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190. ALMOST-ATOLL OF AITUTAKI: REEF STUDIES IN THE COOK ISLANDS, SOUTH PACIFIC

Edited by D. R. Stoddart and P. E. Gibbs

Issued by
THE SMITHSONIAN INSTITUTION
Washington, D.C., U.S.A.

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Reef Studies in the Cook Islands, South Pacific

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PREFACE

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Reproduced by permission of the Lands and Survey Department, New Zealand.

1. SCIENTIFIC STUDIES IN THE SOUTHERN COOK ISLANDS: BACKGROUND AND BIBLIOGRAPHY

D.R. Stoddart

INTRODUCTION

The Cook Islands, in the centre of the Pacific (Figure 1), e remote from centres of recent reef studies in the Marshall .ands and the Tuamotus. The early work of Ladd in Fiji, ?fmeister in Tonga, Mayor in Samoa, and Crossland and Setchell Tahiti, served to indicate the existence of gradients of unal and floral diversity across the central Pacific from st to east, a diversity reflected in the structure and nposition of the reefs and also in terrestrial ecology, but the absence of further detailed studies these gradients uld be only loosely defined. The Cook Islands are of interest o, as Darwin and later workers recognised, for their combi- tion of reef-encircled volcanic islands, almost-atolls, and olls, and for the existence of several islands of elevated rst-eroded limestone locally known as makatea. These ructures have implications for general theories of coral ef development, and they also promise new evidence on the oblems of recent sea-level fluctuations in the open Pacific. thus appeared timely to re-examine the Cook Islands, and e Cook Bicentenary Expedition in 1969, organized by the Royal ciety of New Zealand, provided the opportunity to study allow-water marine communities and some aspects of the rrestrial ecology of reef islands at Aitutaki and at rotonga.

These studies are reported in the present Bulletin, and is introductory paper describes the salient features of the uthern Cooks, outlines the scientific work already carried t there, and presents a bibliography, by way of introduction the more detailed papers which follow.

STRUCTURE AND TOPOGRAPHY

The southern Cook Islands (Figure 2) consist of a linear ries of volcanic and limestone islands extending for 250 km om Mauke to Aitutaki, and the two more isolated islands of rotonga and Mangaia, all rising from the sea floor at depths 4500-5000 m. A detailed chart of the area at 1:1,000,000 th contours at 1000 m intervals has been published by mmerhayes (1969), and an interpretation of the regional thymetry has been provided by Summerhayes (1967). Robertson d Kibblewhite (1966) have drawn attention to the similarity the submarine slope profiles of volcanic islands and of olls with no volcanic rocks now exposed at the surface. The southern Cook Islands appear to comprise a series of volcan of different ages, some recent, with narrow fringing reefs (such as Rarotonga), others capped with thickness of limest and subsequently elevated to form a karst surface locally k as makatea. In the northern Cooks the process of atoll dev ment by Darwinian subsidence has proceeded further, and tru atolls such as Manihiki and Palmerston have been formed. T is no direct evidence of the depth to volcanic basement ben these atolls, but seismic data at Manihiki indicates a dome-shaped basement with volcanic rocks at 0.5 km depth beneath peripheral reef but at only 0.05 km in the centre of the la Aitutaki, as an almost-atoll, is presumably intermediate in between the northern atolls and islands such as Rarotonga.

Rarotonga and Aitutaki form the summits of separate volcanic masses rising from depths of 4000 m, at which dept the cones are 45-55 km in diameter (Summerhayes and Kibblewh 1966, 1967). The lower slopes of the cones average 15-25°, increasing to 30° in the upper 750 m and becoming very stee the surface reef is approached. The Mauke-Aitutaki line of islands is thought to be of early Tertiary age: the surface volcanics are much eroded, with a subdued topography, or are capped with limestones (Wood, 1967; Wood and Hay, 1970). On Rarotonga, where the relief is much stronger (maximum altitu 640 m), radiometric ages of 2.3-2.8 million years date the l as Pliocene (Tarling, 1967). Mangaia, with a cap of Oligoce Miocene limestones, must be much older (Marshall, 1927). Ev dence from the deep-sea drilling programme indicates that th ocean floor in the area of the southern Cooks is Paleogene (22.5-65 million years) in age (Winterer, 1973), thus provid a maximum age for the islands. It is probable that the gros history of the Cooks resembles that of other, better-known reef-capped Pacific volcanic cones known to have been initia in the early Tertiary.

Aitutaki (lat. 18°51'45"S, long. 159°48'10"W), 225 km north of Rarotonga, is an almost-atoll with a total area of 106 km^2 (Figure 3). The main volcanic island, located eccentrically on the northwestern reef rim, has an area of 16.8 k and rises to a maximum height of 119 m. It is thus a much m extensive volcanic residual than that of the only other almo atoll recently studied, Clipperton in the east Pacific (Sach 1962). In addition to the main volcanic island, basalts and agglomerates also outcrop on Aitutaki near the southern reef rim in the islets of Rapota and Moturakau. On the latter th agglomerates include coral fragments, indicating that the la stages of volcanism were contemporary with reef growth. A similar situation has been described for reef-edge volcanic islets at Mayotte in the Comores by Guilcher et al. (1965). The situation at Aitutaki thus contrasts with that in the ot makatea islands of the southern Cooks, where vulcanicity had evidently ended before deposition of the limestone caps had begun. Age estimates of the Aitutaki volcanics range from

:ene to Miocene-Pliocene (Wood and Hay, 1970, pp.36-40).

The peripheral reefs of Aitutaki are roughly triangular shape, enclosing a lagoon with a total area of about 50 km^2 l with a maximum depth of 10.5 m. Detrital reef islands are ncentrated along the eastern (windward) reef, and have a total ea of about 2.2 km^2. Seismic refraction measurements by chstein (1967) indicate a thickness of coral limestone over salt of 13-20 m in the Ootu Peninsula, adjacent to the main lcanic island, and of 150$\pm$30 m at Tavaerua Iti, midway along e eastern reef. Results of gravity surveys at Aitutaki are ported by Robertson (1970), and of magnetic surveys by Lumb d Carrington (1971).

Rarotonga (lat. 21°12'06"S, long. 159°46'33"W) is a larger d more deeply dissected mountainous island, 250 km^2 in area, th maximum dimensions of 8 x 11.5 km, and a maximum elevation 652 m. The geology has been described by Marshall (1930) and Wood and Hay (1970, 10-27). The Pliocene volcanic core is rrounded by Pleistocene gravels and sands of different ages, th remains of a slightly elevated coral reef. The modern efs are fringing and of variable width. In the east, at atangiia, the reef encloses a deeper channel and there are ree small sand cays and a volcanic islet standing on it; ese have been described elsewhere (Stoddart, 1972). In dition to the radiometric dating, geomagnetic studies have en reported by Woodward and Hochstein (1970) and gravity ta by Robertson (1967).

CLIMATE

Aitutaki and Rarotonga both lie in the Southeast Trades, d are influenced by winds from the northeast, east and south-st throughout the year (Hydrographic Office, 1966). Maximum infall occurs during December-March, when the Trades are less eady, and squalls and northerly winds may occur (Figure 4).

Table 1 summarises rainfall data for Aitutaki: monthly infalls for 1930-1971 are given by Taylor (1973) and incomplete cords for 1907-1911 by Hunt (1914, 255). Mean annual rainfall 1984 mm, rather more than half of which occurs during cember-March (Figure 5). This compares with 2103 mm at Raro-nga (where, however, there is considerable local variability cause of orographic effects), 2482 mm at Manihiki, and 2984 mm Pukapuka in the north. Figure 6 shows histograms of the nual rainfall distribution at these stations. All show a milar seasonal pattern, though the dry season is most marked Aitutaki, especially in June-September. According to M. Johnston (1967, p.74), on occasions no rain may fall for er a month. Johnston calculated Thornthwaite potential apotranspiration figures for Aitutaki, confirming the istence of the pronounced dry season.

Table 2 and Figure 7 give temperature records for Aitut The mean annual temperature is 25.6°C. Mean daily maxima exceed 30° during January-April, and mean daily minima fall below 22° during June-October. The highest temperature recorded is 37.2° and the lowest 12.8°. The range in mean monthly temperatures is 3.4°, the daily temperature range is about 11°.

