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OBSERVATIONS ON THE GREEN SEA TURTLE (*CHELONIA MYDAS*) IN WESTERN SAMOA.

—The Western Samoa Fisheries Division conducted a marine turtle research program from October 1970 to May 1973. The biology and ecology of the endangered hawksbill turtle, *Eretmochelys imbricata*, has previously been described (Witzell and Banner, 1980), and although the hawksbill was the only species of marine turtle found nesting in Western Samoa, the green turtle, *Chelonia mydas*, is well known by the Samoan fishermen.

Published information on the ecology and natural history of marine turtles in the central South Pacific islands is severely limited, generally consisting of short notes (Sachet, 1954; Bustard, 1970; Raj, 1976; Balazs, 1978; Witzell, 1981). In addition, H. Hirth and J. Hendrickson reported on the marine turtle resources of the South Pacific islands in unpublished reports, 1971 and 1972 respectively, prepared for the Regional Fisheries Development Agency Project, Food and Agriculture Organization of the United Nations.

Materials and methods.—Observations on the Western Samoa green turtle were made incidentally while studying the nesting hawksbill turtle on three islets off the eastern coast of Upolu Island. These observations were made from small outboard powered boats, outrigger canoes and by diving in and around reefs and reef passages. Monthly low level flights in a small single engine airplane were made around the country and market surveys were conducted in the capital city of Apia. Also, specimens captured by local village fishermen were examined. Coloration and morphometric measurements were recorded whenever possible in order to determine if the Western Samoa green turtles belonged to any identifiable subspecies or nesting population. Although there were many sightings of green turtles, an observation here is defined as an encounter of sufficient duration, whether in the ocean or on land, in which to note and record size, coloration, sex and behavior.

TABLE 1. MORPHOMETRIC MEASUREMENTS OF WESTERN SAMOA GREEN TURTLES. (Maximum straight line measurements in centimeters.)

	Carapace length	Carapace width	Plastron length	Head width	N
Adult females					
Mean	96.9	76.8	80.1	11.5	9
Range	91.5–109	70–84.5	72.5–92	11–12	
Adult males					
Mean	92.2	71.2	73.1	11.4	5
Range	86.5–102	68–79.5	70–78	11–12	
Juveniles					
Mean	38.2	33.6	31.9	—	16
Range	30.5–44	26.5–39	25.5–36	—	

Coloration and morphology.—The majority of green turtles closely observed (Table 1) generally fell into two size categories (straight carapace length measurements): 1) juvenile turtles 30–45 cm, and 2) adult turtles 80+ cm.

A total of 63 juvenile turtles were observed, of which 16 were measured and 5 tagged. There were 36 observations of adult females, with 9 measured and 3 tagged, and 14 observations of adult males, 5 measured and 1 tagged (Table 1).

The coloration of the juvenile green turtles observed, especially the smaller specimens, was found to be fairly uniform: the carapace and top of head light brown; the side of the head and dorsal surface of the flippers dark brown; the beak brown; the plastron, throat and ventral surface of the flippers entirely creamish-white, except for a few light brown scales distally located on the flippers. The larger juvenile turtles occasionally had yellow or black streaks radiating peripherally on the carapace shields, the general color pattern of the entire dorsal surface becoming darker. All interscute areas on the carapace and interscale areas on the head and flippers are well defined and creamish-white.

Adult green turtle coloration, in contrast to that of the juveniles, shows considerable variation: the background coloration of the carapace and top of head ranges from dark brown to light green, generously infused with combinations of yellow, brown and black; beak brown; plastron, throat and ventral surface of the flippers creamish, except for scattered dark centered scales on the flippers. There appears to be no easily recognizable difference in coloration between sexes, as described by Hirth and Carr (1970) and Frazier (1971) for Indian Ocean green turtles, although the sample size (Table 1) of closely observed turtles of both sexes is too small to state definitively. Also, there is no evidence that the Western Samoa green turtles belong to any particular subspecies based on coloration as described in Hirth (1971).

Morphometrically, no recognizable differences are readily apparent between these Western Samoa green turtles (Table 1) and other populations of this species as described in Hirth (1971). However, there were not enough turtles measured of all sizes to conduct proper morphometric analysis for population comparisons as attempted by Hughes (1974) and described by Witzell (1980) for other cheloniids.

Ecology.—Juvenile green turtles were seen year-round on the reefs around Western Samoa, and tended to congregate around reef passages. These turtles were shy and difficult to observe closely for extended periods before swimming away, except at night when they were seen sleeping under coral ledges 5–15 m underwater. The carapaces of these juveniles were clean; sessile organisms such as barnacles, bryozoans and algae were not attached. However, damaged rear flippers, presumably healed shark bites, were occasionally seen. Underwater observational evidence, supported by statements from fishermen, suggests that these juveniles may not move far from their foraging territories.

Adult green turtles were seen infrequently year-round near Samoan reefs except between December and February, when they congregated in substantial numbers near the reef passages which connect with large lagoons located at the eastern and western ends of Upolu Island. These adults were seen feeding on the marine angiosperm, *Syringodium isoetifolium*, which grows in the lagoon shallows, breaks off and drifts out to sea with each tide to form distinct debris lines. Adult female turtles out-

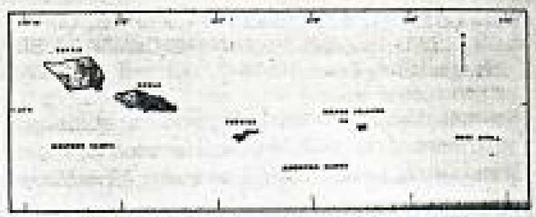

Fig. 1. The Samoa Archipelago.

numbered males along these debris lines approximately 2:1, but neither courtship or mating behavior was seen. These large turtles, like the juveniles, were seen sleeping under coral ledges at night near reef passages. They were also free of attached organisms, and had no noticeable predation damage.

The origin and destination of these adult turtles is not known but they may be part of the population reported in Sachet (1954) to nest in August and September on nearby Rose Atoll, American Samoa (Fig. 1). It would seem likely then that the resident Western Samoa juvenile green turtles may be the progeny of the Rose Atoll nesting population. There have been no reported returns of tagged Samoan green turtles, either nationally or internationally, and no reported captures in Western Samoa of turtles tagged elsewhere.

The Samoan people recognize the difference between green and hawksbill turtles as two forms of a single sea turtle stock. Therefore, the relatively large numbers of juvenile green turtles found year-round on Samoan reefs hinder any conservation efforts for the declining nesting population of hawksbills. Similar situations may exist elsewhere in the Pacific, and can only be resolved by long term conservation education of the local people and by extensive marine turtle surveys throughout the Pacific region.

Exploitation.—The majority of the green turtles seen harvested in Western Samoa were captured by skin divers. The method most frequently used was to affix a high intensity gas lamp to the bow of their outrigger canoe at night and swim along the reef edge looking for sleeping turtles. Large turtles were usually speared in the neck and juveniles were either taken by spear or by hand. The instability of the Samoan outrigger fishing canoe and the flimsy barbless spears used generally precludes capturing large thrashing turtles. Turtle nets were not seen fished, although one group of fishermen on the island of Savai'i reportedly encircles adult green turtles every December with a village owned net. These netted turtles are believed by the fishermen to be attracted to floating taro leaves which they place on the water.

Marine turtles are a valuable resource economically, bringing high prices in the market. Consequently, most turtles observed captured by the rural fishermen were transported by bus to Apia, where they were usually sold to affluent Samoans for consumption at important celebrations.

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AN UNUSUAL AGGREGATION OF ADULT *NOTOPHTHALMUS VIRIDESCENS*.—On 19 March 1980 three large, dense aggregations of adult *Notophthalmus viridescens* were observed in a pond in Leverett, Franklin Co., MA. These clusters resembled those reported and illustrated by Coates, Benedict and Stephens (1970) in *Taricha granulosa*, but have not, to our knowledge, been reported in *N. viridescens*. The aggregations occurred in 18 cm of 5 C water in an ice-free area near a spring at the pond's edge, where many individuals but no clusters had been observed on 13 January 1980.

On 20 March 1980 the temperature 20 cm below the water surface near one of the clusters was 6 C while the temperature in the mass was 8 C. No difference was detected between the water temperature (6 C) in and surrounding another cluster. Some newts were active, swimming to the surface for air and thrashing about while ingesting their molts. Solitary individuals and a few courting pairs were distributed throughout the ice-free area. With three scoops of a dip net, 589 newts were collected from a single cluster (measuring approximately 45 × 30 cm), sexed, and released. The sample contained 299 females (51%) and 290 males (49%). The following morning, after a period of heavy rain, the disturbed aggregation had reformed. By 30 March, when the water temperature was 7 C, it had dispersed.

Twenty newts, in the vicinity of the clusters, were collected on 19 March. Dissection revealed 7 females with mature eggs and 13 males with two-lobed testes. Seventeen of the newts had molt material in their digestive tracts, and one specimen had ingested a sphaeriid clam.

The site of the clusters was again visited on 14 May. No newts were seen in the area where the clusters had been, but a sample collected about 30 m away and 5 m out from the shore in a mass of vegetation contained 37 males and 30 females. The water temperature 15 cm below the surface was 14 C and the water depth was approximately 1 m. Neither this nor the 20 March sample from the cluster differed significantly from a 1:1 sex ratio (chi-square tests, $P > 0.3$).

Smaller winter aggregations of adult *N. viridescens* have been reported. Morgan and Grierson (1932) described clusters of 20–40 semiactive, easily disturbed newts beneath flattened

The view which I here take of the application of the Samoan word *va*,
is confirmed by the word *pada* in the Mota language of New Guinea; *pa-*
da is the same root-word as *va*, and means 'the space between earth and
sky.'
2. *Tuli* or *Turi* is a common bird in Polynesia; it is the *Charadrius ful-*
vus, the 'Golden Plover' of Australia. Every family in Samoa has its
own 'tutelary animal'—*aitu*—a pigeon or some other bird, a fish, &c.
This *aitu* is specially reverenced by the members of the family from
generation to generation, and none of them will ever mention its name.
A convert renounces heathendom by publicly destroying his *aitu*; the
spectators stand by, expecting that he will immediately fall down dead.
It is an odd coincidence that some of the Australian blacks connect
this 'plover' with the acts of Creation. The tribe at Lake Tyers, Victoria,
call the 'grey plover' *bunjil borandang*. Now *Bunjil* is the Victorian
name for the Creator of all things, and the verb *yunjiliko* means 'to make,
fashion, create.'
3. *Tangaloa* is the chief god of the Polynesians. In this poem, line
90 and elsewhere, he is represented as a quiescent god, the origin and
cause of all things. In these respects he resembles the Indian Brahmā.
Tangaloa loves absolute rest (line 12) and peace (line 108). Although
he rests in the heavens, he intervenes in the affairs of men (lines 64 and
115); in his active manifestations he has many forms, as T. *fa'a-tutupu-*
nu'u, T. who 'makes (*fa'a*) the lands (*nu'u*) spring up' (*tutupu*), T.
savali, T. who 'walks,' that is, 'the messenger' or 'ambassador,' *T. totonu*,
T. who puts everything 'straight,' *T. le-fuli*, T. 'the immoveable,' T.
asiasi-nu'u, T. 'the visitor-of-lands,' the omnipresent.
4. The 'wandering current' here seems to be the great Equatorial
current, which crosses the Pacific from east to west.
5. In the text, the word *malolo* means 'to rest absolutely,' 'to be quies-
cent,' but *mapu* means 'to rest from work,' sc. here, from the work of
Creation.
6. *Manuka*, in Samoan *Manu'a*, is not 'great' because of its size, for the
three islands are small (see note 3 on page 203); but it is 'great' in
importance, as the first resting place of the Polynesian race; like the
Delos of ancient Greece, it is the sacred hearth-stone of the race.
7. The Polynesians, like the Gauls and other ancient nations, gave pre-
cedence to the moon, and counted by nights, not by days. The sun, they
say, is 'changeless,' like a statue, and every day is very much like another;
whereas the moon changes, and they can reckon by its phases.
8. The 'waters' here are *vai*, 'fresh water,' and in the next line, *tai*,
'salt water,' is the 'sea.' The poem makes a distinction between *vai*, the
waters "above the firmament" (Genesis I.), and *tai*, the waters below;
the space between is *le Va*. The science of this passage seems to be cor-
rect enough; for as soon as the sun (line 20) sends his hot beams on the
ocean, vapours arise and form reservoirs of fresh water in the clouds above.
9. There is, in Savai'i, a lofty mountain, called *Mauga-loa*.
10. The two *Samatas* are now villages on the south side of Savai'i; at
the west end of the island is the descent to Sa-Fe'e, the Samoan Hades.
Alamisi is another place on the island; the word means a 'land crab';
but the Samoans have a tradition that Alamisi was a quadruped brought
down from heaven for them to feast on long ago.
In line 32, it will be observed that the Fijis, which are Melanesian
islands, are included in Tangaloa's realm, and there he dwells. This is
quite in harmony with statements made in other Samoan poems. In one
of these, Tangaloa in anger changes the colour of two sons of his, the one
he makes brown and the other black. (See note on the name Sina, page
199.)

During the last three and a-half years the value of ore and bullion dispatched from the field was £4,510,966. The value of imports for the same period, £3,344,511.

SOME FOLK-SONGS AND MYTHS FROM SAMOA,

Translated by Revs. T. Powell and G. Pratt,

With an Introduction and Notes by Dr. John Fraser.

[*Read before the Royal Society of N.S.W., November 5, 1890.*]

Introduction.—The Samoans are poets. Their language consists mostly of vowel and liquid sounds, and, for this reason, is called the Italian of the South Seas; its words readily adapt themselves to figurative applications of their meaning; the imagery of the language is oriental; these and other qualities render it a fit vehicle for poetical composition. There is among the Samoans a privileged class of bards who alone know, and can recite, the genealogies of the native chiefs and the legends about the gods; yet the common people, when assembled together, turn ordinary passing events into song, and sing in concert to lighten their toil, while they are engaged in heavy work out of doors, or are using their paddles on board their vessels.

Samoan poetry sometimes has rhyme, but it has no metre; from the nature of the language, the poetry can scarcely have metre; and the lines of a poem may be of very unequal length. A few voices commence the song, and sing a portion of it; then all the rest join in full chorus; along with this, there is dancing and the accompaniment of a native drum or the rhythmical tapping of sticks on a roll of native mats. Of this sort of song—the most common of all—are the Vii and the Muli'au, in praise of chiefs. The Fatu, the Langisolo, and the Vila have no dancing; they are the funeral dirges of chiefs. The Fangono, of which the following love-tale is an example, is a kind of recitative, with bits of song in it here and there. The Solo is a song in praise of the islands or lands over which the chiefs rule, and is sung by one person; the Tala is any narrative tale.

Mr. Powell went to the Samoan group in 1844 and left about five years ago; he died recently in England. He was settled as a missionary on

REEF AND SHORE FAUNA OF HAWAII

Section 1: Protozoa through Ctenophora

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PROTOZOA

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PROTOZOANS are acellular animals, generally microscopic. Many of the functions performed by tissues and organs in more highly evolved animals are performed by subcellular organelles in protozoans. They inhabit fresh and marine waters; some are free-living; many are parasitic; and a number are terrestrial. The free-living forms are well represented in the sea; there are benthonic groups found at most depths and upon most kinds of substrate; and there are planktonic groups which float at various levels. Their study and identification require the use of a microscope. Protozoa fall naturally into four major taxonomic units; the recent classification of Honigberg and others (1964) considers the following units to be subphyla:

Subphylum SARCOMASTIGOPHORA
Subphylum SPOROZOA
Subphylum CNIDOSPORA
Subphylum CILIOPHORA

Other than the Folliculinidae (subphylum Ciliophora) and the Foraminifera (subphylum Sarcomastigophora)—two groups possessing hard shells—the marine protozoans have been poorly studied in Hawaii and are not considered here.

Subphylum CILIOPHORA
Class CILIATEA
Order HETEROTRICHIDA

Family **Folliculinidae**

Eight species of folliculinids are known from Hawaii, but, because the group has been largely overlooked, additional records are to be expected. These "bottle animalcules" are sessile in one stage of life and secrete colored glassy-appearing tubes, or loricae, which are firmly cemented to various substrates. They have been

*The author wishes to thank Miss Ruth Todd for reviewing the manuscript and for making valuable suggestions on the species identifications. The majority of the foraminiferal material was collected by URS Research Company of San Mateo, California, for the Hawaiian Electric Company. Additional specimens identified by Dr. G.L. Harrington were provided by Bishop Museum. Stereoscan photographs of foraminifers were taken by Fred Doroshow and Jay Phillips in the Electronics Research Laboratory, University of California, Berkeley, on a machine supported by NIH Grant No. GM-17523. URS Research Company generously provided financial assistance for photography and manuscript preparation. Photographic prints were made by Robert Pitt.

collected from such varied material as submerged wood, the stems and leaves of marine plants, and the external surfaces of living molluscan shells and crustacean carapaces, as well as being established on inorganic substrate. They are known from shallow water estuaries, tide pools, and other marine habitats.

Folliculinid loricae vary in structure from simple to complex. There is often a twofold division of the lorica into sac and neck (Pl. 1). The sac is somewhat variable within a species, depending upon the convolutions of the substrate to which it is attached, but the neck is more consistent in its characters. The morphology of the neck and the presence and nature, if any, of internal valves dividing the lorica are important taxonomic criteria. Color, although not a primary criterion, is often consistent within a species or even a genus, and serves as a useful clue to identification. Loricae often appear in various shades of bottle green in transmitted light and red in reflected light.

Folliculinids have two morphological life stages: a nonfeeding, free-swimming stage, and a sessile, feeding stage with a lorica. A "swimmer," upon settling, usually secretes a new lorica, but specimens have been known to enter an abandoned lorica of the same species. The "swimmer" then metamorphoses into the feeding sessile stage characterized by peristomal lobes on its protoplast. The size, relative proportions, and nature of projections, if any, of the peristomal lobes are taxonomically significant. The shape of the nucleus—either subspherical or moniliform—is also important.

The classification of the folliculinids is based upon the morphology of both the lorica and the protoplast. The swimming stage is difficult to identify, and empty loricae cannot always be identified to species.

Hawaiian records are presented by Andrews (1944) and Matthews (1953, 1962, 1963, 1964) where details of morphology, substrate preference, and general biology are given.

KEY TO HAWAIIAN FOLLICULINIDAE

1. Lorica possesses internal valves 2
   No internal valves 3
2. Lorica differentiated into sac and short oblique neck
   . . . . *Halofolliculina annulata* (Andrews 1944)
   (Pl. 1, Fig. 4) [see Andrews, 1944; Matthews, 1964 and 1968]
   Lorica rectilinear with a pronounced swelling at base of neck
   . . . . *Parafolliculina violaceae* (Giard 1888)
   (Pl. 1, Fig. 6) [see Matthews, 1962 and 1968]
3. Lorica not divided into distinct sac and neck; an upright slender tube of gradually increasing diameter attached at apex to substrate
   . . . . *Metafolliculina nordgardi* (Dons 1924)
   (Pl. 1, Figs. 1, 2) [see Matthews, 1962 and 1964]
   Lorica divided into distinct sac and neck 4
4. Spiral whorls on neck of lorica 5
   No spiral whorls on neck of lorica 7
5. Neck oblique to substrate . . . . *Eufolliculina lignicola* (Faure-Fremiet 1936)
   (Pl. 1, Fig. 7) [see Matthews, 1963 and 1968]
   Neck perpendicular to substrate 6

6. Neck short with 2 to 3 spiral whorls . . . . *Lagotia viridis* Wright 1858
(Pl. 1, Figs. 8, 9) [see Matthews, 1963, 1964 and 1968]
Neck long with 6 to 7 spiral whorls . . . . . . *Metafolliculina andrewsi* (Hadzi 1938)
(Pl. 1, Fig. 3) [see Matthews, 1963 and 1968]
7. Lateral pouches in sac . . . . *Mirofolliculina limnoriae* (Giard 1883)
(Pl. 1, Fig. 5) [see Matthews, 1963 and 1968]
No lateral pouches; neck very short; foot spatulate
. . . . *Ascobius simplex* (Dons 1917)
(Pl. 1, Figs. 10, 11) [see Matthews, 1953]

Subphylum SARCOMASTIGOPHORA
Class RHIZOPODEA
Order FORAMINIFERA

Among the more common Hawaiian marine protozoans are the Foraminifera. They are an order of rhizopods related to the common amoeba, from which they are distinguished by the construction of a test (shell) of one sort or another, by the granular protoplasm, and by the prolongation of the protoplasm into long, thin pseudopodia which branch and anastomose, as opposed to the rather short, stubby pseudopodia of the amoeba. Foraminifera—informally termed "foraminifers," and often shortened to "forams"—are exclusively marine or brackish water organisms that have adapted themselves to nearly every environment of the marine world. Most species are benthonic, either firmly attaching to the substrate or to algae, or possessing free tests and moving slowly about the bottom in search of food. A few species, often occurring in great numbers, are planktonic and float in the open ocean near the surface. Most foraminifers are in the 0.5 mm to 1.0 mm size range, but some are smaller; in tropical regions such as Hawaii, exceptionally large species of 10 mm or greater size occur. For sheer number of individuals, foraminifers are often the most abundant shell-forming organisms found in marine bottom samples.

