NOTE: This is a digitized copy of the Westinghouse Electric Corporation project report to the U.S. Department of the Interior following a 1969 survey of North Pacific coral reefs to evaluate the threat of *Acanthaster planci* infestations. 63 marine specialists surveyed the coral reefs of 24 islands from Palau in the west to Mokil and Arno in the East, and from Saipan in the north to Kapingamarangi in the south. This was the most wide-spread single assessment of the state of the coral reefs ever done.

The report was published as a special National Technical Information Service report to the U.S. Department of the Interior and was difficult to obtain. This digitized version makes the report available to the general public for the first time.

Richard H. Chesher, Ph.D.
Noumea, New Caledonia, March 2013

Acanthaster planci

IMPACT ON PACIFIC CORAL REEFS

FINAL REPORT to

U. S. Department of the Interior.
Washington, D. C

NATIONAL TECHNICAL
INFORMATION SERVICE PB187631

Research Laboratories
Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

October 15, 1969

UNITED STATES
DEPARTMENT OF THE INTERIOR
OFFICE OF THE SECRETARY
WASHIINGTON, D.C. 20240

FORWARD.

This report is being released at this time in order to make available without delay the results of an extensive survey carried out during the summer of 1969 to determine the extent of predation on Pacific corals by the starfish *Acanthaster planci*, ("Crown of Thorns"). Destruction of corals by this starfish on the Great Barrier Beef off Australia was first reported in 1963. Later information indicated that there may be population increases in other areas and following reports of extensive damage to reefs off Guam many marine scientists became concerned that the phenomena may be widespread throughout the tropical Pacific.

In order to gain further information on this matter, particularly in relation to the islands in the Trust Territory, the Department of the Interior contracted with the Westinghouse Ocean Research Laboratory to organize and carry out a survey of *Acanthaster planci* on selected islands in Micronesia

The Department was joined by the U.S. Navy, the U.S. Coast Guard, and the National Science Foundation in further support of the project. Scientists of the University of Hawaii surveyed the Hawaiian and Marshall Islands. The Navy, in particular, provided outstanding assistance We are grateful to all whose cooperation made the project possible.

Preliminary evaluation of the results of the survey suggest that the starfish infestation is of serious and growing proportions in some areas. While the data and recommendations in the report are undergoing further analysis and consideration by the Department, it is Our intent that they be available for use by others who are carrying out research or contemplating control or, monitoring operations on *Acanthaster planci*

We wish to express our appreciation to the Westinghouse Ocean Research Laboratory for its quick and efficient organization of the survey and to the scientists who participated, many of whom did so at considerable sacrifice to their own research programs and previously planned summer programs.

Wally Hickel

Secretary of the Interior

Acanthaster panci

IMPACT ON PACIFIC CORAL REEFS

Richard H, Chesher, Chief Scientist
Westinghouse Ocean Research Laboratory
San Diego, California 92121

FINAL REPORT TO

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PREFACE

The "Crown-of-Thorns" starfish and its apparent proliferation in the central Pacific first came to the attention of the Westinghouse Ocean Research Laboratory (WORL) in May 1969. WORL sought the guidance of Mr. F. P. Cotter, Vice President, Westinghouse Government Affairs, for making the problem known to the U.S. Government because of the possible economic implications -- especially to the Micronesian trust territory. With the assistance of Mr. W. Pozen and Mr. J.H. Heller of Stroock, Stroock and Lavan - who acted on Mr. Cotters behalf, discussions were held with representatives of the Office of Science Adviser to the President, the Marine Sciences Council and the Department of Interior. These culminated in presentation of a proposal on June 6 to the Undersecretary R.E. Train, Department of Interior. Drs. T.F. Goreau, P.M. Kier, R. Fosberg, J.E.-Stein, and K.R.H. Read were critically helpful in presenting the problem.

Encouraged by Mr. Trains positive reaction to the plan the Westinghouse Ocean Research Laboratory set about fielding teams of scientific specialists to investigate widely scattered remote islands covering an area larger than that of the continental United States. Scientists began to arrive at Guam by July l, and the last field team had been debriefed by August 15. This report summarizes the results of their efforts.

Unusual and commendatory actions were required by a variety of individuals and organizations to make the expedition possible within time and money available. Central coordination among the many facets of the Department of Interior and with other government agencies was ably accomplished by H. H. Eckles. D. E. Heft and his colleagues at the Office of Naval Research not only arranged for scientific participation through existing contracts, but also arranged for part of return transportation, freight and, Navy seaplane transportation to outlying islands. A. Alexiou was instrumental in arranging support for the University of Hawaii scientists under the institutions Sea Grant Program. Advice and guidance, both technical and logistical, was offered from sources too numerous to mention.

R. D. Gaul Program Manager

GLOSSARY

Condition 1, 2, 3, etc.: See section 2.5. Relative conditions of the reefs on an entire island with respect to *Acanthaster planci* populations.

Epidemic: See ;action 5.3:1 and "infestation" below.

Front: See sections 2.5 and 5:3.2. A massive herd of *Acanthaster planci* in the process of migration. Dead coral lies behind the front and live coral ahead of it. The front often takes the form of a tightly aggregated herd of specimens oriented parallel with the shore: The front is, therefore, long (often several - kilometers) and narrow (5 to 100 meters).

Infestation: See section 5.3.1. A population of *Acanthaster planci* which can rapidly deplete the living coral on reefs resulting in large continuous areas of primarily dead coral.

Normal conditions: See sections 2.5 and 5.2. A reef inhabited by sparse concentrations of *Acanthaster planci* such that large continuous sections of dead coral are not produced.

Seed Populations: See sections 2.5 and 5.3.2. Populations of *Acanthaster planci* aggregated into large herds on small portions of reef. These might form the nucleus for an advanced infestation.

SUMMARY

Teams of scientists went to 16 islands within the U.S. Trust Territory under the direction of Westinghouse Ocean Research Laboratory to assess the population structure of the starfish *Acanthaster planci* and the impact of this species on Pacific coral reefs. In a companion effort, the University of Hawaii. directed five teams that surveyed Hawaiian islands, Johnston Island, Majuro, Arno, Kwajalein and Midway.

The findings of the study generally substantiated reports at recent increases in populations of this starfish in the Pacific. The teams located considerable amounts of -coral `reef that had been killed within the past five to ten years by *Acanthaster planci* and found substantial portions of coral reefs currently being attacked, Wherever feeding was observed, the starfish Were eating either scleractinian corals or sessile, colonial coelenterates. The infestations were judged to be of recent occurrence, with the earliest reports dating back to World War II.

A "normal" population was considered to have fewer than 20 specimens per 20 minutes of search. Yap, Ifalik, Woleai, Lamotrek, Kwajalein, Hawaii, Mokil, Midway, Kauai, Oahu, Maui and French Frigate Shoals were found to have normal populations. Ten islands had sufficiently high populations to be considered infested. These were: Saipan, Tinian, Truk, Ponape, Rota, Palau, Ant, Guam, Majuro, and Arno. Johnston Island, Kapingamarangi, Nukuoro and Pingelap are questionable areas, with high population levels of starfish that need to be examined at a later time to establish if an increase or decrease of population is in progress.

Team leaders considered the problem significant and in need of considerable research. A control program, which includes research into various aspects of *Acanthaster planci*, should be instigated immediately. Such a control program should establish an active eradication effort on infested reefs that have economic or scientific value as well as an educational program to inform islanders of the nature of the problem and how they can contribute to research and control programs.

Definite causes of the infestation were not established by the study. Two hypothetical mechanisms appear to offer the most promise for explaining the infestations. In one case a population increase is presumed due to decrease of predation pressure on the larvae by corals in reef areas freshly damaged by blasting and dredging. The other mechanism takes account of reduced predation on adult starfish by tritons that are prized by shell collectors.

ACKNOWLEDGEMENTS

The author and the Westinghouse Ocean Research Laboratory acknowledge the contribution received from a number of individuals in carrying out this study and completing the final report. U.S. Navy Captains Brandenberg and Beuris of COMNAVMARIANAS programmed and carried out seaplane support to the outlying islands. U.S. Navy Lt. James Bell of COMNAVMARIANAS and Milton McDonald provided extensive diving support during field operations in Guam.

The assistance of Peter Wilson of the U.S. Trust Territory Administration was invaluable in planning the logistics for the survey and establishing relations throughout the study area so that the field teams enjoyed full cooperation from all acting District Administrators. He also briefed survey teams on operations within the trust territory. Mr. Swingly of the Liason Office of the trust territory in Guam maintained continuing communications throughout the trust territory under difficult conditions. Dr. A.M. Banner directed the organization of field survey teams from the University of Hawaii. Dr. A. Yamashita, President of the University of Guam, lent his capable assistance in assuring the full cooperation of the University of Guam and its related facilities.

Senator Richard Taitano of the Government of Guam played a key role is the initial studies that preceded the survey program and followed through by volunteering governmental expertise that made it possible to maintain a rapid pace in the Guam environment.

Miss B. Allen, Dr. T. Munson, Mr. F. Speer, Mr. H. Retsky and Mr. H. Strom provided invaluable logistic support. In addition to the Westinghouse contract with the U.S. Department of Interior, the Office of Naval Research, the University of Guam the University of the West Indies, the Smithsonian Institution, and the Office of the Sea Grant Program of the National Science Foundation provided financial assistance to scientific participants.

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1. INTRODUCTION

Reports of widespread coral mortality caused by large populations of a predatory starfish, *Acanthaster planci* prompted Westinghouse Ocean Research Laboratory to initiate a broad-based survey of the coral reefs of the U. S. Trust Territory during July and August 1969. The purpose of the survey was to:

1) ascertain population levels of *Acanthaster planci* in the U. S. Trust Territory;
2) determine the extent of coral damage; and 3) gather data on possible causes and controls of infestations.

The office of the Secretary of Interior, the Office of Naval Research and the University of Guam made funds available. During the same period, the University of Hawaii, supported by the Sea Grant Program of the National Science Foundation, conducted a similar survey in the Marshall and Hawaiian Islands groups. The extent of destruction reported and the rate at which it was reportedly continuing necessitated prompt action. The entire program had to be fielded in less than one month from the time of initiation. This urgency limited the project to a survey operation with the primary objective of discovering if abnormally large populations of *Acanthaster planci* existed elsewhere and if they were, in fact, causing extensive damage on reefs in addition to these already known to be subject to heavy coral predation. Because of the large area to be surveyed, the limited time, the difficulties of logistics, and available support, extensive experimentation or systematic collections were not included in the survey.

The objectives of each field survey team were to:
a. Estimate the sizes and areal distribution of existing populations of *Acanthaster planci*.
b. Examine the effects of these animals on the coral.
c. Seek information relating to possible causes of infestations.
d. Note unusual features of the marine environment.
e. Observe feeding habits and behavior of *Acanthaster planci*.

Despite the limitations, the project did answer the prime questions: I) is the population explosion widespread in the U. S; Trust Territory, and is the amount of coral being killed in excess of that which is desirable; 2) are control techniques necessary, and are they possible; 3) where are the major areas of concern; and `4) what types of experiments and research need to be conducted?

It was the unanimous decision of the team leaders supervised by Westinghouse that the answers to the first two questions are "yes": The population expansion is widespread and is causing considerable coral damage. Control techniques are not only necessary but should be initiated in various degrees as soon as possible.

The analysis and conclusions made in this report are those of R. H. Chesher, Chief Scientist of the project.

The report is a condensation of a considerable body of data. Despite attempts at standardization, there is always a certain amount Of individual novelty in the methods and types of observations made by each team. Analysis of such a composite can result in differences of opinion in interpreting the data. Every attempt has been made to avoid such conflicts by debriefing each team in Guam immediately following their return from the field. These discussions were recorded on magnetic tape and are among raw data available through the Department of Interior. At the time of this writing, the author knows of no disagreement among expedition scientists on major results presented herein. Analysis of discoveries made during the course of this survey was based on what was known from work done previously in Guam and Australia. The most detailed biological information to date has come from these sources and has furnished an indispensable reference for comparisons with observations made elsewhere.

2. MATERIALS AND METHODS

2.1 ISLANDS SELECTED

The islands studied were selected after evaluating their transportation facilities, human, populations, and geographic location.

Palau, which Chesher had surveyed earlier, formed the western terminus of the, survey area. Mokil and Arno, which the Hawaii team covered comprised the eastern border of the survey. Kapingamarangi was the southern border and Saipan the northern. Field teams could not reach Pagan, which vas the intended northernmost island, because its airstrip was closed and there was no surface transportation to it.

Saipan, Yap, Palau, Truk and Ponape (all district centers) were selected because they have economic importance, large human populations, and relatively advanced technological societies. Tinian and Rota were examples of sparsely populated,high islands with fringing reefs. Pingelap, Mokil, Kapingamarangi, Nukuoro; Ifalik, Woleai and Lamotrek were examples of isolated atolls. Ant and Kuop atolls were chosen because of their low (or non-existent) human population and their proximity to larger islands (Ponape and Truk).

The areas that the field teams surveyed are shown in Figure 1.

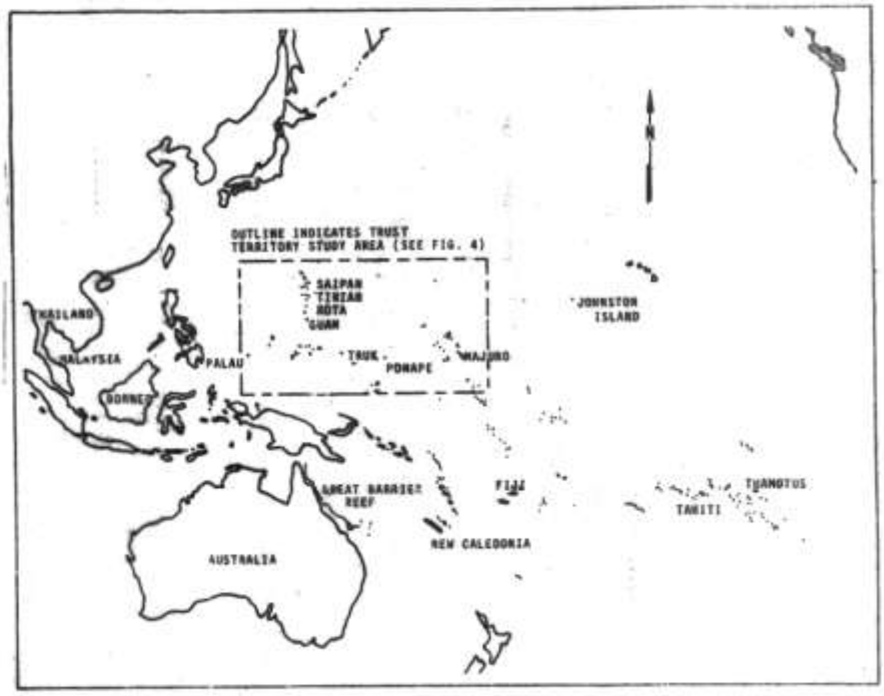


Figure 1. Map of Pacific. Areas of reported infestations.

2.2 FIELD ORIENTATION

All teams, including University of Hawaii participants, passed through Guam, where they received a three- to four day orientation. During this time the chief scientist directed a series of field trips on the Guam reefs to provide experience observing *Acanthaster planci* infestations, to gain their impressions of the Guam infestation, And to establish a standardized survey procedure. The dates when various teams could assemble in Guam precluded holding, one, pre-survey conference to establish standard field procedures. The chief scientist, therefore, established procedures based on his experiences in Guam and Palau surveys

Paragraph 2.6 describes the field procedures.

The orientation period began the day each team arrived in Guam. That afternoon they examined the southern population of *Acanthaster planci* and observed some of the lush coral areas at Piti Bay killed by this same population (Paragraph 3.2). Also on the first day, the team received a history of the infestation and control methods that have been used on Guam.

They spent the second day observing the northern population of *Acanthaster planci* and portions of the reef that the starfish had grazed, between Ritidian Point and Tumon Bay. During both days, they practiced towing procedures and counting procedures (see Paragraph 2.6). The second days program included a dive to 60 meters to observe the depth range of destruction of corals by *Acanthaster planci*.

The team spent the third day checking equipment and attending a briefing session by students from that area of the Trust Territory for which the team was destined. Peter Wilson, Fisheries Biologist for the Trust Territory, also provided information on logistic problems, people to contact and proper conduct in the particular society. If possible the team moved into the field on the fourth day. If not, they made an additional dive in Bile Bay, an area outside the present infestation where a luxuriant coral growth is still extant on Guam.

2.3 INTERISLAND TRANSPORTATION AND COMMUNICATIONS

The teams used five modes of transportation between the Trust Territory islands and-Guam.- Private charter aircraft flew teams to islands with smaller airstrips or where commercial air transport could not be arranged to fit the schedule, Aerodyne Aircraft Co. and Brandenburg Co. flew teams to Saipan, Tinian, Rota, Truk and Ponape, Air Micronesia returned teams from these areas. The U. S. Coast Guard provided air transport to and from Yap. The.U. S. Navy furnished HU-16 seaplanes for transportation to Ifalik, Woleai, Lamotrek, Kapingamarangi and Nukuoro. Teams used a U. S. Trust Territory Field Trip Vessel to go to Pingelap, Mokil and Ant from Ponape.

For local transportation at the islands, the teams rented government or private boats or used inflatable 14-ft. rubber boats with outboard motors.

Communications between the islands and Guam were difficult. The U. S. Trust Territory radio and dispatch communications network and a civilian ham radio network comprised the only means of contact. More remote islands were frequently unable to communicate with Guam, and sending and receiving messages required several days.

2.4 SUPPORT EQUIPMENT`

The amount of support equipment provided the teams depended on facilities available at the various islands. All teams took SCUBA diving and snorkeling equipment with them and most had portable compressors, camping gear, food, and an inflatable rubber14-ft. Zodiac boat with 25-hp. Johnson outboard motors. Teams going to the out-islands received more equipment than those destined for the district centers, hence were self-sufficient. A list of equipment issued to a self-sufficient group is provided in the Reference Report.

2.5 CLASSIFICATION OF INFESTATION

Quantifying the population structure of *A. planci* presented some difficult problems. "Normal" populations (termed Condition 1) have very few animals per unit area. In addition, *A. planci* is a nocturnal species, and cryptic behavior and low densities make it rarely observed during the day.

When, under normal conditions, *A. planci* are seen, there may be two or three specimens within a 1,000-square-meter area, usually with no specimens in adjacent areas. Individuals in a normal population ordinarily do not feed during the day; they are often very large (up to 60 cm. in diameter).

Condition 1 -- normal population-- differed so considerably: from the other conditions that qualitative procedures were adequate to determine It reefs were infested or not. The survey located only one place where more than 8 specimens were found within a 20 minute tow where the population could be considered normal. This was a location on Woleai that contained a herd of about 20 specimens. These were apparently not doing extensive damage, to the reef, although the specimens were large and obviously several years old. It is possible that this was a breeding aggregation that had accumulated to spawn. Here, as elsewhere, however, there was an order of magnitude difference between the numbers of specimens in a condition 1 situation and any condition 2 or 3 occurrences

Condition 2 -- seed population-- is characterized by large groups of 500 to 1,000 specimens located within a very small area.

Coral damage can be moderate to severe with the confines of such a population, but the coral in adjacent areas is alive. Seed populations, as these groups have been termed (Chesher 1969), congregate primarily in shallow water in areas of lush coral, growth. Some seed populations in Palau existed in areas partly exposed during low spring tides. Divers found others, in 10-meter depths.

Condition 3 --infestation-- represents an intermediate stage where the infestation expands rapidly over two or three kilometers (or more) of coastline. *A. planci* is distributed in herds of several hundred specimens. White, recently killed coral can cover several hundreds of square meters near the larger herds. The animals move into all depth zones. Condition 3 is short lived as the starfish rapidly deplete the living coral and the massive herds soon become separated by zones of almost completely dead coral.

Condition 4 --front-- exists when the herds, form a front or fronts that take the form of a tightly-packed, band of animals oriented parallel with the shore and extending for one to many kilometers along the coastline. Thousands of specimens occur in these herds, which migrate actively, leaving almost totally dead reef in their wake. The presence of such a front is easy to detect by its numbers of specimens and the abundance of dead, white coral which becomes an obvious path along the bottom. Once found, such a front can be followed easily from the surface. One such front on Guam extended 12 kilometers along the reef and varied from five to several hundred meters in width (see Figure 2). Large areas of almost completely dead reef adjoin actively migrating fronts.

Condition 5 **--**post infestation-- represents that stage when *Acanthaster planci* has grazed all of the Coral on a particular island. Generally, only a small amount of coral survives in shallow or turbulent water. If this condition is recent, a large population of *A. planci* may still be present. If the condition is old, the starfish might enter an equilibrium condition wherein they are distributed more widely (but not so widely as in condition 1) with the density of specimens depending on the rate of settlement and growth of coral. Under such conditions *Acanthaster planci* destroy the new corals before they reform a framework reef. T. Goreau reported such a condition in the Red Sea in 1964. Alternatively, if the infestation is so serious that all corals are eaten and recruitment of new corals is inhibited by succession communities, the *Acanthaster planci* may not survive, starving to death before the food corals re-establish themselves. Under these circumstances, no resident population of *Acanthaster planci* develops and the reef appears to exist in Kuop (see Paragraph 3.5).