Table 3 gives relative humidity data for Aitutaki at 09 and 1430. These show a similar seasonal trend to rainfall a temperature.

The main source for climatic data is in K.M. Johnston (1967, pp.71-75), based on 37 years of records maintained by the Meteorological Service, Wellington; Tables 2-4 are base on Johnston's data. Slightly different figures are given by Tamashiro (1964), particularly for rainfall and number of raindays. Summaries of climatic data for the Cook Islands, including the northern atolls, are given in Maps of the Cook Islands (Survey Department, Rarotonga), and for rainfall by Taylor (1973).

Hurricanes

The southern Cook Islands lie within the South Pacific hurricane belt, but because of the paucity of records and the scattered distribution of climatic stations, even compared w: the area to the west, little is known of hurricane tracks or frequency. Most studies of south Pacific hurricanes concent on the southwest Pacific area and terminate at 160°W, the longitude of the Cooks. Hutchings (1953) contributes a gene discussion of south Pacific hurricanes, but with few specific records. The fullest listing for the Cooks is still that gi by Visher (1925, 40), but this omits a number of severe storm reported in the early missionary accounts. Table 4 lists the recorded storms, based on Visher's lists with additions; it is certainly incomplete, especially for the present century. It is, however, clear that storms of exceptional severity hav occurred in the southern Cooks during the last 150 years. Th occur mostly during January-March, and approach from the nort east, curving round to the south and the northwest. Being in the southern hemisphere the hurricane winds rotate clockwise about the centre.

MARINE ENVIRONMENT

According to standard sources on the oceanography of the South Pacific (Fiziko-Geograficheskiy Atlas Mira, 1964), the mean sea surface temperature in the southern Cook Islands ran from 27.3°C in January to 25.5°C in June.

Table 1. Rainfall at Aitutaki

Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean monthly rainfall, mm	228.9	286.3	242.3	157.7	141.5	104.6	79.8	79.5	82.0	133.9	188.2	259.3	1984
Mean number of rain days	13	14	10	10	9	8	9	7	8	9	11	13	120
Number of months with less than 61 mm (2.4 in) 1920-60	4	2	-	10	11	20	20	27	20	14	8	1	
Number of months with less than 61 mm as percentage	10	5	-	25	27.5	50	50	67.5	50	35	20	2.5	

Source: K.M. Johnston, 1967

Table 2. Temperature at Aitutaki (°C)

Month	Mean daily temperature	Mean daily maximum	Mean daily minimum	Highest recorded	Lowest recorded
Jan	27.2	30.6	23.9	35.0	17.8
Feb	27.2	30.6	23.9	35.6	17.8
Mar	27.2	30.6	23.9	34.4	20.0
Apr	26.7	30.0	22.8	33.9	16.1
May	25.6	28.9	22.2	31.7	16.7
Jun	24.4	27.8	20.6	31.7	15.6
Jul	24.4	27.8	21.1	31.1	12.8
Aug	23.9	27.2	20.6	31.1	15.0
Sep	24.4	28.3	21.1	31.1	15.0
Oct	25.0	28.3	21.7	37.2	14.4
Nov	26.1	29.4	22.8	32.2	17.8
Dec	26.7	29.4	23.3	33.3	17.8
Means	25.6	28.9	22.2		

Source: K.M. Johnston, 1967, p.71

Table 3. Mean relative humidity at Aitutaki (per cent)

Local time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
0900	80	83	82	81	80	80	79	78	77	75	77	80	79
1430	73	73	73	73	71	68	64	67	70	70	71	72	71

Source: K.M. Johnston, 1967, p.71

Table 4. Hurricanes in the Cook Islands

	Date	Comment
1831	21 December	Rarotonga
1839	22 February/1 March	
1841	February	Rarotonga
1841	17 December	Rarotonga; "gigantic waves"
1842	15-18 December	
1845	16-17 January	
1846	16-18 March	
1848	24 December	
1854	6 February	Rarotonga; hurricane and earthquake (Gill, 1856, 224-5)
1865	25 January/3 February	
1869	4-5 April	
1877	24 February	Towards Austral Islands
1882	2 February	Towards Austral Islands
1882	18 March	Towards Austral Islands
1883	December	Palmerston Island
1887	10-11 April	Towards Austral Islands
1889	18 February	
1890	15 December	Towards Austral Islands
1897	10-11 February	
1923	8 March	Towards Kermadec Islands
1943	4 March	
1946	10 January	

Source: Visher, 1925, p.40; Hutchings, 1953; Gill, 1856

Tides are semi-diurnal and of small amplitude. At Aitutaki the range at springs is 0.49 m and at neaps 0.12 m, and at Rarotonga 0.82 m at springs and 0.24 m at neaps. There is no substantial inequality between successive high and low tides in the semidiurnal cycle.

Tsunamis occur in this area but no major ones have been recorded. Keys (1963) describes the tsunami of 22 May 1960, which was observable at Rarotonga. In this case the small effect may be attributed in part to the fact that the tsunami arrived at a stage in the tidal cycle when the sea was below the level of the reef flat. Tsunamis in the Cooks are much less important than hurricanes in causing coastal inundation.

RECENT HISTORY OF AITUTAKI

Human activities have clearly had a profound effect on the ecology of islands in the southern Cook Group, not only during the one and a half centuries of direct European influence, but also during the earlier period of Polynesian colonisation and settlement. No detailed studies have been made of these effects, and indeed the history of human occupation itself is known only in bare outline. The main sources for pre-Contact history are in oral tradition, initially collected by missionaries such as Wyatt Gill (1876, 1880, 1885, 1894), and accounts of the initial settlement of Rarotonga and Aitutaki from these sources have been provided by Best (1927) and Pakoti (1895). Archaeological work has been begun by Duff (1968, 1971) and Bellwood (1969, 1971, 1973). Beaglehole (1957), Crocombe (1964) and Curson (1973) have presented recent summaries of the pre-contact and early contact periods, and these serve as a basis for the present account.

Cook discovered Manuae during his second voyage in 1773, and Mangaia and Atiu during his third in 1777, but he did not locate either Rarotonga or Aitutaki. Aitutaki was discovered by Europeans on 11 April 1789, when Captain William Bligh arrived on H.M.S. Bounty, before the mutiny. Bligh (1792) briefly but recognisably described the island:

> "...on the 11th, at daylight, land was seen to the S S W, at about five leagues distance, which appeared to be an island of a moderate height. On the north part was a round hill: the northwest part was highest and steep: the southeast part sloped off to a low point. ...we tacked to the southward, and, as we advanced in that direction, discovered a number of low keys, of which at noon we counted nine: they were all covered with trees. The large island first seen had a most fruitful appearance, its shore being bordered with flat land, on which grew innumerable cocoa-nut and

other trees; and the higher grounds beautifully interspersed with lawns. ... On the 12th ... at two in the afternoon, we were within 3 miles of the southernmost key. ...the name of the large island ... was Wytootackee.

The island of Wytootackee is about ten miles in circuit; its latitude from 18°50' to 18°54'S, and longitude 200°19'E. A group of small keys, eight in number, lie to the S E, 4 or 5 miles distant from Wytootackee, and a single one to the W S W; the southernmost of the group is in latitude 18°58'S. Variation of the compass 8°14'E" (Bligh, 1792; 1961 edition, 127-129).

The Pandora, Captain Edwards, called on 19 May 1791, while searching for the Bounty mutineers (Edwards, 1915), and on 25 July 1792 Bligh himself again passed by in the Providence. These early contacts can have had little direct effect on Aitutaki. After the Bounty mutiny, the ship, under Fletcher Christian, apparently called at Rarotonga in 1789; the missionary John Williams (1837) reported a tradition of this visit surviving in 1823, and Christian thus becomes the discoverer of Rarotonga. No other ships called there until 1813 and 1814. Captain Theodore Walker in the Endeavour sighted the island and Captain Goodenough in the Cumberland landed there, searching for sandalwood, and Goodenough is said to have cut a great deal of nono (Morinda citrifolia) in mistake for it at Ngatangiia (Gill, 1856; Gosset, 1940; Maude and Crocombe, 1952). Goodenough subsequently called at Aitutaki (August 1814) and set down a group of Rarotongans he had abducted. The Seringapatam also called at Rarotonga, on 23 May 1814, and was followed by other vessels (Coppell, 1973).