PLATE I
PROTOZOA
Family Folliculinidae

Figure 1.—*Metafolliculina nordgardi* (Dons). Lateral view of specimen with two extensions to its lorica; after Matthews (1964).

Figure 2.—*Metafolliculina nordgardi* (Dons). Lateral view; after Matthews (1964).

Figure 3.—*Metafolliculina andrewsi* (Hadzi). Lateral view; after Matthews (1968); *a*, peristomal lobe; *b*, collar; *c*, spiral whorl; *d*, neck; *e*, moniliform nucleus; *f*, sac; *g*, foot.

Figure 4.—*Halofolliculina annulata* (Andrews). Lateral view of retracted individual; after Matthews (1968).

Figure 5.—*Mirofolliculina limnoriae* (Giard). Oblique ventral view; after Matthews (1968).

Figure 6.—*Parafolliculina violaceae* (Giard). Lateral view; after Matthews (1968).

Figure 7.—*Eufolliculina lignicola* (Faure-Fremiet). Oblique lateral view; after Matthews (1968).

Figure 8.—*Lagotia viridis* Wright. Oblique ventral view of a contracted specimen; after Matthews (1968).

Figure 9.—*Lagotia viridis* Wright. Lateral view of an extended specimen; after Matthews (1968).

Figure 10.—*Ascobius simplex* (Dons). Ventral view of a contracted specimen; after Andrews (1944).

Figure 11.—*Ascobius simplex* (Dons). Lateral view of the specimen shown in Fig. 10; after Andrews (1944).

All foraminifers possess a test of one sort or another: it may be composed entirely of a pseudochitinous material or may be of some other material laid upon a thin pseudochitinous base. The more complex test wall may be made up of foreign particles selectively chosen by the organism and embedded in a variety of cements, or it may be of calcite secreted by the organism itself. Many of the calcareous tests are perforated by pores distributed over all or a part of the test surface. The test is made up of one, a few, or many chambers, which may be assembled in any of numerous plans of growth. Many tests exhibit different plans of growth in a single specimen. For example, a genus may produce a planospirally coiled test when young but may later add a linear series of chambers to the coiled portion. One or more apertures open into the test from the exterior; these may be of many shapes and are found on various portions of the test. Most of the pseudopodia pass through the aperture. In some calcareous perforate genera, pseudopodia also stream through the pores, but many genera secrete pore plugs which effectively prevent this. The group takes its name from the foramina, or openings, which connect adjacent chambers. These are usually previous apertures but may, in part, result from secondary solution of the chamber wall. Surface ornamentation of almost infinite variety occurs among the various species.

Foraminiferal classification is based upon the nature of the test. Generic and suprageneric taxa are defined in decreasing significance by the possession of various combinations of wall composition, plan of growth, and nature and position of apertures. Foraminiferal species are defined on the basis of ornamentation, test size and shape, and relative proportions of various structural elements.

The empty tests of dead foraminifers are a major constituent of most marine sands in Hawaii. Beach sands are often in large part composed of the broken and tumbled tests of the most robust species, *Amphistegina madagascariensis*, and the thickened central portion of *Heterostegina suborbicularis*. Moberly, Baver, and Morrison (1965, p. 594, and Fig. 3 therein) indicate that in many cases foraminiferal tests compose 50 percent of all littoral sand grains on a given beach. Better preserved tests with a much greater species diversity can be obtained by dredging sand from submerged reef areas or by collecting from a thin surface layer along the strand line. The lightweight tests of foraminifers are sometimes worked into concentrated deposits along the shore by wave action. One of these species, *Marginopora vertebralis*, has received public attention as the "paper or sequin shell" used in the manufacture of one type of shell lei ("Hottest Protozoa Around," *Honolulu Star-Bulletin*, Oct. 14, 1974, p. B-1). Such necklaces have been made for generations by residents of the various Pacific Islands where the species occurs. *M. vertebralis* rarely exceeds 10 mm in diameter in Hawaii, but grows to 25 mm in more tropical areas such as the Great Barrier Reef and Tonga. In Australia it is known as the "mermaid's penny." The construction of these necklaces in Hawaii for sale in the tourist trade forms the basis of a small industry. Occasionally, planktonic species are driven ashore by currents and can be collected in large numbers along the strand line.

FORAMINIFERAL STUDY TECHNIQUES

Dead or preserved foraminiferal tests are best examined dry under a stereoscopic microscope. Magnifications from 20× to 100× are normally sufficient. The dry foraminifer-bearing sediment is sprinkled in a thin layer on a dark tray, to contrast with the predominantly light-colored tests, and individual specimens are manipulated with a moist, fine-pointed artist's brush. Single specimens or assemblages can be glued on 1" × 3" cardboard "micropaleontology slides" which are available in a number of formats. The best glue is a thin solution of gum tragacanth (used by druggists as a pill base). It is water soluble, dries clear, and does not shrink and crack specimens upon drying. Glued specimens may be easily reoriented by simply moistening with a wet brush. A drop of formaldehyde in the glue mixture will prevent the growth of bacteria. If muddy samples are to be examined, foraminiferal-sized particles can be concentrated by washing the mud through a 200-mesh-per-inch screen and saving the residue. If foraminifers are rare in a coarse sample, they can be concentrated by floating on heavy liquids, using caution to avoid contact with dangerous vapors. Carbon tetrachloride should not be used as a heavy liquid because it is very dangerous. Alternative heavy liquids include bromoform and perchlorethylene. Care should be taken to keep all equipment clean to avoid contaminating one sample with another.

The traditional technique for the recognition of specimens that were living at the time of collection consists of fixing the sample in 70 percent alcohol, subsequently soaking in a 1-gram-per-liter solution of Rose Bengal dye for 5 minutes, and then washing in water. The dye selectively stains certain proteins red. Care should be taken that a positive stain shows a jelled mass of protoplasm within the test, and not just proteinaceous layers of the test which are preserved long after death. Walker and others (1974) consider this method ineffective and recommend the use of formaldehyde as a preservative and Sudan Black B as a stain. Specimens must not be stored in the formaldehyde preservative, because calcitic components of the test will dissolve with long exposure.

Living specimens that have been collected without physical damage can be examined alive. Many will live for some time in culture dishes, and some have been successfully cultured under laboratory conditions. Some culture techniques are discussed by Arnold (1954, 1974), Ross (1972), and Röttger (1972).

Foraminiferal distribution may be quantified by estimating abundances or by counting specimens. The most commonly used specimen count is the so-called "foraminiferal number," the number of specimens per gram of dry sediment. It is not an ideal statistical tool, however, because it is dependent upon several coincidental variables, such as rate of sedimentation, sediment density, specimen displacement and sorting, and rate of destruction of empty tests, as well as upon such biologically significant factors as rate of reproduction and standing crop. It is largely used by paleontologists who sometimes extend the technique to their neontological studies. A more significant index of abundance is the number of living specimens on or below a unit area of substrate.

Todd (1961) estimates that only 1 percent of the foraminiferal specimens collected in a study of the Gilbert Islands were living when collected; Ross (1972) found that 60 percent were alive in samples from the Great Barrier Reef. The nonliving shells represent previous generations that may have been dead for several years. There is a possibility that such empty tests have been displaced by currents from the area in which they were living. A species can be considered to be in place for ecological studies if it is represented by a number of individuals, shows no signs of abrasion or size sorting, and has various growth stages present. A technique has been described for detecting specimens which were living at the time of collection. Live planktonic foraminifers are sometimes obtained in near-shore plankton tows when a fine mesh (less than 0.5 mm) is used, but they are more common in pelagic waters.

HAWAIIAN FORAMINIFERAL FAUNA

While a fairly uniform foraminiferal fauna exists throughout much of the tropical Pacific, Hawaii lies near the northern limit of this tropical region, and some species from the more southerly areas do not reach it. This fauna is designated the Indo-Pacific fauna by Cushman (1948). One distinguishing feature of this area, as well as of other tropical areas, is the presence of large numbers of species in shallow environments. More than 400 foraminiferal species have been recorded from Hawaiian waters less than 100 m in depth and any given sand sample may contain 100 or more species. Similar shallow environments from more temperate regions would contain only a dozen or so species. A second distinguishing feature is the presence of very large species, all of which are restricted to the tropics, and some only to the tropical Pacific. Several of the large endemic foraminifers are relics whose ancestors were widely distributed about the world in the geological past.

Our present knowledge of the Hawaiian foraminiferal fauna is based upon only a few published reports. Although Alcide d'Orbigny mentioned the occurrence of certain species in Hawaii as early as 1826, the first extensive account of Hawaiian forams was that of Brady (1884) (see also Barker, 1960) in his report on the collections of the *Challenger* Expedition. Station 260A of that expedition off Honolulu in 40 fathoms (73 m) remains one of the richest in terms of local reef species, even though many of them had been displaced from their normal habitat into the deeper water where they were collected. Rhumbler (1906) recorded a number of shallow-water species from Laysan Island, and Bagg (1908) recorded deep-water species collected about the islands by the U.S. Bureau of Fisheries vessel *Albatross*. The monumental work of Cushman (1910-1917) summarized these earlier publications and added many additional records from *Albatross* stations and from the numerous samples collected by the *Nero* while sounding the cable line from Honolulu to Midway. Later papers of Cushman (1924, 1925) also record Hawaiian species. Except for Edmondson's (1946) brief mention of a few species, no additional publications have appeared until very recently. Resig (1969, 1974) has studied the marginal marine faunas of Pearl Harbor, Kaneohe Bay, and Salt Lake; she also records Pleistocene fossil Foraminifera (all living species) from wells on the Ewa Plain.

The calcareous imperforate families Miliolidae and Peneroplidae comprise 50 percent of the species found in Hawaii, but most species of these two families—with the exceptions of *Amphisorus hemprichii, Marginopora vertebralis*, and *Sorites marginalis*—occur in small numbers. Where they occur, these latter three species, along with *Amphistegina madagascariensis* and *Heterostegina suborbicularis*, are the dominant species both in number of individuals and in total mass. They are found to some extent in most samples but are particularly abundant in certain areas such as sandy bottoms immediately seaward of coral reefs.

Both benthonic and planktonic foraminiferal species have relatively restricted optimal conditions under which they occur most abundantly; many have wider tolerances, however, and may occur under other conditions in fewer numbers. The primary factors influencing the distribution of benthonic species are depth, temperature, salinity, and nature of substrate. Many genera—particularly those in the families Camerinidae, Peneroplidae, Alveolinellidae, and Amphisteginidae—contain commensal algae (zooxanthellae) within the test. For this reason, these genera are limited to the photic zone and are intolerant of turbidity which clouds the water and blocks light penetration.

In contrast to benthonic genera all species of *Globigerina*, *Globigerinoides*, *Globorotalia*, *Orbulina*, and *Candeina* are planktonic. They are most abundant in a pelagic environment. *Tretomphalus* is planktonic during the later portion of its life cycle; it attaches to algae as a juvenile, however, and is a near-shore species during that stage. The main factors influencing planktonic foram distribution are water temperature, oceanic currents, and water depth. Many planktonic species also contain zooxanthellae. A general treatment of foraminiferal ecology is given by Murray (1973).

Certain species tend to occur together. More general environments can be recognized by the occurrence of these foraminiferal communities, and details can be filled in by considering particular species.

Shallow muddy embayments that may on occasion have reduced salinities are characterized by a distinctive fauna. Resig (1969, Table 4) found that the following species accounted for more than 90 percent of the specimens in five samples from inner Pearl Harbor:

Ammonia beccarii tepida	34%
Quinqueloculina poeyana	30%
Elphidium gunteri galvestonensis	7%
Nonion sp. (given as *Florius*)	7%
Bolivina striatula	7%
Hopkinsina pacifica	3%
Buliminella elegantissima	3%

The species occur in many parts of the world in shallow environments. *Ammonia beccarii tepida* in particular often occurs in large numbers in low-salinity environments where other species cannot survive.

Kaneohe Bay contains most of the above species. Resig (1969, Table 4) found that the following 8 species accounted for 65 percent of individuals in 9 samples from Kaneohe Bay:

Quinqueloculina laevigata
Ammonia beccarii tepida
Nonion sp. (given as *Florius*)
Bolivina striatula
Quinqueloculina bosciana
Quinqueloculina poeyana
Cornuspira planorbis
Discorbis sp.

Because of the greater diversity of habitats in Kaneohe Bay, several other species are present in smaller numbers.

The majority of Hawaiian species are benthonic and occur in shallow water of normal salinity associated with reef habitats. A study in an area off Kahe, on the west coast of Oahu (Phillips, 1973) showed several species being more common in shallower waters and others more common at greater depths.

2(1) Test conical; umbilical area covered by plate .... *Cymbaloporetta*
[*C. bradyi* (Pl. 11, Fig. 4); *C. squammosa* (Pl. 11, Fig. 3)]
Test compressed; final chambers in adult vertical to base ... *Cymbaloporella*
[see Pl. 14*c*]

Family **Cassidulinidae**

This family is characterized by a calcareous, perforate test, a peculiar biserially enrolled plan of growth, and a slit aperture elongated in the plane of coiling. The genus *Cassidulina* has the characters of the family without further special modifications. In general, it prefers cold water, but several of its species occur in shallow tropical reef areas [*C. minuta* (Pl. 12, Fig. 1); *C. delicata* (Pl. 12, Fig. 2)].

Family **Globigerinidae**

The most distinguishing features of the family are the globular chambers and over-all globular test shapes which reflect the planktonic mode of life of all genera within the family. The plan of growth, at least in juveniles, is a low trochospiral, usually with a large open umbilicus. Chambers may become embracing in adults, and in the morphological end-form known as *Orbulina*, a single spherical chamber covers the earlier trochoid growth stage. *Orbulina* has been considered a genus but is polyphyletic as evidenced by early growth stages of different kinds occurring within the test. The tests of the Globigerinidae are calcareous and perforate; the perforations are often quite large. Many genera possess long spines, which fall off upon death of the organism. Many species within the family are truly pelagic and are found in shallow near-shore waters only when blown in by storms. Certain species do inhabit near-shore waters, however.

PLATE 13
PROTOZOA
Family **Anomalinidae**

Figure 1.—*Anomalina glabrata* Cushman. BPBM no. A153; *a*, evolute side view; *b*, edge view; *c*, involute side view; 100X.

Figure 2.—*Anomalina* sp. BPBM no. A154; *a*, evolute side view; *b*, edge view; *c*, involute side view; 80X.

Figure 3.—*Cibicides lobatulus* (Walker and Jacob). BPBM no. A155; *a*, evolute side view; *b*, edge view; *c*, involute side view; 80X. *(=Nautilus lobatulus, =Truncatulina lobatula)*. Authors have figured forms similar to this as *C. lobatulus*. It is an attaching species that assumes many morphological variations.

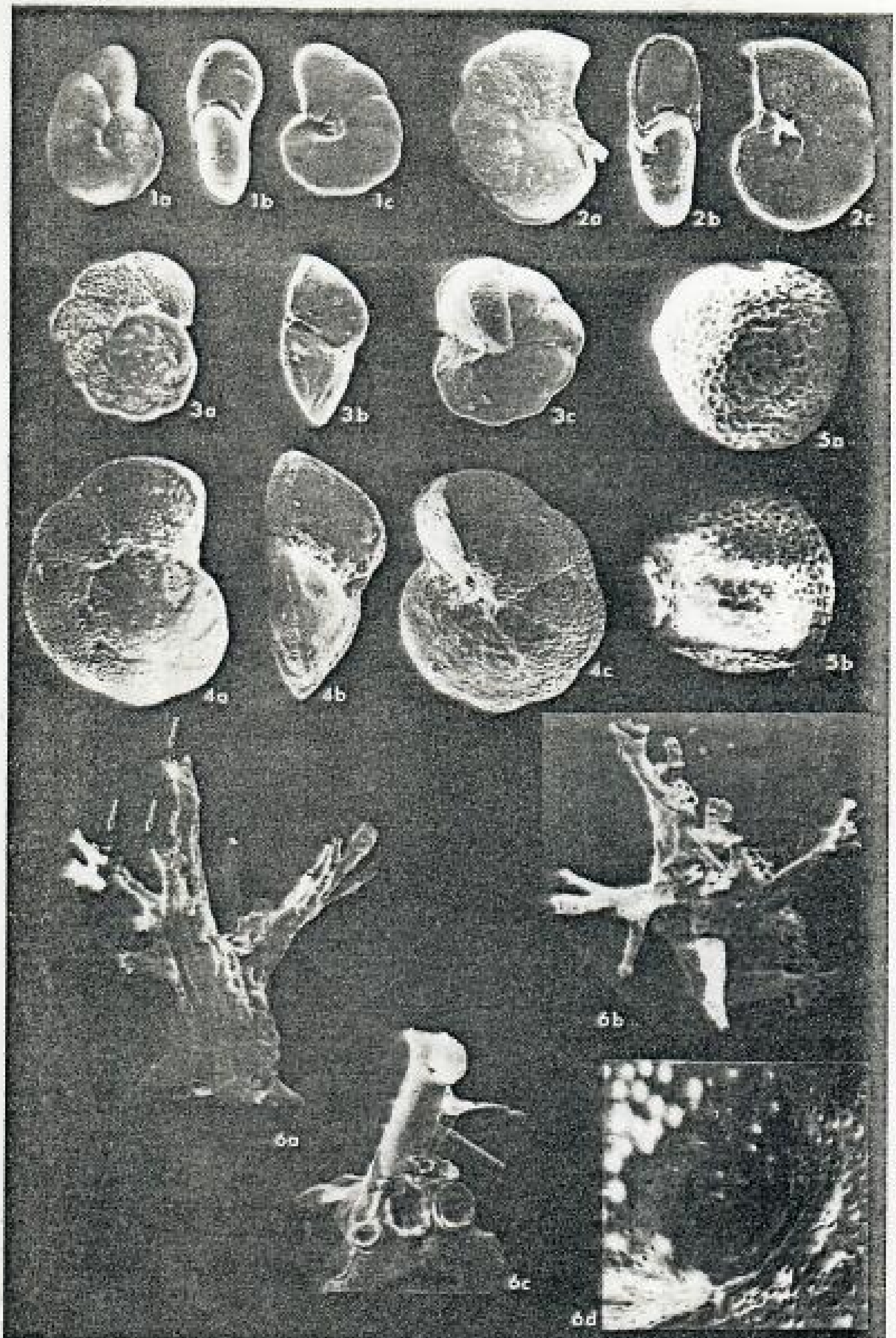
Figure 4.—*Cibicides lobatulus* (Walker and Jacob). BPBM no. A156; *a*, evolute side view; *b*, edge view; *c*, involute side view; 80X.

Family **Planorbulinidae**

Figure 5.—*Gypsina globula* (Reuss). BPBM no. A19; *a*, top view; *b*, edge view; 40X. This has traditionally been considered a valid genus, but Nyholm, as mentioned by Todd (1965), considers it a resting stage in the life cycle of *Cibicides*.

Family **Homotremidae**

Figure 6.—*Miniacina miniacea* (Pallas). BPBM no. A157; *a*, side view, and *b*, top view, 20X; *c*, detail of one branch showing terminal apertures, 100X; *d*, detail of surface showing fine pores and larger surficial aperture (pillar pore), 1000X. *(=Millepora miniacea, =Polytrema miniaceum)*. The arrows point to siliceous sponge spicules that have been picked up by the animal and incorporated into the test wall at the ends of the branches. This habit is typical of the Family Homotremidae.


