisherman-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 Aalivaitea 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. Upusea Taifana of Poloa told us that alamea were abundant around 1932 but were scattered and scarce ever since. Chief Faisa’u of Gymea 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 alanea 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 Taera Banks off the south coast of Tutuila (Appendix B). During the next year, 436,933 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 Sesepasea, 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 5 man-days of snorkeling and reef-walking in 1966, 1968 and 1969. Vine (1970) saw 5 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. Seman
Table 1. Totals of *Acanthaster planci* removed from the ocean and buried on Tutuila during the bounty program, January 23 to October 25, 1978.

<table>
<thead>
<tr>
<th>Location</th>
<th>Collection Dates</th>
<th>Number of <em>Acanthaster planci</em> removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sa'ilele</td>
<td>July 11 - October 19</td>
<td>12,354</td>
</tr>
<tr>
<td>Aoa</td>
<td>May 26 - October 25</td>
<td>125,564</td>
</tr>
<tr>
<td>Umenoa</td>
<td>May 8 - October 25</td>
<td>258,913</td>
</tr>
<tr>
<td>Tula</td>
<td>June 5 - October 18</td>
<td>35,675</td>
</tr>
<tr>
<td>Amouli</td>
<td>February 9 - May 24</td>
<td>109</td>
</tr>
<tr>
<td>Pagai</td>
<td>June 21 - October 19</td>
<td>8,875</td>
</tr>
<tr>
<td>Faga'a'itua</td>
<td>June 12</td>
<td>41</td>
</tr>
<tr>
<td>Alega</td>
<td>January 26</td>
<td>1,437</td>
</tr>
<tr>
<td>Lau'ili'</td>
<td>January 23 - June 7</td>
<td>21,690</td>
</tr>
<tr>
<td>Faga'a'alua</td>
<td>January 23 - March 31</td>
<td>478</td>
</tr>
<tr>
<td>Matu'u</td>
<td>January 27 - January 31</td>
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<td>Pagananeae</td>
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<td>200</td>
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<tr>
<td>Nu'uellu</td>
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<td>Faganalo</td>
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<td>Aumu'u</td>
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<td>Nafanua Banks</td>
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<td>Tsema Banks</td>
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<td>8,083</td>
</tr>
</tbody>
</table>

Total removed 486,933
Total spent in bounty money (7.15 each) $73,039.95
fishermen who were out on the reef nearly every day during the last few decades very rarely saw an alameda (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 81,000 Acanthaster was found moving as a front along Taema Banks (Sector IV, cf. Appendix 3) 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 (386,477 +)
was first seen in May 1978, moving into Aoa and Onenoa Bays at the north-east tip of Tutuila. Alex Sanse, 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 expansion 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 Actogora, the infestations seem to have started at discrete locations, widely separated by Urukthapal (Geruktool), a very long island (Sirkeland 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
<table>
<thead>
<tr>
<th>Year</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>June</th>
<th>July</th>
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**Note:**
- **Jan:** January
- **Feb:** February
- **Mar:** March
- **Apr:** April
- **May:** May
- **Jun:** June
- **Jul:** July
- **Aug:** August
- **Sep:** September
- **Oct:** October
- **Nov:** November
- **Dec:** December

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**Acanthaster breeding season:**
- **Record drought**
- **Heavy rain**
- **Outbreak of Acanthaster**
end of Tumon Bay, one of us (C.Eh) 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; Chesser 1969a, Pearson and Garrett 1978), there does seem 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 (183 inches) was the highest on record (since 1947, cf. NOAA 1978a). May and June of 1974 had 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 Salmis, 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 (Chesser 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 (Chester 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 Tuvalu 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 silation 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 was 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 Victor's 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. (1973) around Eniwetok, an atoll or low island. Further, he found slightly higher values of reactive phosphorus around Guam than Filson and Betzer (1973) found around Eniwetok. 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, Porspe 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 (AEC 1973). 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 Kuoop 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).