Effective contact began with the arrival on Aitutaki of the Rev. John Williams on 26 October 1821. He left native Tahitian missionaries there, and went on to do the same at Rarotonga, having learned of the existence of the latter island from Goodenough's Rarotongans. When Williams returned to Aitutaki in July 1823, the inhabitants had apparently been converted to Christianity. In 1827 he went back to Rarotonga, instituted a code of laws, and installed the first of a series of English missionaries - Charles Pitman at Ngatangiia (1827-1855), Aaron Buzacott at Arorangi (1828-1857), and William Gill (1839-1857). Narrative accounts of the early history of the Rarotonga missions are given by Buzacott (1866), Gill (1856, 1880), and Wyatt Gill (1876a, 1885). Much material on cultural change and the introduction of plants and animals is undoubtedly contained in archival material relating to these missions, notably the journals of Pitman (1827-42), Buzacott (1828-40) and Mrs Buzacott (1830-33), with a manuscript by the latter on life on Rarotonga in the 1830s, in the Mitchell Library, Sydney, and letters in the London Missionary Society archives, but it has not been possible to explore this material in the present study. Beaglehole (1957, 45) has fully documented the progress of disease, occurrence of hurricanes, and social disruption during the first decades of European contact, which reduced the population from ca. 7000 in 1833 to about 2000 between 1845 and 1900: major factors in this decline were the new diseases of measles, whooping cough, mumps, influenza, jaundice and dysentery.

At Aitutaki the first English missionary, Henry Royle, arrived on 23 May 1839, by which time some European beachcombers were already living on the island. He remained there for about 35 years (Plates 1-2). The impact of contact was less catastrophic than on Rarotonga. Epidemics were less serious, though there were notable outbreaks of dysentery in 1843 and measles in 1854. The population declined from approximately 2000 when Royle arrived to less than 1200 in the forty years after 1880. In spite of the alleged early and complete conversion of the people, Royle had a difficult time: disturbances and arson in the early months were followed by serious hurricanes in February 1841 and again in December 1842. His problems were accentuated by the development of the central Pacific whaling industry, for which both Aitutaki and Rarotonga became important victualling stations: thus in 1843 no less than 35 ships called at Aitutaki, and 100 at Rarotonga. Numbers of islanders joined the vessels as crew members, and of course the whalers went ashore. Perhaps the most severe disturbance on Aitutaki, which Royle was powerless to control, occurred in 1847, when two whalers, one American, one French, were wrecked there, and 70 sailors spent a year on the island. It is not surprising that the missionaries took the view that "All runaway sailors were profligate, all Frenchmen licentious, all Roman Catholics venal and corrupt, all traders petty and dishonest" (Beaglehole, 1957, p.75). By the time that whaling declined in these waters in the 1860s, Peruvian slave vessels were cruising in the northern Cooks seeking guano workers, and Cook Islanders were leaving for Makatea and also for New Zealand. By this time the islanders were said to be all clothed, housed, and literate, and Royle was selling Testaments at Aitutaki at the standard rate of 18-20 lbs of arrowroot per copy.

The missionaries took a leading part in the introduction of economic crops and in the transformation of the indigenous economy. Cotton and the sweet potato were on Rarotonga before 1831: Buzacott introduced arrowroot, tapioca, rice and coffee, and also a weaver for cotton cloth. The cultivation of yams, bananas, pumpkins, pineapples and oranges, and the rearing of pigs and poultry were encouraged. Rum was introduced to Rarotonga in 1845, and methods of fermenting oranges, pineapples and bananas were known there by 1851. We have no details of the economic transformation at Aitutaki, but it presumably closely followed that at Rarotonga.

With the conclusion of the initial missionary phase and the economic development of the islands, and with increasing imperial interest in the Pacific, the political status of the Cook Islands required definition. A British Protectorate was therefore declared over Rarotonga, Aitutaki, Mangaia, Mauke, Mitiaro and Manuae on 22 September 1888 (Gilson, 1955). Administration was transferred to New Zealand in 1901. The main economic significance of the islands, linked by schooners, was as a source of copra and other coconut products, but the trade proved a highly variable one (Figure 8), being greatly affected by market fluctuations. After the initial missionary intervention, however, the second major event in the recent history of Aitutaki was the Second World War. When it began the island had a population of about 2000. In 1942 a party of 900 U.S. Marines, including 400 negroes, was established there, and remained until 1944 (K.M. Johnston, 1967). The present airstrip was built on the Ootu Peninsula. After the war a Solent flying boat service was operated by Tasman Empire Airways Ltd to Samoa, Tonga, Fiji and Auckland, and by UTA to New Caledonia and Tahiti The landing area was in the southeast lagoon, with terminal facilities on Akaiami island, linked by launch with a mainland jetty at Tautu. This service was discontinued in 1960, but New Zealand military planes maintain a service from New Zealand via Rarotonga, using the Ootu landing facility. Marine communications were also improved during the war. The reef entrance at Arutanga was dredged and a stone jetty constructed. The jetty has now disintegrated, and the channel, 1.5 km long, carries less than 2 m water. No regular shipping service serves Aitutaki. Matson Line vessels callat Rarotonga, where a new commercial jet airfield has now been constructed. The increased accessibility and development of tourism which will result from this development will certainly lead to major changes in all aspects of life both on Rarotonga itself and on islands accessible from it, including Aitutaki.

It will be apparent that, in spite of the relatively short history of European contact, native life has been subject to major changes since the first missionaries arrived. Active anthropological and ethnological research, other than the often anecdotal records of the missionaries, did not begin until the 1920s: most of the studies, under the influence of Sir Peter Buck, concentrated on artefacts and material culture. In the southern Cooks, studies were made of Aitutaki (Buck, 1927) and Mangaia (Buck, 1934), and in the northern Cooks of Tongareva (Buck, 1932a), Manihiki and Rakahanga (Buck, 1932b), and Pukapuka (Macgregor, 1935; Beaglehole and Beaglehole, 1938). Summaries of the Cook Islands were proved by Buck (1944, 1945). Missionary accounts of Aitutaki traditions were supplemented by Low (1934, 1935).

In spite of these accounts, little is known of the economy and human geography of Aitutaki in pre-contact times. It is reported that villages were originally located at inland sites, on hills, and only moved down to the coast under the influence of missionaries (Beaglehole, 1957, p.6). With the long history of Polynesian occupation, the size of the population in 1830, and the limited land area, it is clear that the landscape of Aitutaki must have been substantially influenced by man before the European discoveries. Population numbers provide a crude but effective index of the subsequent course of human activity. Table 5, based on McArthur (1968), gives census and pre-census population figures for Rarotonga and Aitutaki since 1821. The fall in numbers during the early years of missionary activity on both islands has already been noted. At the census in 1966 the population of Rarotonga was 9971, and of Aitutaki 2579. In the case of Rarotonga the total represents a density of approximately 780 per cultivated square mile, or 500 per mile of coast; in the case of Aitutaki, of 430 per cultivated square mile and 220 per mile of coast. Densely populated islands in the western Pacific, such as the Gilbert and Ellice Islands, the Carolines and Marshalls, have overall population densities of 160-180 per square mile. Largely because of migration the Aitutaki population has been stable over the last decade, whereas that of Rarotonga has increased since 1956 by over 50 per cent; that of atolls on the northern Cooks and of islands such as Mauke has decreased sharply (Curson, 1972). Concurrent changes in agriculture, with increasing emphasis on cash crops (citrus fruits, vegetables, tomatoes), have been treated in detail for Aitutaki by K.M. Johnston (1967).

The scale and intensity of these changes in the recent past must be remembered throughout the subsequent discussion of the vegetation and flora of Aitutaki, and of other aspects of the ecology of the Cook Islands. Remote and little studied as these islands are, they are in no sense unaffected by the work of man.