1a
1b
1c
2a
2b
2c
3a
3b
3c
5a
4a
4b
4c
5b
6b
6a
6c
6d

KEY TO COMMON GENERA OF THE FAMILY GLOBIGERINIDAE

1 Single spherical chamber visible from exterior of adult; apertures numerous large pores scattered over surface .... *Orbulina* [*O. universa* (Pl. 12, Fig. 5)]

Several chambers visible from exterior of adult 2

2(1) Aperture single large umbilical opening; many long slender spines project from test of living animal .... *Globigerina* [*G. eggeri* (Pl. 12, Fig. 4)]

Apertural openings multiple along sutures 3

3(2) Several large supplementary apertures along sutures; large primary umbilical aperture; many fine spines project from test of living animal .... *Globigerinoides* [*G. sacculifer* (Pl. 12, Fig. 6); *G. conglobatus* (Pl. 12, Fig. 7)]

Adult with numerous small apertural openings along sutures; surface smooth; no spines .... *Candeina* [*C. nitida* (Pl. 12, Fig. 3)]

Family **Globorotaliidae**

The Globorotaliidae have a calcareous, perforate test and a trochoid plan of growth. They are planktonic and were derived from the Globigerinidae by the development of a flattened dorsal side giving them a rotalid shape. Chambers are inflated. The genera are largely pelagic, but empty tests of *Globorotalia* are occasionally found in near-shore sands. This genus has the characters of the family and usually possesses a peripheral keel [*Globorotalia* sp. (Pl. 12, Fig. 8); *G. menardi* (Pl. 12, Fig. 9)]. Some authors consider species without the keel to represent another genus.

Family **Anomalinidae**

The genera of this family possess a calcareous, perforate test, a trochoid plan of growth, and all shallow Hawaiian genera have a slit aperture which extends from the ventral side across the periphery. Two genera are commonly found. *Anomalina* has the characters of the family. It often tends to become partly involute on the dorsal side as well as on the ventral side and tends toward a biconvex planospiral test [*A. glabrata* (Pl. 13, Fig. 1); *Anomalina* sp. (Pl. 13, Fig. 2)]. *Cibicides* is planoconvex and is often attached by the flat dorsal side. Some authors consider species that do not attach to be different genera. The aperture usually extends across the periphery and along the dorsal side for most of the length of the final chamber [*Cibicides lobatulus* (Pl. 13, Figs. 3, 4); *Cibicides* sp. (Pl. 10, Fig. 4)].

Family **Planorbulinidae**

The Planorbulinidae have a calcareous, perforate test. In juveniles the plan of growth is similar to that of the Anomalinidae. Adults develop various modified plans of growth. *Planorbulina* [see Pl. 14*e*] becomes annular and develops two apertures per chamber, each of which is covered by a new chamber with two apertures. The flattened test with annular chambers is superficially similar to a few other genera, particularly to *Cymbaloporetta*. The juvenile plan of growth and nature of apertures will distinguish one from another; however, *Gypsina* produces adult chambers that grow on top of one another so that an irregularly spherical mass is formed. The coarse pores serve as apertures [*G. globula* (Pl. 13, Fig. 5)].

Family **Homotremidae**

The three peculiar genera in this family bear little superficial resemblance to other foraminifers; they are often mistaken for bryozoans. Although the juveniles have a typical trochoid plan of growth, the chambers soon become permanently attached to the substrate and grow upward in an irregularly branching mass which obscures the early growth. The genera are also unusual in possessing distinctive colorations of taxonomic significance. They are very common attached organisms, but empty tests are rarely found in sand accumulations. This group is well treated by Hickson (1911).

KEY TO THE GENERA OF THE FAMILY HOMOTREMIDAE

1 Test with slender branching projections; surface finely perforate; larger open apertures; light red color .... *Miniacina* [*M. miniacea* (Pl. 13, Fig. 6)]

Surface not perforate in adult other than by apertures; branches short, stubby 2

2(1) Large apertures covered by perforated plates; dark red color .... *Homotrema*

Apertures not covered by plates; orange red color .... *Sporadotrema*

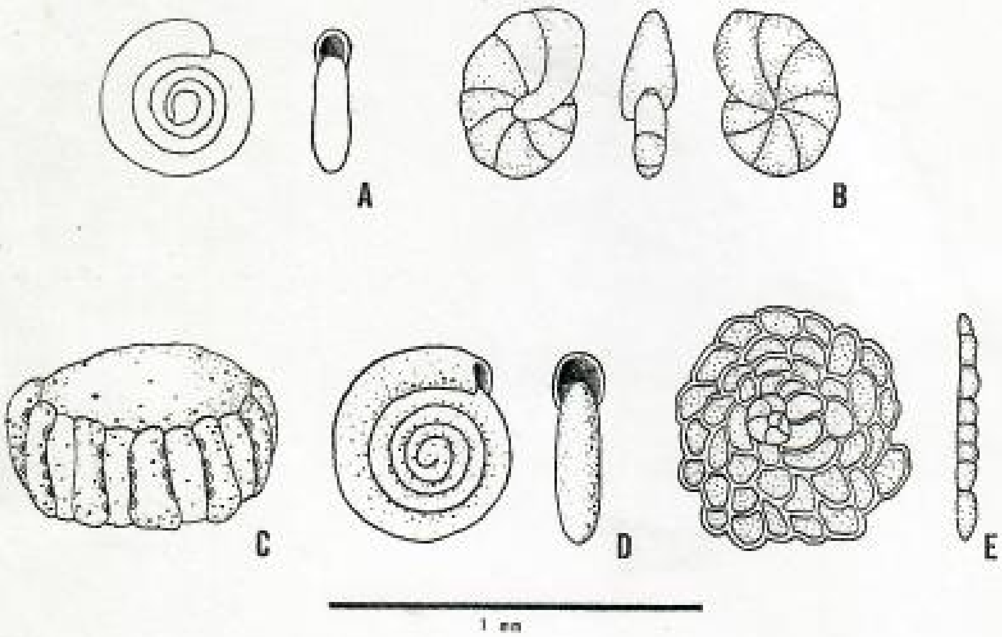


PLATE 14
PROTOZOA

The genera are included in the key to Foraminifera, but are not illustrated on Plates 2 through 13. The drawings are stylized and do not represent particular specimens. *a, Cornuspira; b, Nonionella; c, Cymbaloporella; d, Spirillina; e, Planorbulina.*

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Environmental Impact on a Samoan Coral Reef: A Resurvey of Mayor's 1917 Transect[1]

ARTHUR L. DAHL[2] AND AUSTIN E. LAMBERTS[3]

ABSTRACT: Coral reef sites in Pago Pago Harbor, American Samoa, for which descriptions and quantitative data were obtained by Alfred G. Mayor and the Carnegie Institution of Washington expeditions of 1917–1920, were resurveyed in 1973. Some sites were destroyed and others damaged in the intervening half century, but it was possible to relocate the major quantitative transect at Aua. A reduction in total numbers of corals, a change in the relative proportions of different genera, and a probable reduction in the average size of individual colonies are recorded. Elsewhere in the harbor, more drastic effects on the reefs were noted. Both human and natural impacts may be responsible for the observed changes; it is suggested that the Aua reef may now be recovering from earlier damaging events.

A MAJOR DIFFICULTY in determining the environmental impact of urbanization and human activity stems from lack of adequate baseline data from which to measure change. The lack is particularly acute in the case of complex tropical ecosystems such as coral reefs. Even where there are early studies, they are generally insufficiently documented to permit meaningful comparisons with present conditions. The extensive studies by Mayor (1924*a*, *b*, *c*, *d*) are an exception. These studies, conducted in American Samoa between 1917 and 1920, centered in an area altered by subsequent development and provide a baseline for studies of the long-term impact of human activities on a coral reef. We report on a recent resurvey of some of Mayor's sites.

The Samoan Islands are an eroded volcanic archipelago in the mid-South Pacific (14° S, 170° W), of which the eastern islands constitute the Territory of American Samoa. Tutuila, largest island in the territory, consists of a 32 km long volcanic crest reaching heights of 654 meters but never more than 9.6 km wide. The island runs SW–NE, and is partly encircled by about 55 km of narrow fringing reefs, predominantly on the south side exposed to the full sweep of the southeast tradewinds. The large deep-water Pago Pago Harbor opening to the southeast nearly bisects the island, and contains a fifth of the reef front (Figure 1).

The Polynesian population apparently never exceeded 5000, subsisting in part on seafood gathered from the reefs and on fish caught along the margins of the bays. Pago Pago Harbor became a United States coaling station in 1872, and the territory was ceded to the United States in 1900. Between 1942 and 1945, the military dredged several inshore areas for landfill, there was an increase in harbor traffic, and shipping converted from coal to oil. In 1950, with the transfer of administration to the Department of the Interior, development of Tutuila accelerated. Tuna canneries were established on the north shore of the harbor in 1956, and dredging operations were expanded in 1960.

During the past half century, the population of Tutuila increased to about 30,000, with extensive urban development along the harbor shores. The ready availability of imported food decreased local fishing pressure

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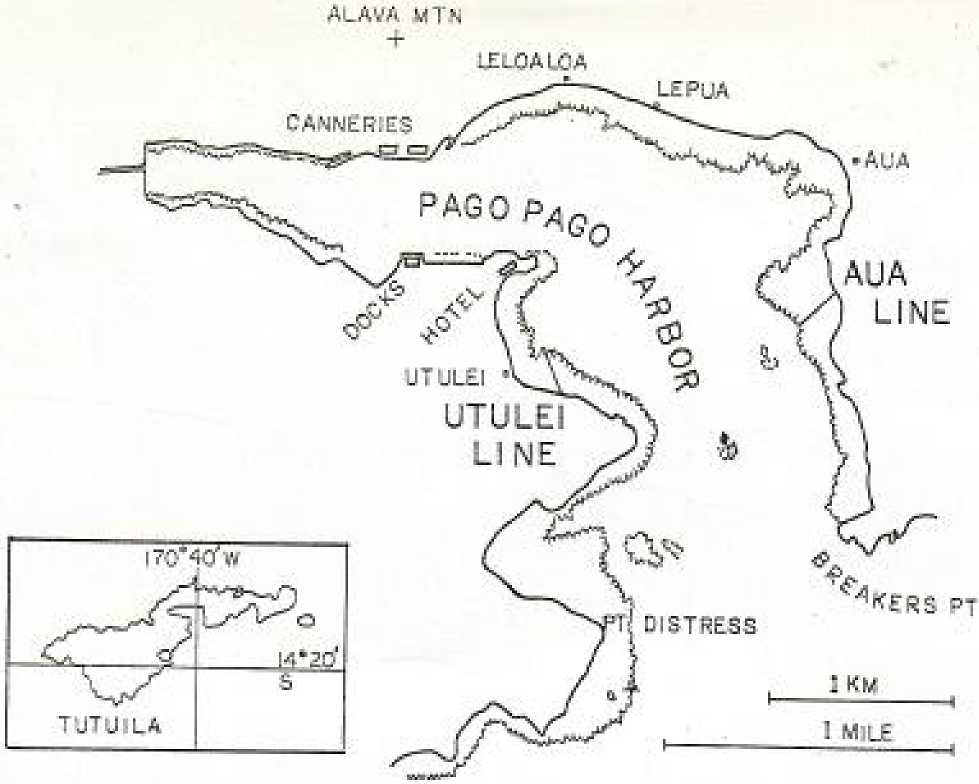

FIGURE 1. Pago Pago Harbor, Tutuila, American Samoa, showing approximate reef margin and Aua and Utulei transect lines.

on the reefs. By 1973, tuna canneries and a marine railway in the harbor serviced an ocean-going fleet of over 250 fishing ships, and the port facilities are increasingly visited by tour ships and utilized as a freight transshipment point.

Pago Pago Harbor is boot-shaped, with the opening facing the oncoming tradewinds. Small tidal amplitude (maximum 1.3 meter) and poor internal circulation allow only slow flushing. There are occasional small oil spills, and urban and industrial wastes drain into the harbor, although collection and treatment projects are now underway. Freshwater from the torrential rains that sweep Tutuila often overlays the reefs: 95 cm (37.5 in.) of rain fell in 4 days in 1920, killing many of the corals (Mayor, 1924*a*). In 1966, a hurricane caused terrestrial damage but only minor harm to the harbor reefs. Torrential rains from 22 to 27 December 1969 may have measured over 760 mm (30 in.) at the harbor entrance opposite Aua, although official records from Tafuna (several miles away) showed 248 mm.

RESURVEY METHODS

The Carnegie Institution program of 1917–1920 remains the only extensive study of the ecology of Samoan reefs. This program included taxonomic studies of various groups, such as corals (Hoffmeister 1925), soft corals (Cary 1931), terrestrial and marine plants (Setchell 1924), geological and ecological studies including reef coring (Bramlette 1926, Cary 1931) and the wide-ranging experiments and observations of Mayor himself (1924*a*, *b*, *c*, *d*). Central to this program were a series of line transects across the reefs in Pago Pago Harbor. Of these, only those of Aua and

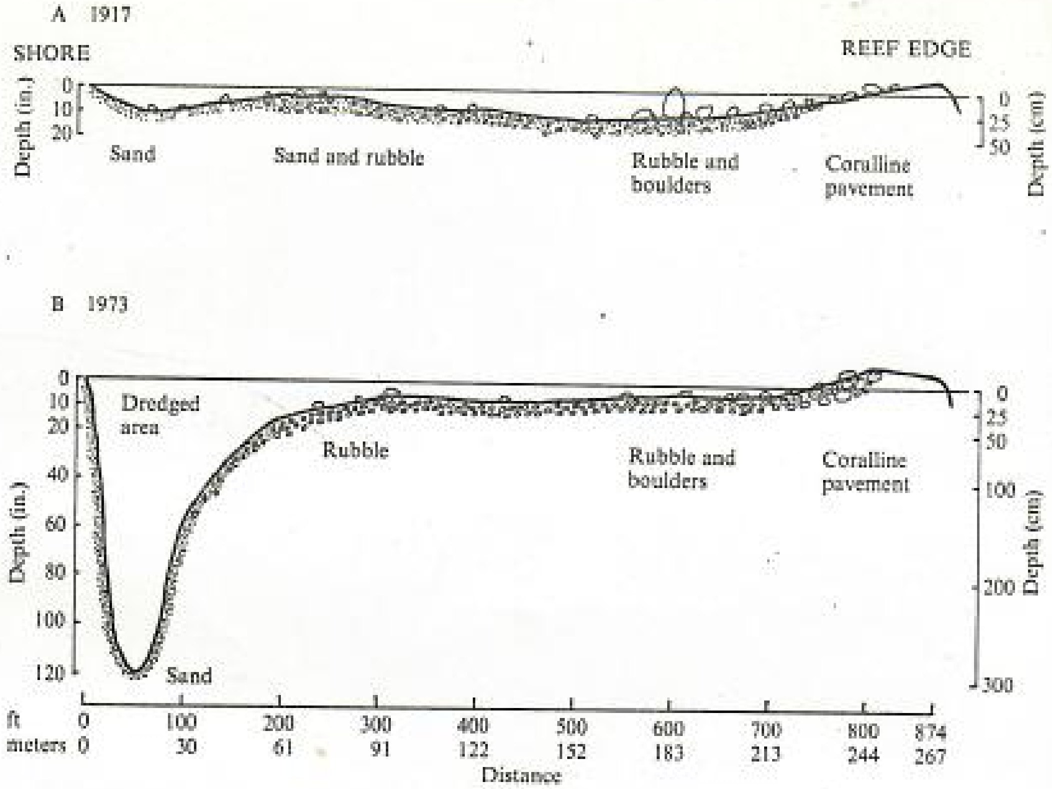

Figure 2. Aua reef transect profiles in 1917 and 1973 (30 times vertical exaggeration).

Utulei still cross living reef (Figure 1). The others have disappeared with dredging and filling in the harbor. A series of surveys of the Tutuila reefs has been undertaken periodically by one of us since 1969 (Dahl 1972).

Mayor defined his Aua transect as running 39.5° W (magnetic) from a large tree on the beach to a conspicuous coral block on the outer edge of the reef (Mayor 1924*a*). In the intervening 57 years, road construction has altered the shoreline, eliminating both beach and tree. To relocate the Aua line, one of us (Dahl), matched Mayor's map (Mayor 1924*a*) with recent maps and the actual shore contour, obtained a new starting point, and aligned the line with respect to the mountain contours opposite to correspond with Mayor's photograph (Mayor 1924*a*, plate 41B). The other (Lamberts) independently positioned a line based on recent charts, Mayor's photographs, and a bearing recalculated from 1917 to 1974. The two lines, established without consultations, were within 1 meter of each other, and passed within 1 meter of a large, well-cemented block, 1 meter above the general contour of the reef edge. Remeasuring the line inward from the reef edge indicated that the margin of the present road fill roughly corresponded to Mayor's starting point. The remeasured line was marked with iron rods at 65.6-meter (200-ft) intervals, and Mayor's quantitative survey method was repeated with squares 7.32 meters (24 ft) on a side marked out at the same distances used in 1917. A team of five members with face masks and underwater slates, each concentrating on a particular group of corals or other organisms, counted genera and species within each square. A voucher collection of corals was later compared directly with Mayor's specimens at the National Museum of Natural History, Smithsonian Institution. Mayor's original measurements and counts were made

TABLE 1

EQUIVALENCE OF MAYOR'S TENTATIVE IDENTIFICATIONS OF *Acropora* SPECIES AND THOSE BY LAMBERTS FOR THIS PAPER

MAYOR	LAMBERTS
Branched *Acropora* related to *A. muricata*	*A. formosa* (Dana)
Brown-stemmed, coarsely branched	*A. hebes* (Dana)
Delicately branched	*A. nana* (Studer)
	A. quelchi Brook
A. samoensis	*A. humilis* (Dana)
A. leptocyathus	*A. rotumana* Gardiner

in March and April 1917; our resurvey was undertaken in July 1973.

Reefs were also examined at Masefau and Fagasa on the north shore, and Amouli, Fagaitua, Matuu, Nu'uuli, Pala lagoon, Airport lagoon, Leone, and Paloa on the south shore.

RESULTS

The dredging of a nearshore lagoon 3 meters deep and over 40 meters wide altered Mayor's first four measured squares too greatly to include them in this study. This lagoon bottom consisted of calcareous sand and mud with occasional outcroppings of coral rock to which heads of *Porites lutea* Vaughan up to 35 cm in diameter were attached, as well as scattered clumps of *Acropora formosa* (Dana) larger than any on the reef flat. The remaining contours and the surface of the Aua reef seem not to have changed appreciably in the intervening years. Comparative profiles of the line in 1917 and 1973 are shown in Figure 2.

Mayor (1924*a*) recorded corals by tentative identification; these could not be entirely harmonized with later identifications by Hoffmeister (1925) or with our findings. Corresponding identifications for *Acropora* are listed in Table 1. Three genera (*Merulina*, *Goniopora*, and *Cyphastrea*) reported by Mayor were not found in 1973. Hoffmeister did not confirm *Goniopora* from the Aua line, and the *Merulina* he reported was from Utulei.

The reef edge near the coralline algal ridge had many crevices and shallow tide pools crowded with small (juvenile) *Acropora*, mostly under 12 cm tall, for which species determinations were not possible.

Most significant are the differences in total numbers and species proportions found in 1917 and 1973 (Table 2, Figure 3). Total numbers of coral heads decreased 28 percent. The same four genera of hermatypic corals still predominate, but their relative proportions have altered. Numbers of *Psammocora* and *Porites* decreased by half, while *Pocillopora*, especially *P. damicornis*, increased fivefold. *Acropora* remained constant.

Counts were also made of the black holothurians *Stichopus chloronotus* Brandt, blue starfish *Linckia laevigata* Linnaeus, and alcyonarians (Table 3). In all cases the numbers observed were roughly triple those reported by Mayor.

Water currents pass obliquely from the harbor entrance across the Aua line. Surface waters generally sweep to the head of the bay where the currents are dissipated. The waters within the confines of the upper harbor are turbid and dark and a plume of discoloration can often be observed in the cannery area. Underwater visibility at the reef edge of the Aua transect in the path of incoming ocean water was 30 meters horizontally, when observed on one occasion, and corals could be distinguished to a depth of 10 meters, comparable to other areas around Tutuila. Visibility gradually decreased up the harbor along the north shore, and at Lepua it was estimated as one-third that of the Aua region.