<table>
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<tr>
<th></th>
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<th>Low Islands (Atolls)</th>
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<td>Conditions 1 and 2</td>
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<td>20</td>
</tr>
<tr>
<td>(normal)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conditions 3 to 6</td>
<td>19</td>
<td>2</td>
</tr>
<tr>
<td>(abundant <em>Acanthaster</em>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>22</td>
</tr>
</tbody>
</table>

\[ \chi^2_{adj [1]} = 21.5 \quad (p << .001) \]
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. Koop is only 3 km from the outer reefs of Truk and Asc 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 Niyan 1973). In both
regions, these periods begin about a month after the beginning of the rainy season.

The larvae of *Acanthaster* 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 *Acanthaster* by combining the breeding season of *Acanthaster* 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 *A. planci* larvae could lead to a high survival rate in larvae and subsequent expansion of juvenile and adult populations" (A.C.R. 1973:16). 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 *Acanthaster* 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 phosphates) which stimulate phyto-plankton blooms which, in turn, provide food for *Acanthaster* larvae. The breeding season of *Acanthaster* 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 flagellate 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 (1937) 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
The breeding season of Acanthaster and the salinity tolerance of their larvae increases 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 Planktrophic Larvae**

Although "plague" is a term reserved for invertebrates such as *Acanthaster* and locusts that are harmful to men 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 Velda (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 planktrophic 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 1971:188). 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 planktrophic 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) *Liochosa 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 Tamaguchi (1973) pointed out, *Liochosa 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 Nasefau Bay. Barry Snitch (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 *Diodon* and *Echinophris* 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. Edean (1977:135) argues that *A. planct* 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 temperate marine systems, but the fluctuations of small mobile 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 planktrophic larvae in being long-lived with very irregular reproductive success. Many tropical marine invertebrates with planktrophic 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

Chester (1969a, b) Randall (1972), Endean (1973, 1974, 1977) and Endean and Chester (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 plancton* has occurred in dense aggregations on the Great Barrier Reef many hundreds of years 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 Gagansu (Ugeangs) Island, south of Kurukarep 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 Fagasas 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>
<thead>
<tr>
<th>Event</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Van Camp took over Pago Pago fish factory and began operation</td>
<td>1954</td>
</tr>
<tr>
<td>Star Kist began operation</td>
<td>1963</td>
</tr>
<tr>
<td>Aerial tramway from Solo Hill to Mt. Alava and educational T.V. station KUZK transmitter on Mt. Alava were constructed</td>
<td>1964</td>
</tr>
<tr>
<td>Rainmaker Hotel was constructed</td>
<td>1961-1966</td>
</tr>
<tr>
<td>Rainmaker Hotel was opened for business</td>
<td>1966</td>
</tr>
<tr>
<td>Typhoon (February)</td>
<td>1966</td>
</tr>
<tr>
<td>Road linking Sagasa Pass to television transmitter on Mt. Alava was constructed</td>
<td>1971</td>
</tr>
</tbody>
</table>
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 Wess 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 Stugman, 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 ballestids were observed, but we never saw ones 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

Dans et al. (1972) suggested that Acanthaster aggregations resulted from food limitation caused by typhoon damage to coral communities.
ever, typhoons on Guam do not kill many of the coral colonies (Randall and Eldredge 1977, Ogg and Koslow 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 38 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 published Acanthaster outbreak. The 1968 outbreak at Guam and the 1977 outbreak at Famas 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 are accompanied by heavy rains but they do not follow "dry" typhoons with equal intense winds.

Behavioral Aggregations

Dana et al. (1972) suggest that Acanthaster interactions 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"
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 corynbose) *Acropora* (e.g., *A. hyacinthus* and *A.*
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 fungoids. For example, during our stay on Tuvalu, *Acanthaster* were moving into Waaseau 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 fungoids are eaten, the *Acanthaster* generally turn to feeding on favids, agariciids, and muzoids, although large pieces of *Discoasteria* (a favid) are often left uneaten. The last scleractinians to be eaten are usually the poritids (*Semiopora*, *Porites* and *Porites* (Synarae)), the stolonariids (*Coccostrea*), and the dendrophyllids (*Tubulina* 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 alcyonaceans 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 *Tubulina*, *Porites*, *Dendrophyllia* and *Millepora* are left alive. At Oneaoa, *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.