SCIENTIFIC STUDIES IN THE SOUTHERN COOKS

Though important observations were made by Cook and his companions, particularly on Palmerston Island in 1777 (Cook, 1967 edition, 92-96, 849-857, 1011-1012), little scientific work was carried out in any part of the group until more than a century had passed. Charles Darwin passed through the southern Cooks on the Beagle in 1835, but did not land. He sighted Aitutaki, and in a passage in his Diary (Darwin, 1933, 358-359), omitted in the published version in Journal and Researches (1839), notes:

> "December 3rd. After several days of light winds, we passed near to the island Whytootacke. We here saw a union of the two prevailing kinds of structure united. A hilly irregular mass was surrounded by a well defined circle of reefs, which in great part have been converted into low narrow strips of land, which as Cook calls them are half drowned, consisting merely of sand and Corall rocks heaped up on the dead

> part of a former reef. The inhabitants made a smoke to attract our attention."

Darwin was at this time drafting the first full statement of his coral reef theory, in which he mentions Aitutaki and speculates in which of his classes of reefs it should be placed (Darwin, 1962, p.7). In his Structure and Distribution of Coral Reefs (1842, pp.154-155), he discussed the matter more fully:

> "Aitutaki was partially surveyed by the Beagle, (see map accompanying Voyages of Adventure and Beagle); the land is hilly, sloping gently to the beach; the highest point is 360 feet; on the southern side the reef projects five miles from the land: off this point the Beagle found no bottom with 270 fathoms: the reef is surmounted by many low coral-islets. Although within the reef the water is exceedingly shallow, not being more than a few feet deep, as I am informed by the Rev. J. Williams; nevertheless, from the great extension of this reef into a profoundly deep ocean, this island probably belongs, on the principle lately adverted to, to the barrier class, and I have coloured it pale blue; although with much hesitation."

After Darwin's brief and distant observations, the only general scientific studies in the nineteenth century were the episodic and anecdotal notes made by the missionary Wyatt Gill. His "Notes on natural history" (Gill, 1877, pp.273-320) and "Zoological and botanical notes" (Gill, 1885, pp.125-210; also Gill, 1888) are, however, of little value. Otherwise the nineteenth century scientific literature is limited to an important paper on the land Mollusca by Garrett (1881), a description of two hydrozoans from Rarotonga by Quelch (1885), and a brief note on the marine algae of Mangaia by Dickie (1875).

Early in the present century, Marshall initiated a long series of studies of the volcanic rocks and elevated limestones of the southern Cooks, particularly of Rarotonga, Atiu and Mangaia (Marshall, 1908, 1909, 1912a, 1912b, 1927, 1930; Chubb, 1927). The reefs of Aitutaki were briefly visited by Alexander Agassiz (1900, 1903) in November 1899, though his observations proved to be characteristically unreliable. Crossland (1928c) and W.M. Davis (1928, pp.406-408) briefly described the reefs of Rarotonga. Crossland in particular published a long series of papers on Tahiti, several of which contain comparative comments on the reefs of Rarotonga (Crossland, 1927, 1928a, 1928b, 1928c, 1929, 1931a, 1931b, 1935, 1939). Agassiz, Davis and Crossland were all concerned with the geological relations of the reefs and their historical implications, rather than with reef biota and ecology: indeed no work seems to have been carrie out on littoral marine ecology in the Cook Islands until recent years. Rather more work has been carried out on terrestrial ecology. Floristic studies of Rarotonga were published by Luerssen (1873), Cheeseman (1903) and Wilder (1930, 1931), though no collections have been reported from Aitutaki or other islands in the southern Cooks. Taxonomic papers on the vascular flora have been published by Copeland (1931), Martelli (1932), Skottsberg (1933), Whitney (1937) and St John (1952), all based on Rarotonga material. Campbell (1932) has listed native names of Rarotongan plants. On other islands in the group, Hemsley (1884) named a few species collected by J.T. Arundel on Palmerston and Suvarov, and Cranwell (1933) gave a list of plants and Linton (1933) contributed brief notes on the vegetation of Manihiki. Lichens of Rarotonga are described by Jatta (1903-5) and Sbarbaro (1939) and Fungi by Karling (1968). The early literature on land animals is remarkably sparse, and with the exception of Garrett's work on land Mollusca and of Christian's (1920) paper on the birds of Mangaia is concerned with anthropods, especially mosquitoes of medical importance. Most of the studies are based on Rarotonga material, with some specimens from the northern Cooks, especially from Manihiki (Marks, 1951; Krauss, 1961; Taylor, 1967; Lieftinck, 1953; Laird, 1956; Tamashiro, 1964; Marples, 1960). The papers by Krauss (1961) and Laird (1956a) deal specifically with collections from Aitutaki. Solem (1972) has also recently published on a new land snail from Rarotonga.

The most important scientific studies in the Cook Islands in recent years have been those of the New Zealand Oceanographic Institute (Manihiki Expedition, 1960; Eclipse Expedition, 1965) and the Cook Bicentenary Expedition of 1969. The Eclipse Expedition carried out much bathymetric work throughout the group and established both regional and local data on submarine topography (Robertson and Kibblewhite, 1966; Summerhayes, 1967, 1969; Summerhayes and Kibblewhite, 1966, 1967, 1968, 1969). In addition E. Dawson and Summerhayes studied marine communities and bottom sediments at Aitutaki and Manuae (Summerhayes, 1971). Extensive collections were made during this expedition and are still being studied; the echinoderms have been listed by McKnight (1972). The results of the Manihiki expedition have been collected by Bullivant and McCann (1974).

The Cook Bicentenary Expedition of 1969 was a joint New Zealand and United Kingdom project working in the Cook Islands and Tonga (Fraser, 1971). The United Kingdom Marine Biology Party (Project 9) consisted of D.R. Stoddart, P.E. Gibbs, and H.G. Vevers. Its main project at Aitutaki concerned shallow water marine communities, geomorphology and sediments in reef, lagoon and beach environments, but it also extended to certain aspects of terrestrial ecology, notably the vegetation. A short supplementary study was also made of similar habitats at Ngatangiia Harbour, Rarotonga, with a subsequent reconnaissance of reefs and islands at Nuku'alofa, Tonga. The party worked on Rarotonga between 21 and 27 August 1969, and on Aitutaki between 27 August and 26 September 1969. A preliminary account of the work was given by Gibbs, Stoddart and Vevers (1971). Gibbs (1972) has published on the polychaete annelids and Stoddart and Pillai (1973) on the corals collected. An account of the Rarotonga reef islands is given by Stoddart (1973), with a list of vascular plants by F.R. Fosberg. Ferns from these islands are included in Brownlie and Philipson's (1971) list of Cook Islands Pteridophyta. In addition to the papers in the present Bulletin, a more detailed account of the corals is in course of publication (Pillai and Stoddart, in press). A preliminary account of the terrestrial invertebrates of Rarotonga, Aitutaki and other islands has been given by Wise (1971).

Some of this work supplements the extensive studies of land geology carried out in August and September 1957 throughout the Group by B.L. Wood (1967; Wood and Hay, 1970). Work during the Cook Expedition on gravity and magnetics (Lumb and Carrington, 1971) also supplemented important recent geophysical studies: on magnetics by Woodward and Hochstein (1970) and Woodward and Reilly (1970), on gravity by Robertson (1970), on paleomagnetism on Rarotonga by Tarling (1967), and on seismic refraction studies by Hochstein (1967).

The soils of the southern Cooks have been studied by Grange and Fox (1953) and Stout (1971), and agriculture and land use by W.B. Johnston (1951, 1953a, 1953b, 1955, 1959), K.M. Johnston (1967), and Bassett and Thomson (1968).

Since the Cook Bicentenary Expedition the Group has been visited by the Westward Expedition from Honolulu, which spent 7-8 March 1971 at Aitutaki and 6-11 March at Rarotonga, making general collections and searching for the Crown-of-Thorns Starfish *Acanthaster planci*. Results of this survey, with information on the reefs, are presented by Devaney (1973) and Devaney and Randall (1973).

BIBLIOGRAPHY

Agassiz, A. 1900. Exploration of the Albatross in the Pacific Ocean. Am. J. Sci. (4) 9: 33-43.

---------- 1903. Reports on the scientific results of the expedition to the tropical Pacific, in charge of Alexander Agassiz, by the U.S. Fish Commission Steamer 'Albatross', from August 1899, to March 1900, Commander Jefferson F. Moser, U.S.N., commanding. IV. The coral reefs of the tropical Pacific. Mem. Mus. comp. Zool. Harv. 28: i-xxxiii, 1-410, 238 pl.