Coral growth on the reef opposite the village of Aua remains vigorous, but along the north harbor shore it becomes sparse. No *Acropora* or branched *Porites* were found beyond Lepua, where *Pocillopora brevicornis* (Dana) is the most prominent inshore coral, associated with *Porites lutea*, *Pavona frondifera*, *Leptastrea purpurea*, and *Montipora* sp. A similar distribution of coral but with fewer individuals was found at Leloaloa. At the reef edges, spur and groove contours are present, and beyond, occasional large heads of *Porites* aff. *lutea* are visible. In the areas adjacent to the canneries no recently dead or

TABLE 2

NUMBER OF LIVING CORAL HEADS UPON EACH 7.32-METER (24-FT) SQUARE ON THE AUA LINE, PAGO PAGO HARBOR, TUTUILA, AMERICAN SAMOA, JULY 1973 (MAYOR'S COUNTS FROM 1917 IN ITALICS)

CORAL		DISTANCE FROM LOW TIDE MARK OF SHORE											
	Meters	61–68	91–99	122–129	140–147	160–168	183–190	213–221	233–241	247–255	259–267		
	Feet	200–224	300–324	400–424	460–484	526–550	600–624	700–724	766–790	812–836	850–874	TOTAL	PERCENT OF TOTAL
Psammocora contigua (Esper)		*2*	*46*	*49*	*259*	*17*	*9*	*1*	*5*			*388*	*10.6*
			10	14	6	12	2	7	33	21	15	120	4.5
Pocillopora damicornis (L.), *P. brevicornis* Lamarck, *P. eydouxi* Milne-Edwards & Haime		*3*	*24*	*23*	*3*	*6*	*35*	*5*	*19*		*31*	*149*	*4.1*
		11	349	75	60	63	32	15	23	46	45	719	27.1
Acropora formosa (Dana)			*3*	*13*	*38*	*59*	*151*	*265*	*407*			*936*	*25.5*
		7	23	3	14	11	30	6	26	15	9	144	5.4
Acropora hebes (Dana)								*1*	*4*	*144*	*8*	*157*	*4.3*
			1			1	16	1	9	15	56	99	3.7
Acropora nana (Studer) and *A. quelchi* Brook				*2*	*2*			*16*	*15*		*15*	*50*	*1.2*
			8	2		3	4	2	19	6	3	47	1.8
Acropora humilis (Dana) or *A. rotumana* Gardiner										*13*	*161*	*174*	*4.7*
			1	1	4	3	8	2	12	36	68	135	5.1
Acropora hyacinthus (Dana)			1		1		6	3		15	36	62	2.3
Acropora sp. "Juveniles"								2	55	265	214	536	20.2
Montipora sp.							*2*	*6*	*13*		*21*	*42*	*1.1*
								4	17	11	13	45	1.7

TABLE 2 (*cont.*)

CORAL	Meters	61–68	91–99	122–129	140–147	160–168	183–190	213–221	233–241	247–255	259–267		
	Feet	200–224	300–324	400–424	460–484	526–550	600–624	700–724	766–790	812–836	850–874	TOTAL	PERCENT OF TOTAL
Pavona frondifera Lamarck			*2*	*1*	*22*	*35*	*10*	*7*	*4*			*81*	*2.2*
			6	5		4	2	1	7	8	10	43	1.6
Porites "massive," mostly *P. lutea* Milne-Edwards & Haime		*82*	*94*	*190*	*205*	*90*	*32*	*18*	*23*			*734*	*20.0*
		68	119	33	22	16	44		1			303	11.4
Porites "branched," mostly *P. andrewsi* Vaughan		*79*	*157*	*317*	*319*	*49*	*2*					*923*	*25.1*
		61	145	31	40	37	8					322	12.1
Favites sp.		*1*					*2*			*1*		*4*	*0.1*
							2		1	1	5	9	0.3
Leptastrea purpurea (Dana)		*1*	*7*	*4*	*10*							*22*	*0.6*
		1	3	2		4	3					13	0.5
Galaxea fascicularis (L.)										*1*		*1*	*0.03*
								1	4	7	29	41	1.5
Millipora sp.			*1*	*2*	*4*			*2*				*9*	*0.2*
											19	19	0.7
Total coral heads		*168*	*334*	*601*	*862*	*256*	*243*	*321*	*490*	*159*	*236*	*3,670*	
		148	666	166	147	154	157	44	207	446	522	2,657	

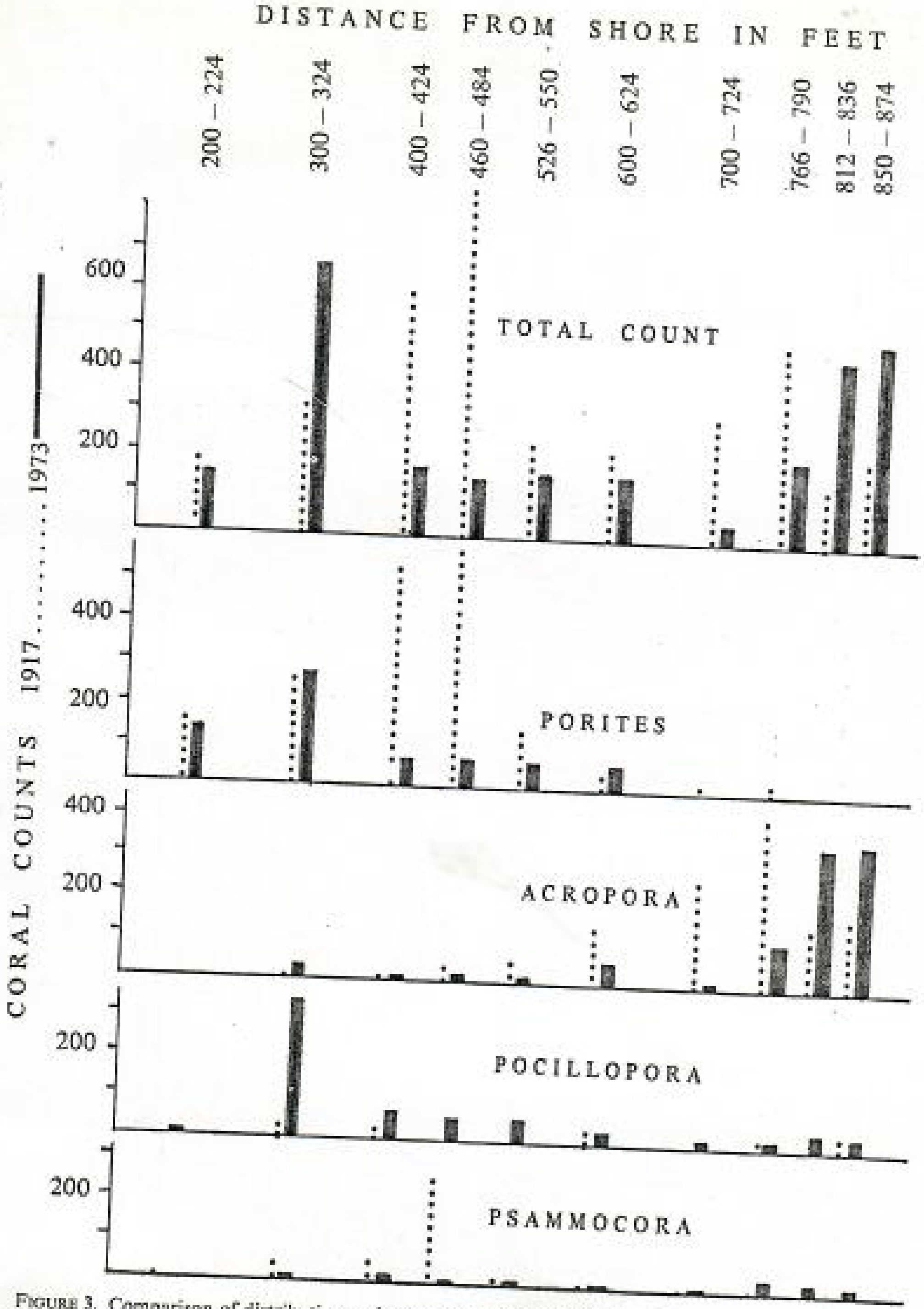

Figure 3. Comparison of distribution and numbers of total corals and major genera observed on the Aua line in 1917 and 1973.

TABLE 3

Numbers of Blue-black Holothurians (*Stichopus chloronotus*), Blue Starfish (*Linckia laevigata*), and Alcyonarians on the Aua Line, Pago Pago Harbor, Tutuila, American Samoa, July 1973 (Mayor's Counts from 1917 in Italics)

		Distance from low tide mark of shore										
	Meters	61–68	91–99	122–129	140–148	160–168	183–190	213–221	233–241	247–255	259–267	
Name	Feet	200–224	300–324	400–424	460–484	526–550	600–624	700–724	766–790	812–836	850–874	Total
Holothurians		*183*	*115*	*170*	*135*	*34*	*12*	*4*	*3*			*656*
		229	173	289	300	410	500	249	38	20		2,208
Blue starfish		*1*		*1*								*2*
			6	1	2							9
Alcyonarians		*3*	*2*		*5*					*3*		*13*
						1	8			18	3	30

live coral was found, except inshore at a depth of 25 cm where *Leptastrea purpurea* and some small heads of *P. lutea* were seen.

As far as could be ascertained, the upper end of the harbor from the canneries to the docks was devoid of living coral. The 300-meter-long area between the docks and our hotel contained a reef that had been dredged in 1969. When examined in 1973, it consisted for the most part of sandy bottom sloping for 50 meters into deep water, with occasional outcroppings of old coral rocks. Living *Porites* aff. *lobata* was found in the mid-portion of this area. In addition, ten coral colonies had established themselves, including *Porites lutea*, *P. andrewsi*, *Leptastrea purpurea*, and *Pocillopora damicornis*. No holothurians were observed.

The Utulei line described by Mayor has been disrupted by dredging near the shore, but the coral reefs on the west shore of the harbor south of the hotel and the outer Utulei reefs appear structurally intact. Water was turbid, with considerable garbage on the bottom. Numerous alcyonarians, large heads of *Porites*, some large heads of *Favites rotumana* Gardiner, and smaller numbers of *Acropora* are present.

DISCUSSION

Measurements from charts indicate that approximately 10 km of reef front once existed in Pago Pago Harbor between Point Distress and Breakers Point. In 1917 when Mayor visited Samoa, a wharf was already present, but from his lack of discussion it is inferred the reefs in the inner harbor were flourishing. Mayor dredged living deep-water corals in the upper harbor and chose Lepua for coral growth studies (Mayor 1924*d*). This site lies in the middle of a 2-mile stretch of reef which now shows considerable decrease in coral abundance compared with the Aua reef. Also, 2 km of reef in the innermost part of the harbor showed no living coral in 1973.

The combination of sedimentation and eutrophication has caused destruction of many coral reefs in Kaneohe Bay, Oahu, Hawaii (Banner and Bailey 1970, Caperon et al. 1971, Smith et al. 1973), and physical conditions in Pago Pago Harbor are in many ways comparable to those found in Kaneohe Bay. Dredging activities in the upper harbor have been continuous for several years with attendant water turbidity and silt. Johannes (1972, personal communication) and Pillai and Gopinadha (1971) implicate siltation as the most significant factor in reef destruction. In Pago Pago Harbor some of the sediment formed by dredging is carried by currents to areas outside the harbor, but this circulation does not normally affect the Aua line. Wastes from the canneries are, for the most part, washings and other organic fish residues which appear to contribute to progressive eutrophication of the bay.

The decrease in total number of coral heads and change in species proportion on the Aua transect since 1917 cannot readily be attributed to any specific natural fluctuation or human disturbance, although it may be related to the processes that have killed the corals of the inner harbor and generally impoverished the reefs of the north harbor shore. The changes in both numbers and proportions relative to distance on the transect suggest that major alterations in community structure have taken place. While *Acropora* continues to be a major contributor to the structure of the reef, *Psammocora* has been reduced by two-thirds. In the midzone, *Pocillopora*, especially *P. damicornis* and *P. brevicornis*, have increased fivefold, occupying a zone once dominated by *Porites*.

Unfortunately, Mayor did not record the sizes of the colonies counted, although his photographs suggest considerable numbers of large colonies. Comparison of coral sizes at Aua with those of other reefs on Tutuila shows that young corals now predominate at Aua. *Porites lutea* frequently forms colonies 1 meter or more in diameter on Tutuila reefs, but at Aua the heads observed were as small as 3 cm. In other reef moats on Tutuila, it is common to find patches of *Acropora formosa* many square meters in extent and 1 meter or more in height. The lower parts of these thickets are often dead, and the upper parts killed in a sharply demarcated line, presumably corresponding to extreme low tide level. No such large patches were observed at Aua. The many small colonies and lack of large ones suggests a reef subjected to intermittent severe stress, or one gradually recovering from an earlier traumatic event (for example, the freshwater inundation of 1969). What is known of species tolerances in corals also supports the view that the Aua reef is gradually recovering from earlier stress. *Acropora* requires pure, clean water and is intolerant to siltation. The presence of some mature *A. formosa* in the dredged area and at the reef edge suggests impure water has not been a recent problem. *Pocillopora damicornis* is most tolerant of adverse conditions and is often found near shore where there is silt and fluctuating water temperature. This species and *P. brevicornis* are good colonizers of denuded areas because the planulae are released frequently and in large numbers. A fivefold increase in numbers of *Pocillopora* is thus not unexpected.

One species greatly reduced in numbers at Aua was *Porites andrewsi*, and on the Lepua reef it was not found at all. On other reefs on Tutuila it is often found in conjunction with *P. lutea* though there are inshore areas outside the harbor where one species was present in large numbers and the other absent.

Our recount of the number of black holothurians, *Stichopus chloronotus* Brandt, showed triple the number found in 1917, possibly suggesting an increase in organic material in the sediments.

The Aua transect in 1973 showed healthy recent coral growth with species diversity consistent with that found on other sections of the Tutuila reefs. However, the total number of colonies was less than that in 1917, species proportions are considerably altered, and the number of small colonies is high. Whether the reef will eventually return to the state recorded over 50 years ago by Mayor, will further decline under the impact of natural or man-induced stress, or will achieve some new equilibrium state can only be determined by future surveys. Fortunately, the foresight and skill of the Carnegie Institution studies will make such a determination possible.

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Ecology and Community Structure of Some Tropical Reef Algae in Samoa

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While benthic marine algae other than encrusting forms are not often conspicuous in coral reef habitats, they frequently form complex associations with high species diversity but low biomass. Data from the initial phase of a detailed ecological survey of the algae on the fringing reefs around Tutuila, American Samoa, demonstrate the widespread occurrence of algal turfs, and illustrate the interactions between species that help to maintain the algal communities. Associations between algal species are often mutually beneficial, and create significant microhabitats. Algal communities also help to control substrate availability, and are themselves altered by the types of substrate available. In spite of their low biomass, other algae must be considered along with encrusting forms as significant components in the coral reef ecosystem.

INTRODUCTION

Coral reefs are one of the world's most complex and productive ecosystems and are the only biological community known to produce massive geological formations. Although these reefs are widely distributed along coastal margins in tropical waters, the diversity of coral reef forms and their complexity have made it difficult to characterize ecological features that may be common to many reef areas and that may help to determine the nature and form of reef development.

American Samoa, a small group of largely volcanic islands in the South Pacific (lat. 14°S, long. 170°W), is typical of many island areas in which coral reefs are a prominent local resource. As part of a long-term survey and monitoring program, 10 line transects were established across the intertidal and high subtidal portions of the fringing reefs around Tutuila Island and on nearby Aunuu Island, representing a variety of exposures and habitats. Additional sites were also examined in detail. The initial surveys were established in January 1970, and most stations were repeated in July 1970. Collections and rough quantitative estimates of percent coverage were made for each 10 m transect segment across the reef flat. A general description of the area and several environmental parameters were also noted for each transect. This approach served to characterize the major reef flat features and populations on a repeatable basis within the limited time available. This paper will focus on one aspect of the data from this program concerning the occurrence of algal turfs and their role in the reef community structure.

Algal turfs can be defined as relatively dense associations of one or more species of filamentous or foliose algae of small stature, attaining a height or thickness of 1 to 30 mm. Turfs are a frequently occurring algal feature, particularly in tropical marine benthic habitats, and have been periodically noted and described (eg., *1, 3, 4, 6, 7*). Generally, however, attention has been concentrated on the individual species within the turf, rather than on the nature of the associations between species or the role of the turf community in the ecosystem.

Turfs may be of particular significance in tropical reef areas where other benthic algae are scarce. They may make a significant contribution to productivity, aid in the consolidation of reef materials, and control substrate availability. They are frequently highly complex and diverse assemblages. Species composition, community structure, and habitat vary greatly, even within the same area. A much greater mass of data will be required before any generalizations about the turf community can be substantiated. It is nevertheless useful to consider this association as a unit with respect to its role in coral reef ecosystems.

Little information has been published on the marine algae of American Samoa. The paper by Setchell is perhaps the most substantial, yet it was apparently based on fragmentary collections and is incomplete (*5*).

RESULTS

The fringing reefs around Tutuila Island, American Samoa, are relatively small, extending no more than a few hundred meters from the shore. On the south shore, the reefs extend for most of the length of the island and generally consist of a shallow moat near the shore (200 to 400 mm depth at low tide), a relatively solid reef flat extending out perhaps 100 m., which is barely exposed by the lower tides, and the reef front itself (Fig. 1). Living corals occur primarily on the outer portion of the reef flat and beyond. Breaks in the reef are generally associated with areas of freshwater runoff. Reef development on the north shore is primarily restricted to the bays. All the reefs tend to be highly variable in structure and dominant organisms, depending on the local conditions. The flora of the basaltic outcrops was distinctly different from that of adjacent carbonate rock substrate. For further information on the structure of the reefs at Tutuila, see Mayor (*2*).

A profile of the reef site near Nuuuli (Fig. 1) illustrates several of the features of the Samoan reef flat habitats. The inshore area consists largely of sand and a loose coral rubble of fragments less than 100 mm long. Scattered small coral heads towards the seaward edge of the moat merge into the solid reef flat extending to the outer edge of the reef. Semiconsolidated calcareous rubble predominates on the inner portion of the reef flat with an increasing percentage of living coral towards the reef front. Algal turfs cover most of the available solid surface in the reef moat with fleshy crusts also common on coral fragments. Turfs decrease in coverage toward the outer margin of the reef flat to be replaced by crustose forms and then living coral. *Halimeda opuntia* is common in the interstices of the rubble on the reef flat.

In terms of percent coverage, turfs are frequently the most significant algal component in shallow reef areas. On some other transects, the relative role of encrusting coralline algae increased, particularly on loose coral rubble and on the outer margin of the reef, but turf remained dominant in the more stable areas. Extensive turfs were also noted along subtidal channels and on the dead portions of coral heads.

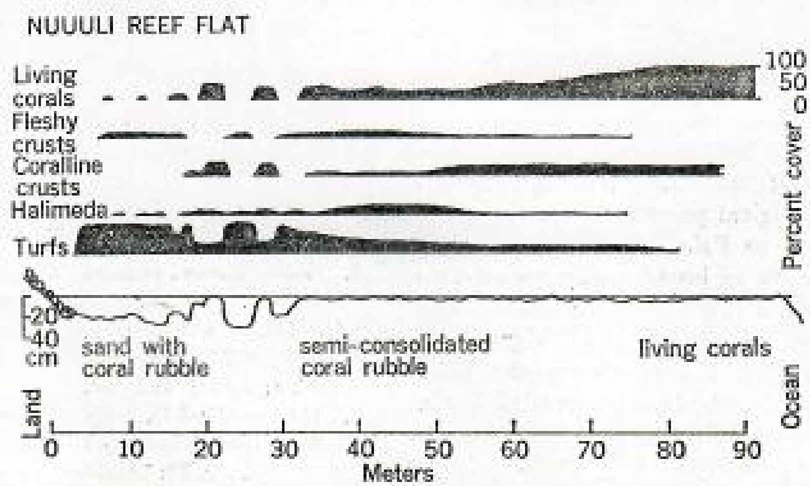

FIG. 1. Profile of the reef flat near Nuuuli, Tutuila Island, American Samoa, showing the percent coverage of the dominant forms.