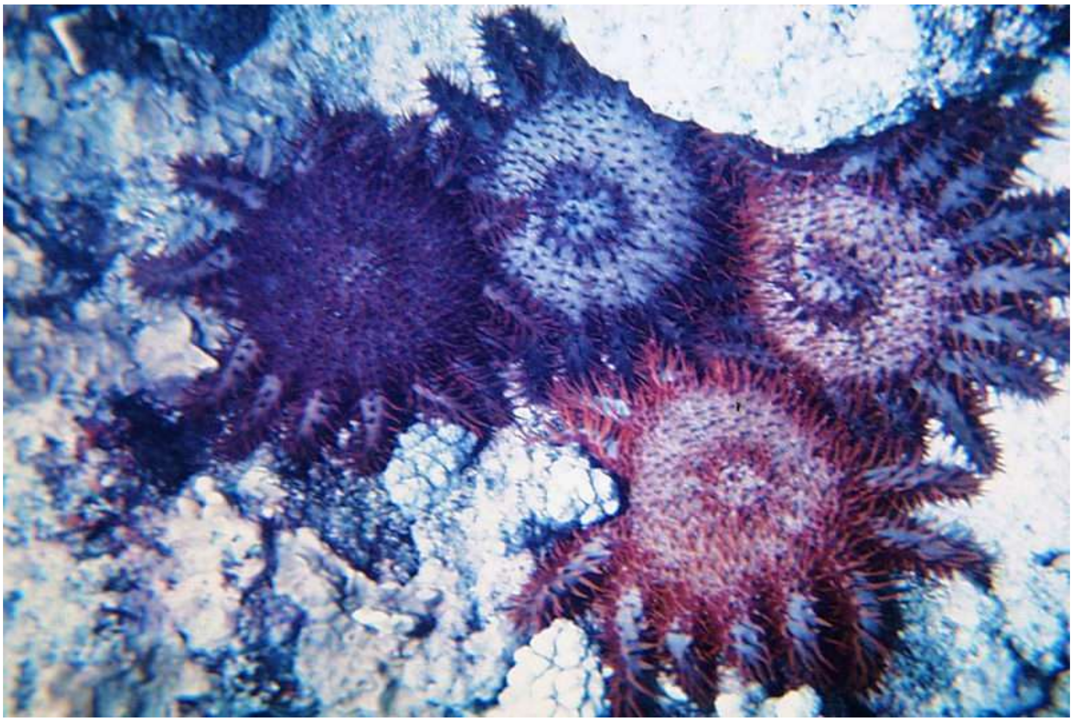


Figure 2. Portions of Migrating Fronts of *A. planci*

Tinian represents an early stage of condition 5 where large numbers of *Acanthaster planci* still exist (see Paragraph 3.14).

Condition 6 represents a minor population explosion, apparently to the level of condition 2, which does of gain adequate recruitment to continue its development and disperses after killing off only a few kilometers of reef. B. Wilson delineated this case in Nukuoro after the survey was completed. Assurance that this hypothesis is valid and condition 6 exists requires additional substantiation.

Conditions 1 through 5, however, have been observed in a sufficient number of independent localities to assure their accuracy. Endean reports an unmistakable condition 4 in Australia, and the history of the Great Barrier Reef infestation indicates it went through similar stages of development. Considering the several stages of severity in the *Acanthaster planci* infestation, it was evident from the project start that determination of the distribution and nature of the *A. planci* population would necessitate surveying a considerable part of each island -- if not the entire reef system of each island.

2.6 FIELD METHODS

Fortunately, Chesher's and others experiences in Guam and Palau showed that swimmers towed behind a boat at 2 or 3 knots could easily identify white, freshly killed coral from the surface, even when this was limited to single, isolated specimens. It was possible to cover the large distances involved by towing divers behind boats, thus surveying at least one nautical mile in an hour. When they observed white patches, the divers stopped and investigated. If they found *Acanthaster planci* to be the cause of the white coral, the field team made a more detailed study by SCUBA or skin diving in that vicinity. In areas of heavy infestation it was not necessary to stop at every white patch as these were usually continuous for long distances and the grazing animals were evident from the surface (Figure 2).

Program personnel made attempts to define the limits of the larger populations topographically on the infested reefs and to estimate densities. Counts from the surface were considerably lower than counts made by a SCUBA examination. The number of animals missed by the towed divers varied with the nature of the terrain. If the bottom was smooth, their counts could be 80 to 90 percent accurate. If the bottom was extremely rugged and the coral growth was lush, counts could be 10 to 20 percent correct. To ascertain precisely how many *Acanthaster planci* were on a particular reef would have required an impossibly long time and was not needed to determine the relative degree of infestation.

Extreme differences between normal and infested reefs permitted making an accurate qualitative judgment of the density and of the obvious effect of the predator on the reef. Hundreds of square meters of white coral (killed within the past 48 hours) on a small portion of a reef was a clear indication that the predator was overpowering the preys replacement ability.

Acanthaster planci normally leaves white coral heads randomly scattered and rare on the reef. During infestation conditions, feeding is less patchy with larger coral heads attacked and completely stripped of living tissue. White patches several meters in diameter appear commonly.
The field teams estimated population sizes by recording the number of animals seen per 20-minute tow or swim. When possible, they converted the duration of the tow to distance by indicating the exact area covered on the charts. Divers counted specimens and an observer in the boat recorded the total number seen at the end of the tow. Although more, animals could be found in a particular location by swimming, towing covered more territory and thus increased the chances of finding additional specimens. Swims were generally made in areas where the terrain was extremely rugged or shallow or where additional, detailed information was sought on a particular population. Tows were the primary method of search and were designed to locate large populations and to gain an overview of the general reef condition. Not all teams operated in this fashion; some split into two-man teams to cover a larger area, and others adapted alternative towing methods to suit the particular situation:
The data sheets and charts show the large areas covered by towing, which far exceeded what could have been examined by swimming. only. Clear water and the ease with which the freshly killed coral could be seen from the surface assured that the areas covered could be competently examined.
In some locales, towing was not possible. These teams resorted to swimming, employing the usual "buddy system" of diving and following normal safety practices. Decompression dives were not permitted.

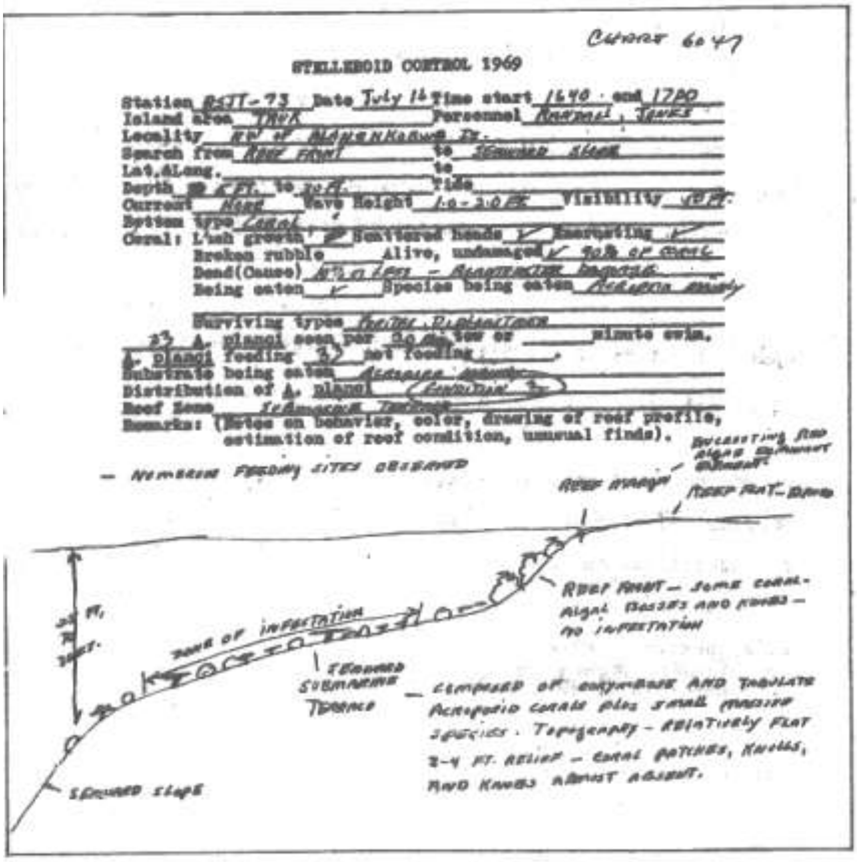
Each survey followed an orderly search pattern except as modified by local submarine topography and wave action. The chief scientist discouraged teams from making periodic "spot checks" or unconnected vertical transects.

When divers sighted *Acanthaster planci* they stopped the boat, photographed the area and the specimens, inspected the animals to determine if they were feeding, and examined the reef for additional specimens that might not be evident from the surface. They also investigated white, freshly killed coral. Where *Acanthaster planci* infestations were heavy, it was not necessary to stop more than once or twice to examine the activities of the specimens.

Most of the entries on the data sheets (Figure 3) are self-explanatory "Island area," for example, would be the particular locality on that island. Since many of the stations included tows, the observer noted the beginning and end of each tow in "search from to . .". "Bottom type" refers to the general nature of the substrate; when it was coral, the divers elaborated upon the nature of the bottom-after "coral". The number of *Acanthaster planci* seen per unit of tow or swim served as the prime index of infestation.

The divers commented on the animals general behavior in the section on feeding and distribution. The data sheets provided space for additional comments on behavior, color, reef condition, evidence of blasting, nearness to human populations, or other pertinent observations.

Determining what caused areas of dead coral was sometimes difficult, particularly when no *Acanthaster planci* were present and the kill was several years old.



STELLEROID CONTROL 1969

Station ______ Date July 16 Time start 1640 end 1700
Island area TRUK Personnel ______
Locality ______
Search from REEF FRONT to SEAWARD SLOPE
Lat.&Long. ______ to ______
Depth ______ Tide ______
Current NONE Wave Height 1.0-2.0 FT. Visibility ______
Bottom type CORAL
Coral: Lush growth ______ Scattered heads ______ Encrusting ______
Broken rubble ______ Alive, undamaged ______
Dead(Cause) ______
Being eaten ______ Species being eaten ______
Surviving types ______
A. planci seen per ______ tow or ______ minute swim.
A. planci feeding ______ not feeding ______.
Substrate being eaten ______
Distribution of A. planci ______
Reef Zone ______
Remarks: (Notes on behavior, color, drawing of reef profile, estimation of reef condition, unusual finds).

Figure 3. Field Data Sheet.

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In determining the causes of coral kills, the following criteria proved useful:

a. Coral growth poor but living -- Fauna mostly low, encrusting corals and smaller coral heads scattered on open coralline pavement. Attributed to the area being naturally poor for coral growth. Occasional dead corals or white areas were usually species-specific, caused by unknown agents. This situation is common on coral reefs throughout the tropics. Many reefs that could be expected (from a physical standpoint) to have lush coral growth are poorly developed. The cause of this situation is not known, but as it occurs in the West Indies where *Acanthaster* and other pan-specific large-scale coral predators are absent it is probably not related to predation.

b. Coral skeletons abundant, but mainly dead rubble with small, living corals -- Attributed to physical damage such as from severe storm waves or dynamiting. Often large, massive heads are undamaged and alive even if overturned. Dynamited areas usually have a characteristic appearance of a distinct crater or center from which the rubble radiates outward.

c. Coral skeletons abundant, standing as in life but eroded and covered with algae--Traceable to siltation or other physical environmental stresses or to *Acanthaster planci*. If the coral growth was originally lush, conditions favorable to coral growth must have existed for a long period of time.

An extensive coral kill by siltation requires either a pronounced meteorological change or an alteration in nearby land drainage. Sediment resistant species of corals should persist in large numbers and living corals should be present. Massive corals might show some living polyps on exposed portions, but the polyps in crevices or niches within the-reef structure would be the most severely affected by sedimentation. Superficial evidence of sedimentation might vanish with time, but silt should remain in nearby sediments or in crevices within the reef structure or within the dead corals themselves.

Coral kills can also occur through hydrological changes. An example would be through containment of water within an atoll or bay that has lost its natural circulation from blockage of the major passages. When water circulation decreases to a certain point, high temperatures and salinities can kill the corals. The results of such a kill would be difficult to distinguish from *Acanthaster* predation, particularly if the area is investigated after normal circulation had been restored for a few years. Kills such as this are not common, however, and do occur on the outside of fringing and barrier reefs.

Low tides and rain can cause extensive coral kills but death of shallow water corals with a sharp demarcation of the killed zone corresponding to the water level at the time of kill characterizes these.

Acanthaster kills are unique in that dead corals stand as in life, frequently are covered with algae and are primarily located from below the surf zone to the depth limit of reef building corals. Surviving corals are octocorals; hydrocorals and helioporids. Intertidal corals or corals in an active surf zone where the predators cannot feed frequently survive (in contrast to kills by sedimentation, fresh water or exposure where the shallow corals die first). Corals in crevices and coral polyps in depressions or niches particularly on the surfaces of more massive domes survive (in contrast to coral kills from sedimentation). Neumann of Woodleys Truk team pointed out growth of the massive corals often began as a small dome arising from cracks and crevices of dead coralla. Where wave action is strong, the center portions of large, evenly rounded *Porites* heads often survive.

Where specimens of *Acanthaster planci* still feed actively on live coral, numerous white patches of freshly killed coral exist. The corals remain white (and easy to see from the surface) for one to two days, depending on the rate of algal settlement. Following that period, the color turns first to light and then dark green. In a few weeks the color shifts to grey or grey-green, as calcareous algae cover the coralla.

Other predators, diseases and elevated temperatures can cause white coral, C*ulcita*, the "pincushion star," feeds on coral much in the same way as *Acanthaster*. Masses of the gastropod *Drupella cornus* feed on species of *Acropora*, leaving white patches of rather small size. Investigators have also observed species specific deaths resulting in white coral, that may be caused by bacterial disease or other unknown agents. *Acanthaster planci*, however, produces the largest and most numerous white patches. After dead coral has been subject to several years of degradation, analyzing the causes of mortality. becomes correspondingly more difficult. The teams investigated causes of the infestation, in part, by interviewing the local populace and inquiring about changes (or lack of change.) In the environment, methods of fishing, and local use of marine facilities. They also sought clues in the environment itself.

Since triton fishing was an important parameter, they investigated the populace of tritons and the nature of the triton fishery, on each island. they inquired into the history of blasting or dredging for each island and assessed the relative effect of the human population on the environment. They considered the effects of fishing with dynamite and with Clorox, of dredging and destruction of reefs by humans searching for food or shells. Where there was an infestation they investigated its origin, documenting the reports of first occurrence and locating the seemingly oldest dead areas. Events occurring within three to five years preceding the estimated time of origin of the infestations were considered pertinent. Where there were no infestations, the teams gathered similar evidence to compare to the data from infested areas.

Evidence contained in reports from the local populace. is, of course, extremely circumstantial. Occasionally, however, evidence found in the field supported such statements. Since many of the local inhabitants in most areas investigated dive and make use of the marine resources, they frequently proved knowledgeable about the major environmental aspects of their reefs. For example, where the field team found *Acanthaster planci*, the islanders were familiar with the animal and had a particular name for it. On islands Where *Acanthaster planci* was rare, however, islanders were unfamiliar with it. , On Lamotrek, the survey uncovered only one specimen, and none of the islanders remembered ever seeing one before. In contrast, on Yap, where the species is present, but still uncommon, the islanders knew where to find the specimens and about how many were there. They were of the impression, moreover, that populations have been greater in recent years than previously.

On Truk, people were familiar with the starfish and remembered large populations as long ago as World War II. Their recollection correlated with field evidence: the areas reportedly infested following World War II appeared to be the oldest kill areas and regenerating corals seemed best developed there. Similarly, the time of reported infestation of the high islands of Truk correlated with field observations by one of the team members in previous years. One of the more accurate Trukese informants thought that such infestations were recent, probably caused by the war, and did not remember anyone of the preceding generation ever speaking of this particular starfish.

Reliable information is not available about much of the marine history of the area. It may be possible through future research to supplement such data with information on the amount of insecticides used on various islands, the tonnages of bombs dropped on particular islands, and fluctuations in oceanic conditions (such as temperature) over the past decade, The gathering of such information was outside the scope of the present study,

3. RESULTS

Each island, separated by oceanic depths and often hundreds of miles from other islands, must: be considered a separate, independent unit of investigation. The only link between populations of *A. planci* on these islands is by pelagic larvae. The checkerboard distribution of infestations and the presence of adult *A. planci* on all islands investigated, indicates that larvae can reach uninfested islands but do not survive there in sufficient numbers to form infestation conditions. The specific results of the survey, therefore, must be considered as applying only to the islands studied.

This section lists observations on, each of the islands studied, arranged alphabetically by island name. Additional information and field observations are included in the Reference Report. Table 1 groups the islands by conditions of *A. planci* population. Figure 4, identifies the trust territory islands where there are definite *Acanthaster planci* infestations.

Table I. Summary of Results

Condition 1. Few *Acanthaster planci*; reefs healthy and undamaged:

Yap, Woleai, Mokil, Ifalik, Lamotrek, Kwajalein

Condition 2. Large populations of *A. planci* concentrated in one or more local shallow water reefs damage to reef slight; no extensive dead reef:

Palau Kapingimarangi(?), Arno, Pingelap(?)

Condition 3. Large populations of *A. planci* in all depths, damage to reef fresh and extensive; patches--of live reefs Interspersed with completely dead reef zones. This is a condition of short duration. Ponape may have recently passed from condition 3 to condition 4.

Condition 4. Large populations of *Acanthaster planci* arranged into one or more fronts, separated by; or-leaving-behind extensive, almost completely dead reefs.

Saipan, Guam, Ponape, Rota, Truk

Condition 5. Entire. island with primarily dead reefs.

Tinian, Ant, Kuop

Condition 6. *A. planci* population expansion failed to pass Condition 2 and dispersed following localized coral kill (hypothetical answer to conditions reported in field, requires confirmation after a year or more of development):

Kapingimarangi(?), Pingelap(?), Nukuoro

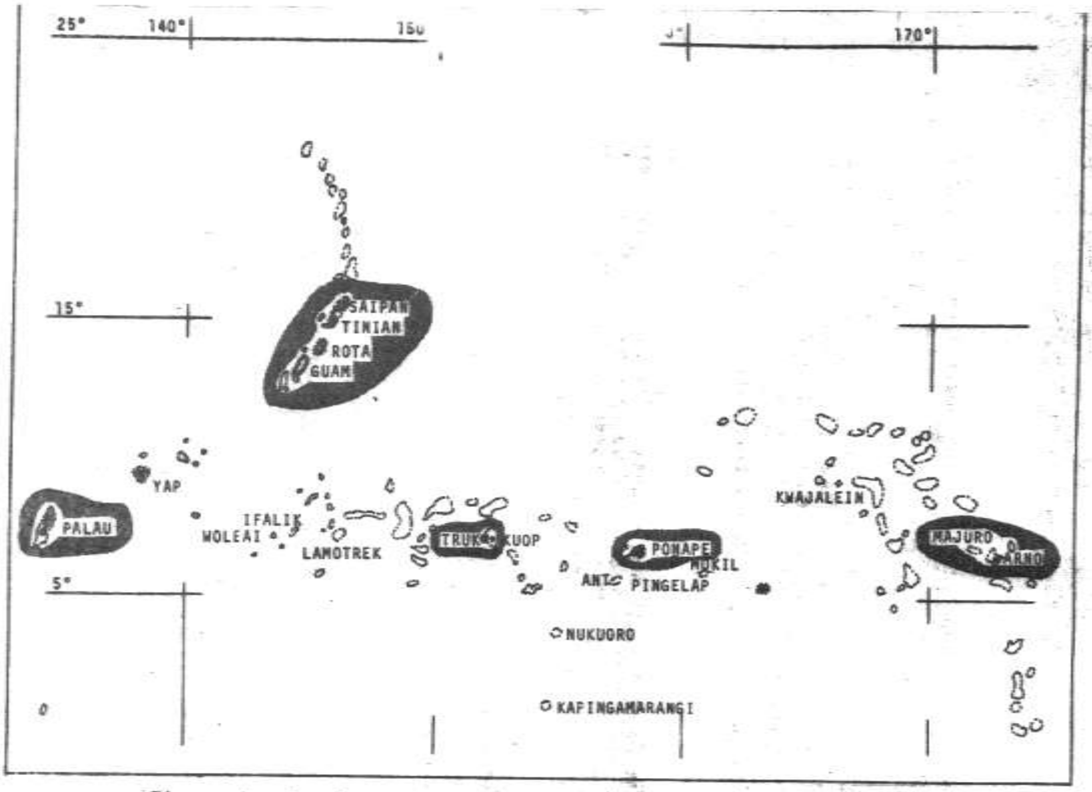

Figure 4. *A. planci* Infestations on Trust Territory Islands.