Allen, B. 1971. Wet-field taro terraces on Mangaia, Cook Islands. J. Polynes. Soc. 80: 371-378.

Anonymous. 1906. Cook and other islands. Wellington: New Zealand Parliamentary Papers A-3: 1-105.

Armstrong, J.C. 1941. The Caridea and Stomatopoda of the Second Templeton Crocker-American Museum Expedition in the Pacific Ocean. Am. Mus. Nov. 1137: 1-14 /Penrhyn/.

Banner, A.H. and Banner, D.M. 1967. Contributions to the knowledge of the alpheid shrimp of the Pacific Ocean. XI. Collections from the Cook and Society Islands. Occ. Pap. Bernice P. Bishop Mus. 23: 253-286.

Bassett, I.G. and Thomson, K.W. 1968. Land use and agrarian change on Aitutaki, Cook Islands. South Pacific Bull. 18: 25-30.

Beaglehole, E. 1944. Islands of danger. Wellington: Progressive Publishing Soc. 212 pp. /Pukapuka/.

------------- 1957. Social change in the South Pacific: Rarotonga and Aitutaki. London: George Allen and Unwin Ltd. 268 pp.

Beaglehole, E. and Beaglehole, P. 1938. Ethnology of Pukapuka. Bishop Mus. Bull. 150: i-v, 1-419.

Bellwood, P.S. 1969. Archaeology on Rarotonga and Aitutaki, Cook Islands: a preliminary report. J. Polynes. Soc. 78: 517-530.

------------- 1971. Varieties of ecological adaptation in the southern Cook Islands. Archaeol. phys. Anthrop. Oceania, 4: 145-169.

------------- 1973. The prehistory of the Cook Islands. Abstracts 9th Congress Intern. Union Quat. Res. (Christchurch, 1973): 16-17.

Best, E. 1927. The discovery and settlement of Rarotonga by Polynesians. J. Polynes. Soc. 36: 122-134.

Boschma, H. 1929. The Fungidae (Anthozoa) collected by Mr Cyril Crossland at Tahiti and neighbouring islands. Proc. zool. Soc. Lond. 1929: 43-47.

Brownlie, G. and Philipson, W.R. 1971. Pteridophyta of the southern Cook Group. Pacif. Sci. 25: 502-511.

Buck, P.H. 1927. The material culture of the Cook Islands (Aitutaki). Bull. Board of Maori ethnol. Res. (New Plymouth: Avery), 1: i-xxv, 1-385.

---------- 1932a. Ethnology of Tongareva. Bishop Mus. Bull. 92: i-iv, 1-225.

Buck, P.H. 1932b. Ethnology of Manihiki and Rakahanga. Bishop Mus. Bull. 99: 1-238.

---------- 1934. Mangaian society. Bishop Mus. Bull. 122: 1-207.

---------- 1944. Arts and crafts of the Cook Islands. Bishop Mus. Bull. 179: 1-533.

---------- 1945. Introduction to Polynesian anthropology. Bishop Mus. Bull. 187: 1-133.

Bullivant, J.S. 1974a. Manihiki Atoll survey 1960: general account and station list. Mem. N.Z. oceanogr. Inst. 31: 5-16.

---------- 1974b. Lagoon and reef morphology of Manihiki Atoll. Mem. N.Z. oceanogr. Inst. 31: 17-21.

---------- 1974c. Crabs from Manihiki. Mem. N.Z. oceanogr. Inst. 31: 41-43.

Bullivant, J.S. and McCann, C. 1974. Fishes from Manihiki Atoll. Mem. N.Z. oceanogr. Inst. 31: 49-60.

Bullivant, J.S. and McCann, C., eds. 1974. Contributions to the natural history of Manihiki Atoll, Cook Islands. Mem. N.Z. oceanogr. Inst. 31: 1-63.

Burnett, F. 1910. Through tropic seas. London: Griffiths. xvi, 173 pp. [Penrhyn, Manihiki, Rakahanga].

Buzacott, A. 1866. Mission life in the islands of the Pacific. Being a narrative of the life and labours of the Rev. A. Buzacott. Edited by J.P. Sunderland and A. Buzacott. London: John Snow and Co. 288 pp.

---------- MS. Letters. London Missionary Society archives. Microfilm, Turnbull Library, Wellington, New Zealand.

---------- MS. Journals and papers, 1828-1840. Mitchell Library, Sydney.

Buzacott, E. MS. Journals, 1830-33. Mitchell Library, Sydney.

---------- MS. Life in Rarotonga in the 1830s (ca 1839). Mitchell Library, Sydney.

Campbell, J.D. 1932. Native names of common plants of Rarotonga. J. Polynes. Soc. 41: 212-213.

Chamisso, A. von. 1821. Remarks and opinions ... of the naturalist of the expedition. In O. von Kotzebue: A voyage of discovery into the South Seas and Bering's Straits (London, 3 vols.), III, 1-318, 436-442 /Penrhyn/.

Choris, L. 1822. Voyage pittoresque autour du monde, avec des portraits de sauvages ... des iles du Grand Océan. Paris: Didot. 104 pl. /Penrhyn/.

Cheeseman, T.F. 1903. The flora of Rarotonga, the chief island of the Cook Group. Trans. Linn. Soc. Lond. (1) 6: 261-313.

Christian, F.W. 1920. List of Mangaia Island birds. J. Polynes. Soc. 29, 87.

Chubb, L.J. 1927. Mangaia and Rurutu: a comparison between two Pacific islands. Geol. Mag. 64: 518-522.

Cook, J. 1961. The Journals of Captain James Cook on his voyages of discovery. The voyage of the Resolution and Adventure 1772-1775. Edited by J.C. Beaglehole. Cambridge: University Press. clxx, 1021 pp.

---------- 1967. The Journals of Captain James Cook on his voyages of discovery. The voyage of the Resolution and Discovery 1776-1780. Edited by J.C. Beaglehole. Cambridge: University Press. I, ccxxiv, 718 pp.; II, viii, 721-1647 pp.

Copeland, E.B. 1931. Rarotonga ferns, collected by Harold E. and Susan T. Parks. Miscellaneous oriental pteridophytes. Univ. Calif. Publs Bot. 12: 375-382, 383-418.

Coppell, W.G. 1973. About the Cook Islands: their nomenclature and a systematic statement of early European contacts. J. Soc. Océan. 29: 23-56.

Cowan, J. 1936. Suwarrow gold and other stories of the Great South Sea. London. 253 pp.

Cranwell, L.M. 1933. Flora of Manihiki, Cook Group. Rec. Auckland Inst. Mus. 1: 169-171.

Crocombe, R.G. 1964. Land tenure in the Cook Islands. Melbourne: Oxford University Press. xv, 180 pp.

Crossland, C. 1927. Recession of the Tahitian coral reefs. Nature, Lond. 119, 597.

---------- 1928a. The island of Tahiti. Geog. J. 71: 561-583, discussion, 583-585.

---------- 1928b. Notes on the ecology of the reef-builders of Tahiti. Proc. zool. Soc. Lond. 1928: 717-735.

Crossland, C. 1928c. Coral reefs of Tahiti, Moorea and Rarotonga. J. Linn. Soc. Lond. 36: 577-620.

---------- 1929. Recession and age of the Tahitian coral reefs. Nature, Lond. 124: 576.

---------- 1931a. The reduced building-power and other variation in the astraean corals of Tahiti, with a note on Herpetolitha limax and Fungia spp. Proc. zool. Soc. Lond. 1931: 351-392.

---------- 1931b. The coral reefs of Tahiti compared with the Great Barrier Reefs. Geogrl J. 77: 395-396.

---------- 1935. Coral faunas of the Red Sea and Tahiti. Proc. zool. Soc. Lond. 1935: 499-504.

---------- 1939. Further notes on the Tahitian barrier reef and lagoons. J. Linn. Soc. Lond. (Zool.) 40: 459-474.

Curson, P.H. 1972. Population change in the Cook Islands - the 1966 population census. N.Z. Geog. 28: 51-65.