The species composition of Samoan algal turfs is both complex and highly variable. One sample of about 400 mm^2 from a basaltic substrate at Lepisi Point contained over 30 species. Some species occur only in turfs; others are found elsewhere, often growing in turf in a reduced form. Some of the dominant turf genera include *Jania*, *Polysiphonia*, *Ceramium*, *Hypnea*, *Cladophora*, *Gelidium*, and *Laurencia*. A detailed listing of the algae present is beyond the scope of this paper.

Discussion

How do such complex associations as the algal turf community arise, and what significance do they have in the reef ecosystem? From the present monitoring surveys, it is only possible to conclude that such turfs are widespread and are frequently composed of numerous species in close association. It may be useful to suggest possible contributing factors, but detailed experimental confirmation will be required.

First, a number of features can be noted about the turf habitat. It would appear to have high potential for productivity, with ample light and a supply of nutrients washed onshore by reef currents and carried down from the adjacent land. There would also be high grazing pressure, at least intermittently when high tides permit grazing fish and other animals to emerge or to come inshore from the outer reef. At least some turf areas are subject to exposure at low tide, as well as to environmental extremes such as high light intensity, and salinity variations with heavy rains and freshwater runoff.

There may well be species interactions within the turf community that help to counter these ecological pressures. For example, the entrance to Pala Lagoon near Nuuuli consists largely of broad shallow sand flats carpeted with a simple association of *Halimeda* and *Dictyota*. A dense mat of *Dictyota* and scattered *Padina* largely covers the area, anchored in place by hummocks of *Halimeda*. The *Halimeda* provides the only firm attachment in the sand for the *Dictyota*, the *Dictyota* alters conditions under the mat in a way that may or may not be beneficial to the *Halimeda*.

In the turf community, *Jania*, *Laurencia*, or *Hypnea* may serve a similar anchoring function for other algae, or even for the substrate. In one area of loose rubble on the reef flat near Anapeapea, the coral fragments have been bound together by turf to form a dense resilent mat. Such binding might foster the consolidation of the rubble into reef rock by coralline algae or chemical processes.

One might also expect certain algae with greater resistance to grazing or abrasion to serve as a shelter for more delicate forms. The dense turf form could similarly provide protection from extreme light intensities or exposure, producing an internal microhabitat more favorable to survival and growth. There may also be nutritional, antibiotic, or other biochemical benefits within the close confines of the community. A dense turf association may be better able to regenerate rapidly after injury, or to change its species composition with changing conditions. It is, in all likelihood, a dynamic rather than static association.

The significance of algal turfs for the whole reef ecosystem is similarly open to conjecture. This may well be an area of high productivity, in which rapid growth is balanced by heavy grazing, resulting in low biomass but high turnover. Turfs may also control substrate availability, preventing the settlement of coral larvae and other organisms.

The widespread occurrence of algal turfs in tropical reef habitats suggests that they may play a significant part in reef structure and function. Not until the roles of this and other reef communities are more fully explored will we begin to understand the complex ecosystem that is a coral reef.

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ACANTHASTER IN THE CULTURES OF HIGH ISLANDS

by

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Residents of high islands in Micronesia, Melanesia and Polynesia usually have their own special names for *Acanthaster*, each have similar advice on curing the sting of the spines, and each claim that *Acanthaster* has been abundant at certain times in the past. I believe that this familiarity of *Acanthaster* in some high island cultures implies that outbreaks are a naturally recurring phenomenon around high islands. An apparent lack of familiarity of *Acanthaster* in the cultures of atolls implies that outbreaks of *Acanthaster* are much less frequent around atolls (low islands).

In Palau (Micronesia), the *Acanthaster* is called *rrusech* (Birkeland, 1979) while other starfish are called *btuch* or *tengetang*. At Fiji (Melanesia), *Acanthaster* is called *bula* (a homonym of "hello") while the general terms for "starfish" are *gasagasan* or *basage* (Atelaite Smalley, pers. comm.). In the Cook and Society Islands (Polynesia), *Acanthaster* is called *taramea* and in Samoa and Tonga (Polynesia), *Acanthaster* is called *alamea* (Garlovsky and Bergquist, 1970; Birkeland and Randall, 1979; Flanigan and Lamberts, 1981).

In contrast, the languages from atolls appear to not contain terms for *Acanthaster*. There is no special word for *Acanthaster* on Pingelap (Spensin James, pers. comm.); the crown-of-thorns is merely referred to as *isu*, a term used for all starfish. Similarly, *Acanthaster* is called *talwalyol* on Ulithi, a general term for all starfish (Eulalia Harui, pers. comm.). Abo et al. (1976) list 12,000 entries with information on about 30,000 Marshallese words. Many fishes, three groups of sea cucumbers, and other marine organisms are mentioned, but there was no word for *Acanthaster*. It must not be important to the Marshallese.

The Gilbert Islands (Kiribati), the Ellice Islands (Tuvalu) and Fanning Island are all atolls. Lobel (1978) presented a list of 407 names of fishes and 95 names of marine invertebrates used by Gilbertese and Ellice Islanders on Fanning Island, but *Acanthaster* was not listed. These inhabitants of atolls had their own specific names for many species of fishes, mollusks and crustaceans and even distinguished between three groups of holothurians, but all seastars came under one name. *Acanthaster* may have never been abundant on these atolls.

There is an exception from the atoll of Mokil (near Ponape) at which the people do call *Acanthaster* by the name *larmi*. Of course there may be other exceptions. However, there does seem to be a general presence of words for *Acanthaster* in high island languages and an apparent lack of words for *Acanthaster* in low island languages. These tendencies suggest that *Acanthaster* may be more common around high islands.

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Atoll Res. Bull. No. 255: 55-58, 1981.

People from atolls say they rarely, if ever, see *Acanthaster* and they have never heard of them being common (Matuatua Smit, Takapoto Atoll, Tuamotu, French Polynesia; Eulalia Harui, Ulithi, Yap District; Spensin James, Pingelap, Ponape District, pers. comms.). Around high islands, the people remember previous outbreaks. According to local fishermen, there was an outbreak in American Samoa in 1938 (Flanigan and Lamberts 1981). Vine (1970) reported that fishermen in the Solomon Islands (Melanesia) remembered large concentrations of *Acanthaster* about 1930, forty years previous to 1970. Chesher (1969) reported that Micronesians remember an outbreak on Ponape just after World War II.

Michael Parke talked to an old Palauan fisherman who described an extensive infestation that took place just prior to World War II. According to this fisherman, the *Acanthaster* soon disappeared, leaving algae in the place of coral. Then urchins became abundant during the early years of World War II. The fisherman felt that *Acanthaster* were transitory and no real problem. The abundance of urchins that resulted were a benefit. Old people could easily collect them for food within wading depth on the reef flat. We have not heard of other cases of an abundance of urchins following *Acanthaster*. It will be interesting to see if herbivorous urchins become common following the present devastation in Palau. Except for areas around artificial sea walls, breakwaters and ramps, regular urchins are remarkably scarce in Palau at the time of this writing.

The people on high islands tell of dangers of stepping on *Acanthaster* when fishing at night at times when *Acanthaster* is abundant (Vaolui, pers. comm.; Flanigan and Lamberts, 1981). A cure for injury from stepping on *Acanthaster* is claimed by several high island cultures to be their own discovery. When I was studying an *Acanthaster* outbreak in Palau, I accidentally jabbed my knee strongly against an *Acanthaster* and came to the boat with a lot of blood dripping out of six cuts in my knee. The boatman, Ngirbauliad ("Yahd") Mineich, advised me to take one of the *Acanthaster* and place it mouth down on the bloody knee. (This was tried, but was not found to be of great help.) When asked if he heard of this cure from a Samoan or Fijian, Yahd said it has always been common knowledge in Palau. Ramon Rechebei, another Palauan, said that he knew of this cure since he was a boy.

Spensin James told me that this cure had worked for him when he tried it. This cure was common knowledge among Ponapean fishermen and it works if you are sure to use the same individual *Acanthaster* that harmed you as the individual to cure you. If you are jabbed by one *Acanthaster* and lift another to cure your pain, it will be of no use. (I am not sure I used the same individual in Palau.)

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

This same cure has been known on Tonga (Richard Braley, pers. comm.), and as a proverb on Western Samoa (Garlovsky and Bergquist, 1970) and American Samoa (Birkeland and Randall, 1979; Flanigan and Lamberts, 1981).

The Secretariat of the British Solomon Islands Protectorate (1970) noted that this same cure by turning over and stepping on the underside of the *Acanthaster* was known in the Solomon Islands, New Britain, Manus Islands, and Gambier Islands.

The apparent history of recurring abundances of *Acanthaster* around high islands but not around atolls may be explained by the causal mechanism of *Acanthaster* outbreaks as suggested in Birkeland and Randall (1979) and Birkeland (1980). *Acanthaster* larvae may survive in much greater abundance following heavy rainfall. This might be because phytoplankton blooms are triggered by terrestrial runoff and this provides an abundant food source for *Acanthaster* larvae. Terrestrial runoff resulting from rains on high islands trigger phytoplankton blooms (Marsh 1977), but it is doubtful that terrestrial runoffs from low, sandy atolls carry an amount of nutrients into the coastal waters adequate to trigger blooms.

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MARINE BIOLOGY

Terrestrial Runoff As a Cause of Outbreaks of *Acanthaster planci* (Echinodermata: Asteroidea)*

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Abstract

Outbreaks of adult *Acanthaster planci* (Linnaeus) have appeared at irregular intervals, arriving 3 yr after heavy rains (>100 cm in 3 months) following droughts (<25 cm in 4 months) or 3 yr after rains exceeding intensities of 30 cm in 24 h. Outbreaks of *A. planci* follow typhoons that bring heavy rains, but do not follow "dry" typhoons of equivalent wind force. Outbreaks occur around the high islands in Micronesia and Polynesia, but not around the atolls at intermediate locations. Phytoplankton blooms appear off high islands at the beginning of the rainy season in bays with large watersheds and with sufficient residence time of the waters; these are the initial sites of *A. planci* abundance on Guam. The spawning seasons of *A. planci* occur at the beginning of the rainy season on both sides of the equator. I hypothesize that, on rare occasions, terrestrial runoff from heavy rains (following the dry season or a record drought) may provide enough nutrients to stimulate phytoplankton blooms of sufficient size to produce enough food for the larvae of *A. planci*. The increased survival of larvae results in an outbreak of adults 3 yr later. This hypothesis can be tested by predicting future outbreaks. An outbreak of *A. planci* on Saipan in the summer of 1981 was predicted on the basis of heavy rains in August 1978.

Introduction

Outbreaks of *Acanthaster planci* are a natural phenomenon that recur at irregular intervals. That outbreaks recur is evidenced by aggregations of skeletal remains in sediment core samples (Frankel, 1977), by a second recent increase in abundance on Guam, and by the folklore and memories of Samoans (Birkeland and Randall, 1979), Solomon Islanders (Vine, 1970, 1973), New Ireland Islanders (Pyne, 1970), Ponapeans (Chesher, 1969a) and Palauans (Birkeland, 1979) of previous outbreaks of *A. planci* (Fig. 1). That outbreaks are a natural phenomenon is implied by their occurrences hundreds of years ago (Frankel, 1977), by their occurrences in areas far from agricultural activity or industrial and urban development [e.g. the north coast of Tutuila, American Samoa (Birkeland and Randall, 1979) and south of Urukthapel Island, Palau (Birkeland, 1979)] and by the lack of correlation of timing of any construction or industrial activities with the local outbreaks of *A. planci* (Birkeland and Randall, 1979). Only rainfall with terrestrial runoff was correlated with the outbreaks and evidence for this is presented in this paper.

Observations

Abruptness of the Population Increases

Initial outbreaks of *Acanthaster planci* (Linnaeus) appear suddenly, within a few months, and do not build up gradually over years. This characteristic of outbreaks of *A. planci* is fundamental to my hypothesis.

Acanthaster planci appeared suddenly in American Samoa in late 1977. Despite their frequent and widespread activity, fishermen who were on the reef nearly every day during the last few decades very rarely saw an *A. planci* from about 1938 to late 1977 (Birkeland and Randall, 1979; Flanigan and Lamberts, 1981). Weber and Woodhead (1970), Vine (1970), and Devaney (Devaney and Randall, 1973) reported *A. planci* to be very scarce in American Samoa between 1966 and 1971. R. C. Wass (personal communication) saw no more than 6 individuals during 3 yr of extensive diving around American Samoa prior to November 1977. The first group of *A. planci* (roughly 50 per 30 min) was seen in November 1977 at Fagatuitui Cove, northeast of Fagasa Bay on the north coast of Tutuila (Wass, 1979). In the next month, an aggregation of about 83 000 individuals moved as a front

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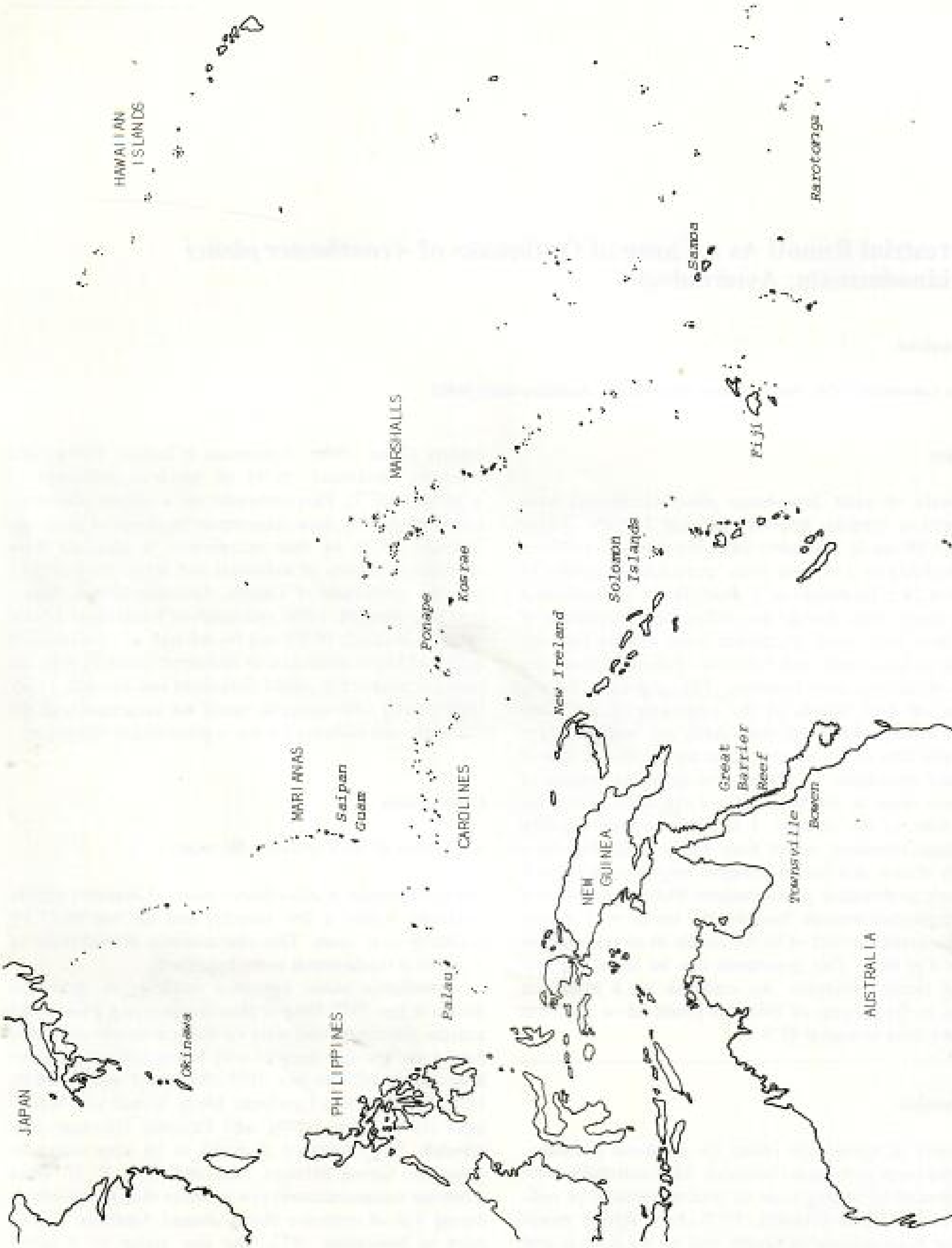

Fig. 1. *Acanthaster planci.* Location of places of outbreaks

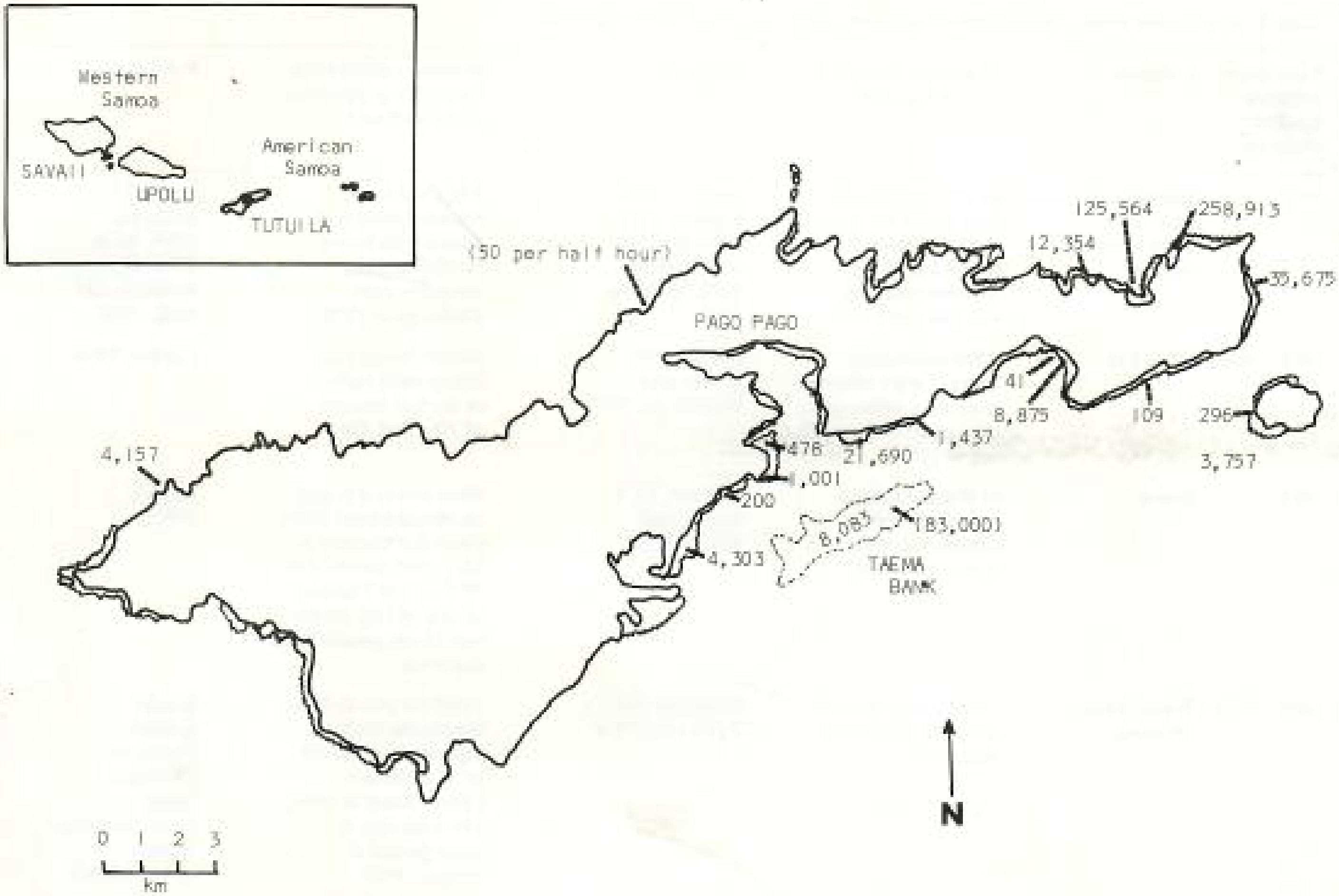

Fig. 2. *Acanthaster planci.* Numbers removed from the ocean for bounty (open numbers) or observed in surveys (numbers in parentheses) at Tutuila, American Samoa

along Taema Banks off the south-central coast of Tutuila (Wass, 1979). In early 1978, 384 477 individuals were collected from two small bays on the northeast coast (Fig. 2). A total of 486 933 individuals were removed from the ocean less than a year from the time the first group was observed (Birkeland and Randall, 1979).