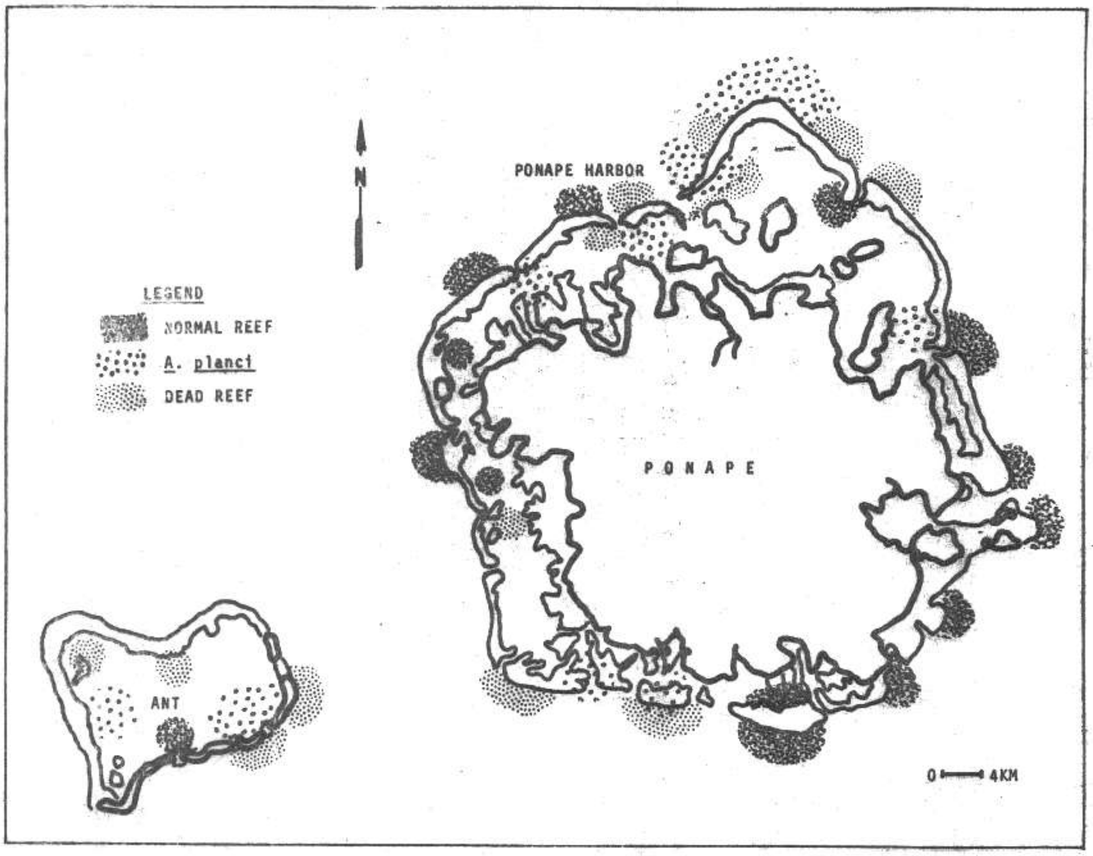

Figure 5. Ant and Ponape Survey.

3.1 ANT

a. Area Surveyed -- Spot checks around the inner portion of the barrier reef and on the eastern portion of the outer reef, as indicated in Figure 5.

b. Personnel -- K, Read, team leader; G. Anderson, associate scientist; A. Johnson; J., Johnson.

c. Dates -- Juiy 26 to July 27, 1969

d**. Populations of A. planci** -- There were two populations, a small one on the inner portion of the western lagoon reef and a larger one on the lagoon side of the passage. The atoll of Ant has been infested for some time, probably three or four years, and much of the coral has been killed. With the exception of a single patch reef on the southern portion of the atoll, the examined areas contained primarily dead coral probably killed by *Acanthaster planci*.

e. Comments -- Ant is a privately owned atoll and its owner is a strict conservationist. He does not allow fishing within the lagoon. Tritons have not been collected. Explosives are not: used. The period of conservation has been in effect for several years, and may have been established prior to the war. Fish were abundant and unafraid of divers.

3.2 GUAM

a. Area Surveyed -- The entire coast of Guam, as shown in FiguraA ;

b. Personnel -- R. Chesher; all team members made orientation dives on Guam as did A. H. Banner, K. Chave, G. Losey, J. Randall, J. Branham and H. Snider, all of the University of Hawaii.

c. Dates -- Nov. 1968 to Aug. 25, 1969.

d. Populations of *A. planci* -- The distribution of populations and migrations of *A. planci* on Guam over a 2-1/2 year period are documented by Chesher (Science, 1969).

e. Comments -- At the time of the orientation dives, control efforts had removed about 12,000 specimens from the two major *Acanthaster planci* populations. High seas that occurred during the orientation periods for some of the later teams caused the remaining specimens to migrate into deeper water along the northern front and to hide under coral heads in the southern front. These rough sea conditions also made observation difficult. In spite, of these difficulties, only one team failed to observe the northern front, and they corrected this deficiency when they returned through Guam and participated in a control dive.

The orientation dives were extremely useful because they enabled specialists of many fields of marine ecology to examine the same set of conditions and contribute to the analysis of the situation. In addition, T. Goreau and J. Randall had observed the Guam reefs previously and furnished information on the changes they observed after lapses of several months and a year, respectively.

Participants commented that the conditions were "far worse than I suspected" "depressing" "fantastic" or some variation of these. Everyone who observed the destruction felt the situation was clearly an important phenomenon representing an extreme unbalance and an unnatural ecological condition. Banner, who has considerable experience diving throughout the Pacific said he saw more specimens of *Acanthaster planci* in five minutes of observation on the Glass Breakwater along the entrance to Apra Harbor than in his entire career.

The observations by T. Goreau and J. Randall confirmed earlier reports and reconstructions of developments and movements of *Acanthaster planci* populations on Guam as reported by Chesher (1969).
T. Goreau, J. Randall, Graham and Sears examined algal growths on the corals of Guam and contributed the information that succession communities of algae seem to include coverage by a layer of diatoms, secondarily a layer

of filamentous brown and red algae, and occasionally a grey-green growth of calcareous algae.

Following the survey, Brauer conducted physiological experiments on the feeding habits of *Acanthaster planci* His report, which substantiates field reports of feeding preferences (see Section 4) is to be published separately.

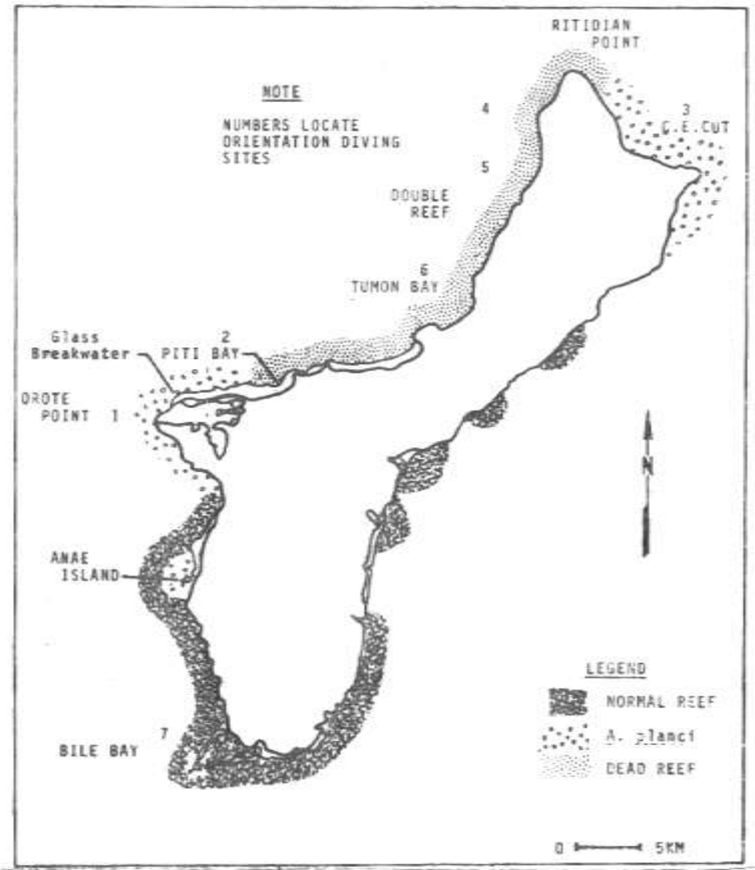

Figure 6. Guam Survey. Area surveyed indicated by numbers.

3.3 IFALIK

a. Area Surveyed -- The entire atoll, inside and out, from 1 to 20 meters, with spot checks to 40 meters; total of nine stations and tows, as indicated in Figure 7.

b. Personnel -- L. McCloskey, team leader; A. Antonius, associate scientist; J. Larson; A.

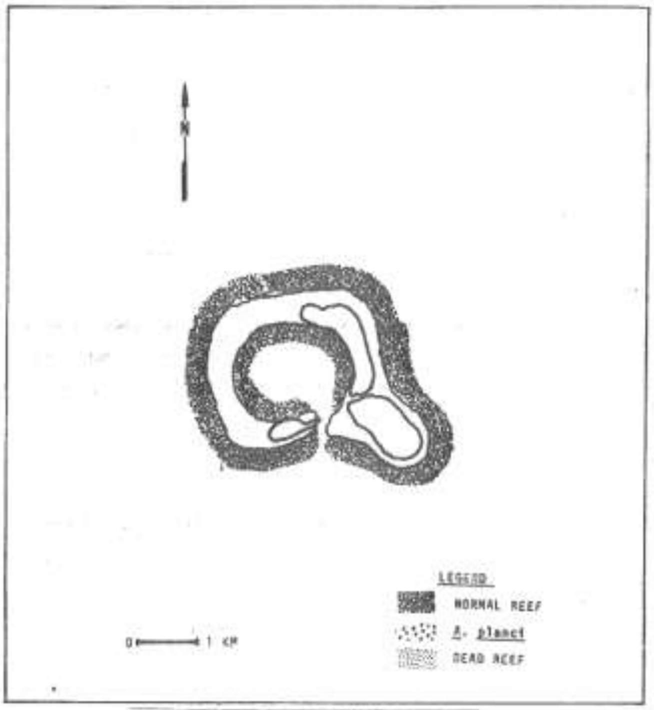

Figure 7. Ifalik Survey.

Wolfson.

c.. Dates -- July 17 to July 21, 1969,

d**. Populations.of *A. planci*** -- The team saw a total of three animals during the Ifalik survey. These were widely separated, with one animal inside the lagoon; one in the pass and one on the outer barrier. They were feeding on coral. The reefs were alive and healthy.

e. Comments -- No,blasting or dredging activities occur on Ifalik. Insecticides are not used there. Tritons have high value as trade items the local divers actively seek them. They do not find many, however, only five or six collected in a years time. The survey team saw none.

3.4 KAPINGAMARANGI

a. Area Surveyed -- The passage, the inner edge of the western portion of the lagoon, some patch reefs, and portions of the outer barrier reef, as shown in Figure 8.

b. Personnel -- B. Wilson, team leader; K. DaVico; R. Ibara; J. Harding.

c. Dates -- July 18 to July 24, 1969.

d. Populations of *A. planci* -- There was a single large concentration of *Acanthaster planci* along the southwest, inner lagoon reef in depths of 1 to 3 meters and a smaller population in deeper water (about 20 meters) on the southwest portion of the outer barrier reef. The animals were large and feeding on coral, but the damage to the reef was not too severe. The estimated size of the present population inside the reef was about 100 animals per kilometer and is far higher than would be anticipated in a balanced condition.

B. Wilson believed that this was either a seed population or the residual of a population explosion that "fizzled out". It could be either, but it is doubtful that the present reef can withstand the feeding pressure of such a large population.

Figure 8. Kapingamarangi Survey.

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e. Comments -- Local divers collect tritons as trade items but the gastropods are not common. They usually occur with the *Acanthaster planci* population. The islanders reported that no abnormal activities, such as dynamiting, or changes in the environment had occurred there in the past few years.

3.5 KUOP

a**. Area Surveyed** -- The entire island, except for portions of the outer barrier reef, as indicated on the map of Truk (see Figure 17).

b. Personnel -- Both Truk teams (see Paragraph 3.15) surveyed Kuop.

e. Dates -- Jones team: July 12 and 13; Woodley team: July 30, 1969.

d. Populations of *A. planci* -- There was only one specimen of *Acanthaster planci* but the entire atoll appeared to have been substantially killed off some time in the past. Most of the inner and outer portions of the northeastern half of the atoll had 80 to 90 percent dead coral, with slight to, good regrowth on the eastern, inside portion of the reef. The southwestern half of the atoll had a larger population of corals but their small size and the predominance of *Millepora* and soft corals indicated that this portion had also been killed previously. There were living coral heads that, may be 8 to 10 years old along the inner portion of the southwestern reef in a few areas.

e. Comments -- Chief Petrus of Moen stated that *Acanthaster planci* infested Kuop immediately following World War II. At that time he said specimens were extremely common on the reefs of Kuop. Both teams believed that Kuop had, indeed, been stripped of its living coral many years ago and that the corals were regrowing in a few portions of the reef. Following the American bombing raids during the war, the isolated Japanese personnel imposed a heavy fishery using dynamite to support their needs.The Japanese also instigated the major interest in collecting tritons, collecting them for food as well as ornamentation. Tritons are still collected today, but neither survey team saw any.

The channel between Kuop and Truk is at least 500 meters deep and two kilometers wide. It is unlikely, therefore, that adult *Acanthaster planci* migrated across this gap. One must assume that if *Acanthaster planci* caused the coral mortality at Kuop the species could not maintain a permanent population after eliminating its rood supply. The corals-should recover, given sufficient time and providing there is no reinfestation.

3.6. LAMOTREK

a. Area Surveyed -- All of the outer barrier reef, a large portion of the inner edge of the barrier reef and several patch reefs, as indicated in Figure 9.

b. Personnel -- R. Brauer, team leader; D. Lees, associate scientist; J. Sears; M. Jordan.

c. Dates -- Aug. 6 to Aug. 10, 1969.

d. Populations of *A. planci* -- There was one *Acanthaster planci* the coral was lush, healthy and normal.

e. Comments -- The local people had never seen *Acanthaster planci* before .and showed great interest in the single specimen captured. White patches of coral, but no additional specimens of *Acanthaster planci*, were seen on several tows. *Culcita* was common and could have caused the white patches. Blasting and dredging nave not occurred on Lamotrek.. The local people dive and collect tritons as items for trade. They find few, however, and produced none when they tried to find one that had been caught and cleaned to show to the team.

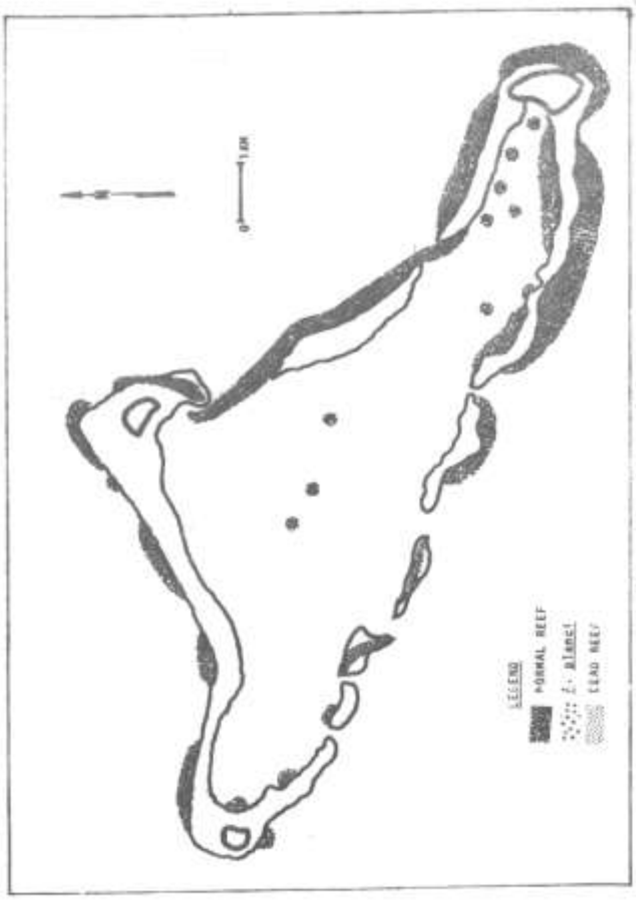

Figure 9. Lamotrek Survey.

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3.7 MOKIL

a. Area Surveyed -- The entire western and southern reefs,, as indicated in Figure 10.

b. Personnel -- K. Read, team leader; G. Anderson, associate scientist; A. Johnson; J. Johnson.

c. Dates -- July 18, 1469.

d. Populations of *A. planci* -- Although not excessively numerous, there were *Acanthaster planci* along the entire western coast of Mokil. Station 4 yielded only one specimen per 20-minute tow, but a SCUBA dive in the same area showed eight specimens along two vertical transects. The animals were feeding on coral, and frequent white patches were evident. The coral in shallow water was poorly developed, but in depths over 10 meters it was lush and alive even though specimens of *Acanthaster planci* were present.

e. Comments -- The teams stay on Mokil was too brief to establish much about the history of the reefs or of the fishing on Mokil.

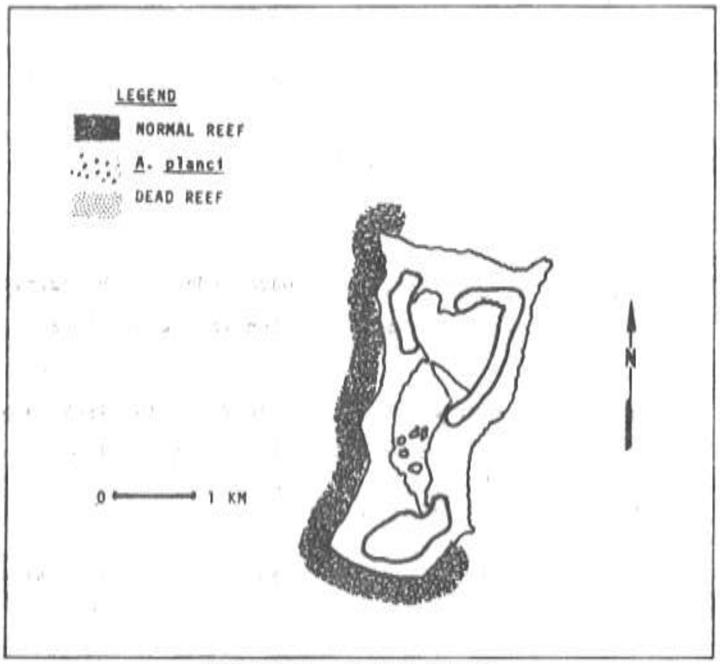

Figure 10. Mokil Survey.

3.8 NUKUORO

a. Area Sureyed -- The entire outer edge of the barrier reef, except for a small portion in the southwestern sector, most of the inner edge of the barrier reef; and isolated Patch reefs as indicated in Figure 11.

b. Personnel -- B. Wilson, team leader; K: DaVico; R. Ibara; J. Harding.

c. Dates -- July 21 to Aug. 6, 1969.

d. Populations of A. planci -- There was a fairly large population of *A. planci* on the outer edge of the barrier reef along the southern margin of the atoll, in depths from 3 to 50 meters. Most of the coral was dead near the pass and along the barrier reef east of the pass. The coral outside the passage was poorly developed, with small, scattered heads that apparently represent regenerating corals.

B. Wilson suggested that the situation probably reflected a small population explosion in the vicinity of the passage five or six years ago followed by a lack of recruitment and by adequate dispersal or mortality of the original population to prevent the animals from maintaining the infestation. The small size of the, existing coral heads seemed to represent a constant cropping by the *Acanthaster planci* population that still resides there.

e. Comments -- The channel was blasted to improve its navigability, five or six years ago. Tritons are fished from the area of the passage on a limited basis. The way of life on Nukuoro has not changed obviously during the past five to ten years;.

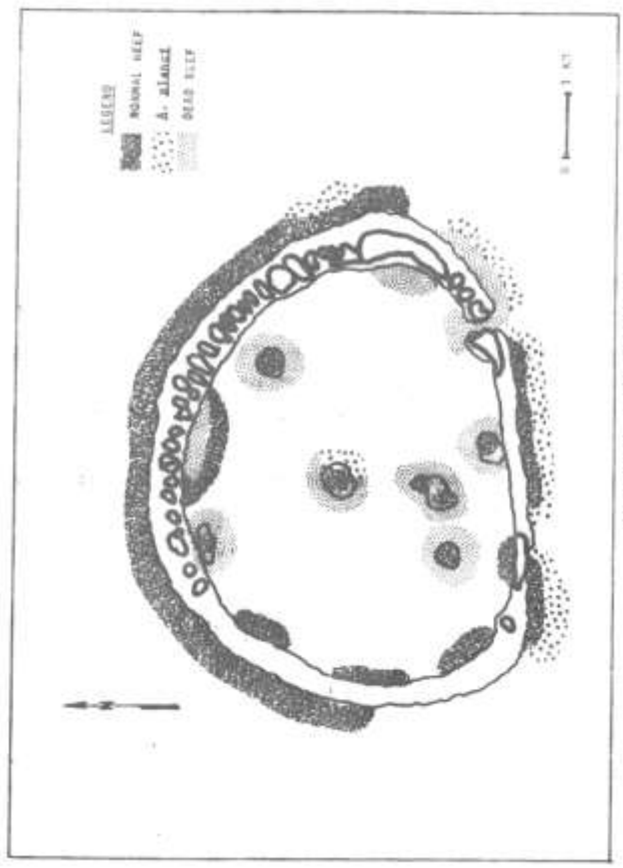

Figure 11. Nukuoro Survey.