---------- 1973. Birth, death and migration: elements of population change in Rarotonga 1890-1926. N.Z. Geog. 29: 103-119.

Darwin, C.R. 1842. The structure and distribution of coral reefs. London; Smith, Elder and Co. xii, 214 pp.

---------- 1933. Charles Darwin's Diary of the Voyage of H.M.S. "Beagle," edited from the MS by Nora Barlow. Cambridge: University Press. xxx, 451 pp.

---------- 1962. Coral Islands. With introduction, map and remarks by D.R. Stoddart. Atoll Res. Bull. 88: 1-20.

Dashwood, R.J. 1956. Shell news from the Cook Islands. Hawaiian Shell News, 4(11): 116.

Davis, T.R.A. and Davis, L. 1954. Doctor to the islands. Boston. 331 pp. /Rarotonga, Palmerston, Pukapuka/.

Davis, W.M. 1928. The coral reef problem. Spec. Publs Am. geogr. Soc. 9: 1-596.

Devaney, D.M. 1973. Zoogeography and faunal composition of south-eastern Polynesian asterozoan echinoderms. Oceanography of the South Pacific 1972, R. Fraser, ed. (Wellington: New Zealand National Commission for UNESCO): 357-366.

Devaney, D.M. and Randall, J.E. 1973. Investigations of Acanthaster planci in southeastern Polynesia during 1970-1971. Atoll Res. Bull. 169: 1-23.

Dickie, G. 1875. Notes on algae from the island of Mangaia, South Pacific. J. Linn. Soc. Bot. 15: 30-33.

Duff, R. 1968. Archaeology of the Cook Islands. In I. Yawata and Y.H. Sinoto, eds.: Prehistoric culture in Oceania (Honolulu: Bernice P. Bishop Museum Press): 119-132.

Duff, R. 1971. Notes on the prehistory of Atiu, Cook Islands. Bull. R. Soc. N.Z. 8: 41-48.

Edmonds, S.J. 1974. Sipunculids from Manihiki. Mem. N.Z. oceanogr. Inst. 31: 33.

Eschscholtz, F. 1821. General information in O. von Kotzebue: A voyage of discovery into the South Seas and Bering's Straits (London, 3 vols.), III, 321-330 [Penrhyn].

Finsch, O. and Hartlaub, G. 1871. On a collection of birds from Savai and Rarotonga Islands in the Pacific. Proc. zool. Soc. Lond. 1871: 21-32.

Fraser, R. 1971. A narrative of the Cook Bicentenary Expedition. Bull. R. Soc. N.Z. 8: 21-28.

Frisbie, R.D. 1928. At home in Puka-puka. Atlantic Mon. 142: 1-12.

---------- 1929a. The book of Pukapuka. New York: Century. 356 pp.

---------- 1929b. Mrs Turtle lays her eggs. Atlantic Mon. 143: 462-466 [Pukapuka].

---------- 1930. South Sea fairylands. Atlantic Mon. 146: 190-202 [Manihiki, Penrhyn].

---------- 1932. A copra island. Atlantic Mon. 150: 192-200.

---------- 1935. Uninhabited island. Atlantic Mon. 156: 534-541.

---------- 1944. The island of desire. New York: Garden City. 234 pp. [Pukapuka, Suvarov].

---------- 1948. Miss Ulysses from Puka-puka. New York. 241 pp. [Pukapuka, Suvarov].

Garrett, A. 1881. The terrestrial Mollusca inhabiting the Cook's or Harvey Islands. J. Acad. nat. Sci. Phila. (2) 8: 381-411.

Gibbs, P.E. 1972. Polychaete annelids from the Cook Islands. J. Zool., Lond. 168: 199-220.

Gibbs, P.E., Stoddart, D.R. and Vevers, H.G. 1971. Coral reefs and associated communities in the Cook Islands. Bull. R. Soc. N.Z. 8: 91-105.

Gill, W. 1856. Gems from the coral islands; or, incidents of contrast between savage and Christian life of the South Sea islanders. Vol. II. Eastern Polynesia: comprising the Rarotonga Group, Penrhyn Islands, and Savage Island. London: Ward and Co. xviii, 320 pp.

---------- 1880. Selections from the autobiography ... of his life in the South Sea islands. London: Yates and Alexander, for private circulation. iv, 316 pp.

Gill, W. Wyatt. 1876a. Life in the southern isles; or, scenes and incidents in the South Pacific and New Guinea. London: Religious Tract Society. viii, 360 pp.

---------- 1876b. Myths and songs from the South Pacific. London: King. xxiv, 328 pp. /Rakahanga, Manihiki/.

---------- 1880. Historical sketches of savage life in Polynesia; with illustrative clan songs. Wellington: George Didsbury, Government Printer. viii, 232 pp.

---------- 1885. Jottings from the Pacific. London: Religious Tract Society. 248 pp.

---------- 1888. Zoologische Miszellen aus der Südsee. Mitt. geogr. Ges. Thüringen, 7: 18-37.

---------- 1894. From darkness to light in Polynesia, with illustrative clan songs. London: Religious Tract Society. 383 pp. /Mangaia/.

Gilmour, A.E. 1974. Tidal measurements at Manihiki Atoll. Mem. N.Z. oceanogr. Inst. 31: 29-30.

Gilson, R.P. 1955. Negotiations leading to British intervention in Rarotonga (Cook Islands). Hist. Stud. Austr. N.Z. 7: 62-80.

Given, R.B. 1964. The coconut termite in the Cook Islands (Calotermes). S. Pacif. Bull. 14(3): 25-26.

Gosset, R.W.G. 1940. Notes on the discovery of Rarotonga. Aust. Geog. 3: 4-15.

Grange, L.I. and Fox, J.P. 1953. Soils of the lower Cook Group. Bull. N.Z. Soil Bureau, n.s. 8: 1-55.

Guilcher, A., Berthois, L., Le Calvez, Y., Battistini, R. and Crosnier, A. 1965. Les récifs coralliens et le lagon de l'ile Mayotte (Archipel des Comores, Océan Indien): géomorphologie, sédimentologie, hydrologie, foraminifères. Mém. Off. Rech. scient. tech. Outre-Mer, 8: 1-210.

Guilcher, A., Berthois, L., Doumenge, F., Michel, A., Saint-Requier, A. and Arnold, R. 1969. Les récifs et lagons coralliens de Mopelia et de Bora-Bora (Iles de la Société). Mém. Off. Rech. scient. tech. Outre-Mer, 38: 1-103.

Hague, J.D. 1868. Some coral islands and islanders. Atlantic Mon. 22: 36-51 [Manihiki, Suvarov].

Hedley, C. 1899. A zoogeographic scheme for the mid-Pacific. Proc. Linn. Soc. N.S.W. 24: 391-417.

Hemsley, W.B. 1884. Report on the botany of Juan Fernandez, the south-eastern Moluccas, and the Admiralty Islands. Sci. Rep. Voy. H.M.S. Challenger, Botany, 3: 1-333 [Rarotonga, Palmerston, Suvarov].

Hochstein, M.P. 1967. Seismic measurements in the Cook Islands, southwest Pacific Ocean. N.Z. J. Geol. Geophys. 10: 1499-1521.

Hornell, J. 1936. The canoes of Polynesia, Fiji and Micronesia. In A.C. Haddon and J. Hornell: The canoes of Oceania. Spec. Publ. Bishop Mus. 27: 1-454 [Manihiki].

Hunt, H.A. 1914. Results of rainfall observations made in Queensland. Melbourne: Government Printer, 285 pp.

Hutchings, J.W. 1953. Tropical cyclones in the southwest Pacific. N.Z. Geog. 9: 37-57.

Hydrographic Office. 1966. Atlas of Pilot Charts: South Pacific and Indian Oceans. Washington: Hydrographic Office, H.O. Publ. 107.

Jatta, A. 1903-5. Licheni esotici dell'Erabrio Levier raccolti nell'Asia Meridionale e nell'Oceania. Malpighia, 17: 3-15; 19: 163-186 [Rarotonga].

Johnston, K.M. 1967. Village agriculture in Aitutaki, Cook Islands. Pacif. Viewpoint Monogr. 1: 1-122.