<table>
<thead>
<tr>
<th>Acropora group</th>
<th>Number of random points contacting</th>
<th>living</th>
<th>dead</th>
</tr>
</thead>
<tbody>
<tr>
<td>tabular (mostly A. hyacinthus)</td>
<td>164</td>
<td>170</td>
<td>339</td>
</tr>
<tr>
<td>arborescent (mostly A. acuminata)</td>
<td>639</td>
<td>90</td>
<td>729</td>
</tr>
<tr>
<td></td>
<td>808</td>
<td>260</td>
<td>1068</td>
</tr>
</tbody>
</table>

$\chi^2 = 179.5 \quad p << .001$
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*.

<table>
<thead>
<tr>
<th></th>
<th>Tabular <em>Acropora</em> (mostly <em>A. hyacinthus</em>)</th>
<th>Arboreal <em>Acropora</em> (mostly <em>A. acuminata</em>)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of surface</td>
<td>169</td>
<td>639</td>
</tr>
<tr>
<td>cover of living <em>Acropora</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of <em>Acanthaster</em></td>
<td>60</td>
<td>4</td>
</tr>
<tr>
<td>Counted on the coral</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>229</td>
<td>643</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
\chi^2_{[1]} = 162.3 \quad p \ll .001
\]
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.B.R.) noted that when an _Acanthaster_ was pulled loose and being tossed by the surge, damselfishes would pack at or just 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 Alofa 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 Stufaga 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 _Mataei_ 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. Selective 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 Stufega Point. The crustose coralline algae and filamentous algal turf were mainly contacted on dead Acropora.

<table>
<thead>
<tr>
<th>Depth</th>
<th>1 to 3 m</th>
<th>6 to 8 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of quadrats</td>
<td>17</td>
<td>102</td>
</tr>
<tr>
<td>Number of random points</td>
<td>612</td>
<td>3672</td>
</tr>
<tr>
<td>Percent cover</td>
<td>3.8</td>
<td>90.2</td>
</tr>
<tr>
<td>crustose coralline algae and filamentous algal turf</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acropora hyacinthus (tabular)</td>
<td>77.8</td>
<td>1.9</td>
</tr>
<tr>
<td>Acropora acuminatus (arborescent)</td>
<td>16.9</td>
<td>3.8</td>
</tr>
<tr>
<td>other Acropora spp.</td>
<td>.7</td>
<td></td>
</tr>
<tr>
<td>Montipora spp.</td>
<td>.8</td>
<td></td>
</tr>
<tr>
<td>Postliopora spp.</td>
<td>1.3</td>
<td>2.2</td>
</tr>
<tr>
<td>favulids</td>
<td></td>
<td>.2</td>
</tr>
<tr>
<td>Gonipora sp.</td>
<td></td>
<td>.08</td>
</tr>
<tr>
<td>Pavona sp.</td>
<td></td>
<td>.08</td>
</tr>
<tr>
<td>Galaxea sp.</td>
<td></td>
<td>.03</td>
</tr>
<tr>
<td>Dysidea herbacea (grey encrusting sponge)</td>
<td></td>
<td>.14</td>
</tr>
</tbody>
</table>
devastated areas after the Acanthaster had moved away. Arboreal Actopora often spread by the reattachment of broken branches. The thinly spaced and lengthy branches readily wedge into crevices in the reef framework or between the branches of other arboreal, cespitose, or foliaceous corals. They have two mechanisms for reattachment. The Actopora cement 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 Actopora and cements the two corals together.