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3.9 PALAU

a. Area Surveyed -- Koror, Aulon islands, Seventy Isles Preserve, Rock Islands, Northern Babelthuap and portions of the barrier reef and patch reefs, as indicated in Figure 12.

b. Personnel -- R. Chesher, team leader; J. Bell.

c. Dates -- April 3 to April 12, 1969.

d- Populations of *A. planci* -- There were large populations of *Acanthaster planci* at Iwayama Pass, the Seventy Islands off Konrei (northern Babelthuap), and along the reef fringing the western coast of Koror. These populations concentrated in distinct herds that clearly were damaging the reefs: For example, in Iwayama Pass more than 500 animals concentrated near the small island in the center of the pass. Dead coral outside the pass indicated that the animals were moving toward Iwayama Bay.

The size and structure of these populations indicated that they could be seed populations similar to those found on Guam prior to the major population. expansion. Damage to valuable coral areas (recreational and scientific study areas,) was already in progress.

e. Comments -- The-local divers collect tritons but seldom find any. Explosives have been used for fishing but supposedly not for some years. The large population in the Seventy Isles formed exactly where movie makers had recently filmed and their barges and boats had damaged the reef.

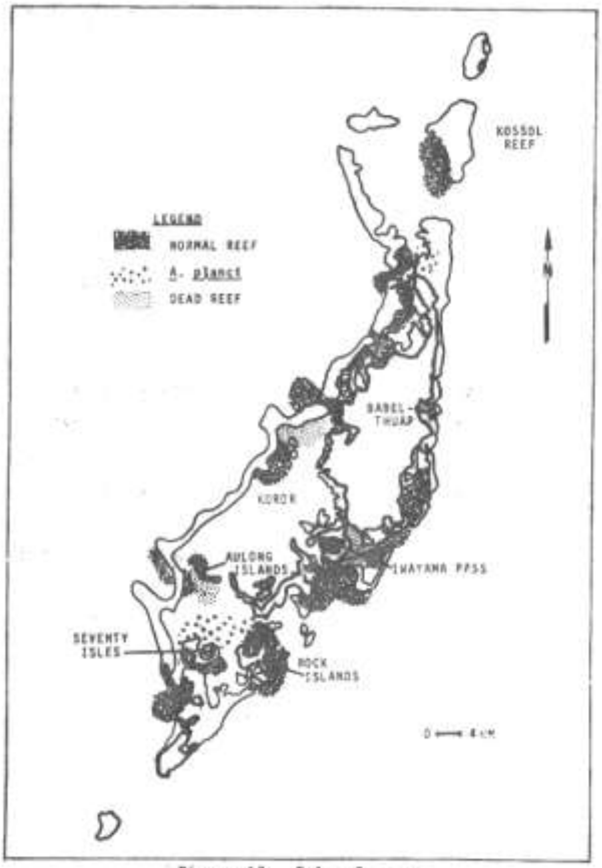

Figure 12. Palau Survey.

3.10 PINGELAP

a. Area Surveyed -- The entire island and lagoon, as indicated in Figure 13; 1 to 15 meters deep, with spot check to 40 meters.

b. Personnel -- K. Read, team leader; u. Anderson, associate scientist; A. Johnson; J. Johnson.

c. Dates -- July 10 to July 16, 1969.

d. Populations of *A. planci* -- There were relatively large numbers of *Acanthaster planci* along the southern and western coasts of.Pingelap, in depths greater than 3 meters. Numerous freshly killed corals were evident, and much algae-covered coral was present. Coral elsewhere appeared normal.

e. Comments -- The existing *Acanthaster planci* population evidently was large enough to kill the coral faster than it could regenerate. If the reports from the islanders indicating the infestation began about two years ago are true, the population is not expanding at a rate comparable to that at Guam. Chesher believed that Pingelap had a seed population that did not receive sufficient recruitment to continue rapid expansion and that if no such recruitment occurred, mortality of *Acanthaster planci* and individual movements would establish a more balanced relationship. The local people collect tritons as trade items but do not actively fish for them. The team discovered no evidence of any pronounced disturbances to the reefs on Pingelap in the past decade.

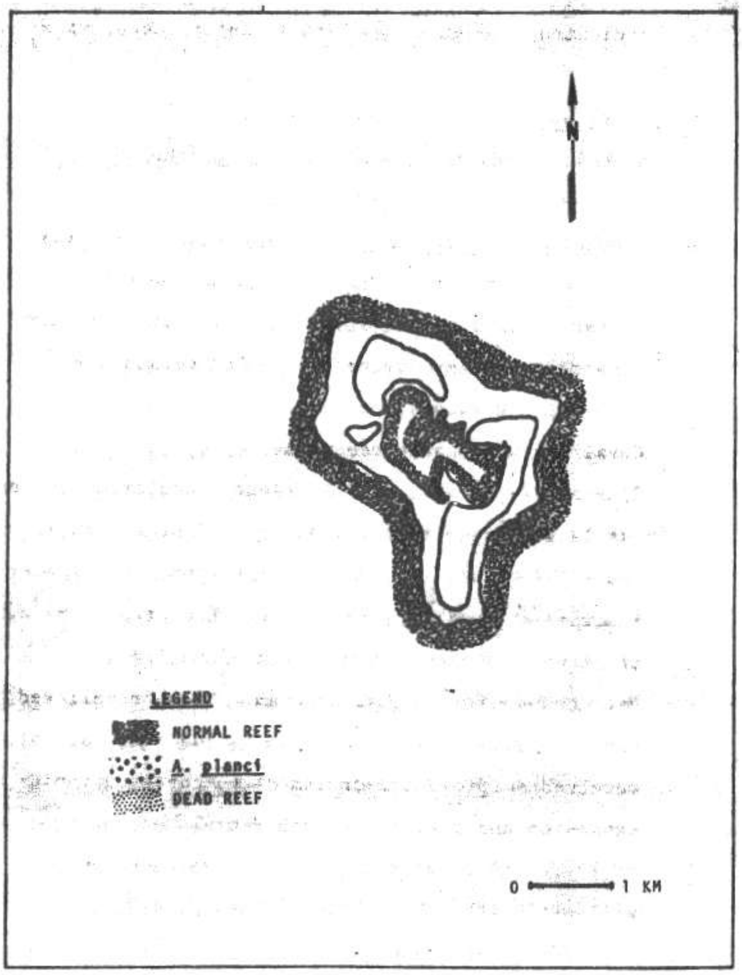

Figure 13. Pingelap Survey.

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3.11 PONAPE

a. Area Surveyed -- Regularly spaced spot checks along the barrier and patch reefs of Ponape, as indicated in Figure 5. Poor visibility and the large area to be covered impeded this survey.

b. Personnel -- K. Read, team leader; G. Anderson, associate scientist; A. Johnson; J. Johnson.

c. Dates -- July 6 to July 7, July 22 to July 25, July 29 to Aug. 3, 1969.

d. Populations of *A. planci* -- There were three heavily infested areas. One population was on the southern reefs of Ponape on the inner portion of the barrier reef, another was on the inner portion of the barrier reef on the northeast coast of the island and the third and possibly largest was on both inner and outer portions of the northern barrier reef. Lack of time prevented delimiting the first two populations. The portion of the population of the seaward terrace of the northern barrier reef formed a migratory front with specimens "too numerous to count" in a narrow and parallel to the reef in water 12 to 15 meters deep. Freshly eaten coral was abundant in this zone, with older dead coral and live coral adjacent to the front. There were dead reef corals on both ends of the front but most extensively on the western end leading into Ponape Harbor. The patch reefs of the harbor were already dead or being killed by *Acanthaster planci.*

e. Comments -- The infestation in Ponape appeared to be less than three years old and probably began in the vicinity of Ponape Harbor then expanded outward, with the majority of animals moving onto the outer barrier reef. it is possible that the population at Station 45 was part of that same population expansion. The infestation in the south was-clearly of separate origin, and the team learned too little about its extent to substantiate any statements other than it is there and is probably destroying significant amounts of coral. Micronesian sources indicated that Ponape may have been infested just after the war but that the infestation did not expand to do extensive damage; a regrowth has replaced what coral was killed. The present infestation (in the north) has all the characteristics of the severe infestation in Guam, and there is no reason to expect it will not continue to destroy reefs.

Ponape islanders have collected tritons, but the gastropods are not common and are not actively sought. Few tourists visit Ponape and the gastropods are not removed from the reef in large numbers. Ponape Harbor. has been the site of dredging and blasting for several years during the construction of an airstrip (still under construction).

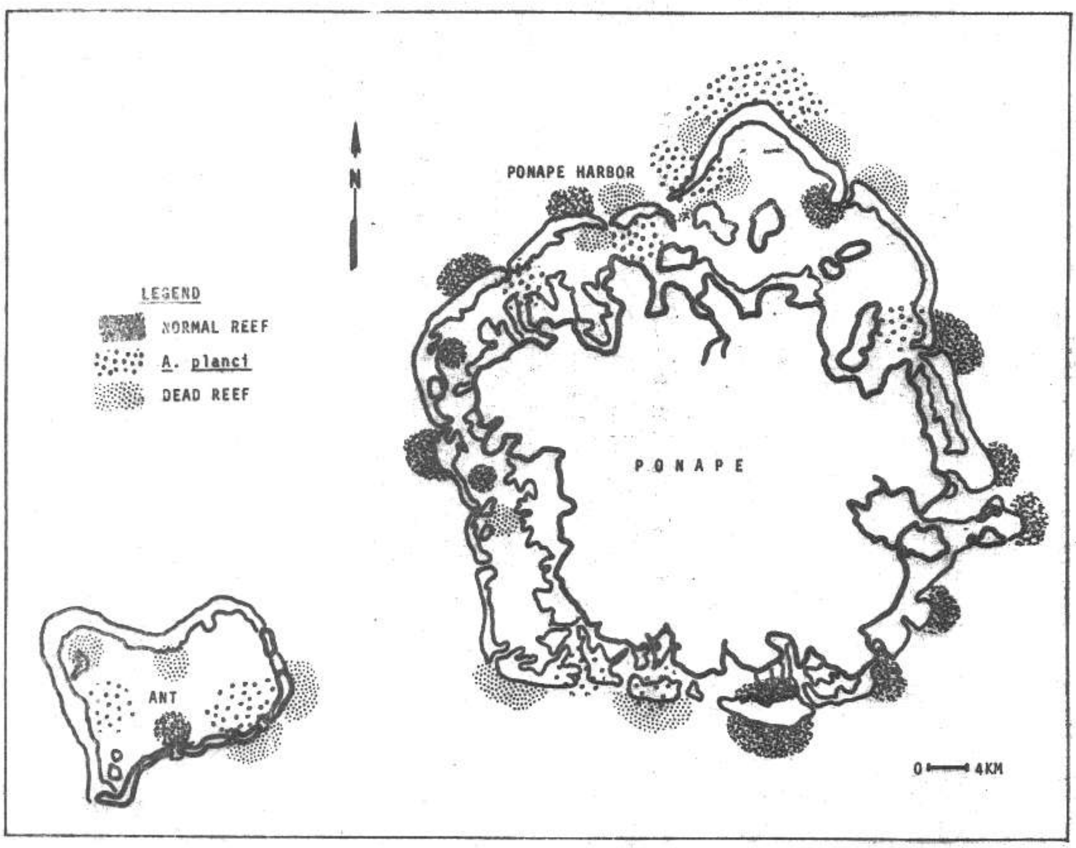

Figure 5. Ant and Ponape Survey.

3.12 ROTA

a. Area Surveyed -- The fringing reefs along the southern coast of Rota and along much of the northwestern coast, as indicated in Figure l4.

b. Personnel -- J. Reardon, team leader; R. Paull.

c. Dates -- July 16, to July 22, 1969.

d. Populations of *A. planci* -- There were two large populations of *Acanthaster planci* separated by an expanse of dead coral. The southern population was smaller than the northern and tended to exist as large, scattered herds located in the lush, coral live growth near. Poniya Point. The northern population was in an area of sparse coral growth and formed a well-defined front parallel to the share in depths of 10 to 20 meters. The coral was 80 to 90 percent dead between the two populations, except in water shallower than 4 meters, where numerous corals survived.

The oldest kill was in the vicinity of the village (Rota), indicating that the infestation began near the village within the last three years and afterward migrated in two major fronts moving away from each other. The animals grazed over most of the coral along the western, southern, and northeastern coastlines in depths greater than 3 meters. Probably the existing populations began as a single population in Sosanjaya Bay or possibly Sosanlagh Bay.

e. Comments -- The local people do not actively collect tritons. There have been both blasting and dredging for some time in both bays during the construction of dock facilities. Reportedly, large amounts of DDT are used for fly control, and Reardon speculated this may have some relation to the existing infestation.

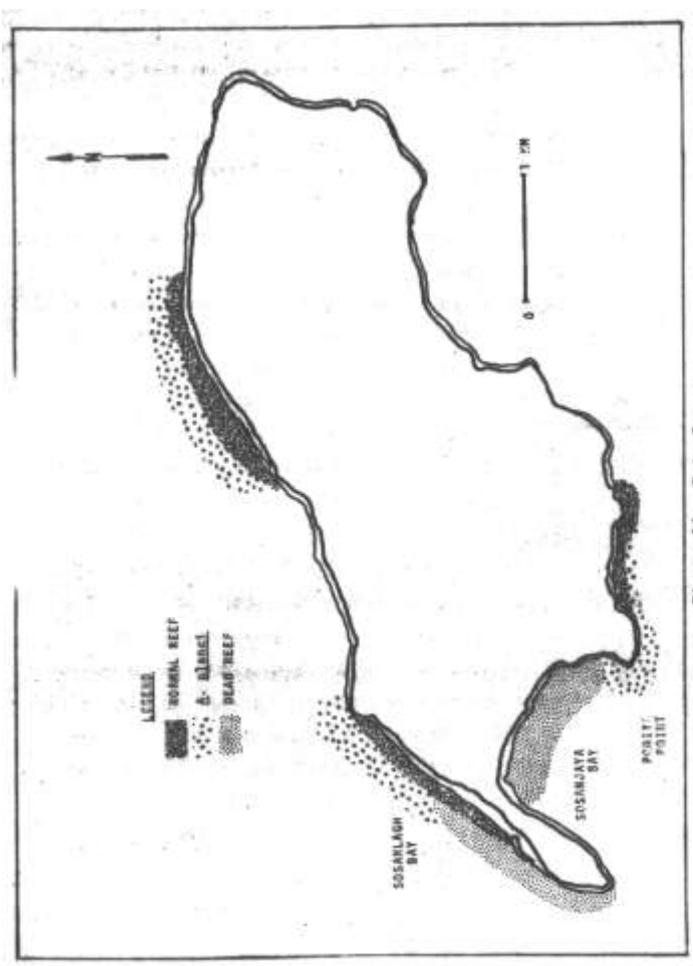

Figure 14. Rota Survey.

3.13 SAIPAN

a. Area Surveyed -- The entire coastline of Saipan, as indicated in Figure 15.

b. Personnel -- T. Goreau, team leader; J. Lang, E. Graham, P. Goreau.

c. Dates -- July 22 to Aug. 6, 1969.

d. Populations of *A. planci* -- There were three large populations of *Acanthaster planci* on Saipan. The smallest was on the northeast tip of the island, and the two largest were on the western side, one near the boat harbor, the other southwest of the island. The coral reef had sustained major damage between the two large fronts and the team gained the impression the two fronts were moving away from each other similar to the migratory movements on Guam. All of the lush coral growth on the western side of Saipan was either dead, or *Acanthaster planci* was killing it.

It appeared that the infestation began in lush coral growth on the western portion of the fringing reef. The infestation is probably not more than three years old. There was no evidence that a similar infestation happened in the past and T. Goreau estimated that some of the lush, framework corals that have died probably represent 1,000 years of continuous growth with some of the larger individual coral heads more than 200 years old.

e: Comments -- After the initiation of control measures in Guam, local divers discovered *Acanthaster planci* at Saipan and the Saipan legislature set a bounty of 15 cents per starfish. In less than a week, islanders collected 4,000 animals from a single area and exhausted the government fund. Subsequent action awaits the publication of the results of the present survey. There is no active fishery for tritons, but a few have been collected from the Saipan reefs. Explosives are reportedly not used for fishing, and the harbor has not been dredged for some time.

Figure 15. Saipan Survey.

3.14 TINIAN

a. Area Surveyed -- All reefs of the leeward (western) side and most of the reef on the eastern side as indicated in Figure 16.

b. Personnel -- R. Brauer, team leader; D. Lees, associate scientist; J. Sears; M. Jordan.

c. Dates -- July 2; to Aug. 2, 1969.

d**. Populations of *A. planci* --** There were *A. planci* in above normal concentrations at almost all stations. The largest herd was -on. the northern tip of the island, where the animals consolidated into a front. The coral was dead almost everywhere, apparently having died some years in the past. Between 5 and 10 percent of the coral survived or had regenerated. There was good coral growth in shallow water in several localities, and on the windward side live coral extended to depths of 10 meters in isolated spots. *Acanthaster planci* was present bordering live coral areas.

It is likely that *Acanthaster planci* infested Tinian four or five years ago and that the animals have grazed the reefs completely around the island, leaving some live corals in shallow water presumably because wave action limits the upper feeding zone. Heavy surge on the windward side could account for the deeper upper limit of feeding on some reefs.

e. Comments -- The local people indicated that excessive numbers of *Acanthaster planci* appeared in 1964 or 1965. Considering the extent of damage, such a time span appears realistic. There has been some blasting and dredging in Tinian, and the islanders may use explosives for fishing. No one collects tritons on Tinian, they are not common, the islanders do not often dive, and few tourists or shell collectors go to Tinian.

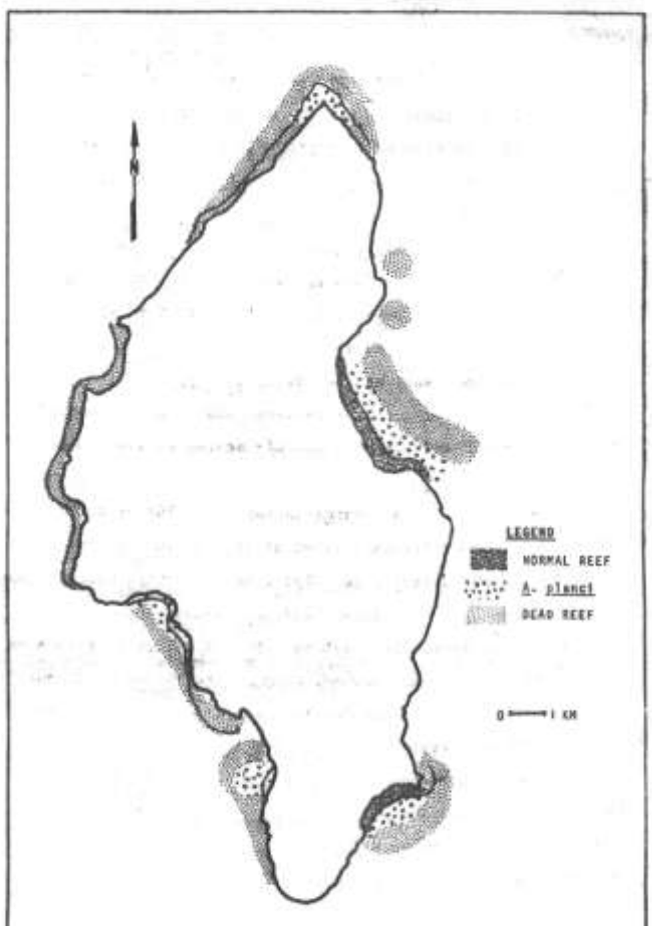

Figure 16. Tinian Survey.

3.15 TRUK

a. Area Surveyed -- Truk has the largest lagoon in Micronesia., A chain of "high islands" divides the large, triangular-shaped barrier reef into northern and southern lagoons, Team 1 surveyed the northern lagoon and team 2 the southern. Northern and southern lagoons, including almost the entire barrier reef and many of the fringing reefs on the high islands and patch reefs, as indicated in Figure,17.

b. Personnel -- Team 1; R. Jones, team leader, F, McAllister, associate scientist, R. Randall, M. Struck. Team2; J. Woodley, team leader, Y. Neumann, associate scientist, J. Jackson, J. Wells, D. Barnes, A. Takesy.

c. Dates -- Team 1: July 6 to July 22, 1969; Team 2: July 27-to Aug, 11, 1969.

d. Populations of *A. planci* -- There were three large populations of *Acanthaster planci* and there was considerable damage to the reefs. The largest population was along the northern, outer edge of the barrier reef in a distinct, front, similar to fronts at Guam, Saipan, Tinian, Rota and Ponape. The front was on the seaward submerged terrace between Pis and Falalu Islands with the specimens oriented in a narrow band parallel to the reef in depths of 3 to 7 meters. Population density within this front was about one specimen per 4.6 square meters. (Figure 17 indicates the zone of infestation.)