Johnston, W.B. 1951. The citrus industry of the Cook Islands. N.Z. Geog. 7: 121-138.

Johnston, W.B. 1953a. Some aspects of land use on Rarotonga, Cook Islands. Rep. 7th Sci. Congr. R. Soc. N.Z. (Christchurch, 1951): 161-162.

---------- 1953b. Land, people and progress in the Cook Islands. Econ. Geog. 29: 107-124.

Johnston, W.B. 1955. The Cook Islands: settlement in an island group of the southwest Pacific. Malayan J. trop. Geog. 5: 1-11.

---------- 1959. The Cook Islands. J. trop. Geog. 13: 38-57.

Karling, J.S. 1968. Zoosporic Fungi of Oceania, I. J. Elisha Mitchell scient. Soc. 84: 166-178.

Kelsey, J.M. 1945. A termite damaging coconut-palms on Suwarro Island: Calotermes (Neotermes) rainbowi Hill. N.Z. J. Sci. Technol. 27B: 69-75 [Suvarov, Pukapuka].

Keys, J.E. 1963. The tsunami of 22 May 1960, in the Samoa and Cook Islands. Bull. seismol. Soc. Am. 53: 1211-1227.

Kotzebue, O. von. 1821. A voyage of discovery into the South Seas and Bering's Straits. London. 3 vols. [Penrhyn, Suvarov].

Krauss, N.L.H. 1961. Insects from Aitutaki, Cook Islands. Proc. Hawaii. ent. Soc. 17: 415-418.

Laird, M. 1956a. The mosquitoes of Aitutaki, southern Cook Islands. Bull. ent. Res. 45: 423-427.

---------- 1956b. Studies of mosquitoes and freshwater ecology in the South Pacific. Bull. R. Soc. N.Z. 6: 1-213.

Lamberty, E.W. 1952. Met de "Kroja" naar Taha-uku. Amsterdam. 240 pp. [Penrhyn].

Lieftinck, M.A. 1953. Notes on some dragonflies (Odonata) of the Cook Islands. Proc. Hawaii. entom. Soc. 15: 45-49 [Pukapuka].

Linton, A.M. 1933. Notes on the vegetation of Penrhyn and Manihiki Islands. J. Polynes. Soc. 42: 300-307.

Low, D. 1934-35. Traditions of Aitutaki, Cook Islands. J. Polynes. Soc. 43: 17-24, 73-84, 171-186, 258-267; 44: 26-31

Luersson, C. 1873. Ueber die Farnflora der Cooks- oder Hervey-Inseln. J. Mus. Godeffroy, 1: 59-62 [Rarotonga].

Lumb, J.T. and Carrington, L. 1971. Magnetic surveys in the south-west Pacific and rock sampling for magnetic studies in the Cook Islands. Bull. R. Soc. N.Z. 8: 81-89.

Macfarlane, J.H. 1887. Notes on birds in the western Pacific, made in H.M.S. 'Constance' 1882-5. Ibis (5) 5: 201-215 [Penrhyn].

Macgregor, G. 1935. Notes on the ethnology of Pukapuka. Occ. Pap. Bishop Mus. 11(6): 1-52.

Marks, E.N. 1951. Mosquitoes from southeastern Polynesia. Occ. Pap. Bishop Mus. Bull. 20: 123-130 /Manihiki/.

Marples, B.J. 1960. Spiders from some Pacific islands, Part IV. The Cook Islands and Niue. Pacif. Sci. 14: 382-388.

Marshall, P. 1908. Geology of Rarotonga and Atiu. Trans. N.Z. Inst. 41: 98-100.

---------- 1909. Note on the geology of Mangaia. Trans. N.Z. Inst. 42: 333.

---------- 1912a. Coral reefs of the Cook and Society Islands. Rep. Australas. Ass. Advmt Sci. 13: 140-145.

---------- 1912b. Alkaline rocks of the Cook and Society Islands. Rep. Australas. Ass. Advmt Sci. 13: 196-202.

---------- 1927. Geology of Mangaia (Cook Islands). Bishop Mus. Bull. 36: 1-48.

---------- 1929. Mangaia and Rurutu - A comparison between two Pacific islands. Geol. Mag. 66: 385-389.

---------- 1930. Geology of Rarotonga and Atiu. Bishop Mus. Bull. 72: 1-75.

Martelli, U. 1932. Pandanaceae of Tahiti and Pandanaceae of Rarotonga. Univ. Calif. Publs Bot. 17: 149-185.

Martens, E. von. 1872. Conchylien von Cook's Reisen. Malakozoologische Blätter, 19: 1-37.

Maude, H.E. 1959. Spanish discoveries in the central Pacific: a study in identification. J. Polynes. Soc. 68: 284-322, appendix by G.H. Heyen, 323-326 /Pukapuka, Manihiki, Rakahanga/.

Maude, H.E. and Crocombe, M.T. 1952. Rarotongan sandalwood: The visit of Goodenough to Rarotonga in 1814. J. Polynes. Soc. 71: 32-56.

McArthur, N. 1968. Island populations of the Pacific. Canberra: Australian National University Press. xiv, 381 pp.

McCann, C. 1974a. Scleractinian corals from Manihiki Atoll. Mem. N.Z. oceanogr. Inst. 31: 31-32.

---------- 1974b. Mollusca from Manihiki Atoll. Mem. N.Z. oceanogr. Inst. 31: 35-40.

McCann, C. 1974c. Reptiles from Manihiki Atoll. Mem. N.Z. oceanogr. Inst. 31: 61-63.

McKnight, D.G. 1972. Echinoderms collected by the Cook Islands Eclipse Expedition 1965. Rec. N.Z. oceanogr. Inst. 1: 37-45

---------- 1974. Echinoderms from Manihiki lagoon. Mem. N.Z. oceanogr. Inst. 31: 45-47.

Miner, R.W. 1938. On the bottom of a South Sea pearl lagoon. Natn. geogr. Mag. 74: 365-390 [Penrhyn].

Nightingale, T. 1835. Oceanic sketches. London. 132 pp. [Palmerston].

Numa, J. 1939. Penrhyn Island. Nat. med. Pract. Fiji, 3: 415-416.

Pakoti, J. 1895. First inhabitants of Aitutaki: the history of Ru. J. Polynes. Soc. 4: 59-70.

Pease, W.H. 1871. Catalogue of the land-shells inhabiting Polynesia, with remarks on their synonymy, distribution, and variation, and descriptions of new genera and species. Proc. zool. Soc. Lond. 1871: 449-477.

Philipson, W.R. 1971. Floristics of Rarotonga. Bull. R. Soc. N.Z. 8: 49-54.

Pitman, C.E. MS. Journal, 1827-1842. 6 vols. Mitchell Library, Sydney.

Quelch, J.J. 1885. On some deep-sea and shallow-water Hydrozoa. Ann. Mag. nat. Hist. (5) 16: 1-20 [Rarotonga].

Ridgway, N.M. 1974. Hydrology of Manihiki lagoon. Mem. N.Z. oceanogr. Inst. 31: 23-28.

Robertson, E.I. 1970. Additional gravity surveys in the Cook Islands. N.Z. J. Geol. Geophys. 13: 184-198.

Robertson, E.I. and Kibblewhite, A.C. 1966. Bathymetry around isolated volcanic islands and atolls in the South Pacific Ocean. N.Z. J. Geol. Geophys. 9: 111-121.

St John, H. 1952. A new variety of Pandanus and a new species of Fimbristylis from the central Pacific islands. Pacif. Sci. 6: 145-150 [Rakahanga].

Sbarbaro, C. 1939. Aliquot Lichenes oceanici in Cook insulis (Tonga, Rarotonga, Tongatabu, Eua) collecti. Arch. bot. 15: 101-104.

Schofield, J.C. 1966. Evidnece of Quaternary sea-levels from the Cook Islands and the effect of density changes on post-Glacial sea-level rise. Proc. Pacif. Sci. Congr., 11th, Abstr. Papers, Geol. Sci., 4.

---------- 1967. 1. Post glacial sea-level maxima a function of salinity? 2. Pleistocene sea-level evidence from the Cook Islands. J. Geosci. Osaka Univ. 10: 115-120.