Acanthaster planci appeared in large numbers on Western Samoa (at Upolu, 59 km from Tutuila) during 1977 (A. Banse, personal communication). *A. planci* thus appeared at approximately the same time in widely separated locations (on all sides of Tutuila and at Upolu, Fig. 2).

Sudden increases in abundance of *Acanthaster planci* occurred at Guam in late 1967 and in 1979. *A. planci* started to appear frequently in June 1967 and by June 1968 about 200 individuals could be observed per dive at Tumon Bay (Randall, 1971). I observed a total of less than 20 individuals during about 240 dives (averaging about 30 min each) in 4 yr from August 1975 to May 1979. Beginning in May 1979, we could find 29 to 50 individuals per 30-min period at the north ends of Agana and Tumon Bays.

A sudden and widespread increase in abundance of *Acanthaster planci* occurred in Palau (Belau) in the spring of 1977 (Government of Palau Office of Marine Resources, personal communication). Over 354 470 *A. planci* were removed from the area around Ngadarak (Ngederrak) reef (S. Birk, personal communication). The outbreaks seemed to have started at discrete locations, widely separated by Urukthapel (Ngeruktabel), a very long island (Birkeland, 1979). Although each outbreak was concentrated on a geographic scale, occurring in some island groups but not in others, the outbreaks appeared suddenly at more than one location within these groups across an area subjected to similar climatic conditions.

"Secondary infestations" (Endean, 1973) sometimes follow initial outbreaks. Examples were found at Guam (Chesher, 1969 b), in Palau (Birk, 1979), and on the Great Barrier Reef (Kenchington, 1977). This paper is only concerned with causes of the initial outbreaks. Endean (1973, 1974) and Kenchington (1977) discuss secondary infestations.

Outbreaks and Rainfall Records

All major outbreaks of *Acanthaster planci* have been associated with unusually heavy rainfall 3 yr previous to their first appearance (Table 1). If we accept the spawning

Table 1. *Acanthaster planci.* Association of outbreaks with heavy rainfall 3 yr previous

Year when outbreak was first observed	Location	Minimum estimates of outbreak size	References	Weather event at the location 3 yr previous to the outbreak	References
1962	Queensland Coast between Townsville and Bowen	44 000 individuals were killed by control measures at Green Island, but the outbreak was was more extensive	Barnes, 1966; Endean, 1973, 1974; Endean and Stablum, 1975; Harding, 1968	The third most intense typhoon on record with heavy rainfall causing extensive river discharge in 1959	FS, DO, Brisbane, 1959; ACR, 1975: 16; Newman and Bath, 1959
1967 – 1968	Suva, Fiji	9 860 individuals; "many" were observed in an area where none were observed the year before (1966)	Owens, 1971; Weber and Woodhead, 1970	Severe floods and heavy rains early in the wet seasons of 1964 and 1965	Cooper, 1966
1968	Guam	63 000 individuals were destroyed by control measures, but many remained	Randall, 1971; Marsh and Tsuda, 1973	Most severe dry spell on record (since 1956) came in February to May 1965 followed by 39.9 cm (15.7 inches) of rain in July which was 12 cm greater than expected	NOAA, 1980 b
1969 – 1972	West-Central Okinawa	240 000 individuals removed by control measures	Nishihira and Yamazato, 1974	119.4 cm rain at Nago during the early reproductive season of *Acanthaster* (April–June) in 1966; 154.2 cm rain in same period at Nago in 1969	Koichi Kujirai, Director-General, Japan Meteorological Agency (pers. comm.)
1973	Rarotonga, Cook Islands	80 974 individuals killed by control measures	Cook Island News, 19 February 1973	117.5 cm rain fell during the early reproductive season of *Acanthaster* (December 1970 – February 1971)	JMA, 1975
1977	Tutuila, American Samoa	486 933 individuals were collected for bounty, thousands more remained	Birkeland and Randall, 1979	Record drought in 1974 (13.5 cm [5.3 inches] in 4 months) immediately followed by heavy rains (112 cm [44 inches] in 3 months)	NOAA, 1980 c
1977	Palau	354 470 individuals were removed from Ngederrak Reef, but more remained south of Urukthapel	Serge Birk (personal communication)	The highest annual rainfall on record for Palau was 470 cm (185 inches) in 1974; 35 cm (13.9 inches) on a single day in January	NOAA, 1980 a
1979	Guam	scattered aggregations of up to 200 individuals	Personal observations and personal communications from others	68.6 cm (27 inches) of rain on 22 May 1976 and a total of 83.8 cm in 2d with Typhoon Pamela	Records at the NOAA station on Guam
1981	Saipan	"thousands" of individuals	Joaquin Villagomez, Chief, Division of Marine Resources, Commonwealth of the Northern Marianas (pers. comm.)	114 cm (45 inches) of rain in 48 h in mid-August 1978	

season of *A. planci* north of the equator to be June–August (Yamazato and Kiyan, 1973) and south of the equator to be November–January (Lucas, 1973), and if we define a "rainy spawning season" to be a three-month period in which there is more than 100 cm of rain, then we find a significant tendency for *A. planci* outbreaks to be associated with heavy rainfall during the spawning season three years previous (Table 2).

It is not certain whether there were one or two outbreaks of *Acanthaster planci* off west-central Okinawa. The outbreak of *A. planci* at Okinawa was first observed in 1969 and the population was still abundant in 1972 (Nishihira and Yamazato, 1974). Weather records show that the heaviest rains during the spawning seasons in Okinawa were in 1966 and 1969. I have not been able to determine whether there were one or two outbreaks because *A. planci* were common throughout this period and 240 000 individuals were removed intermittently over a prolonged period (Nishihira and Yamazato, 1974). If there was only one outbreak at west-central Okinawa in 1969, there was a total of 6 outbreaks in 173 place-years (Table 2). If there was a second outbreak in 1972 (cf. Nishihira and Yamazato, 1974), then there were 7 outbreaks in 173 place-years.

If we set operational definitions of "heavy rains" (> 100 cm during 3-months of the spawning season) following "droughts" (< 25 cm of rain during 4-months immediately preceding the spawning season) and "intensive" rains (> 30 cm in 24 h) and examine areas for which daily precipitation records exist (Table 3), we find that all outbreaks have occurred 3 yr after one of these two weather events ($P < 8.1 \times 10^{-6}$ that this association is a matter of chance).

This association of future outbreaks with the weather allows predictions to be made. There were 45 inches (114 cm) of rain in a 48-h period on Saipan in August 1978. Predictions were made (Birkeland and Randall, 1979; Birkeland, 1980) that an outbreak would occur on Saipan in the summer of 1981, three years after the rains. Several thousand *Acanthaster planci* were found as a moving front in southern Saipan in August 1981 (J. Villagomez, Chief of the Division of Marine Resources, Northern Marianas, personal communication). I predict an outbreak of *A. planci* in Palau in the summer of 1983 because there were 17 inches (43 cm) of rain in Palau on 13 April 1979.

Tests of hypotheses can be made by predicting previous weather records. "Huge numbers" of *Acanthaster planci* were last seen (prior to the 1977 outbreak) on American Samoa in 1938 (Flanigan and Lamberts, 1981). I have not yet been able to obtain daily weather records for Tutuila for January 1935, but I predict that they would contain records of exceptionally intensive rains around January 1935.

Vine (1970, 1973) was informed that an outbreak occurred in the Solomon Islands about 40 yr prior to 1970. The weather records for Honiara, Guadalcanal (JMA, 1975), show extremely heavy rains during the spawning season of *Acanthaster planci* in 1923. There were 1 506 mm (59.3 inches) of rain in January 1923, 2 639 mm of rain during the spawning season (November 1922 to January 1923) and 7 964 mm (314 inches) of rain for the year (April 1922 to March 1923). This was over 3 times the expected rainfall for January, the spawning season, and the year.

Table 2. *Acanthaster planci.* Association of outbreaks with heavy rainfall (> 100 cm) during 3 months of the spawning season 3 yr previous. Monthly rainfall data were from American Samoa (1960 – 1979), Rarotonga (1899 – 1980), Palau (1947 – 1979), Guam (1956 – 1979) and Nago, Okinawa (1966 – 1979)

Acanthaster planci outbreak	No. years with rainfall (during spawning season) 3 yr previous	
	< 100 cm	> 100 cm
present		6
absent	116	51

$P(6) = \left(\frac{57}{173}\right)^6 = 0.0013$ (assuming one outbreak at Okinawa)

$P(7) = \left(\frac{57}{173}\right)^7 = 0.00042$ (assuming two outbreaks at Okinawa)

Table 3. *Acanthaster planci.* Association of heavy rains (> 100 cm in 3 months) following droughts (< 25 cm in 4 months) or intensive rains (> 30 cm in 24 h) with *A. planci* outbreaks 3 yr later. Daily records are from American Samoa, Palau, and Guam

Outbreak of *Acanthaster planci*	Heavy rains following drought or intensive rains	
	No. years with	No. years without
present	4	
absent		71

$P(4) = \left(\frac{4}{75}\right)^4 = 8.1 \times 10^{-6}$

Wet and Dry Typhoons

Typhoon Karen and Typhoon Pamela were two very strong typhoons that struck Guam with sustained winds of 220 to 270 km h^{-1}. Typhoon Pamela brought 83.8 cm (33 inches) of rain (68.6 cm in 24 h) in May 1976 and was followed by an increase in abundance of *Acanthaster planci* first seen in May 1979. Typhoon Karen (1962) was a dry typhoon with a wind intensity equivalent to that of Typhoon Pamela; it caused tremendous structural damage on Guam, but brought no flooding. Typhoon Karen was not followed by an increase in abundance of *A. planci*.

The only recent major typhoon in American Samoa was a dry typhoon in 1966; it was not followed by an outbreak in 1969. A wet typhoon in Fiji in 1965 (Cooper, 1966) was followed by an increase in abundance of

Acanthaster planci in 1968 (Weber and Woodhead, 1970). The intense typhoon on the Queensland coast in 1959 (Newman and Bath, 1959) was accompanied by heavy rains and followed by an outbreak of *A. planci* in 1962 (Endean, 1973). The 1968 outbreak at Guam and the 1977 outbreak of Samoa followed heavy rains, but not strong winds.

Role of Rainfall and Terrestrial Runoff

The main spawning season of *Acanthaster planci* south of the equator is November–January (Lucas, 1973). The main spawning season north of the equator is June–August (Yamazato and Kiyan, 1973). In both regions, these periods begin about a month after the beginning of the rainy season. Field studies off Guam led Marsh (1977) to conclude that phytoplankton blooms "... are usually associated with the beginning of the rainy season. It is probable that heavy rains coming after an extended dry season wash a pulse of nutrients, especially phosphorus, off the watershed and stimulate a bloom. Eventually, as the most easily available nutrients wash off the land, the runoff water becomes more dilute and the plankton bloom in the bay dies out. With the onset of the dry season, accumulation of easily leachable nutrients begins again on the watershed and the seasonal cycle is repeated". Marsh (1977) noted that no phytoplankton blooms have been observed in Pago Bay which has a generally smaller watershed and a lower input of groundwater than Tumon Bay. Phytoplankton blooms have been recorded in Tumon Bay as far back as the earliest Spanish occupation of Guam (Marsh, 1977). Outbreaks of *A. planci* originating in Pago Bay have not been seen, but outbreaks have originated twice at the north end of Tumon Bay, near San Vitores cut, where Marsh did his study. Outbreaks of *A. planci* generally seem to start around Agana and Tumon Bays, large bays with large watersheds.

Phytoplankton blooms may be necessary for abundant larval recruitment of *Acanthaster planci*. Lucas (1974) determined that the greatest percentage of larval *A. planci* survived to late brachiolaria stage at 5 000 diatom cells ml^{-1}. Marshall's (1933) study is the only comprehensive analysis of phytoplankton on the Great Barrier Reef (Lucas, 1974). Marshall sampled phytoplankton for almost a year and found most samples to contain phytoplankton at very low concentrations, about 2 cells ml^{-1}. At irregular intervals, phytoplankton (mostly diatoms) reached maximum concentrations of about 170 cells ml^{-1}. These phytoplankton densities are a small fraction of the minimum densities required to support larvae of *A. planci*.

High Islands and Atolls

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

Cowan and Clayshulte (1980) found that the total soluble inorganic nitrogen in waters surrounding all high islands sampled (Kosrae, Ponape, Moen, Dublon, Yap, and Koror) to be higher than in waters around any of the atoll islands sampled (Majuro, Ebeye, Gugeegue). Except for Yap, which had unusually low orthophosphate levels, the waters around the high islands had higher calculated potentials for phytoplankton blooms or biomass yields than did waters around any of the atolls.

If phytoplankton blooms are more likely to occur around high islands than around atolls because of nutrient runoff following rains, and if phytoplankton blooms are necessary for initial outbreaks of *Acanthaster planci*, then we would predict that outbreaks should occur more frequently around high islands or continents than around atolls. Indeed, Okinawa (Nishihira and Yamazato, 1974), Guam (Chesher, 1969 a, b), Palau (Birkeland, 1979), Truk (Chesher, 1969 b; Cheney, 1973), Ponape (Chesher, 1969 b), Upolu (Western Samoa, cf. Garlovsky and Bergquist, 1970), Tutuila (American Samoa, cf. Birkeland and Randall, 1979), Rarotonga (Cook Islands, cf. Devaney and Randall, 1973; Syme, 1980), Tahiti (Devaney and Randall, 1973) are all high islands and the initial outbreak at the Great Barrier Reef appeared to have begun near the continental coast of Queensland, Australia (ACR, 1975). Outbreaks have been found around the high islands of Palau (Chesher, 1969a, b; Marsh and Tsuda, 1973; Birkeland, 1979) but not around Kayangel, the atoll of Palau (Marsh and Tsuda, 1973).

To test the hypothesis of more frequent occurrence of *Acanthaster planci* outbreaks around high islands, we can analyze the data in Marsh and Tsuda (1973). Marsh and Tsuda categorized islands as high islands or atolls and ranked the abundance of *A. planci* on a scale from 1 to 6. Conditions 1 and 2 were essentially normal conditions of abundance of *A. planci*, Conditions 3 to 5 designated large populations of *A. planci*, and Condition 6 indicated a case in which *A. planci* was not actually seen but the coral community appeared to have been influenced extensively by predation. Condition 6 was excluded from the analysis because of inadequate documentation. Further explanation of this scale of ranking can be found in Chesher (1969a) and in Marsh and Tsuda (1973).

Outbreaks of *Acanthaster planci* have a significant tendency to occur around high islands and rarely around atolls (Table 4). The two instances of abundant *A. planci* on atolls (Table 4) might be disregarded for two reasons. First, only one individual was actually seen on Kuop and only a few were seen on Ant (Marsh and Tsuda, 1973). These atolls were categorized in Condition 5 because the

Table 4. *Acanthaster planci.* Results of surveys 1969–1972, in Micronesia. The data were tallied from Table 1 in Marsh and Tsuda (1973) and "normal" and "abundant" conditions are defined in that reference.

	High islands	Low islands (Atolls)	Total
Conditions 1 and 2 (normal densities of *A. planci*)	4	20	24
Conditions 3 to 5 (abundant *A. planci*)	19	2	21
	23	22	45

$\chi^2_{adj\,[1]} = 21.5$ ($P \ll 0.001$)

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

Other sources of evidence for a long-term tendency of outbreaks of *Acanthaster planci* to occur around high islands but not around atolls are the linguistics and cultures of peoples from the respective island groups. People from high islands remember previous outbreaks, have traditional cures for punctures from *A. planci*, and have species-specific names for *A. planci* (Flanigan and Lamberts, 1981; Birkeland, 1981). People from atolls do not remember previous outbreaks and refer to *A. planci* with names that are general terms for starfish (Birkeland, 1981). Hypergeometric distribution analysis of names for *A. planci* among island groups (Birkeland, 1981) indicates a probability of less than 0.04 that the association of terms for *A. planci* with high islands rather than atolls is a matter of chance.

Water Residence Time in Lagoons

Kosrae and Ponape are high islands which have the greatest potential for phytoplankton blooms of all of the Carolines (Cowan and Clayshulte, 1980). *Acanthaster planci* was common in Ponape just after World War II and in 1969 (Chesher, 1969a), in 1970, 1971, 1972 (Cheney, 1973; Marsh and Tsuda, 1973), and in 1979 (R. A. Croft, personal communication), but it was not common in Kosrae in 1973 (Wass, 1973) or 1979 (Eldredge *et al.*, 1979). Ponape is surrounded by a lagoon which is enclosed by a barrier reef. Kosrae is surrounded by fringing reefs. Although the waters off Kosrae contain enough nutrients to allow phytoplankton blooms (Cowan and Clayshulte, 1980), the waters probably move away from the island before the phytoplankton have undergone enough cell divisions to build up a standing crop sufficient to support larvae of *A. planci*. At Ponape, the lagoon may act as an incubator with the water in the lagoon having a long enough residence time to allow phytoplankton to build up a standing crop large enough to support larvae of *A. planci*. The dispersion of water could also thin out the concentration of *A. planci* larvae as well as the food supply of the larvae. Studies of fish larvae indicate that upwelling of nutrient-rich water leads to phytoplankton blooms, but the movement of the upwelling waters disperse food organisms so that the food particles are too low in concentration to support larval anchovy growth (Smith and Lasker, 1978).

The populations of *Acanthaster planci* at Guam increased originally at the northern ends of Agana and Tumon Bays in both 1968 and 1979, but not in Pago Bay. After heavy rains, the sediment flume is carried directly out of Pago Bay and dispersed into the open sea. The movements of waters on the reef flat at the north end of Tumon Bay is sluggish and probably has a relatively long residence time in the areas in which phytoplankton blooms are observed (Marsh, 1977).

Owens (1971) showed that *Acanthaster planci* was significantly more abundant on inshore fringing reefs of the high island of Viti Levu, Fiji, than on the offshore barrier reefs. D. L. Woodland (personal communication) pointed out that the densities of *A. planci* given on Owen's (1971) survey map declined along a gradient from the relatively rainy southeast [Suva, with about 120 inches (305 cm) per year] to the relatively arid northwest [Lautoka, with about 30 inches (76 cm) per year] on the south coast of Viti Levu.

Discussion

Initial outbreaks of *Acanthaster planci* occur suddenly, within a year, which implies that outbreaks originate from especially successful larval recruitment during particular seasons. Populations of adult *A. planci* do not appear to build up to outbreak levels gradually over several years or generations, a response which could result from release from predation or competitive pressure. The magnitudes of the initial outbreaks also imply that increases must result from survival of larvae, where a small percent increase in survival could produce great increases in absolute numbers of adults. *A. planci* suddenly appear in such numbers in so many localities in an area that major outbreaks are difficult to attribute to behavioral aggregations.

Acanthaster planci were 25–35 cm in diameter when they first appeared in abundance in American Samoa (Birkeland and Randall, 1979), Palau (Birkeland, 1979), and Guam (Birkeland, unpublished observation). Juveniles were difficult to find; they apparently stay concealed within the interstices of the reef. R. Caldwell (personal communication) found juveniles under coral and rubble fragments covered with crustose coralline algae at Phuket (Thailand), at Moorea (Society Islands), in the Gulf of

Chiriqui (Panama), and on the coast of Australia between Cairns and Townsville. Lucas (1974) in Australia and Yamaguchi (1974) on Guam each raised *A. planci* from the egg to the juvenile stage and independently obtained similar growth curves. Analysis of size frequency data from field studies by Kenchington (1977) gave growth curves compatible with the information from laboratory studies by Lucas (1974) and Yamaguchi (1974) and also with field experiments of Pearson and Endean (1969). Although size classes are very poor indicators of age classes in asteroids (Mead, 1900), results from these four studies provide the best estimate available and indicate that *A. planci* requires about three years to reach 25–35 cm diameter.