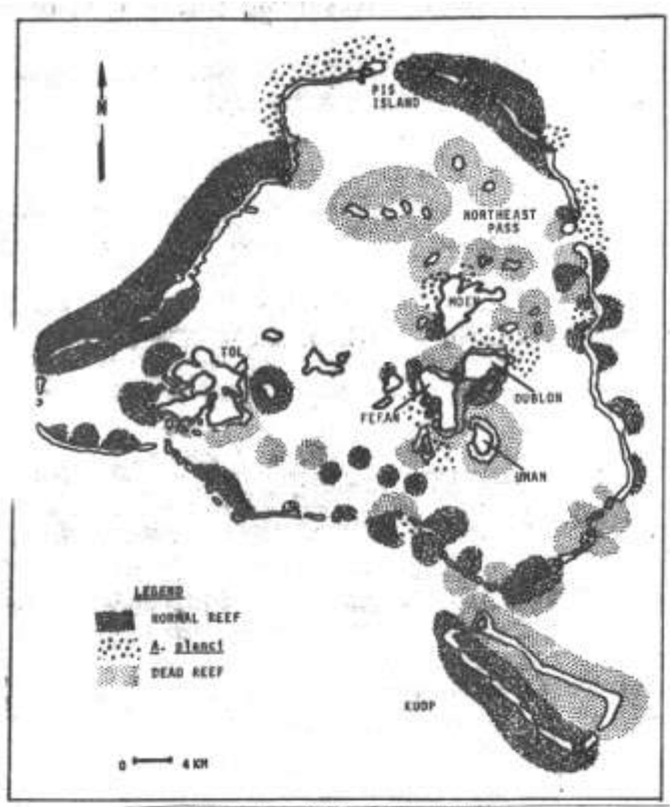

Figure 17. Truk and Kuop Survey.

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The animals were actively feeding on coral, and estimating from the amount of freshly killed coral in the northern front, they will graze large sections of the reef clean in the next year. There was a second population on the seaward side of Basis and Nor Islands, near Northeast Pass, and a third on the northern coast of Dublon Island. The fringing and patch reefs of the lagoon have suffered a heavy coral mortality and, in many places, above normal populations of *Acanthaster planci* still exist. Portions of the fringing reefs of the high islands and much of the barrier reef were still intact, although *Acanthaster planci* often infested adjacent coral areas, and there is no reason to believe that they will not attack the surviving coral in the future.

e. Comments -- it was evident from the proportion of freshly killed coral to alive, undamaged coral, that the large *Acanthaster planci* population on the northern barrier had not been in that locale very long. As the animals were full-sized adults, they probably had migrated onto that reef within the past year. This case would conform with observations made in Guam and Saipan where fronts formed during active migration. Patch reefs and fringing reefs of the northern lagoon have suffered coral kills of 80 to 90 percent, but relatively few *Acanthaster planci* remain on the dead reefs to account for the damage. It is probable, therefore, that the starfish migrated out of the lagoon and onto the northern barrier reef.

It is not clear whether the eastern and southeastern populations are part of the population that destroyed the reefs of the northern lagoon. Possibly the Dublon population came from another location (perhaps from Fefan). The population near Northeast Pass probably arose in the northern lagoon. According to work by Team 1, the oldest dead reef areas were along the southeastern portion of the barrier reef. Interviews with Chief Petrus of Moen and other Trukese indicated that some of these areas may have been killed by *Acanthaster planci* following World. War II. Some portions of these reefs showed signs of regeneration or regrowth, but the corals were small and the percentage of coral cover low. According to local reports, the high islands were attacked five or six years ago. Observations made by Takesy, who noted large concentrations of *Acanthaster planci* on the southeast coast of Moen in 1963, substantiate the reports. Team 2, with Takesy, resurveyed the area Takesy surveyed in 1963 and found that only a small percentage of corals had survived the attack. Regrowth had been slight.

Team 2 observed that there often were patches of live coral along reefs that seemed otherwise to have been severely attacked by *Acanthaster planci*. Trukese do collect tritons. The use of explosives for fishing is very common and during the survey, the teams frequently saw patches of coral that had been blasted. Truk was also-severely damaged during World War II. Also during that time, Japanese troops fished the reefs of Truk intensively, using explosives to kill the fish.

3.16 WOLEAI

a. Area Surveyed -- Inside and outside of the reef along the northern portion of the atoll, spot checks elsewhere, as indicated on Figure 18. Depth range was from 2 to 20 meters.

b. Personnel -- L, McCloskey, team leader; A. Antonius, associate scientist; J. Larsen; A. Wolfson.

c. Dates -- July 25 to Aug 1, 1969.

d. Populations of *A. planci* -- One population, on the inside, of the lagoon, consisted of about 20 individuals on a small portion of the reef. There was some disagreement between team members as to the amount of damage to the reef in this area, but they evidently found no other animals on surrounding reefs; the damage was not excessive. Conditions seemed to be normal.

e. Comments -- This team felt uneasy about the extent of dead coral they observed and about white patches of coral that appeared in some stations without evidence of *Acanthaster planci*. They saw numerous specimens of *Culcita sp*. which could account for many of the observed white patches. The 20 specimens of *Acanthaster planci* observed in a single herd could possibly have been a breeding aggregation that later dispersed. The specimens were large and probably several years old. It would he worthwhile to re-examine this spot in one or two years to gain more insight into the dynamics of the population.

There has been no blasting or dredging there. Tritons are actively collected. Few are found, however, and the survey team saw none.

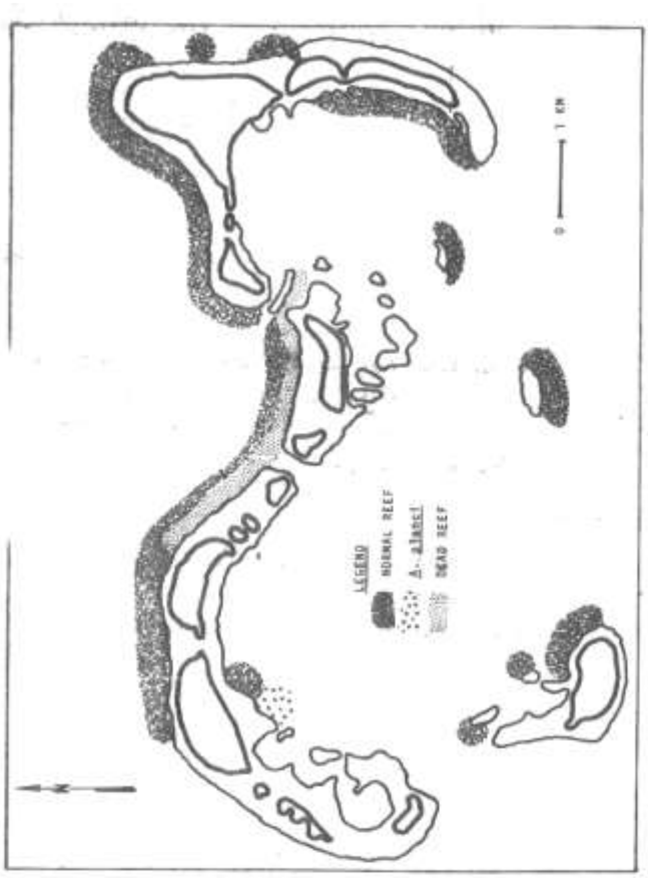

Figure 18. Woleai Survey.

66

3.17 YAP

a. Area Surveyed -- The entire barrier reef and many of the lagoon reefs from 1 to 10 meters deep, with spot checks in deeper water using SCUBA; 66 tows and stations; as indicated in Figure 19.

b. Personnel -- P. Kier, team leader; D. Devaney, associate scientist T. Phelan; R. Kiwala.

c. Dates -- July 14 to July 24, 1969.

d. Populations of *A. planci* -- There were no large populations. The team located 20 specimens during the entire survey. The few specimens seen were herding together at widely separated places on the coral reef. Even under this low population pressure, the animals were feeding on coral.

The largest population consisted of 11 specimens in lush coral growth outside the barrier reef along the southeast coast. They were large and there was relatively little damage to the reef, indicating the coral predation was balanced with reef production in that area.

e. Comments -- The Yapese knew the locations of the small populations of *Acanthaster planci* on Yap, indicating that they could provide some information on past population expansion. The islanders reported no previous population expansion of *Acanthaster planci*, and they thought there were more *Acanthaster planci* present currently than before.

Yapese collect tritons when they see the gastropods but do not actively fish them. The survey team saw none, There has not been prior blasting or dredging activities in Yap, but these are currently being initiated.

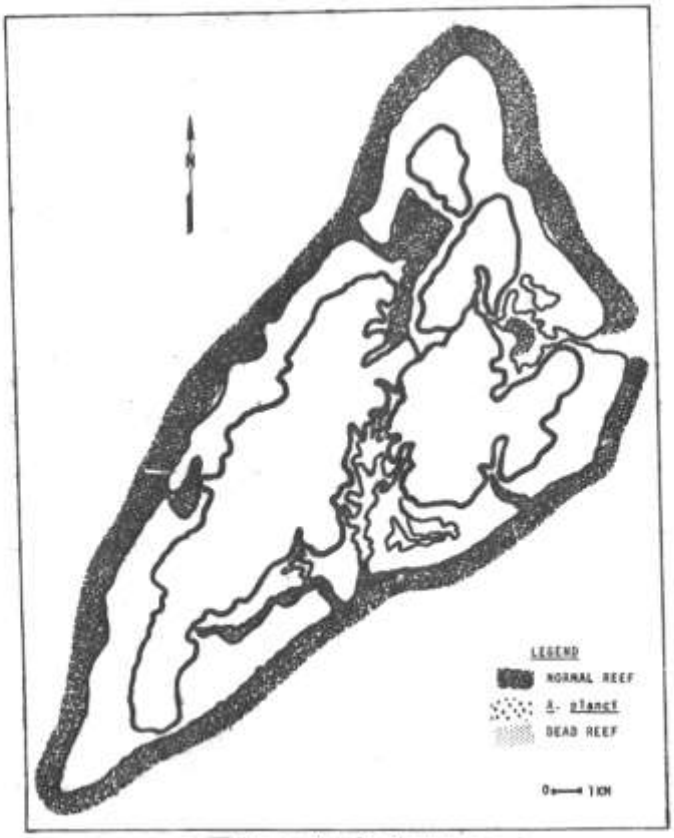

Figure 19. Yap Survey.

4. SURVEY REPORTS FROM OTHER AGENCIES

4.1 SURVEYS WITH STANDARDIZED TECHNIQUES

4.1.1 Australia.

R. Endean, University of Queensland, directed an Australian survey. In an unpublished report (included, in. the Reference Report) Endean presented the results of his two year study of the distribution of *Acanthaster planci* on the Great Barrier Reef and of certain aspects of its biology. His research provided much valuable information on the biology of *Acanthaster planci* and identified both the urgency and the seriousness of the Acanthaster infestation on the Great Barrier Reef. The salient features of his report were:

a) Massive destruction of living corals has occurred on most of the patch and fringing reefs of the Great Barrier Reef, along a 200-kilometer section of the Great Barrier Reef bounded by Cooktown and Townsville.
b) On infested reefs over 90 percent of the corals have been killed, and coral predation is expanding at an alarming rate. There were indications that *Acanthaster planci* was spreading to reefs
c) South of Townsville in massive herds that migrate from patch reef to patch reef.
d) The infestation apparently began off Cairns, Innisfail, Townsvifle, Port Douglas and Cooktown in the years 1959- to 1965.

e) There has been negligible regeneration of corals on reefs destroyed eight to ten years ago. Soft corals have dominated many of these reefs and may prolong coral regrowth.
f) Recolonization and regrowth by the corals may be hampered by reinfestation by *A. planci*.
g) The major cause for the plague in Australia seems to be release from the predation pressure by the triton shell, *Charonia tritonis* and experiments indicated that this gastropod does feed on both juvenile and adult *A. planci* (*C. tritonis* has been subjected to increasing fisheries pressure from tourists and professional shell collectors.) ,
h) Populations of *A. planci* are expanding at an increasing rate. Recruitment is high because of increased survival of larvae during metamorphosis. And when *A. planci* feeds, it increases the area suitable for survival of the settling larvae. Thus, the more adult starfish that are feeding, the better the chances for survival of the settling larvae.
i) Recommended actions include a program of containment by killing starfish by hand; establishment of a research program to study both *A. planci* and aquiculture of *Charonia tritonis*; importing live *C. tritonis*; banning collection of C. tritonis; and restricting shell collectors.
j) Other Pacific regions that are reportedly infested include New Britain, Samoa, New Caledonia, Fiji and Rabaul.

Dr. Endean and G. Harrison, Director of Fisheries for the Government of Queensland, Australia, went to Guam as consultants in the Westinghouse survey. They indicated their willingness to support United States research projects concerning *A. planci*. and suggested establishing an exchange program for both personnel and information to help combat the problem. It is their opinion that controls are necessary and that these should take the form recommended to the Government of Queensland in Endean's report summarized above.

4.1.2 Other Pacific Islands.

Teams under the direction of A. Banner (University of Hawaii) surveyed Hawaiian islands, Midway, Johnston Island, Majuro, Kwajalein and Arno. Data from these reports are included in the Reference Report. The remainder of this section summarizes their findings.

4.1.2.1 Hawaii.

a. Area Surveyed -- Tows and spot checks along the leeward side and spot checks at Punaluu and Puna on the windward side.
b. Personnel -- J. Randall, team leader; T. Chess; H. Randall.
c. Dates -- Aug. 1 through Aug. 19, 1969.
d**. Populations of *A. planci* --** Summary from report: "A total of 17 stations were carried out for which the original field data sheets are enclosed. We encountered no alarming concentrations of *Acanthaster*. We found the greatest numbers off City of Refuge and off Napoopoo Each of us counted 8 in a swim of two hours (not swimming together, but usually within calling distance) south from the location of the-home now rented by Dr. Edmund S. Hobson at Napoopoo."

4.1.2.2 Other Hawaiian Islands

a. Area Surveyed -- Other islands surveyed by the University of Hawaii personnel included: Kauai, five typical areas (windward, southern and western coasts); Oahu, ten areas (two on windward coast, two on southern coast, five on western coast, and one on northern coast); Molokai, two inshore areas; Maui lee coast ten reef areas; and Leeward Hawaiian Islands of French Frigate Shoals.
b. Personnel -- J. Bailey, E. Preston, M. Rice, E. Reese, G. Losey, R. Warshauer and J. Maciolek.
c. Dates -- Aug. l to Sept. 6, 1969.
d. Populations of A. planci -- Summary from all reports: "On most Hawaiian reefs no Acanthaster were seen. In a few leeward areas of Oahu and Hawaii small populations were observed on the reefs which probably were at the normal population levels (one specimen off Waikiki, two specimens at

Nanakuli and eight at Kahe seen per three man-hours of search). However, on a small, semi-isolated coral knoll in 60 feet of water off Molokai a heavy concentration of the starfish was found, a possible seed population; this population is currently being further investigated."

4.1.2.3 Midway

a. Area Surveyed -- Inside the lagoon. No diving is permltted outside the barrier reef.

b. Personnel -- A: Pardini, team leader; members of the, Koral Kings of Midway, a SCUBA diving club.

c. Dates -- Compilation of information accumulated over a year of observations and dated September 7, 1969.

d. Population of *A. planci* -- There were *A. planci* in limited numbers inside the lagoon. The largest population contained ten specimens per twenty minutes of search. Coral damage was not severe and the lush coral was undamaged.

4.1.2.4 Majuro

a. Area Surveyed -- Most of the lagoon and ocean periphery; progression around the atoll was not continuous.

b. Personnel -- J. Branham, team leader; R. Snider; J. Christofferson; D. Mense.

c. Dates -- June and July, 1969.

d. Populations of *A. planci* -- There was a single large population near the windward pass on the lagoon side of the barrier reef. Branham reported, "Numerous patches of white were observed along the lagoon side of those reefs in two areas, each about 200 yards long. Closer examination revealed abundant *A. planci*, usually on the underside of table *Acropora*. Examination of 20 such white patches revealed 53 *A. planci*, or 2.6 per white patch. Two observers towing along the extent of one area counted 150 white patches or about 400 *A. planci* in the particular area."

e. Comments -- This team reported many large expanses of dead coral but reached no conclusions about the cause of death.

It is evident from the reported concentrations and amount of dead coral that the feeding rate of the starfish in the reported area greatly exceeds the rate of coral replacement. A large area of dead coral on the outside of the pass suggests that perhaps the observed herd has killed off a section of reef and is slowly moving from one locale to another. Additional information is being sought on this population.

4.1.2.5 Arno

a. Area Surveyed -- Leeward and lagoon reefs; discontinuous tow and spot checks.

b. Personnel -- J.Brauhsm, team leaded R. Snider; J. Christofferson; D. Mense.

c. Dates -- July 1969.

d. Population of *A. planci* -- There were two populations of *A. planci*. One was on the leeward lagoon slope of the windward barrier reef near Namoji Island. It was a localized concentration of feeding adults (about 100 seen in an unknown period of time). A second population was reported to have killed "about 104 square yards" of coral near Dodo Island the preceding year. The present survey found skeletons representing a lush growth of delicate corals and small heads of organ pipe coral. Only 12 large specimens of *A. planci* were found. Spot checks at Chiran Island and Tagelib Islands (adjoining Dodo Island) revealed more dead, but still standing, coral on the lagoon side. Dead, abundant coral skeletons covered a pinnacle in the lagoon behind the passage.

4.1.2.6 Johnston Island

a. Area Surveyed -- Along the north coast of Johnston Island and on the inner and outer portions of the northern barrier reef plus Donovans Reef.

b. Personnel -- J. Randall (University of Hawaii), team leader; W. Hashimoto; P. Galloway; D. Lyman.

c. Dates -- June 23 to June 29; July 3 to Aug. 29, 1969.

d. Populations of *A. planci* -- Spot checks along the northern barrier reef at Johnston Island revealed excessively high numbers of *A. planci* at station 19, 32 specimens were reported for a 30 minute swim. There were 42 specimens at station 20 during the same time. 26 specimens were found at station 13 during a 20-minute swim and 33 specimens at station 21 during a 30-minute swim. The section of the reef investigated was about 8 kilometers long. At only one location, station 7, were specimens common inside the barrier reel. At this station, 18 specimens were found in one hour of search.

e. Comments -- Outside the reef, the coral growth is reported as sparse with scattered heads. The field data sheets make little comment concerning the specimens of *A. planci* found and register the coral as alive and undamaged. The high population density of *A. planci* and the reportedly sparse but live coal growth make this an unusual situation and one that needs clarification for a better understanding of the reefs condition and the activity of the starfish.

4.1.2.7 Kwajalein

a. Area Surveyed -- Four pass areas: Bigej, Eniwetok, North and, South, Ambo Channel; and South Pass. In each pass observers were towed around the ends of the bordering islands and across the pass and observers swam along the lagoon, side of the bordering islands.

b. Personnel -- J. Branham, team .leader; R. Snider; J. Christofferson; D. Meuse

c. Dates -- July 1969.

d. Populations of *A. planci* -- The largest concentration reported was 26 specimens seen per 20 minutes of swimming by four observers near Bigej Island.

4.2 NON-STANDARDIZED SURVEYS

4.2.1 Fiji

Several sources reported infestation conditions at Fiji. Endean and Banner both reported infestations there,, and J. Weber has published an account of this infestation (1969). The reports do not establish the extent of damage and the size or location of the populations.

4.2.2 Borneo.

C. Yonge (1968) reported an infestation of *A. planci* at Borneo.

4.2.3 Rangirora.

B. Halstead (1969) reported infestation conditions at Rangirora.

4.2.4 Tuamotu Islands.

Halstead (1969) reported infestations at Tuamotu Islands. K. Link of the Fisheries Research and Development Project, Maracaibo, Venezuela, also reported infestation conditions in the Tuamotu Islands in 1961 near the islands of Makomo, Puka-Puka, Taenga, Bora-Bora, and Raiatea.

4.2.5 New Caledonia.

Endean reported infestation conditions at New Caledonia. Link reported infestations near the Loyalty Islands, Belep and the northern part of New Caledonia. Near Neba, one could count 75 to 120 specimens in a day of diving, which indicates an abnormal condition. There were dead reefs in this area.

5. CONCLUSIONS

5.1 SUMMARY

Of the 19 trust territory islands surveyed, 10 were clearly infested, showing extensive coral damage and large populations of *A. planci* in either developmental states or already formed into massive, migrating fronts. Three islands had populations large enough to be producing areas of dead coral but these may be in a process of development or decline, and six clearly were not infested. These areas are listed in Table 1.

Data from this survey and prior records provide a set of criteria, that may be used to distinguish between a "normal" and an "infested" condition. Paragraphs 5.2 and 5.3 outline these criteria.

5.2 NORMAL CONDITIONS

Reports from this survey, the Australian work, the Hawaiian survey and information in the literature indicates that *A. planci* normally occur in low population densities. Such populations are generally represented by four or five specimens per kilometer of reef. Sometimes these aggregate, but more frequently they are distributed as individual specimens. Specimens are absent from the majority of reefs. On only two occasions did any bf the field teams find more than 15 animals within a 20-minute period of search in what was concluded to be a natural situation. On Woleai 20 specimens herded together in a relatively small area of the reef and there were 26 specimens in a pass on Kwajalein. These may have been breeding aggregations. Damage to the reef at these points and on adjacent reefs was slight.