The easily broken, easily wedged, and reattached branches of arboreal Actopora 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. Planulæae 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 (Kirkeland 1977). Planulæae 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 attack to living tissue. Actopora 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 Actopora appears to be the coral most rapid in invading the area if the surge zone refuge exists. Of course there is no reason to interpret this as an adaptation by Actopora to Acanthaster. Acanthaster outbreaks are irregular and Acanthaster is generally scarce. The problem
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 agaricids generally spread by planulation as evidenced by themselves 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 Yig 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 *Acropora* 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 nearby 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 coralligenous *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 Sufaga Point, at Alofau, and about halfway between Ausili Point and Leitu Point. These sites are labeled "A", "B", and "C", respectively, in Figure 1 in Appendix C. At Sufaga 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 35 branches of *A. acuminata* , 4 *A. abrotanoides* , 11 *A. hyacinthus* right side up, 4 *A. hyacinthus* upside down and 7 *Pocillopora*. Between Ausili Point and Leitu 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 surveillance. Transplant experiments have also been set up at three sites on Palau (Sirkeland 1979).
ARE THERE ADAPTATIONS TO Acanthaster INFECTIONS?

Although Acanthaster 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. Chironcis tritoris prefers several other asteroids. Cassia corune usually feeds on irregular urchins. Gymnactium locutum and Murax wo. will probably take other small echinoderms or molluscs if Acanthaster are scarce. Bursa rubens will probably take other small echinoderms or polychaetes if Acanthaster are scarce. Hymenopora plicata prefers smaller asteroids (Clym 1977), especially ophiasterids. Dendrolophus sp. is most likely to survive on other small echinoderm prey. Xanthid crabs and Harpactus sp. are usually omnivorous. The group Pectuncus laccopiatus will probably take small fish and crustaceans if Acanthaster are scarce. Although Bajacostus viridis and Arothron hispidus were observed near Acanthaster in Samoa,
we never saw one attack an Acanthaster. Ormond and Campbell (1974) document
the predation of Archechon hispidus, Balisnoides viridescens, and Pseudoballistes
flavimarginatus on Acanthaster, but according to the information from Hait
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 (Zdredge, in Tsuda 1972:15-17; Cannon
1972). Most of these are associates of other species as well, but there
are protozoas (Cannon 1971), a copepod (Bunes 1970), and a parasitic flat-
worm (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 communi-
ties 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 Tuvalu, 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, reefs 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 Marquessas, 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 plancti 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 plancti 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 aesthetic or economic reasons to reduce the abundance of Acanthaster in certain areas. Studies on these matters should be undertaken, but as advised by Johannes (1973:42), 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 weigh 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 48,793 *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 Malekal Channel (N. M. Hammer, 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 Micronesia between 1969 and 1972 and Marsh and Tsuda (1973) attributed this in part to control efforts; approximately 236,000 *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 753 *Acanthaster* and the resurvey of October 1972 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 rhinoceros 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 1923, Moorehouse 1916, Dawson 1959, Nishikira and Yamazato 1974, Johannes 1973). 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 (Nishikira and Yamazato 1974). Only time will tell. Examples of coral communities replaced by algal communities because of environmental changes are given by Dawson (1939) 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 perpetuate itself until it developed into
a reef. These communities not reacting 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 1971). 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 of 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
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 alama, control will be most intense when alama 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 specimen, the bounty system would only be effective where Acanthaster are abundant enough to be a problem.

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We are grateful to Henry Sasepesara, Director of the Office of Marine Resources, and to the Honorable Peter T. Coleman, Governor of American Samoa, for inviting us to come to American Samoa to do this study and for providing air fare and per diem. The idea to do this study on Acanthaster in Samoa was suggested by Patrick G. Bryan, Fisheries Specialist. Richard C. Wess was a very valuable source of information as evidenced by Appendix 3 and he was generous with his time, taking us out on his boat to Fagatele Bay. Ieremiau Laupapa, Senior Biologist, helped us talk with the Samoan Natai and fishermen. Ieremiau himself was a source of a lot of information on Samoa and we learned the proverb from him. William Pedro and Roger Pfium were of help in several ways. Frank Cushing was essential to our field work and without his constantly keeping the boat motor in repair, we might still be drifting at sea.
REFERENCES CITED


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 trusach. At Fiji (Melanesia), Acanthaster is called buls (a homonym of "hello") while the general term for "starfish" are gasagasan or basage (Aceleite "Laita" Smalley, pers. comm.).