The initial outbreak of *Acanthaster planci* in Samoa occurred on both sides of Tutuila and on Upolu, 59 km away (Birkeland and Randall, 1979). The outbreak at Palau occurred in at least two locations, separated by a long island (Birkeland, 1979). Therefore, I looked for meteorological events because they would cover areas of this magnitude. An examination of weather records produced a significant association between initial outbreaks of *A. planci* and unusually heavy rains 3 yr previous, but heavy rains (>100 cm per spawning season) was too general a category for predictive value. Therefore, I examined those situations which would facilitate nutrient runoff and found a very significant association between heavy rains (>100 cm in spawning season) following droughts (<25 cm of precipitation in 4 months prior to the spawning season) or intensive rains (>30 cm in 24 h) and outbreaks of *A. planci* 3 yr later.

If nutrient runoff is the ultimate cause of *Acanthaster planci* outbreaks, then land-clearing activities by humans should increase the chances of outbreaks (Nishihira and Yamazato, 1974; Pearson, 1975). Although land-clearing for agriculture and urban development could conceivably facilitate nutrient runoff to the point of increasing the frequency of outbreaks of *A. planci* in the future, there is no direct evidence in my studies for this having occurred. This is concluded because outbreaks probably have been occurring for hundreds of years (Frankel, 1977) and the sites of the two most intensive outbreaks on record (Table 1), American Samoa and Palau, are in relatively pristine areas, isolated from any agricultural, industrial, or urban land-clearing activities (Birkeland and Randall, 1979; Birkeland, 1979).

Lucas (1973) demonstrated that survival of larvae of *Acanthaster planci* increased as the salinity was lowered to 30‰ S. According to Pearson and Lucas (in: Advisory Committee on Research, 1975), "...the right combination of heavy run-off (lowering salinity), light wind conditions (preventing mixing with more saline water) and an abundance of *A. planci* larvae could lead to a high survival rate in larvae and subsequent expansion of juvenile and adult populations". Pearson (1975) found optimal salinity levels for development of larval *A. planci* as a result of terrestrial runoff into reef waters near the coast of Queensland where infestations were common.

Heavy runoff may be favorable to the survival of larvae of *Acanthaster planci*, but the main benefit of the runoff is not the lower salinity itself (a proximate adaptation), but the ultimate increase in nutrients (nitrate-nitrogen and reactive phosphates) which stimulate phytoplankton blooms (Aleem, 1972; Marsh, 1977) which, in turn, provide food for the larvae. The spawning season of *A. planci* coincides with the beginning of the rainy season. The larvae are adapted to relatively low salinities (30‰ S) in which ample nourishment most probably occurs. Himmelman (1975, 1978, 1980) presented evidence from both controlled laboratory experiments and field observations which indicated that phytoplankton induced spawning in chitons and the echinoid *Strongylocentrotus droebachiensis*.

Many coastal marine invertebrates with planktotrophic larvae show irregular recruitment (Coe, 1956). They may generally be related to terrestrial nutrient runoff. Sutcliffe (1972, 1973) showed that correlations exist between the amounts of land drainage or river discharge and bivalve, fish, and lobster catches. As with the 3-yr lag between the unusual terrestrial runoff and the appearance of an outbreak of adult *Acanthaster planci*, the correlations of river discharges with commercial catches are found if lag periods are included to account for the time that is required for the animals to grow to commercially harvestable size. The timing of the runoff is important. Sutcliffe found the runoff data must be taken from early in the reproductive season for each species under consideration, just as we must remember that relevant rainfall data for the *A. planci* study are 6 months apart on the two sides of the equator because of the different reproductive seasons in the two hemispheres. Sutcliffe (1973) found that the major effect of land drainage was in increased production of larval stages, probably through increased primary production. The degree of correlation was highest for the earliest larval stage and decreased with increasing larval stages. Ben-Tuvia (1960) and Chidambaram and Menon (1945) showed positive correlations between abundances of juvenile sardines and rainfall during the preceding peak spawning season. Aleem (1972) found that when nutrient concentrations in the Nile flood water decreased, the phytoplankton blooms associated with the flood disappeared and, consequently, the fisheries catches decreased to 3.7% of their former level.

Loosanoff (1964), from 25 consecutive years of observations, showed that the abundance of adult *Asterias forbesi* (starfish) and the size of sets had no predictive relation to each other. Individual female *Acanthaster planci* can produce hundreds of thousands of eggs. When conditions favoring abundant larval survival occur, the high reproductive potential of even a few adult *A. planci* may allow the production of a massive settlement of juveniles. In fisheries studies, there is often no correlation between the size of the reproductive stock and the size of the resultant year class (Lasker, 1978). Larval survival and the size of the resultant year class may be predicted more reliably from availability of larval food (Hjort, 1926; May, 1974; Lasker, 1975, 1978; Arthur, 1976; Methot and Kramer, 1979).

It might be contended that phytoplankton constitute only a minor fraction of the organic matter in seawater anywhere and organic detritus might be more important as a source of larval food in nature. However, larvae may rarely, if ever, starve in nature; quality and quantity of larval food may only influence rate of development. Methods for determination of age of larval anchovy have shown that growth of anchovy in the sea is always faster than the growth of anchovy on limited rations in the laboratory (Methot and Kramer, 1979). If larvae survive, then they have apparently obtained enough food for rapid growth. The slower growing and presumably weaker individuals may never actually die of starvation, but may be more susceptible to predation.

Plagues of insects in the tropics may also be related to rainfall pattern and added nutrition for larvae, although for different reasons. White (1976) reviewed the literature for 7 species of locusts from around the world and found that very young locusts usually have an inadequate or too thinly dispersed food supply. Most individuals die before reaching maturity. When there are periods of alternating unusually dry and wet seasons, the food supply becomes more favorable for the very young locusts. An increased survival of very young locusts later results in a plague. Parasites and predators have little influence on their abundance; the determining factor is added nutrition for early instars which results from extreme changes in rainfall patterns. Wolda (1978a) presented evidence that fluctuations in populations of tropical herbivorous insects were strongly affected by irregularities in rainfall. I suggest that this situation is generally the same for shallow-water marine invertebrates with planktotrophic larvae. Outbreaks occur when runoff of terrestrial nutrients coincide with the reproductive season of the marine invertebrates.

It is sometimes asserted that "... pronounced short-term fluctuations in population densities are not features of the population ecology of specialized coral reef species and *Acanthaster planci* can be shown to be such a specialized coral reef species" (Endean, 1977). The definition used for the term "specialized" (Endean, 1974) is not definitive enough to clearly include or exclude most species, but if we consider tropical marine invertebrates with planktotrophic larvae, we find that many species are characterized by great year-to-year fluctuations in recruitment success. Frank (1969) characterized tropical gastropods as being long-lived with irregular reproductive success. Marsh *et al.* (1977) noted that an extensive settlement of *Diadema setosum* and *Echinothrix diadema* occurred in 1973 and the abundant year class of 1973 was still prevalent in 1977 (and perhaps longer). Outbreaks of *A. planci* have received more attention than have outbreaks of other species because of the spectacular effects the *A. planci* outbreaks have on the coral reef communities. Many species with planktotrophic larvae may be characterized by an occasional year of abundant recruitment followed by several years of very sparse recruitment. The abundant recruitment comes at different times for different species, possibly because of different combinations of factors favoring larval development and successful settlement for each species. Similarities in larval biology alone, however, does not necessarily produce similar patterns of reproductive success. The survival rate of the very similar lecithotrophic brachiolaria larvae of *Mediaster aequalis* and *Hippasteria spinosa* was about the same, but *H. spinosa* has much greater percent mortality shortly after metamorphosis in both field and laboratory (Birkeland, 1974).

Endean (1977) argued that infestations of *Acanthaster planci* were not periodic or cyclic because coral reef systems are regarded as having "... a particularly stable or predictable organization because they are biologically accomodated". I suggest that coral reef systems might fluctuate as do temperate marine systems, but the fluctuations of small motile invertebrates have been unnoticed and unstudied while the fluctuations in coral and sponge populations are on a long-term time scale because of the longevity of individuals. Tropical insect populations were assumed to fluctuate less than temperate insect populations on the basis of the diversity-stability hypothesis. Once comparative data were obtained from the tropical rain forest (Wolda, 1977, 1978b), it was found that there was no empirical basis for the theoretical assumption of less fluctuation of invertebrates in tropical rain forests. The same might hold for coral reef systems.

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— No mention of Rose or sea turtles

APPENDIX B

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

by

Richard C. Wass

INTRODUCTION

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

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

METHODS

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

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

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

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

RESULTS

Taema Bank Survey

Sector I

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

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

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

Sector II

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

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

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

Sector III

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

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

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

Sector IV

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

The first quadrat survey was conducted on January 24, 1978 at a location along the starfish front in line with a bearing between the television tower on Alava Mountain and the navigation light on Breakers Point. Two quadrats at this location averaged 400 starfish each. On February 1, 1978 the starfish front was surveyed again at two more locations. Two quadrats at the first of these two survey sites, located on a bearing in line with the television tower on Alava Mountain and the top-most peak at Breakers Point, averaged 364 starfish inch. At the second survey site, located on a bearing in line with the television tower on Alava Mountain and the middle part of Breakers Point, two quadrats averaged 340 starfish each. Based upon densities from these three survey sites the average starfish density along the front was estimated at $15.2/m^2$. Using this average density value and on area 800 meters long by 6.5 meters wide, the total starfish front population was calculated to be about 80,000.

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

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

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

Offshore Patch Reefs and Nafanua Bank Surveys

Offshore Patch Reefs A-D

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

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

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

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

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

Nafanua Bank Surveys

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

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

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

Tutuila Island Surveys

Reef Flat Surveys Along the Southeast Coast

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

Forereef Slope Surveys Along the Southern Coast

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

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

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

Forereef Slope Surveys Along the Eastern Coasts

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

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

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

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

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

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

Forereef Slope Surveys Along the North-Central Coast

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

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

Forereef Slopes Surveyed Along the Northwestern Coast

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

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

Survey at Fagatele Bay Along the Southwest Coast

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

Other Surveys

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

along the margin of sand channels, 6 to 8 feet (2 to 3 m) deep. The shallow margins of these channels support small, apparently young, coral heads. Massive microatolls of Porites lutea 10 feet (3 m) across and up to 4 feet (1.2 m) high are present. Thickets of P. andrewsi are equally large, but stands of this coral show considerable dead branches encrusted with coralline algae. Sea anemones and anemone fishes are evident between the branches. The algae, Valonia sp., Actinotrichia sp., and Halimeda discoidea, are present in low abundance along the edges of coral thickets (ASCRI-OL1B9).

Fish populations are abundant and the fauna diverse. At least 80 species inhabit the southeastern portion of Asaga Strait. The high diversity appears related to variations in bottom types. The damselfishes, Glyphidodontops glaucus and Stegastes albofasciatus, the surgeonfish, Acanthurus triostegus, and the wrasse, Halichoeres trimaculatus, are most common inshore, in areas of volcanic rubble where bottom relief is low. Most of the fishes in this zone are juveniles or sub-adults. Toward the center of the strait, in areas of rich coral growth, the dominant species are the surgeonfish, Ctenochaetus striatus, the damselfish, Stegastes nigricans, and the parrotfishes, Scarus oviceps and Scarus spp. In deeper parts of the strait, Acanthurus triostegus, Ctenochaetus striatus, and Stegastes nigricans are most common in the middle of a channel (ASCRI-OL1F3). Of intrest is the presence of the green sea turtle (Chelonia mydas) (74). ? Wass 1979a App. B

FRINGING REEF (SOUTH OF ASAGA STRAIT)

The inner reef flat southeast of Tamatupu Point is nearly devoid of coral, with only occasional Porites lutea heads. Turf forming algae cover about 75% of the rubble bottom. Encrusting coralline algae are common, with some Halimeda discoidea and Jania sp. present (ASCRI-OL1B7).

Coral cover reaches 10% on the middle reef, about 300 feet (90 m) from shore. A bank of staghorn Acropora is conspicuous. The upper parts of the coral branches (a few inches from the surface at low tide) appear dead. At the interface of the Acropora and rubble bottoms, the sea cucumber, Holothuria argus, is common. The sea urchins, Diadema sp. and Echinometra mathaei, are evident (ASCRI-OL1B8).

ASAGA STRAIT

Prior to construction of a bridge and causeway across Asaga Strait, underwater visibility was over 40 feet (12 m). Strong currents are reported in the deepest parts of a sand channel through the center of the strait but currents are much less elsewhere (74). During construction of the viaduct, the strait was temporarily closed by a boulder causeway (200;202).

TAMATUPU POINT

Access to the shoreline near Tamatupu Point is difficult

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southwest Fisheries Center
Honolulu Laboratory
P. O. Box 3830
Honolulu, Hawaii 96812

January 17, 1983 F/SWC2:GHB

Dr. M.-H. Sachet
Atoll Research Bulletin
Smithsonian Institution
Washington, D.C. 20560

Dear Dr. Sachet:

I am writing to ask if you can provide me with copies of the following news articles relating to Rose Atoll.

Dumstrey, H. 1920. Official visit to the islands of the Manu'a district. O Le Fa'atonu 18(2):1-2.

Anon. (or A. G. Mayor?). 1920. Rose Island (Nuu O Manu) - Report to the Governor of Tutuila, printed both in Samoan and in English in - O Le Fa'atonu 18(7).

Anon. 1922-26. Flag Day at Manua. O Le Fa'atonu 20(6), 21(6), 22(6), 24(6).

Most of these articles were referenced in your excellent report on Rose Atoll that was published in Atoll Research Bulletin in 1954. Without success, I have tried to obtain copies from the Government of American Samoa, Brigham Young University, and the Hawaiian-Pacific library collection at the University of Hawaii. I am in the process of writing a report on sea turtles in American Samoa, so would appreciate your help in obtaining these obscure articles. Thank you for any help you are able to offer.

Sincerely,

George H. Balazs

George H. Balazs
Fishery Biologist

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Sincerely, ~~MHS~~ Sachet

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Pages 623-624

"Le 7 Octobre, nous entrames dan l'hemisphere Sud; et le 19 du meme mois, nous apercumes les iles du Danger, doit nous determinames la position geographique. Deux jours apres, etant a l'Est des iles des Navigateurs, nous decouvrimes un elot qui n'etoit pas marque sur nos cartes, it que j'appelai ile Rose, du nom d'une personne qui m'est extremement chere. Ayant, dans la partie Nautique de notre voyage, consigne la description de sette petite ile entouree de recifs, nous ne la reproduirons point ici."

Transcribed by G.H. Balazs 1/83

ATOLL RESEARCH BULLETIN

NO. 172 Dec 15, 1974

Comparative Investigations of Tropical Reef Ecosystems: Background for an integrated coral reef program

Edited by Marie-Hélène Sachet and Arthur L. Dahl

Issued by
THE SMITHSONIAN INSTITUTION
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p37 - 120

PACIFIC AREA

In the Pacific Ocean, coral reefs are scattered over a vast geographic area. The only safe generalization about Pacific reefs is that no two reefs are identical. However, in spite of the great diversity in form and composition that characterizes these communities, a number of features demonstrate the underlying relationships within this assemblage. The coral fauna is remarkably uniform throughout the Indo-Pacific (Wells, 1969), with the highest diversity and the center of evolutionary radiation in the western tropical Pacific (Stehli and Wells, 1971). This fact frequently leads to the statement that reefs in the western Pacific are "rich" while those to the east are "impoverished." Whether this applies to all elements of the flora and fauna, however, has yet to be demonstrated. The atoll reef form is another common Pacific feature, although involving many structural variations on the basic theme. The presence of a *Porolithon* algal ridge is often believed to be characteristically Pacific, and is certainly common there, while it rarely occurs on Atlantic reefs.

The great number and diversity of tropical Pacific reefs has made the search for data on research sites very difficult. Information was compiled from many sources on reef structure and composition, and on logistic and practical arrangements. Most published descriptions of Pacific Islands include only terrestrial geography; specific local descriptions are rare, and only the shallow reef is mentioned. Charts from the U. S. Army Map Service and the Navy Hydrographic Office indicate with fair accuracy the presence or absence of shallow reef structure, and sometimes the nature of the offshore slope and the depth to which coral development might be expected. A few scientific papers include reef descriptions of some sort, but not for the deeper areas important to a complete reef program, and generally in localities that are otherwise unsuitable. Most of the past research on Pacific reefs was conducted either by ship-borne expeditions to otherwise inaccessible islands, or in areas that have since been disturbed by development. Also, published information tends to be too dated to be reliable for current reef conditions; much of it predates World War II.

While many questionnaires were returned by Pacific reef specialists, their information did not always meet program requirements, perhaps because of the great size and complexity of the area. Personal experience tended to be limited to a few sites and to what could be seen from above the water. Areas of field experience and interpretations of reef quality depended on the respondant's special interest (an interesting reef to a coral specialist would not necessarily be selected by a bird or sea-snake expert, for example). Also, the information was often too generalized, referring to island groups rather than to specific reefs. The areas recommended and a summary of the questionnaire responses for the Pacific area are listed in Table II.

A Comparative survey of coral reef research sites by A. L. Dahl, I. G. Macintyre and A. Antonius

TABLE II: Questionnaire Response - Pacific Area

Site	Reef Structures*	Undisturbed	Accessible	Local Facilities	Political Status+	Number of Recommendations
Caroline Islands						
Palau	+	±	+	+	+	6
Helen Reef	0	+	-	-	+	1
Yap	+	±	+	0	+	1
Ulithi Atoll	+	±	+	0	+	2
Woleai	+	+	0	0	+	1
Ifaluk Atoll	0	+	-	-	+	1
Truk	+	-	+	0	+	1
Ponape	+	-	+	0	+	4
Ant Atoll	0	+	+	0	+	1
Pakin Atoll	0	+	+	0	+	1
Kapingamarangi	0	+	-	-	+	2
Marshall Islands						
Majuro	+	-	+	0	+	2
Arno	+	±	+	0	+	2
Ailuk	0	+	-	-	+	1
Eniwetok	+	±	+	+	-	2
Ellice Islands						
Funafuti	+	-	-	-	+	2
Phoenix Islands						
Canton Island	0	±	0	0	+	2
Fiji Islands						
Lau	0	+	-	0	+	1
Viti Levu	+	±	+	+	+	1
Samoa Islands						
Samoa	0	±	+	0	+	3
Rose Atoll	0	+	-	-	+	1

Site	Reef Structures*	Undisturbed	Accessible	Facilities	Political Status+	Number of Recommendations
Cook Islands						
Hervey Islands (Manuae)	0	+	-	0	+	1
Line Islands						
Christmas Island	0	±	0	0	+	1
Fanning Island	0	+	0	+	+	2
Society Islands						
Tahiti	+	+	+	0	-	1
Other						
New Caledonia	+	±	+	+	-	1
Port Moresby, Papua New Guinea	+	±	+	+	+	1
Ashmore Reef, Timor Sea	0	+	-	-	+	1
Heron Island, G.B.R.	+	+	+	+	+	1
Low Isles, N. Queensland	0	+	+	0	+	1
Aldabra, Indian Ocean	-	+	-	+	+	1

Sites suggested by name only: Saipan, Marianas Islands; Nukuoro, Caroline Islands; Wotho, Marshall Islands; Onotoa Atoll, Gilbert Islands; Butaritari Atoll (Makin), Gilbert Islands; Phoenix Islands; Buka, Bougainville, Solomon Islands; Rabaul; New Britain; Bismarck Archipelago.

Key: + = favorable or present 0 = unknown or possible - = unfavorable or impractical ± = variable

* see selection criteria above, p. 38

+ basically the anticipated government attitude to a large international but U.S. funded program

Questionnaires and equivalent information on Pacific sites were returned by the following: A. Antonius, A. L. Bloom, A. L. Dahl, M. S. Doty, F. R. Fosberg, R. Hagemeyer, H. Heatwole, R. Johannes, H. S. Ladd, E. G. Menez, H. A. Rehder, R. W. Schreiber, J. Sieburth, W. A. Starck, D. R. Stoddart, J. N. Weber, C. M. Yonge, and University of Hawaii.

the windward wide of the Ponape barrier reef revealed a smooth rocky flat at 4 m depth with 20-30 percent coral coverage and low species diversity. The water was rather turbid, and one gray shark 2.5 m long was seen. The frequent heavy rainfalls in Ponape might cause technical problems for a research program, as well as affecting the reef.