The famous echinodermologists H. L. Clark, who collected throughout the Pacific, and Mortensen, who organized his own Pacific expedition, captured few specimens of *A. planci* during their searches. H. L. Clark, in 1913, for example, found only three specimens in the Murray Islands. The Albatross Expedition through the Pacific collected a total of four specimens between 1907 and 1910.

Endean has explored the Great Barrier Reef for 18 years and encountered only four specimens of *A. planci* during the period preceding the infestation. Banner, and other participants with many years of diving experience throughout the Pacific, had never observed more than a few specimens on any particular reef.

On reefs adjacent to infestations, the normal population is approximately one specimen per kilometer of reef. Occasional areas, particularly near passes through the reef and where there is lush coral growth, may have as many as five or six specimens per kilometer of reef.

5.2.1 Definition of Normal Conditions

One can define "normal conditions" as a concentration of *A. planci* whose combined predation pressure is balanced by the regrowth of coral. How many specimens constitute a normal population varies depending on local abundance of coral, rate of coral growth and type of coral. While it would be very difficult to define this condition in the field, the existing data reveal that the number rarely exceeds 20 individuals per 20 minutes of swim or tow. It is possible to find more specimens in a locale by swimming, but, in a corresponding period, towing covers a much greater distance and thus offers a greater probability of finding specimens. During this study, the results of the two methods were often similar; where 20 specimens were found by towing, at least 20 specimens could be found in the same time period by swimming and looking under coral heads. Therefore, where there are more than 20 animals per 20 minutes of swim or two, the ecological situation warrants careful consideration.

The results of the combined studies indicate that the next increment above 20 specimens is a marked increase to 100 or more in a 20-minute tow or swim (normally more).

5.2.2 Areal Distribution.

A. planci normally occurred in a wide range of ecological conditions. It was found in depths as great as 40 meters and as shallow as reefs exposed at low spring tides. There was one report of a single specimen at 100 meters off Hawaii (see Reference Report, Hawaii). *A. planci* inhabited lagoons, embayments, leeward and windward portions of outer barrier reefs, and vertical escarpments. They were most common in lagoons, in lush coral growth, where rapid currents prevailed and wave action was slight. They were least common in the vicinity of surf and were absent from shallow reefs on windward buttresses. Aggregation in and near strong currents is common among echinoderms and may be related to the low respiratory efficiency of these animals. With *A. planci* however, aggregation in strong currents may relate to the lushness of coral growths - particularly *Acropora* - that flourish in moderately strong currents. A likely place to begin a search for *A. planci*, therefore, is near passes through a barrier reef, especially on the lagoon side.

5.2.3 Feeding.

Other characteristics of a normal population included the following feeding habits. Random feeding left small numbers of white coral patches scattered throughout the living coral. The animals generally fed at night and were cryptic during the day, but during the survey a few specimens were observed feeding during the day under normal conditions.

Frequently, *A. planci*., attacked only a portion of a particular coral head, leaving the remainder alive. The starfish moved onto another coral head after retreating during the day. When only a portion of the coral head died, the remainder continued to grow. Field teams occasionally found a white coral head with a specimen of *A. planci* more than 10 meters away, indicating that the starfish may normally move some distance before feeding again.

Whenever divers observed the animals feeding, corals were the prey. In Guam, the starfish were observed feeding (even under normal conditions) on hydrocorals and octocorals, but such observations were rare. *A. planci* almost inevitably attacked madreporarian corals. Species of *Acropora* were their most common food, and species of. *Synaria* the least common. *A. planci* was never observed feeding on Heliopora. Brauer conducted experiments in aquaria on the reaction of *A. planci* to various extracts from corals. His results indicated a strong positive chemotaxis for *Acropora* extract and a negative chemotaxis for *Synaria*.

5.3 INFESTATION CONDITIONS

Observations of infestations and the conditions that prevail therein appear in the Australian report (Endean, 1968), in the work of Chesher (1969), and in the field reports filed by returning members of this survey. The numbers of animals in infested areas differed so markedly from the normal condition that there was little chance of misinterpreting the data.

From a maximum of 20 animals per 20 minutes of search, the densities jumped to more than 100 per 20 minutes of search and more often to several hundred. Endean, for example, recorded 5750 starfish were counted in 100 minutes on a small section of the reef flat at Green Island in July, 1966. During 100 minutes, 4640 starfish were counted on a small section of the fringing reef at Fitzroy Island in March, 1967. Chesher (unpublished data) during control activities on Guam, removed about 20,000 specimens from 11 kilometers of shoreline.

In the densest portion of the Guam populations, animals frequently stacked one on top of the other (Figure 20) and grazed large, tabular *Acropora* coralla clean overnight. In Truk, Joness team laid down quadrats along the front located west of Pis Island and counted an average of one specimen per 4.6 square meters. Because of the rugged terrain, it is likely that they overlooked some specimens. Jones reported pulling about 30 specimens from under a single coral head.
Field teams observed similar population densities in Saipan, Tinian, Rota and Ponape.
Is Palau, where infestation was apparently just beginning, there were large isolated populations with densities of about one animal per three square meters. Divers reproved about 500 animals from the narrows surrounding the small island in Iwayama Pass during control efforts.

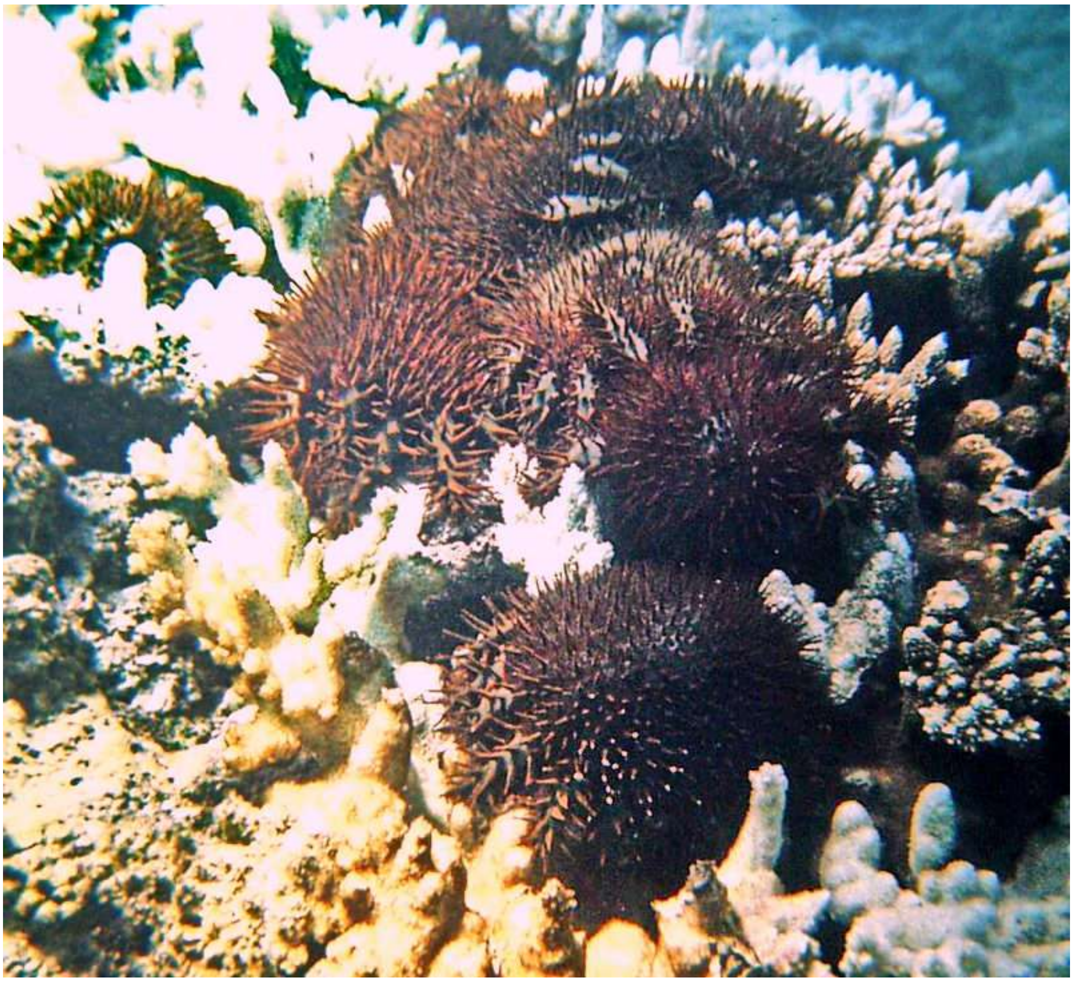

Figure 20. Aggregation of starfish feeding on coral in Guam

5.3.1 Definition of Infestation.

One can define an "infestation" as a concentration of *A. planci* whose combined feeding effort clearly exceeds what can be supported by the existing coral growth and whose survival and recruitment rate are such that migration and dispersion do not result in a balanced condition.

Generally, this is an obvious state in which white, freshly killed coral is abundant and older, dead coral covers a noticeable portion of the reef. Difficulties arise in analyzing the early stages of an infestation. In general, it seems that populations In excess of 20 animals seen per 20 minutes of search constitute an pre-infestation condition while umbers in excess of 100 specimens seen per 20 minutes of search identify an infestation.

5.3.2 Areal Distribution.

In early stages of infestations numerous specimens aggregate in compact herds called seed populations (Chesher 1969). Searchers have most frequently found these in shallow water. There were two such populations on Guam reefs and four at Palau in depths less than two meters. A second stage was distinguishable at Guam, in which specimens became much more numerous and spread to all portions of the reef. In the peak stage of infestation the animals form an actively migrating front in a long, narrow band only five to a few hundred meters wide extending several kilometers along the coastline. The field teams found fronts from 1 to 40 meters deep but only outside barrier reefs.

5.3.3 Feeding

During infestation conditions coral heads were attacked by several *Acanthaster* and were completely stripped of their living tissue. Dead, white coral was abundant and often continuous for many square meters. In the vicinity of a front, predation created a swath of white, freshly killed coral that could be followed for many kilometers along the reef. Observations on the leading point of a migrating front at Guam revealed a tendency for two to three animals to graze over a coral head then advance along the reef for about 25 meters before attacking another coral head. In moving from one coral to the next, they bypassed many live corals. Even in a thoroughly grazed portion of reef, there were coral heads occasionally untouched or only partly eaten. Frequently, specimens of *A. planci* moved rapidly along the bottom, bypassing live corals. The cause of this erratic feeding behavior has not been discovered. Judging from the areas which were killed two years ago on Guam, the starfish eventually eat almost all the corals.

A. planci does not kill 100 percent of the corals on reefs subjected to predation, but it was difficult to estimate just what percentage they did eat. Large sections were completely stripped of living coral, but small, local patches (often only a few square meters in area) survived as did corals in the intertidal or surf zones. In some .areas, entire embayments protected by a barrier reef survived the initial attack (as, at Tinian, Guam and Saipan) but they may be subject to predation at a later date.

5.3.4 Migration.

The Australian research indicated that herds of starfish migrated from one area to another after killing the coral. At Guam, tagging individuals and observing the movements of the major fronts demonstrated that the herds could move across a poorly developed, dead reef at slightly less than three kilometers per month. An average figure for the rate of destruction of the coral, based on a six-month study in Guam, was approximately one kilometer per month. This included predation on the corals from just below the surf zone to the depth limit of coral growth.

5.3.5 Navigation.

During mass movements of herds, a pronounced orientation away from ,the area of destruction was evident (Chesher 1969). The nature of the precise navigation ability exhibited by these herds was not clarified by any of several attempts at analysis. Starting from a point near

Tumon Bay, Guam, one herd of *A. planci* split, migrating both north and south. Although their paths led in and out of embayments and throughout the depth distribution of corals, the herd persisted in moving away from Tumon Bay. Movements of individual specimens did not correlate with water movements, wave action, slope or nature of the substrate, or any other obvious factor.

5.4 POSSIBLE RECURRENCE

The field teams obtained no evidence to support a hypothesis that similar population explosions of *A. planci* have been a common or repeating phenomenon in the past. If such were the case, the periodicity of the cycle must exceed 100 years and possibly 1,000 years. The evidence prompting this statement is as follows.

Biological information about the Great Barrier Reef is available for about 100 years. Collections by various workers indicate *A. planci* was present only in very low densities. The Great Barrier Reef Expedition in 1928, for example, collected only one specimen during 15 months of intensive biological work.

In the same area during the past decade, *A. planci* devastated the living coral. The animals large size, unusual appearance, sharp spines, shallow-water habitat, and high population densities during infestations plus the profound effects of this predator on coral reefs make it improbable that past infestations would have gone unrecorded. The startling contrast of the pure white, freshly killed coral against the living reef would hardly have escaped previous biologists attention and the sharp, venomous spines make it well known to the general populace even when it occurs in very low population densities.

Chesher is confident that if dense populations of *A. planci* had been "normal" during the 100 years of observation on the Great Barrier Reef, someone would have noticed them. The present population of animals has reportedly eaten more than a total of 100 square miles of reef. If there had been earlier kills of this magnitude, certainly the literature would record some evidence of it. Assuming a lush coral growth at the outset of the present observation period, and allowing time for that to have regrown following a hypothetical previous explosion, a period exceeding 200 years would be the minimum for a cyclic recurrence of *A. planci* devastation in Australia.

The same arguments apply to, the entire Pacific. It would indeed be strange if such a profound natural occurrence were a "normal" process of reef ecology that the folklore of people who have been fishing the reefs for more than 2,000 years fails to mention it. The islanders interviewed during the survey were aware of the starfish and had a name for it in their particular dialect, but they know it only as an uncommon inhabitant that one must avoid stepping on. (Their antidote, incidentally, for wounds from *A. planci*'s sharp spines is to turn the offender over and let it suck the poison out with its fleshy stomach. Interestingly, natives from Fiji to Saipan almost universally recommend the same cure. During the control efforts on Guam, one diver rubbed a portion of an *A. planci* stomach over a spine-wound and claimed that it did indeed reduce the pain and that the wound healed with surprising rapidity.)

On most tropical islands the coral is not evenly distributed around the entire coastline. Some areas have poorly developed coral growth, and a few others have extremely lush, framework-building corals. On Guam, there are five zones of lush coral growth along the western coast. These include the Bile Bay to Toguan Bay reef, Anae Island to Nimitz Beach, the Piti Bay reef, the northern end of Tumon Bay, and Double Reef. There are very large coral heads here that probably represent several hundred or possibly 1,000 years of continuous growth. Coral heads of one single species grow to diameters greater than 9 meters. Massive corals two and three meters in diameter are not uncommon, and there are whole sections of reef composed entirely of very large old corals. Such reef complexes form only over long periods.

A. planci predation has occurred in three of these areas. Portions of some large *Porites lutea* heads and a few other patches of corals have survived, but the majority of larger corals along with the smaller, younger corals, have been grazed clean.

It is not possible for the corals to have developed to their complex state if a similar infestation had occurred on Guam within the past 100 years and it is highly improbable that an infestation happened within the past 200 years. The speed at which the present infestation was spreading before control activities began and the vast extent of reef already killed indicate that without control none of the lush coral areas on the island would have survived the present infestation. It is improbable, therefore, that *A. planci* in epidemic proportions had previously grazed the coral reef areas that existed on Guam three years ago within at least 200 years.

Goreau estimated that some corals that have been killed represent more than 1,000 years of continuous development. Probably even that span is an underestimate, but it is almost a surety that an *A. planci* infestation as is now occurring has not occurred within the past 200 years. (It is possible; although rather pointless, to construct a theory that accepts a 200-year cycle for an invertebrate that would recur on an inter-ocean scale.)

The overwhelming evidence is that this current population explosion is not a limited, local occurrence or a common reef phenomenon and that it is not the type of cyclic phenomenon discussed by Coe (1956) and exhibited by local population blooms of *Asterias* along the eastern coast of the United States.

In past years, however, limited population expansions (as seen in many marine invertebrates) may have been common for *A. planci* as well, and seed populations may have formed in response to temporarily favorable environmental conditions. If so, they did not receive sufficient recruitment to overcome mortality and attrition from migration. In the present infestations, however, recruitment is more than adequate to keep the infestation growing. Small specimens of these animals abound at Guam and Rota, and at least three size groups are evident in the populations at Guam.

On Nukuoro, Kapingamarangi and Pingelap, however, there is evidence that a minor population expansion killed a limited extent of coral before the animals dispersed and the rate of damage slowed.

Whatever the element is that assures rapid and prolonged recruitment to the initial population expansion, it is the cause of the present massive populations of *A. planci.* As all the evidence suggests this is s recent phenomenon, some change in the, general environment or in the biology of the species must have occurred.

5.5 CAUSES OF INFESTATION

There are two likely. possibilities for the rapid population expansions: a change in the environment or a change in the animal. Changes in the environment could be physical changes that result in improved survival of *A. planci* or biological changes that result in release of pressure from predators at some stage in the *A. planci* life Cycle. The latter enjoys the most active support at this time.

5.5.1 Physical Changes in the Environment.

Proponents of this hypothesis point out the wide occurrence of the phenomenon and argue that such widely spread population explosions are probably caused by the sudden appearance of physical oceanographic conditions favorable to this particular animal.

5:5.2 Biological Changes in Environment.

Basically, proponents of the biological change hypothesis offer variations of a general theory centered around release from predator pressure. *A. planci* undergo predation in all portions of their life cycle. The following four paragraphs outline a life cycle which is typical for many starfish and which preliminary evidence, suggests is typical for *A. planci*. It is stressed that the outline contains many uncertainties and needs substantiating research throughout,

1) Eggs and Larvae
   a) Time Span -- Larval life span is about 16 days (Mortenson 1931) but may be shorter or longer, depending on local ecological conditions.
   b) Habitat -- The larval habitat is assumed to be pelagic, oceanic. (Some larvae may become trapped in local current systems and contribute to local recruitment.)
   c) Probable Predators -- Several hundred or perhaps thousand species of zooplankton.
   d) Defenses -- The larvae have no obvious defensive system. They swim by ciliary action and probably have a generalized photic and chemical sensory response.
2) Metamorphosis,
   a) Time span -- This is a brief period of the life cycle during which the developing starfish must. settle out of the planktonic community and become benthic creatures.
   b) Habitat -- The larvae settle onto coral reefs:
   c) Probable predators -- During settlement, predators include the myriad filter feeders that cover the shallow water benthos in tropical waters and after settlement, many detritus feeders and smaller scavengers feed on the newly settled starfish. Corals and other coelenterates, sponges, various mollusks, and filter feeding echinoderms must capture a very large percentage of both larvae and settling starfish.
   d) Probable defenses -- There is no obvious defensive system during metamorphosis.
3) Post-Metamorphic
   a) Time Span -- During approximately the first month as a juvenile, starfish are extremely cryptic..
   b) Habitat -- coral reefs.
   c) Probable Predators -- Predators at this stage of the life cycle are not known but may include anemones, annelid worms, crustaceans and other small animals.
   d) Probable Defenses -- Although they have spines, the young starfish are effectively defenseless because of their small size up to 2 cm. in diameter).
4) Adults
   a) Life Span -- Unknown, but in excess of three years.
   b) Habitat -- Coral reefs, from the intertidal zone to the depth limits of reef-building corals.
   c) Probable Predators -- The only confirmed predator is *Charonia tritonis*, the giant triton shell. Other mollusks that will feed on *Acanthaster planci* in captivity (but probably are not active predators under natural conditions) are *Cassis* and *Murex*. Chesher observed a large sea anemone (*Stoichactis sp*.) catch and eat one *A. planci*. It is possible that anemones prey on small specimens of the starfish. A large wrasse (*Cheilinus undulatus*) has been reported to be an active predator of A. planci and, according to reports, captured specimens have shown evidence of spines imbedded in the mouth tissue (P. Wilson, personal communication).

To gain some idea of the predation pressures involved, it is necessary to know something of population size. Endean (1468) reported that each adult female produces 12 to 24 million eggs per year. To maintain a steady-state condition, two specimens must reach maturity for every male and female that die. Assuming the average life span is five years and the annual egg production (conservatively) is 10^7 eggs, a pair of adult *A. planci* produce a total of 5 X 10^7 offspring (out of which only two can reach maturity, to preserve the balanced state). Night observations show that under normal conditions starfish greater than 2 cm, in diameter are less common than adults. Although specimens of this size emerge at night to feed, one can assume that they are more difficult to find because of their small size. Based on field observations, a very conservative estimate is that they are not more than twice as common as adult specimens, and they absolutely are not 100 times as common as adults. Therefore the greatest mortality must occur before *A. planci* reaches 2 cm. in diameter. In fact, even assuming that there are 100, 2-cm. survivors for every adult, 99.9998 percent of the deaths would still occur before the animals reach 2 cm. in diameter.

Any hypothesis explaining the population explosion must also account for the configuration of the seed population at the initial stages. In instances where divers have observed seed populations (Guam, Palau, Australia and possibly Kapingamarangi they consisted of a large number of individuals aggregated in a localized area of a lush, shallow water reef. The theory must also account for the high level of recruitment.