In contrast, the languages from atolls might not contain terms for Acanthaster. The Gilbert Islands (Kiribati), the Ellice Islands (Tuvalu) and Fanning Island are all atolls. Lobel (1978) presented a list of 407 names of fishes and 93 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 boomer, Ngirbualiad ("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 Rechbei, 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 Samos have occurred, as cited by Samoans, are given in the Introduction of this report. Fine (1970) reported that fishermen in the Solomon Islands (Melanesia) remembered large concentrations of *Acanthaster* about 1930, forty years previous to 1970. Cheshire (1969b) reported that Micronesians remember an outbreak on Pohnpei 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, breakwaters and ramps, regular urchins are remarkably scarce in Palau at the time of this writing.
APPENDIX B

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

by
Richard C. Mass

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 "alalame", 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 Tausa Bank along the southeast coast. At this time, similar coral banks between Tausa Bank and Anua 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 Ioni Villages. These initial observations, along with increasing reports of other reefs infected 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. Wess and Mr. Jan Van 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, Mauuli, Fagamanas, Natu, Laulituaili and Asasi Villages; 2) reef front and seaward slope zones at Pagaetea Bay, Steps Point, and Fagotui Cove; Aua, Asasi, and Tuta Villages and the entire coast between Breakers Point and Sinuau Point; and 3) offshore coral banks and patch reefs between Tafuna Airport and Amunau 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 Ta'ema Bank, Hafanau Bank, and several other patch reefs situated between these two regions were resurveyed on April 16, 1978. On May 5, 1978 the reef front zone of fringing reefs along Tuulii'a's south coast near Fagamanas and Fatumati Villages were surveyed and reefs at Alega and Laalituai 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 Asasi Village on the south coast to Pupuqati 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 Launa Rocks at Cape Taputapu. Fagastel 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. planaci* 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. planaci* 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 fore reef 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. planaci* 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. planaci* observed within a certain period of time and estimated the resulting coral damage.

Because of the large population of *A. planaci* observed at Taena Bank, a more intensive survey was conducted there to measure starfish density so that an estimate of the coral 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 fore reef 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 quadrates 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 11, 1978. The transects across this sector of the bank were run on a bearing in line with Fatu Rock.
and the television towers located on Alava Mountain. Relatively few A. plancti 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 ashamed from 18 to 15 meters. Over 90 percent of the reef corals were dead and only three A. plancti were observed. Scattered Porites 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. plancti were observed and about 20 percent of the coral coverage was still alive. Originally the reef community in this zone was composed mostly of Porites and some arborescent Acropora species. The fore reef 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 some A. plancti were seen at 31 meter depth feeding on a single unidentified coral species with large conspicuous calices.

Based upon average starfish densities the current A. plancti population for Sector I was estimated to 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 rangemarker.
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 fore reef 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 fore reef slope. Only four *A. planci* were observed in this zone.

A total of 51 *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 m² for the three transects and an overall population for Sector II at 1300. 

**Sector III**

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

Corals on the backreef slope were mostly dead with less than 5 percent of them still living. All the table corals *Acropora* species, most of the arborescent *Acropora* patches, and all but a few scattered *Porites* 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 181 were counted along the two transects.
starfish were especially abundant along the seaward edge of the upper bank surface but upon reaching the forereef slope they were conspicuously 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 m² and an 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" described 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 Tautu 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 346 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 740 starfish each. Based upon densities from these three survey
sites the average starfish density along the front was estimated at 15.4/m².
Using this average density value and an area 800 meters long by 6.5 meters
wide, the total starfish front population was calculated to be about 82,000.

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
Tasman Bank was estimated to be about 217,000 with an estimated 80 to 90
percent of all the corals killed.