Arno and Majuro

Majuro (7°05'N, 171°10'E) and adjacent Arno (7°05'N, 171°45'E), two large atolls in the southern Marshall Islands, are the only accessible atolls in the area without government entry restrictions. Majuro has two weekly flights from Hawaii, and Arno can be reached easily from Majuro. Majuro has been reported as being disturbed, while Arno is relatively untouched but dives on both atolls revealed rich reefs with an excellent configuration.

15. Kinajon (Arno)

The outer reef off Kinajon on Arno is on the sheltered south side (Fig. 36). The rocky fore reef flat 100 m wide develops good coral coverage and surge channels towards its edge at 10 m depth (Fig. 37). A steep slope with *Porites* heads dominant drops to 30 m where the angle of slope lessens and sand patches appear. *Pachyseris* then becomes dominant. At 60 m the coral cover is still 20 percent and continues as far as can be seen. The water was warm and exceptionally clear (the water surface was visible from 60 m), with no change in temperature. The reef in general seemed excellent; on the other side where the deep entrance is, it is reportedly even better developed.

16. Laura (Majuro)

On Majuro the reef was surveyed off Laura, a sheltered location on the southwest side (Fig. 36). The 60 m wide fore reef consisted of 20 m of bare surface, 20 m with a dense algal cover, and 20 m with corals, mainly *Acropora*, leading to the rugged reef edge at 5-8 m depth (Fig. 38). Deep surge channels cut into the reef. There is no real drop-off, but a gently rounded slope with valleys and ridges perpendicular to the shore, and also many shore-parallel steps. The coral cover decreases from 90 percent at the edge (5-8 m) to 60 percent at 12 m, to 50 percent at 20 m with increasing algal cover. The slope gets steeper with depth, becoming vertical at 40 m, where the coral cover is 20 percent. This site is accessible by road from Majuro, and has good reef features and clear water. Fishes were very abundant, but no sharks were observed.

AMERICAN SAMOA*

The Samoa Islands (14°15'S, 170°00'W) are a chain of volcanic

*Field survey: September 7-12, 1971 by A. L. Dahl and A. Antonius (assisted by S. Ritterbush).

islands with fringing coral reefs in the South Pacific. While rather far from the center of coral diversity, their ready accessibility by direct flight from Hawaii and the strong interest of the local government warranted detailed examination of the reefs. The Manua Islands are remote from the main island of Tutuila and can be reached by government or commercial boat in about 8 hours. There has also been an intermittent float plane service. Because transportation is difficult it was only possible to dive on the reefs in the vicinity of the main anchorage of each island. Since the reefs in the Manua Islands were not transected no diagrams are given.

17. Tau (Manua)

At Tau the dive was made off the northwest side (Fig. 39), a leeward but exposed area, about 300 m offshore. There is a rocky flat with huge boulders at 20-25 m depth. Few coral species are present, mainly Porites and Pocillopora, and specimens are small and scarce.

18. Olosega (Manua)

The dive off Olosega was on the sheltered leeward (west) side about 200 m offshore, at 20-25 m depth (Fig. 39). The bottom is rocky, with huge blocks, forming valleys and ridges. Coral cover is more extensive and with more species than Tau, with huge coherent colonies of table-like Acropora and Porites (lobata?). Many alcyonarians are also present.

19. Ofu (Manua)

The anchorage of Ofu is on the west side in a very sheltered location (Fig. 39), 200 m offshore from Alaufau, where the water is 10-20 m deep. The bottom has marked topographic relief, with small corals and red algae on top of the elevations, dense coral cover and good species diversity on the walls, and white sand in the bottoms of the troughs. The water was clear and warm. Fishes were abundant, but no sharks were observed.

Two dives were made on the fringing reefs on the north and south sides of Tutuila, the main island of American Samoa.

20. Leone Bay (Tutuila)

At Leone Bay on the windward south west side (Fig. 39), the reef was surveyed out to 350 m from the shore near Logologo Point (Fig. 40). The reef structure is irregular, somewhat resembling a spur and groove system, with a shallow reef flat, and then large reef patches in deeper water, extending down to 25 m. The coral cover is very variable, sometimes almost 100 percent, as at Ofu, but many helioporas are also present. A large flat of white completely detritus-free coarse sand occurs at 15 m depth. The water was warm and clear, with many fishes and no sharks.

21. Ogegasa Point (Tutuila)

On the north side of Tutuila, at Ogegasa Point (Fig. 39), there is a vertical basaltic rock slope from the surface to 3 m, followed by a rocky flat with small scattered corals extending 50 m offshore to a depth of 7 m (Fig. 41). From here a slope with spur and groove configurations drops to 15 m and then a very steep slope down to 30 m, ending in an extensive sand flat. This slope has the best coral coverage and richest species diversity of all the Samoan sites observed. The water was warm and slightly turbid, perhaps from a recent rainfall. Again the area was rich in fishes but lacked sharks. Apparently there are no good near-shore drop-offs around the islands of American Samoa.

It was not possible to reach Rose Atoll, as the seaplane was damaged shortly before our arrival, and time and weather precluded boat transportation. Discussions with the Office of Marine Resources which recently surveyed the atoll, indicated that the land area was inadequate for any facility, so that it could only be used for short visits.

CONCLUSIONS

The overall evaluation of the site information leads to the following conclusions for the Smithsonian-planned programs. In the Caribbean, the logistic problems and unique character of the San Blas Islands, the disturbance and political problems at Discovery Bay, and the poor reef structure of St. Croix and Acklins Island left Glover's Reef, British Honduras as the preferred site. In the Pacific no final decision was possible without further field surveys, but several areas showed good potential, including Pakin, Ulithi, and Arno. Ulithi was not visited by a survey team, and so requires further examination. A more detailed study of areas in Fiji and the Gilbert and Ellice Islands could also be productive. However, once the scientific suitability of a site was determined, it would still be necessary to negotiate with the local inhabitants for space and permission to work on their reefs.

It is important to remember that the areas reported on here were selected and described in accordance with the specific program criteria listed in the introduction, not all of which would necessarily apply to other projects. We hope that others searching for a suitable location for a coral reef research program will be able to use this information, with due caution for its limitations, in selecting a site most appropriate to their needs.

Figure 39 – AMERICAN SAMOA
14°15'S 170°00'W

Figure 40 – SITE 20 - LEONE BAY, TUTUILA

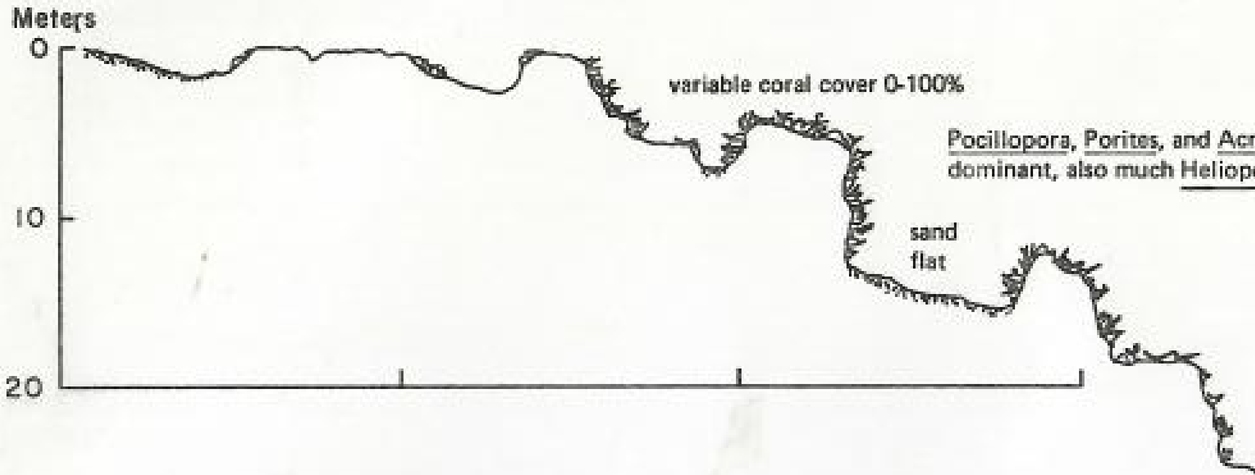
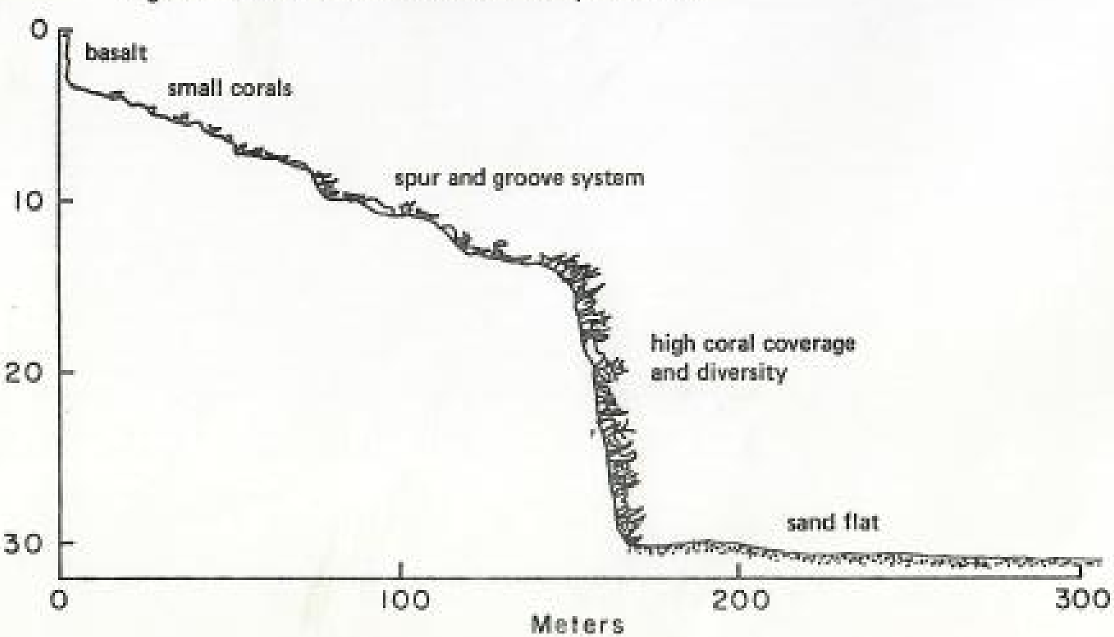


Figure 41 – SITE 21 - OGEGASA POINT, TUTUILA



Narrative of a Rose - p 158

by Arago, J.E.V. 1790-1855 Amsterdam, N. Israel; N.Y, Da Capo Press

LETTER CXXXII.

At Sea.

I BEGIN to think myself very foolish to entertain such apprehensions at the commencement of our voyage; and to perceive, that nothing is in fact more easy than to make the tour of the world. What Mediterranean sailor would not consider a voyage to the Canary Islands as a mere trip? What seaman on the western coasts would think any thing of an expedition to Martinique, Cayenne, or Brasil: from Brasil to the Cape of Good Hope, not the least obstacle occurs, not the slightest reef of rocks. If you would get into a higher latitude in search of the general winds, the island of *Tristan d'Acunha* is the point where you ought to stop and put about. On the contrary, would you approach the coast of Africa, you will salute as you pass St. Helena, now associated with such important recollections, and the latitude is given. From the Cape to the Isle of France is not above seven or eight hundred leagues; and the wind pent up in the channel of Mosambique will hurry you over this distance in a short time. Bourbon touches on the Isle of France: and, if the passage thence to Endracht's Land be longer, nothing detains you on it, you have avoided the zone of calms. Timor, Amboyna, Waigiou, pass before your eyes, without your having time to perceive them; and simple canoes make these easy trips daily

Freycinet, L.C.D. 1779-1842.

Occasionally you will heartily curse the heat and the calms: but what situation in life is without its inconveniencies and vicissitudes? Be prudent and above all provident, and you will have water to quench your thirst: calculate your resources, and these trips will not be more laborious than others. At the Marianne Islands you will forget some slight crosses, and inhale strength and spirits to reach the Sandwich Islands. After having studied the manners of the savage inhabitants of that Archipelago, you will reach Port Jackson by passing amid the *Feejee* or Friendly Islands, which are not always such to strangers. If travelling by land amuse you, you may hire horses that will carry you beyond the Blue Mountains, in Europe deemed impassable, and return to Sydney, not to Botany Bay, as is still imagined among us; after having seen those savage hordes, which are gradually disappearing from this fifth quarter of the globe, and whose wretched existence you cannot help deploring. To return to your own home, you will double Cape Horn, after enjoying the sublime view of those enormous masses of ice, that have been torn from the pole by impetuous winds, and driven to a less rigid clime. If you are wise, you will take *a good offing* from that little known point of the American continent, and you will be enabled to meet with tranquillity, the assaults of those terrible hurricanes, that ravage those antartic regions. On returning to that Atlantic Ocean, *swept*, as I may say, by so many vessels of so many nations, you are at home.....but no; sometimes pointed rocks sport with your confidence, and punish you for being too happy or too presumptuous. Let us hope, that we shall escape this trifling inconvenience; and that our prudence and sagacity will guard us from every kind of misfortune.

Do you know, my friend, that I begin already to calculate? and that, it seems as if two-thirds of our course are already passed. This idea imparts to my heart such lively joy, that I finish my letter hastily, as if a courier were at the door, ready to take it and deliver it.

LETTER CXXXIII.

At Sea.

HAVE you received my last letter? Have you answered it? I have already proceeded a long way, since the last courier departed, and I have something to tell you. Friendship is communicative; for whatever interests us must also be interesting to our friends.

After having quitted Woahoo with much regret at not being able to visit Atooi, where we might have completed our observations on the natives of the Sandwich Islands, our ship's head was directed nearly South, and we might conjecture at our ease where she would stop next. We were persuaded, that we should first touch at Otaheite; and read with avidity those pleasing pages of the narrative of our Bougainville, where he describes the pleasures his crew tasted in that island, exhibited by his original mind as a terrestrial paradise. Our most ardent wishes carried us to that point of Venus, consecrated by so many feasts: we counted our handkerchiefs, our buttons, our necklaces; in short, we reckoned up all our wealth, and the most economical of us congratulated themselves on having saved from the seductions of the Marianne and Sandwich Islands, a number of trifles, which they hoped not to carry so far as Port Jackson. For my part, my friend, I had no longer any thing to reckon; my wealth had vanished; a few waistcoat buttons composed the whole of my fortune, and I endeavoured to reconcile myself before-hand to the privations that threatened me.

The wind was favourable, and we were advancing with rapidity......On a sudden orders are given to alter our course, and stand to the westward. Certainly our voyage had already been pretty long, and we could not be otherwise than a little fatigued with so many cruises; yet a little gloom overshadowed our countenances, as soon as we had reason to fear that we should no touch at Otaheite.

The care and attention bestowed on the observation,showever, led us to presume, that our Captain was seeking one of the nodes of the magnetic meridian; and we thought with some reason, that, after having found it, we should turn back, and at length visit the desired island. You know, my dear Batlle, we love to believe, what is the wish of our hearts.

We have just found this node of the magnetic meridian, but our course is not altered. The possessors of European trifles already begin to disdain them, while they who have none left no longer regret their prodigality. Two days, three days, succeed; we are already far from Otaheite: we renounce the hope, that had so much seduced us. We are steering our course toward New Holland. At least, may the distance that separates us from it be soon passed over!*

We have made land..... it is *Pilstaart* Island. It perfectly resembles a bower. Rocks as pointed and slender as church steeples, have been placed there by nature in a poetic fit. At a distance you would say a squadron of ships was endeavouring to take the island. The foot of these pyramids, beaten incessantly by the waves, preserves its dingy hue; while the upper part, the resort of millions of birds, is covered with a white coat, that well resembles at some distance the sails of a ship.

* I cannot express to you the regret we all felt, at not touching at any of the little known islands of this vast ocean. Otaheite had particularly excited our wishes: and we supposed that our Captain must have been bound by his instructions not to touch there, by steering a different course when we were so near it. However, Otaheite at present would have offered no result of importance to the sciences: and it is probable, that this consideration alone determined M. Freycinet to steer at once for Port Jackson.

The nearer we approach, the better we distinguish the needles. The *coup d'œil* is truly magnificent, and I am endeavouring to take an accurate view of it.

If we may credit mariners, this island is uninhabited and uninhabitable ; accordingly we pass by, without complaining of the winds that carry us from it. But we think we distinguish a canoe beyond one of the most pointed rocks : we are certain of it : it is manned by three persons, who are rowing with all their might : they are coming towards us : they wave a piece of white cloth on the end of a paddle : perhaps they are some poor fellows, whom a storm has driven thus far : perhaps they are persons unfortunately shipwrecked, to whom providence sends unexpected succour.* Let us wait for them, should there even be some danger in doing it so near the land.....The breeze continues, the island sinks, the rocks are already confounded with the vegetation..... alas! we are at a considerable distance : at length we bring to ; but night is coming on,—we can no longer distinguish the canoe, our hearts sink within us. How many days may elapse, before such another opportunity offers itself to those unfortunate men!

LETTER CXXXIV.

At Sea.

AT last we have made a geographical discovery : a small spot of land appears in the horizon not laid down in the charts. If

* It is possible, that they were three natives of Pilstaart, and that the island is inhabited, for we saw there some very fine clumps of cocoa trees. It would have been gratifying to have landed there ; and we requested the Captain to do so, but in vain ; though no doubt he would have been very ready to have done it, had it been practicable.

it should prove a continent! If it should be an island like Sumatra, or Borneo! Should it only be such a one as Timor, or Manilla!.....We draw near; it displays itself in all its majesty. Congratulate us, my dear Batlle; it may be a short quarter of a league in diameter: I flatter it;—it is near a quarter of a league in circumference. Lengthened reefs surround it, and render its vicinity very dangerous. A few trees crown its summit, on which thousands of birds take refuge.

Let us see; what shall we call it? Let it be a flowery name. Shall it be Green Island, Red Island, or ..... No, I suppose it will be *Rose* Island.

Perhaps it might be beneficial immediately to point out its latitude and longitude, since it may prove fatal to some voyager: but I am forbidden to disclose the secret, and I am dumb.

LETTER CXXXV.

In sight of New Holland.

IT is so true, that one pleasurable moment effaces from the mind of the voyager, even the remembrance of past vexations, that now we are arriving at a new colony, where we cannot fail to gratify our impatient curiosity, we no longer venture to complain of the motives that carried us to a distance from Otaheite; and on the contrary, congratulate ourselves on seeing the happy moment that will again show us our native land, approach with more rapidity.

We are now off New Holland; every step will now bring us nearer Europe: one more laborious course, and we shall revisit the Atlantic Ocean.

The coast that shows itself before us, though woody at intervals, is far from answering the idea we had formed of it from exaggerated descriptions. The foregrounds in particular are extremely barren, and intersected by little coves, which must afford excellent shelter for boats. A little higher up, a tolerably vivid vegetation shows itself here and there; while in a clear distance, grayish mountains, on which sparkle fires, kindled no doubt by the savages, crown the landscape with a tolerably fine effect.

How vexatious that night is coming on! one hour's daylight more, and we should enter the river..... Impossible, my friend. The breeze dies away, and we must ply off and on, till to-morrow morning.

Harbours on our right hand, harbours on our left; Sydney river, with its light-house before us; it seems impossible, that we should miss the anchoring place, since our Captain has studied the geography of the coast.

It is seven o'clock in the morning, we are still plying to windward, and I am afraid we shall not see Port Jackson to-day. How vexatious!

But the wind suddenly ceases; we have a chopping sea, as after a violent storm; flashes of white lightning furrow the cloud, that flies rapidly over the mountains, already enveloped in dark night. This vast mass of vesicular vapour separates from the earth, and remains motionless at a small elevation; other copper-coloured clouds fall on it, they become tornadoes, collect, and change their shapes and hues. The eye perceives balls of fire, sheaves, phantoms. You wish to point out an object; it is gone. Rapid fires rend them, the thunder sullenly growls: you would say, that all the elements in confusion were warring against each other in the air. The ship is motionless and prudently awaits the issue of the turmoil it witnesses. The sails are brailed up. Presently the sea boils around it: it is agitated;