The existing hypotheses to account for the population explosion cover each of the stages of the life-cycle. The following three paragraphs outline hypotheses accounting for decreases in predation at each stage in the *Acanthaster planci* life cycle:

a. Decrease of Egg and Planktonic Larval Predation --

Concentrations of organo-chlorines and other man-made pollutants have been increasing in the marine environment during the past few decades. These pollutants might have either eliminated planktonic predators, decreased the zooplanktonic standing population, or reduced the reproductive capacity of the zooplankters so that the zooplanktonic community can no longer expand rapidly enough to check the influx of large swarms of *A. planci* larvae during spawning seasons. This, theory might apply to both oceanic and reef zooplankton.

There are problems with the theory. If a pollutant were operating on oceanic zooplankton, the population explosions should occur on all islands but they do not; they occur on a random basis (for example, Truk is infested, while Lamotrek is not).

If the pollutant affected the reef zooplankton, the pollutant would have to be derived from the local environment, and there should be a one-to one correlation between concentrations of pollutants and infestations.

Initial data on these parameters are limited and in need of investigation.

A related hypothesis suggests that predators of the adult *Acanthaster planci* (i.e., Tritons) might accumulate organo-chlorines in their tissues and that this might reduce the reproductive capacity of the predators. Subsequent release from predation might lead to the current population explosions.

b. Decrease of Predation During Settling --

Continual mechanical damage to coral reefs might provide settling areas for zooplanktonic larvae, leading to sudden, large increases in population numbers through increased survival in localized areas. *A. planci* larvae apparently settle out in shallow water, and the multitude of zooplankton predators that live in tropical, shallow waters is such that they occupy almost every portion of the bottom. For an *Acanthaster planci* infestation to develop there must be an abundance of coral present to sustain the young starfish. Thus areas that are low in filter feeders (coralline pavements, beds of algae, etc.) need not be considered. Mortality at the time of contact with the substrate must be very great. After settlement, there may be a period of a few days to a week when the tiny starfish move very little, do not feed, and contain no protective skeleton. This must also be a period of high mortality, attributable to small predators of the reef and detritus feeders.

Dynamite explosions on a lush coral reef break and overturn coral, but only a small portion of the coral actually dies. For a time, bare surfaces of $CaCO_3$ are available for settlement of larvae immediately adjacent to living coral, and the effects of an explosion are such that those surfaces constitute a single, concentrated area on the reef. If concentrations of larvae were present and attempted to settle within a few hours or perhaps a few days following a blast, survival of the young would be substantially improved.

The result of this situation might be a new population of several thousand small starfish concentrated in the center of a lush coral area.

The actual means of inflicting physical damage to the lush coral is not critical. Chlorox fishing, breakage of coral by shell hunters, or dredging might have the same effect. The significant criterion is that the damage occur amid lush coral, in shallow water, and just prior to the larvae attempting to settle out.

There is field evidence to support this theory. The resulting population would have the prerequisite characteristics of being a large number of similar sized individuals aggregated in a localized area of lush coral reef. Both Ponape and Truk reportedly experienced population explosions of *A. planci* following World War II. Blasting has been a common method of fishing on Truk since the Japanese occupation, and Truk has one of the oldest infestations. There have been both dredging and blasting on Ponape for a period of several years and the northern infestation on that island seems to have originated in the area of blasting. Rota has had blasting and dredging activities near the supposed site of initial infestation throughout the period when the infestation began. A similar situation was reported from the pass at Nukuoro.

There was considerable blasting on the reefs of Guam during the period preceding the infestation. During the spawning season of 1968 a channel was blasted through the reef near Cocos Island at the southern tip of Guam (in an area outside the existing infestation). Inspection of the vicinity following the completion of the channel in February disclosed no *Acanthaster planci.* In June, inspection of the same area showed the presence of numerous specimens between six and eight centimeters in diameter. Specimens were there in coral adjacent to the canal on the inner portion of the lagoon reef.

Arguments against the theory contend that destruction of sections of coral reefs by man has been common since before the war and that numerous explosions occurred on the reefs during the war without resultant population explosions. Also, storm damage produces fresh coral surfaces, and storms are certainly not new.

While true (according to the theory) that any major damage might favor settlement of a large population of *A. planci*, the surfaces would probably remain suitable for settlement only a few days (at most). Catastrophic events like World War II bombings or storms would be much less likely to provide A suitable surface than regular, methodical efforts to obtain fish or open a passage or harbor using explosives. Typhoons striking a particular reef system when *A. planci* larvae are abundant is probably a rare occurrence; in Guam, larvae settle in the months of December through February, whereas typhoons are most common during the summer. Storm damage to coral is usually not very great in protected lagoons and is not concentrated in one portion of a reef.

Lagoon coral, particularly on the leeward side where seed populations appear to begin is normally, protected unless a typhoon hits the island directly. Although seed populations might begin in this manner, there are no data documenting how many seed populations fail to develop into true infestations and disperse because of lack of food or recruitment.

Since World War II, blasting and dredging activities have increased steadily. Some of these activities might have induced the rise of seed populations that later died out. Some might have initiated large scale infestations, as have been reported for Truk. There might, therefore, have been an increasing *A. planci* population throughout the Pacific for the past 25 years. Following the chance establishment of a seed population, adequate recruitment needs to occur for a fullscale infestation to arise. Perhaps the gradual increase of A. planci reached a point the larval population provided a greater probability of recruitment.

In summary, this hypothesis proposes that localized mechanical damage to coral reefs in shallow, tropical Pacific waters might result in a gradual build up of large, populations of *A. planci*. The resulting increase in larval production might reach a point where recruitment to the seed populations was assured. Before the widespread, systematic use of explosives, starfish population increases caused by local disturbances to the coral (such as storms), would have received inadequate recruitment and dispersed or died out.

This hypothesis would seem to apply to Guam, Rota, Ponape, Truk and Nukuoro but not to Ant or Australia. There is some question as to its applicability to Tinian, Saipan, and Palau where there are infestations but dredging and blasting was not common. Yap, Lamotrek, Ifalik and Woleai with no recent physical damage to their reefs and no infestations would fit the theory.

c. Decrease of Adult predation (Triton Hypothesis) --

A large population of adults might arise from a gradual population build-up over several years, caused by decreased predation on the adult stages. As each adult has an estimated life span of at least five years, numbers could increase beyond a "critical mass" level in only a few years if predation on juveniles stopped. There are other reported predators of adults, but the triton is the only one that has been proven effective. This hypothesis maintains that shell collectors might have reduced the population of tritons below that necessary for control of *Acanthaster planci* populations. Endean (1968) presented much evidence in support of this hypothesis in Australia.

Following the gradual build-up, a point would be reached where the enlarged *Acanthaster planci* population might generate its own increased recruitment by either increased larvae production or increased larvae survival during settlement. The corals grazed clean during feeding by the adult starfishes would constitute favorable substrate for larvae to settle on. Since the adults frequently miss portions of the living coral within the matrix of the reef, the younger specimens would have adequate food for early survival. There is evidence for and against the hypothesis.

Endean (1968) cited the increased professional triton fishery in Australia, the increased collection of tritons by tourists and the correlation between tourist sites and *Acanthaster planci* outbreaks. He also pointed out that reefs still having specimens of tritons were only partly killed by *Acanthaster planci* attacks.

Feeding experiments with tritons indicated that they feed on several species of asteroids and that a triton eats only one adult starfish per week. Chesher found that attacks on large *Acanthaster planci* were not always fatal, as a large portion of the animal occasionally escaped and regenerated the missing tissue. Endean pointed out, however, that while Triton predation on adults might not account for proper biological control of natural populations, their predation on the young starfish might be much more effective. This is a strong possibility and depletion of triton stocks might be responsible for the population explosion.

To determine if there has been a depletion of tritons, some estimate of the "normal" condition must be made. Tritons are nocturnal so chances of discovering them during daylight are small. The field teams observed no tritons during the entire Westinghouse survey. .During a 6-month study on Guam prior to the survey, divers found only 7 tritons. These were large individuals, indicating they had escaped collection for some years.

Guam abounds with shell collectors, who use modern diving equipment and avidly collect mollusks. Tritons are highly prized and even badly eroded specimens are taken. Reports from long-term residents of Guam indicate that tritons have never been "common". The fact that they still occur and grow to adult size probably reflects their cryptic behavior.

By contrast, there is relatively little diving along the extensive reefs of Truk and even less at Palau and Ponape. If tritons can grow to a large size on Guam, it is improbable they would be depleted in places like Ponape, Tinian or Truk where diving activities are much more limited. Yet these three islands have *Acanthaster planci* infestations.

Conversely, the tiny islands of Ifalik, Woleai and Kapingamararangi are inhabited by marine oriented people who do considerable diving. Because of the limited reef areas there, the waters are well known and heavily fished. The island inhabitants collect tritons for trade purposes. The incentive to hunt tritons is strong; a single triton can bring its finder a greater profit than any other natural product of the reef. Tritons are, therefore, heavily fished on these islands and have been for some time. The islanders consider the triton a rare animal and capture only a few each year. While probability is much greater that these islanders would deplete their triton stocks than that shell collectors working the Great Barrier Reef would deplete that stock, these islands have normal *Acanthaster planci* populations. Ant, conversely, is owned by an avid conservationist who does not allow fishing in the lagoon. Tritons are not taken there, but the island is infested with *A. planci*. Nonetheless this theory offers a plausible model, and it is true that tritons are subjected to heavy fishing pressure. Lowering of triton stocks in localized areas frequented by divers might be sufficient to raise population levels of *A. planci* beyond a critical minimum. Such a disturbance could have happened on Guam and most of the other islands.

Almost all *Acanthaster planci* outbreaks have begun near human populations. It seems a conservative assumption to believe that the population explosions, in one way or another, correlate to human activities. Of the three preceding theories (there are several others that have been suggested, that Endean summarized and discredited) related to release from biological controls, the triton predation and the blasting effects seem to offer the greatest credibility. Both explanations still face certain objections, however, which would have to be settled before either could be accepted as conclusive.

5.5.3 Changes in A. planci.

A second class of theory proposes that there might have been a change in the animal, a mutation that improved its ability to survive. One example would be an improvement in or development of the ability of the larvae to seek out adults of their own species to settle near. Many marine invertebrates do demonstrate such an ability and it is present in the specimens of *A. planci* which are involved with the present population explosion. The field teams found young *Acanthaster planci* only in the vicinity of adults or in areas where adults had been feeding during the settlement period (with the exception of the dynamited area on Guam mentioned above). Perhaps (although there is no evidence to support this) the ability to seek out adults was not present or well developed and, through mutation, it appeared.

The arguments against would seem stronger than those for the theory. Field teams found no evidence to support the theory, but it is a subject that would yield to investigation. Such a mutation would greatly improve chances of larval survival during settlement and would account for the population explosion. One test any valid explanation must satisfy, however, is the almost simultaneous occurrence of this phenomenon over remote oceanic distances. Link reported infestations from the Tuamotu Islands in 1961 and Endean reported the Australian infestation began in 1958 or 1959.

Guam became infested in 1967 as did (apparently) Saipan and Rota. Palau was infested just recently, but Tinians (between Rota and Saipan) infestation seems about five years old. There is no apparent orderly pattern to these occurrences. If a mutation were the cause of the infestation, an advancing wave of outbreaks should occur, following the several currents that carried the new strain of *Acanthaster planci.* This did not happen. The random distribution of infestations also suggests that the cause is not due to physical oceanographic changes and points to local disturbances. The proximity of the infestations to human populations may be chance or it may reflect a causal relationship between man and the infestations.

5.6 CONCLUSIONS ABOUT CAUSES

According to the field data collected by the survey, ten islands have infestations of *Acanthaster planci* The existing evidence implies that the infestations are induced by human activities; collection of tritons; local destruction of reefs and pollution offer plausible explanations of the outbreaks. Various interpretations of the available evidence can be offered in support of any of the three. Possibly all are simplifications.

It might be that collecting tritons from and destruction to the reef are both causes of the outbreaks. There may be other causes yet to be considered. It is not necessary to identify the causes before implementing limited controls to halt infestations.

6. RECOMMEDATIONS

The question of whether the present population explosion is novel or is an event in a cycle with a 100 or 200 year period and the answer to why the explosion is occurring are somewhat academic at this. point. The investigation Showed that destruction of coral reefs is going on at an alarming rate, and all investigators on the trust territory study agreed unanimously that the problem. required both research into numerous unknown parameters of reef ecology and localized control.

6.1 NECESSITY OF CONTROLS

The questions should controls be initiated and if so, when, what kind and where, were asked of each team returning to Guam. There was complete agreement among the team leaders that controls should be instituted and as soon as possible. They believe wholesale destruction of living coral is definitely not a normal element of reef ecology. Recovery by the reefs is possible, even likely, but will require more than 25 years before noticeable improvement occurs and an undetermined period before the reefs regain the stage of development existing before the infestation occurred. Recovery assumes there will be no further reinfestation of a damaged reef, but there is no evidence that reinfestation will not occur.

Tropical pacific reefs contain a very wide variety of coral species and a dense, lush coral growth, but the numbers of any one species of coral on a particular reef are usually low. Destruction of the coral of an entire island must inevitably reduce the numbers of many species of corals below the point where the colonies can reproduce. If this occurs on a broad enough basis, it may be an exceedingly long time before such species are able to reestablish their populations (if they ever can).

The process of recolonization is complicated by succession communities of algae and soft corals. Since no studies have been conducted on the subject over long periods, there is little basis for making statements about how long it will take the coral to reestablish itself. The oldest known coral kills are on the Great Barrier Reef. There has been only a feeble regrowth of coral in a few localized portions of a reef killed 9 years ago. If *A. planci* killed the coral reefs of Kuop following World War II, there is evidence that a fair coverage of small coralla might reestablish itself after about 25 years. On the other hand, Goreau (1964) presented evidence that a stable resident *Acanthaster planci* population might maintain itself on a semi-permanent basis for an unlimited time and in doing so, prevent formation of framework-building corals.

The process of recolonization becomes even more of an unknown factor as the *Acanthaster planci* population explosion spreads. The total population of corals in the southern Marianas Islands, for example, must be drastically lower than it was three years ago. As the starfish infest more islands, the production of coral larvae necessarily decreases. This decrease will probably slow recolonization of the depleted reefs.

Biologically, the drastic elimination of living corals by *A. planci* predation constitutes destruction of a community of long standing. The coral reef association is a complex ecosystem. Elimination of a basic element of this ecosystem--coral--inevitably disturbs the entire biological community. Fish, for example, that have become adapted to living coral reef through eons of evolution are suddenly, placed in a different environment. Algae-feeding fish, particularly the small acanthurids and scarids, become extremely common whereas chaetodonts and serranids become less common. Although counts of number and species of fish were not made before and after a coral kill, field teams observed abundant subjective evidence that the fish population of the dead reefs had significantly altered. Larger food and game fish were almost totally absent, and the majority of brightly colored "tropical" fish usually abundant on living coral reefs were missing from the algae-covered reefs.

The irregular growth of living corals provides a multitude of protective niches for reef-dwelling animals. These crevices and miniature caverns are attractants that contribute to coral reef productivity. Loss of the existing niches from overgrowths of algae and biological and physical degradation gradually eliminates the multitude of living spaces on the reef. The effects might eventually affect the pelagic fish populations as well.

The death of living coral means a decrease in fisheries production--at least temporarily--for nearby societies who depend heavily upon marine sources of protein. Living coral reefs are also an economic asset for the tourist trade. Tourism offers more for the future economic development of the U. S. Trust Territory than any other single prospect. Coral reefs and clear waters can attract substantial revenue for the islanders.

The atolls of the Pacific were constructed by living coral and coralline algae. The mountains that formed the original islands have gradually subsided into the sea floor. As they subsided, the coral surrounding these islands grew upward, constructing solid reefs that, over millions of years, have formed limestone caps up to -a mile thick. Occasionally, the corals added to the island slower than the rate of subsidence and these atolls submerged, now existing as guyots.

Coralline algae also is important in the development of reefs. It acts, as cement, bonding building blocks of coral together into a solid, wave-resistant buttress. It seems safe to assume that atolls could not have formed or maintained their existence without both constituents, living coral and coralline algae. Since living coral was instrumental in the formation and maintenance of atolls, it seems logical to assume that it is required for preservation of the atoll. Evidence tends to indicate that there is no immediate danger of atolls "washing away", but there is a possibility that repeated breakage of dead coral by storm waves could result in wave erosion of portions of the shoreline. Because of the nature of atolls, the islands, (with the exception of the "high" islands) are only about one or two meters above sea level and are quite small. For these islands, erosion of even a small portion of shoreline by storm waves is a serious threat.

Should controls-be used? Some observers who did not participate in the survey advised, "Let Nature take its course," or "It's a natural phenomenon and doesn't need control" and "Let's study it for awhile." The trust territory field teams interpreted all available evidence to indicate that the extensive *Acanthaster planci* predation is not a natural phenomenon; it appears to be man-induced, and "Natures course" would be no more desirable here than in an uncontroiled forest fire.

Coral reefs constitute a valuable natural resource for local inhabitants, Protection of human welfare requires the protection of many such resources by imposing controls Locust plagues are not man-induced, and other biological epidemics are produced naturally. There can be little debate about the value of control over these natural catastrophes. Destruction of coral reefs by *Acanthaster planci* is as potentially disastrous to the coral island as continuous forest fires are to a watershed, and the corals probably will require a longer time to recover than does a forest.

Controls are, therefore, needed. There is no question about the need for further study as part of the control program, but the institution of limited controls should not be delayed while study of the problem continues; valuable reefs should be actively protected.

6.2 CONTROL RECOMMENDATIONS

Considering how rapidly *A. planci* can destroy reefs and the still, uncertain aspects of where the next infestation may occur, Chesher suggested a three-phase control program:

a) Organize groups of divers to kill existing major populations or to protect valuable reefs;
b) Administer an educational program to alert the populace of the islands to the problem and how they can help prevent loss of living coral on a civic basis.
c) Increase scientific investigation into the biology of *Acanthaster planci* and of its predators and the dynamics of reef degeneration and regeneration.

On islands that are badly infested, control of the large starfish populations (considering the numbers of animals and the depths to which these populations range) requires the use of trained SCUBA fivers equipped with Formalin injector guns (Figure 21) such as those developed by Chesher. Chesher advised training Micronesian divers to use SCUBA apparatus and to build and maintain the Formalin guns.

Using Formalin guns, a diver can kill up to 600 or 700 *Acanthaster planci* per day, depending on the density of animals. Six divers can clear about one mile of roof per day in areas of heavy infestation. Divers killed 20,506 *Acanthaster planci* in Guam, eliminating the two major fronts and several large population centers during the first nine months of weekend control dives. Working full-time they could have eliminated the same population in two months. The injector gun delivers 5 cc of full-strength Formalin directly into the coelom of *Acanthaster planci* and has a reservoir containing enough Formalin to kill more than 256 animals. The Reference Report describes construction and operation of the gun.

The first year of an infestation apparently transpires in shallow water. Limited numbers of *Acanthaster planci* are present in the seed populations (about 166 to 1,006). On most of the Micronesian islands there are enough diving fishermen to assure someone noticing such a build-up when the seed population first appears. If they become aware of the potential threat such a seed population represents, these divers might be induced to either report the presence of the population to government authorities or perhaps actively fish out the animals. It was the consensus of the participants of the Trust Territory Survey that an educational movie on the *Acanthaster planci* problem could be effectively introduced into the high school system in Micronesia. Such a movie or slide show would require one video tape or film copy for each district narrated in the local language.

All control activities should be placed under the direction of a competent biologist or committee of biologists, These recommendations are expediencies, and will suffice only as a temporary control to decrease the rate of coral destruction until studies in more detail are complete and long-term biological controls are established. They could not reduce the *Acanthaster planci* populations below normal levels.

6.3 STUDY RECOMMENDATIONS

6.3.1 Biology of A. planci.

Studies of the biology of *A. planci* completed to date grossly outline the problem. What are required are detailed studies into predators of the starfish, reproductive habits, navigation, and larval biology. The literature contains nothing of surety on larval predators, methods of larval dispersement or settlement, larval life-span, or if recruitment to the adult population is an open or closed system. Studies of *Acanthaster planci* behavior, physiology, predators, parasites and diseases are essential to the development of long-term biological controls.

6.3.2 Biology of Corals.

The field teams found it surprising just how little is known about the dynamics of coral reefs. Coral predators, competition between algae and coral, breakdown of dead coral, coral regeneration and regrowth, succession communities and recolonization are poorly understood.

6.3.3. Environmental Utilization.

The possibility of transplanting corals to rebuild dead reefs merits exploring. Studies of the possibility of using grazed areas for increased yield through aquiculture should be initiated. Perhaps introducing the proper herbivore to a tropical environment poor in filter feeders and covered with algae could raise reef productivity to its former level or even beyond.

6.3.4 Control Techniques.

Methods other than killing animals by hand and biological control should be investigated. Toxic fences, vibrating fences, electrical barriers, etc. warrant evaluation as means of containing planci. Considerable caution should be used when advising any control techniques to prevent undesirable side effects.