A resurvey of the eastern tip of Tasman Bank (Sector IV) on April 28,
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 60 meters in depth and rises to within 20 meters of the surface at places. Seventy-nine A. planct 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. planct during a three minute observation period on the patch reef slope below 35 meters in depth. Most of the tabletop Acropora species were dead, but more than half of the arboreal 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. planct. 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 preferred corals of A. planct, were mostly dead on Patch Reef A 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 arboreal 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 rowed along the entire fore reef 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 fore reef 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 shallow than 15 to 20 meters were still living and free of A. planci. Starfish density on the fore reef 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 fore reef 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 easter movement of the previous large populations observed on
Taena 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 Taena 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 Lauluitua 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 Fagatutu 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 Fagatule Bay, Steps Point, and Lagalu Cove; Aue, Aausi, 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 fore reef slopes near Aega and Lauitu Ath Villages were resurveyed by two divers by making five minute scuba dives in opposite directions. At Aega Village no A. planci were observed, but one fresh and one old feeding scar, possibly attributable to starfish feeding, were seen. At Lauitu 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.

Fore reef slopes west of Pago Pago Harbor entrance near Faganesea Village (Sweet Rock) and Patamaufi Village were also surveyed on May 5, 1978 by making five minute scuba dives in opposite directions. At Faganesea Village site 14 A. planci were counted (6 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 Patamaufi Village no A. planci were observed, but numerous feeding scars were observed at 20 to 23 meters depth.

Fore reef Slope Surveys Along the Eastern Coasts

Fore reef slopes were surveyed on June 1, 1978, by making ten minute dives with a single diver at Ausa and Tula Villages and along the entire coast from Nuiolo Rocks to Puputagi Point.

No A. planci were observed along the Ausa and Tula Village towns. Earlier surveys at these two villages produced similar results during the
first five weeks of 1978.

Between Nuatele 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 Papaloa Point and Ogefa village 1080 A. planci were counted. Even so, the distribution of the starfish were rather patchy. Corals in particular, at the b asal 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 24.5 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 those found in the shallow reef areas.

Between Ogefa 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 reef sectors surveyed along this coastline the numbers of starfish counted steadily decreased from 200 between Solo and Motusaga Point, to 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 Nuatele Rocks. The large size range of the starfish suggests that the popul-
tion is composed of individuals from several larval recruitment periods.

Fore reef Slopes Surveyed Along the North-Central Coast

The reefs along the north-central part of Tutuila Island were surveyed at twelve sectors between Tapeta Point and Pagasga Bay on June 6, 1978. Acanthaster planci counts and condition of the reef corals were made by tow- ing 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 Tapeta Point and Manase Reef Plate, 212 between Nusetega Island and Lepua Point where they were more or less restricted to projecting points of land; none between Tapeta Point and On Village, Vainuu Point and Anapsapa Cove, Craggy Point and Amalau, Veta Village school and Pala Island, and along the reefs within Vasogeorge Cove; 51 between Manofa Rock and Puanavea Point where they were mostly restricted to a point of land at Manofa Rock; and 11, 13, 12, and 0 along four contiguous sectors between Nultivaleigano Point and the back side of Pagasga 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 interspersed among the dead regions.

Fore reef 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. planct* were observed: 27 between Luanita Rocks and Tiaoalili Rock, 10 between Tiaoalili Rock and Leopard Point, 112 between Patalulu and Faga Point, 236 between Faga Point and Malataa Bay, 30 between Paganalo Village and Paganalo Cove, 39 between Pa Cove and around Square Head, 6 between Tolotolo Oceoti and Matea Mateale Point, none between Aolau Bay and a prominent point to the east, 3 in the vicinity of Nuatavana Rock where considerable dead corals were found, none between Silage Point and Asau Village, none between Fagatele and Opagasa Points, and none between Agalua Rock and Cape Larsen. With the exception of the sector in the vicinity of Nuatavana 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. planct*, but now was found to have very little live coral down to depths of 45 or more meters. The shallow fore reef 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. planct* 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 interspersed among 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.