6.3.5 Research on causes.

Research should be conducted on causes of the infestations and on the historical aspects of *A. planci* populations.

6.3.6 Ecological Impact of Infestations.

Research is needed into the impact of reef alterations by A. planci predation, particularly in respect to fish populations.

6.4 RECOMMENDATIONS BY ISLAND AREA

Not all islands showed signs of infestation. Some had past the stage where controls could be effective and thus provide localities for scientific study without potential economic loss. Areas that the starfish were attacking which would have economic value to island residents are where controls are most needed.

6.4.1 Ant.

Although the survey did not cover the entire atoll, many of the reefs of Ant have already been attacked by *A. planci*. Because the owner of the island does not allow fishing in the lagoon Ant offers valuable potential for research into the effects of coral depletion by *A. planci* on an undisturbed fish population.

6.4.2 Guam.

Guam is continuing its control program. A few lush coral reefs remain uninfested but large populations of *A. planci* still exist on some portions of the coastline.

6.4.3 Ifalik and Lamotrek.

Ifalik and Lamotrek were not infested. The people of small atolls like Ifalik depend on their marine resources for protein. They should be made aware of the threat *A. planci* presents and should be encouraged to report any sudden influx of large numbers of A. planci or even to participate in an active fishery for these animals.

6.4.4 Kapingamarangi, Mokil, Nukuoro.

A field team observed a fairly large population of *A. planci* on these atolls. The reefs should be reexamined in one or two years to determine if the population is in equilibrium, is decreasing or is increasing.

6.4.5 Kuop.

Kuop is in the process of regeneration after a coral kill some years ago. It requires no immediate controls but might prove useful as a research area for investigations into beneficial uses of reefs that have suffered attacks.

6.4.6 Palau.

Following the survey in April 1969, Chesher recommended eliminating the observed seed populations. Working on weekends, school children of Palau visited the reported sites and removed the major portion of the populations at Iwayama Pass, north of Babelthuap, and in several other localities. They removed more than 650 specimens from the Babelthuap population. Fishermen were asked to report other large concentrations of *A. planci* to the Fisheries Department in Koror. This program is still active under the direction of P. Wilson.

6.4.7 Pingelap.

(See Ifalik, Paragraph 6.4.3:) The development of the population along the southern portion of the atoll should be monitored.

6.4.8 Ponape.

Ponape is on the verge of developing a tourist industry. Fishing is also a valuable and growing industry on this island. The reefs are seriously infested with *Acanthaster planci.* Control action should begin as soon as possible. The large starfish population and the depth at which the animals occur necessitate SCUBA diving techniques. Initial efforts at control should concentrate on the large front on the northern, outer barrier reef. More extensive survey ,work must be completed on this large island, but the initial results suggest that Ponape still retains some of the best developed and least explored coral reefs in the U. S. Trust Territory.

6.4.9 Rota.

The small size of Rota and its proximity to Guam simplify control logistics. Rota is now a growing center for tourism. The lush coral. growth at Poniya Point should be preserved as a tourist resource. A team of two control divers should be able to eliminate the major populations of *canthaster planci* on Rota in a few months.

6.4.10 Saipan.

Only small portions of the reefs on the leeward side of Saipan survive. The reefs constitute an important asset in Saipan's tourist industry and should be protected. SCUBA diving techniques and Formalin guns are needed for prompt control.

6.4.11 Tinian.

Since most of the reefs of Tinian have been subjected to *Acanthaster planci* predation and since the islanders are not active fishermen, no control action need be instigated there against *Acanthaster planci*. It would be particularly valuable to survey the reef periodically to study reef recovery or the long-term balance of the residual *Acanthaster planci* population.

6.4.12 Truk.

Large patches of fringing reefs and much of the barrier reef remain in normal condition. Fishing is an active and expanding industry in Truk and tourism is only beginning.The living reefs, therefore, constitute a valuable asset to Truk and should be protected from continued damage by *Acanthaster planci* The large starfish populations will require SCUBA divers using formalin guns for initial control activities. Reefs bordering or close to the major high islands should receive first attention. The large front west of Pis Island should be eliminated as soon as possible.

6.4.13 Woleai.

(See Ifalik,Paragraph 6.4.3..) It was McCloskey's opinion that the coral was in no immediate danger from excessive *A. planci* predation on Woleai. Some disagreement existed between members of the team about the relative threat of the large starfish population along the western portion of the lagoon. Another reconnaissance is highly recommended in a year or two.

6.4.14 Yap.

Blasting and dredging activities were scheduled to begin in Yap within the next few months. There would be great value in observing the blasting activities and determining if *Acanthaster planci* subsequently increases in that vicinity.

6.4.15 Other Islands.

Midway shows no evidence of infestation inside the lagoon and requires no immediate action. The large size of the Hawaiian Islands requires additional survey time. Surveys and studies are still continuing, particularly in the vicinity of a large population on Molokai.

Kwajalein appears, on the basis of the survey, to have a normal population of *Acanthaster planci* and requires no immediate action.

Majuro and Arno have large populations of *Acanthaster planci*. While they are not yet of major infestation proportions, they are doing considerable damage to the reefs. Large amounts of dead coral were reported and although these could not be correlated directly with *Acanthaster planci* predation, the reported nature of the kill strongly suggests that this is the cause. Branham's report referred to "evidence of siltation" near some of the dead areas. Additional information is being sought relative to this. Regardless, the large population near the windward pass at Majuro is detrimental to the preservation of the very lush and attractive coral reef, which should be of particular economic potential as a developing tourist attraction, and is a favorable recreational area. The starfish population at Arno should be surveyed later and studied in more detail, but the population at Majuro, according to Chesher, constitutes an economic liability that should be removed.

In summary, islands that need control activities are Guam, Rota, Saipan, Palau, Truk and Ponape. Control activities have started at Guam and Palau. A second survey, after a year or more, is needed for Kapingamarangi, Nukuoro, Wolea , Mokil and Pingelap. Tinian, Ant and Kuop should be reserved as research areas, as should portions of Guam and Palau. Educational programs should be instituted throughout Oceania so that future population explosions or presently unknown infestations will be reported.

7. STUDY PARTICIPANTS

Figure 22 identifies the key personnel who participated in the overall survey of Pacific islands for *Acanthaster planci* and depicts their roles in the program.

Anderson,G.L. Research Assistant, University of Puerto Rico.: B.A. (Geology), Gustavus Adolphus College, 1968; Candidate for Masters Degree (Physical Odeanography), University of Puerto Rico, 1967-1969. Area of Specialization: Marine Geology.

Antonius, A. Research Professor of Marine Ecology, Instituto Oceanografico, Universidad de Oriente, Venezuela. M.A. (Zoology, Paleontology, and Animal Behavior), University of Vienna, 1964; Ph.D. (Zoology, Paleontology, and Animal Behavior), University of Vienna, 1968. Area of Specialization: Coral Ecology.

Banner, A.H. Professor of Zoology, University of Hawaii, Marine Biologist, Hawaii Institute of Marine Biology, University of Hawaii. B.S., University of Washington, 1935; M.S., University of Hawaii, 1939; Ph.D., University of Washington, 1943. Area of Specialization: Coral Reef Biology.

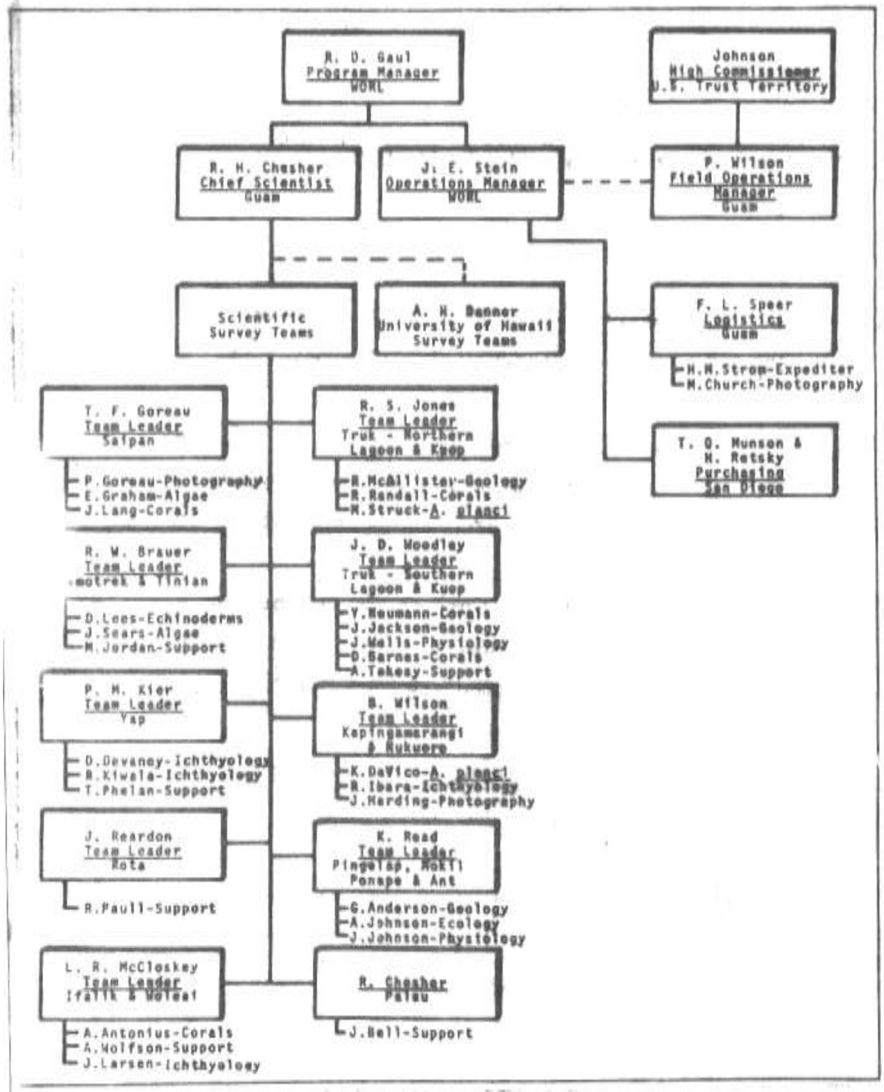

Figure 24. Organization of Field Survey.

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Barnes, D.J. Research Assistant in Physics, University of Newcastle upon Tyne, England. Area of Specialization: Coral Growth.

Branham, M.B. ;Assistant Professor, Department of Zoology, University of Hawaii. B.S., Florida State University,: 1956; M.S „ Florida State University, .:1958; Ph.D., Florida State University, 1963; Postdoctoral N.I.H. Fellowship, Institute of Animal Genetics, Edinburgh, 1965-1967. Area of Specialization: Genetics.

Brauer, R.W. Director,; Wrightsville Marine Bio-Medical Laboratory; Professor of Physiology and Pharmacology, Duke University; and Research Associate, School of Veterinary Medicine, University of California. A.B. (Chemistry), Columbia University, 1940; M.S. (Biochemistry), University of Rochester, 1941; Ph.D. (Biochemistry), University of Rochester, 1943. Area of Specialization: Physiology.

Chave, K.E. Professor of Zoology, University of Hawaii. Area of Specialization: Coral Reef Ecology.

Chesher, Richard H. Associate Professor of Zoology, University of Guam. B.Sc. (Zoology), University of Miami, 1962; Ph.D. (Marine Sciences), Institute of Marine Sciences, University of Miami, 1967;

P.S.F. Postdoctoral Fellow, Harvard University, 1963-1964.Area of Specialization: Echinoderm Ecology and Systematics.

Church, M. Field Engineering Specialist, Westinghouse Ocean Research Laboratory. Area of Specialization: Phbtography.

Devaney. D.M. Invertebrate Zoologist, Bishop Museum; National Research Council-Smithsonian Research Associate, Division of Echinoderms, Smithsonian Institution A.B. (Biology), Occidental College, 1960; N.A. (Zoology), University of California, Los Angeies, 1962; Ph.D. (Zoology), University of Hawaii, 1968. Area of Specialization: Systematic Zoology, Zoogeography and Ecology.

DaVico, K. Machinery Group Training Supervisor, U.S.N. Ship Repair Facility, Guam. Area of Specialization: Support Control Agent, 1968-1969 Acanthaster Research Control Program, Guam.

Gaul, R.D. Manager and Senior Scientist, Westinghouse ocean Research Laboratory. B.S. (Civil Engineering), Texas A&M University, 1955; M.S. (Physical Oceanography), Texas A&M University,.1957; Graduate Study (Physical Oceanography) Scripps Institution of Oceanography; Ph.D. (Physical Oceanography), Texas A&M University, 1967. Area of Specialization: Physical Oceanography.

Goreau, P.D. Underwater Photographer, University of West Indies. Area of Specialization: Photography.

Goreau, T.F. Professor of Marine Sciences, University of the West Indies; Professor of Biological Sciences, State University of New York at Stony Brook; Director, State University of New York-University of the West Indies Marine Laboratory, Discovery Bay-. B.A., Clark University, 1946; M.Sc., Yale University, 1947; Ph.D., Yale University, 1956. Area of Specialization: Physiology of Corals.

Graham, E.A.R. Physiology Department, University of the West Indies. Area of Specialization: Ecology and Systematics of Calcareous Algae.

Harding, J.H. Photojournalist, John Harding Underwater Photography, Glebe, Australia. Area of Specialization: Underwater Photography.

Ibara, R. Research Assistant, University of California, Santa Barbara. Candidate for Ph.D., University of California, Santa Barbara.. Area of Specialization: Ichthyology.

Jackson, J.B.C. Research Assistant, Kline Geology Laboratory, Yale University. Candidate for Ph.D., Yale University: Area of Specialization. Geology.

Johnson, A. C. Research Assistant, Marine Institute, Northeastern University. Candidate for Ph.D. - Area of Specialization Marine Ecology.

Johnson, J. Research Assistant, Department of Biology Boston University. Candidate for Ph.D. Area of Specialization: Biochemistry.

Jones, R.S. Professor of Zoology and Director, Department of Marine Studies, University of Guam. Ph.D., University of Hawaii Area of Specialization: Ichthyology.

Jordan, M.R. Research Assistant, Wrightsville Marine BioMedical Laboratory; Principal Field Agent, Cape Fear Specimen Co. Undergraduate Studies (Marine Biology), University of North Carolina at Wilmington; Graduate of Coastal School of Deep Sea Diving, Oakland, California. Area of Specialization: Support.

Kier, P.M. Chairman, Department of Paleobiology, U.S. National Museum, Smithsonian Institution. B.S., University of Michigan, 1950; M.S., University of Michigan, 1451; Fulbright Scholar, Cambridge, 1951 - I952; Ph.D., Cambridge, 1954. Area of Specialization: Fossil and Recent Echinoderms.

Kiwala, R. Scientific Collector, Scripps Institution of Oceanography: Area of Specialization: Support.

Lang,J.C. Research Assistant, University of the West Indies. M.Sc., Yale.University Candidate for Ph.D., Yale University. Area of Specialization: Coral Ecology.

Larsen, J.A. Research Assistant, Florida Atlantic University. B.S., (Biology) Florida Atlantic University.. Area of Specialization: Ichthyology.

Lees, D.C. Data Analyst, Marine Environment Division, U.S. Naval-Electronics Laboratory Center: B.A. Zoology), University of California, Santa Barbara, 1961; Candidate for M.S. (Biology), San Diego State College. Area of Specialization: Echinoderm Ecology

Losey, G.S. Research Fellow, National Institutes of Medical Sciences; Research Affiliate, Hawaii Institute of Marine Biology, University of Hawaii Ph.D., University of California, San Diego, 1958. Area of- Specialization: Ecology.

McAllister, R.F. Professor of Oceanography, Florida Atlantic University; Principal Investigator and Project Director, Florida Ocean Sciences Institute. B.Sc. (Geology), Cornell University, 1950; M.S. (Geology), University of Illinois, 1951; Graduate Studies (Marine Geology), Scripps Institution of Oceanography, 1951 - 1954; Ph.D.,(Geological Oceanography), Texas-A&M University, 1958. Area o£ Specialization: Oceanography

McCloskey,, L.R. -Research Associate, Woods Hole Marine Biological Laboratory. B.A. (Biology, honors), Atlantic Union College, 1961: M.A. (Zoology), Duke University, 1965; Ph.D. (Zoology), Duke University, 1947. Area of Specialization: Invertebrate Physiology and Ecology.

Munson, T.O. Staff Scientist, Westinghouse Ocean Research Laboratory, A.B. (Zoology), University of California, Berkeley, 1963; M.S. (Biochemistry), University of Wisconsin, 1965; Ph.D. (Biochemistry), University of Wisconsin, 1968. Area of Specialization: Biochemistry.

Neumann, Y. Research Assistant, University of the West Indies. B.A., Tel Aviv University; M.Sc., Tel Aviv University; Candidate for Ph.D., University of the West Indies: Area of, Specialization: Coral Ecology

Phelan, T. Research Assistant, U.S. National Museum, Smithsonian institution. Area of Specialization: Echinoderms.

Paull, R.C. Research Associate, Department of Biology, Southeastern Massachusetts University; Director, Marine Research Associates. B.A. (Biology), Harvard Universtiy, 1963; LL.D., Harvard University. Area of Specialization: Aguaria Management.

Randall, J.E. Marine Biologist, Hawaii Institute of Marine Biology, University of Hawaii; Ichthyologist, Bishop Museum. B.A., University of California at Los Angeles, 1950; Ph.D., University of Hawaii, 1955. Area of Specialization: Ecology and Systematics of Tropical Marine Fishes.

Randall, R. Science Teacher, George Washington High School, Agana, Guam. Candidate for M.Sc., University of Guam. Area of Specialization: Systematics and Ecology of Pacific Corals.

Read, K.R.H. Associate Professor of Biology, Boston University; Research Director, New England Aquarium. B.Sc,, McGill University, 1953; S.B.., S.M., Massachusetts Institute of Technology, 1956; Ph.D. (Biology), Harvard University, 1963; Postdoctoral Studies, Harvard University and Harvard Medical School, . 1963-1964. Area of Specialization: Biochemistry and Marine Ecology.

Reardon, J.J. Professor of Biology and Chairman of Department, Southeastern Massachusetts University. B.S., Harvard University; M.S., Harvard University; Ph.D., University Of Oregon; Postdoctoral Studies, Stanford University Marine Laboratories and Cornell University. Area of Specialization: Marine Ecology.

Retsky, H. Headquarters Support Engineer, Marine Operations Department, Westinghouse Advanced Electronic Technology Certificate, RCA Institutes, 1958; Undergraduate Studies, (Business Management), Johns Hopkins University. Afea of Specialization Finance.

Sears, J.F. B.A. (Biology), University of Oregon, 1964, M. S., University of Massachusetts, 1966; Candidate for Ph.D., University of Massachusetts. Area of Specialization: Algae.

Snider, H. Research Assistant, Institute of Marine Biology, University of Hawaii. Candidate for Ph.D. Area: of Specialization: Ecology.

Speer, F:L. Field Engineering Specialist, Westinghouse Eclectic Corporation: Area of Specialization: Logistics.

Stein, J.E. Senior Scientist, Westinghouse Ocean Research Laboratory. B.S., University of New Hampshire, 1949; M.S., University of New Hampshire, 1952; Ph.D, Texas AVM University, 1957. Area of Specialization: Aquatic Environmental Management.

Strom, H.M., Jr. Biology Teacher, Government of Guam. B.A., Stanford University, 1963; Diploma in Education, University of East Africa, Uganda; Graduate Studies (Biology), University of Guam. Area of Specialization: Support.

Struck, R. Communications. Technician Second Class, U.S. Navy. Area of Specialization: Field Operations Manager 1968-1969 Acanthaster Research Control Program, Guam.

Takesy, A. Trust Territory Student from Truk. Candidate for B.Sc. (Zoology), University of Guam. Area of Specialization: Support.

Wells, J.M., Jr. Research Assistant, Scripps Institution of Oceanography. B.S. (Biology), Randolph Macon College, 1962; Candidate for Ph.D. (Marine Biology),, Scripps Institution of Oceanography. Area of Specialization: Ecology.

Wilson, B.R. Curator of Molluscs, Western Australian Museum. B.Sc. (Second Class Honors), University of Western Australia, 1960; Ph.D., University of Western Australia, 1966. Research Fellow in Pharmacology, Museum of Comparative Zoology, Harvard University, 1964: Area of Specialization: Molluscs.

Wilson, P. Manager, Fisheries Biology, U.S. Trust Territory Administration, Koror, Palau. Area of Specialization: Fisheries.

Wolfson, A.A. Research Assistant, Scripps Institution of Oceanography. B.A. (Zoology), University of California, Santa Barbara, 1966; Candidate for Ph.D. (Marine Biology), Scripps Institution of Oceanography. Area of Specialization. Ecology.

Woodley, J.D. M.A., Oxford University; Ph.D. Oxford University, 1967. Area of Specialization: Ecology and Morphology of Echinoderms.

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Bailey, J.H. Christofferson, J.P. Galloway, P.C. Gossett, J. Hashimoto, W.Y. Lyman, D.X. Maciolek, J. Members of Koral Kings Club of Midway, Mense, D.C., Pardini, A.A. Preston, E. Reese, E. Rice, M. Warschauer, R:

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