---------- 1970. Notes on late Quaternary sea levels, Fiji and Rarotonga. N.Z. J. Geol. Geophys. 13: 199-206.

Schofield, J.C. and Suggate, R.P. 1971. Late Quaternary sea level records of the Southwest Pacific. Quaternaria, 14: 243-253.

Seelye, C.J. 1943. The climate of Aitutaki. Climatol. Notes N.Z. meteorol. Off. 4:1-8.

---------- 1943b. The climate of Pukapuka - Danger Islands. Climatol. Notes N.Z. meteorol. Off. 3: 1-8.

Shadbolt, M. 1967. Paradise in search of a future. Natn. geogr. Mag. 132: 202-231.

Shepard, F.P. 1961. Sea-level rise during the past 20,000 years. Zeitschr. Geomorph. N.F., Supplbd. 3: 30-35 [Aitutaki].

Skottsberg, C. 1933. Myoporum in Rarotonga. Acta Horti Gothoburg. 8: 147-167.

Smith, K.G.V. 1964. A remarkable new genus and two new species of Empididae (Tachydrominiinae, Grapetini) from the Cook Islands. Pacif. Insects, 6: 247-251.

Smith, S.P. 1889. Tongarewa or Penrhyn Island, and its people. Trans. Proc. N.Z. Inst. 22: 85-103.

Solem, A. 1972. Tekoulina, a new viviparous tornatellid land snail from Rarotonga, Cook Islands. Proc. malac. Soc. Lond. 40: 93-114.

Sterndale, H.B. 1874. Memoranda on some of the South Sea islands. Appendix J. N.Z. House Repres. 1874A, 3B: 1-55.

---------- 1890. A lone land and they who lived on it. Mon. Rev. Wellington, 2: 195-204, 269-279, 345-355, 385-392, 435-443 [Suvarov].

Stephenson, W. and Campbell, B. 1960. The Australian Portunidae (Crustacea: Portunidae). IV. Remaining genera. Aust. J. mar. Freshwat. Res. 11: 73-122.

Stevenson, F.V. de G. (Mrs R.L.). 1914. The cruise of the Janet Nichol among the South Sea islands. New York. 189 pp. /Nassau, Pukapuka, Manihiki, Penrhyn/.

Stoddart, D.R. 1972. Reef islands of Rarotonga, with List of vascular flora by F.R. Fosberg. Atoll Res. Bull. 160: 1-14.

Stoddart, D.R. and Pillai, C.S.G. 1973. Coral reefs and reef corals in the Cook Islands, South Pacific. Oceanography of the South Pacific 1972, R. Fraser, ed. (Wellington: New Zealand National Commission for UNESCO): 475-483.

Stout, J.D. 1971. The distribution of soil bacteria in relation to biological activity and pedogenesis. Part 2. Soils of some Pacific islands. N.Z. J. Sci. 14: 834-850 /Rarotonga, Aitutaki/.

Summerhayes, C.P. 1967. Bathymetry and topographic lineation in the Cook Islands. N.Z. J. Geol. Geophys. 10: 1382-1399.

---------- 1971. Lagoonal sedimentation at Aitutaki and Manuae in the Cook Islands: a reconnaissance survey. N.Z. J. Geol. Geophys. 14: 351-363.

Summerhayes, C.P. and Kibblewhite, A.C. 1966. Aitutaki provisional bathymetry. N.Z. Oceanographic Institute Chart, Island Series 1:200,000.

---------- 1967. Rarotonga provisional bathymetry. N.Z. Oceanographic Institute Chart, Island Series 1:200,000.

---------- 1968. Mangaia provisional bathymetry. N.Z. Oceanographic Institute Chart, Island Series 1:200,000.

---------- 1969. Mauke provisional bathymetry. N.Z. Oceanographic Institute Chart, Island Series 1:200,000.

Survey Department, Rarotonga. No date. Maps of the Cook Islands.

Tamashiro, M. 1964. Observations on the larval ecology of Aedes (Stegomyia) polynesiensis Marks on Aitutaki, southern Cook Islands. World Health Organization Report WHO/EB2/22, 7 October 1964, 29 pp., 7 figs.

Tarling, D.H. 1967. Some paleomagnetic results from Rarotonga, Cook Islands. N.Z. J. Geol. Geophys. 10: 1400-1406.

Taylor, R.C. 1973. An atlas of Pacific Islands rainfall. Hawaii Institute of Geophysics Data Report No. 25.

Taylor, R.W. 1967. Entomological survey of the Cook Islands and Niue. 1. Hymenoptera--Formicidae. N.Z. J. Sci. 10: 1092-1095.

Te Rangi Hiroa. See Buck, P.H.

Thomson, R.W.F. 1968. Spacing and nutrition of Cocos nucifera under atoll conditions in the Cook Islands. Oléagineux, 23: 449-451.

Thorogood, B. 1960. Not quite paradise. London: London Missionary Society. viii, 119 pp.

Tupper, Captain. MS. Report upon a visit to the following islands: Nassau, Danger, Humphrey, Rierson, Penrhyn, Suwarrow in H.M.S. Plyades, 1899. British Consulate Papers, Samoa.

Vayda, A.P. 1959. Native traders in two Polynesian atolls. Humanités Inst. Sci. écon. appl. 5: 119-137 [Manihiki, Rakahanga].

Veeh, H.H. 1966. Th^{230}/U^{238} and U^{234}/U^{238} ages of Pleistocene high sea level stand. J. Geophys. Res. 71: 3379-3386 [Mangaia].

Visher, S.S. 1925. Tropical cyclones of the Pacific. Bishop Mus. Bull. 20: 1-163.

Ward, M. 1939. The Brachyura of the Second Templeton Crocker-American Museum Expedition to the Pacific Ocean. Am. Mus. Nov. 1049: 1-15 [Penrhyn].

Ward, W.T., Ross, P.J. and Colquhoun, D.J. 1971. Interglacial high sea levels--an absolute chronology derived from shoreline elevations. Palaeogeogr. Palaeoclimat. Palaeoecol. 9: 77-99 [Mangaia].

Whitney, L.D. 1937. A new species of Garnotia from Rarotonga. Occ. Pap. Bishop Mus. 13: 77-78.

Wilder, G.P. 1930. Some observations on the flora of Rarotonga. Spec. Publs Bishop Mus. 16: 16.

---------- 1931. Flora of Rarotonga. Bishop Mus. Bull. 86: 1-113.

Wilkes, C. 1845. Narrative of the United States Exploring Expedition during the years 1838, 1839, 1840, 1841, 1842. Philadelphia. 5 vols. [Penrhyn].

Winterer, E.L. 1973. Sedimentary facies and plate tectonics of equatorial Pacific. Bull. Am. Ass. Petrol. Geol. 57: 265-282.

Wise, K.A.J. 1971. A preliminary report on the terrestrial invertebrate fauna of the Cook Islands, collected during the Cook Bicentenary Expedition, 1969. Bull. R. Soc. N.Z. 8: 55-64.

Wood, B.L. 1967. Geology of the Cook Islands. N.Z. J. Geol. Geophys. 10: 1429-1445.

Wood, B.L. and Hay, R.F. 1970. Geology of the Cook Islands. Bull. N.Z. geol. Surv., n.s. 82: 1-103.

Woodward, J.D. and Hochstein, M.P. 1970. Magnetic measurements in the Cook Islands, south-west Pacific Ocean. N.Z. J. Geol. Geophys. 13: 207-224.

Woodward, J.D. and Reilly, W.I. 1970. Note on magnetic vertical force anomalies on Manihiki Atoll, Cook Islands. N.Z. J. Geol. Geophys. 13: 225-227.

Table 5. Population of Rarotonga and Aitutaki

Year	Rarotonga	Aitutaki
1821		ca 2000
1839		ca 2000
1845	3000	2000
1854-5	2374	1750
1871-2	1936	1450
1881	2000	1146
1902	2060	1170
1906*	2334	1154
1911*	2620	1221
1916*	2853	1277
1921*	3287	1343
1926*	3731	1417
1936*	4818	1707
1945*	5307	2332
1951*	5802	2358
1956	6417	2590
1961	8676	2582
1966*	9971	2579
1971*	11388	2854

*census return

Source: McArthur, 1968; New Zealand Official Yearbook (annual)

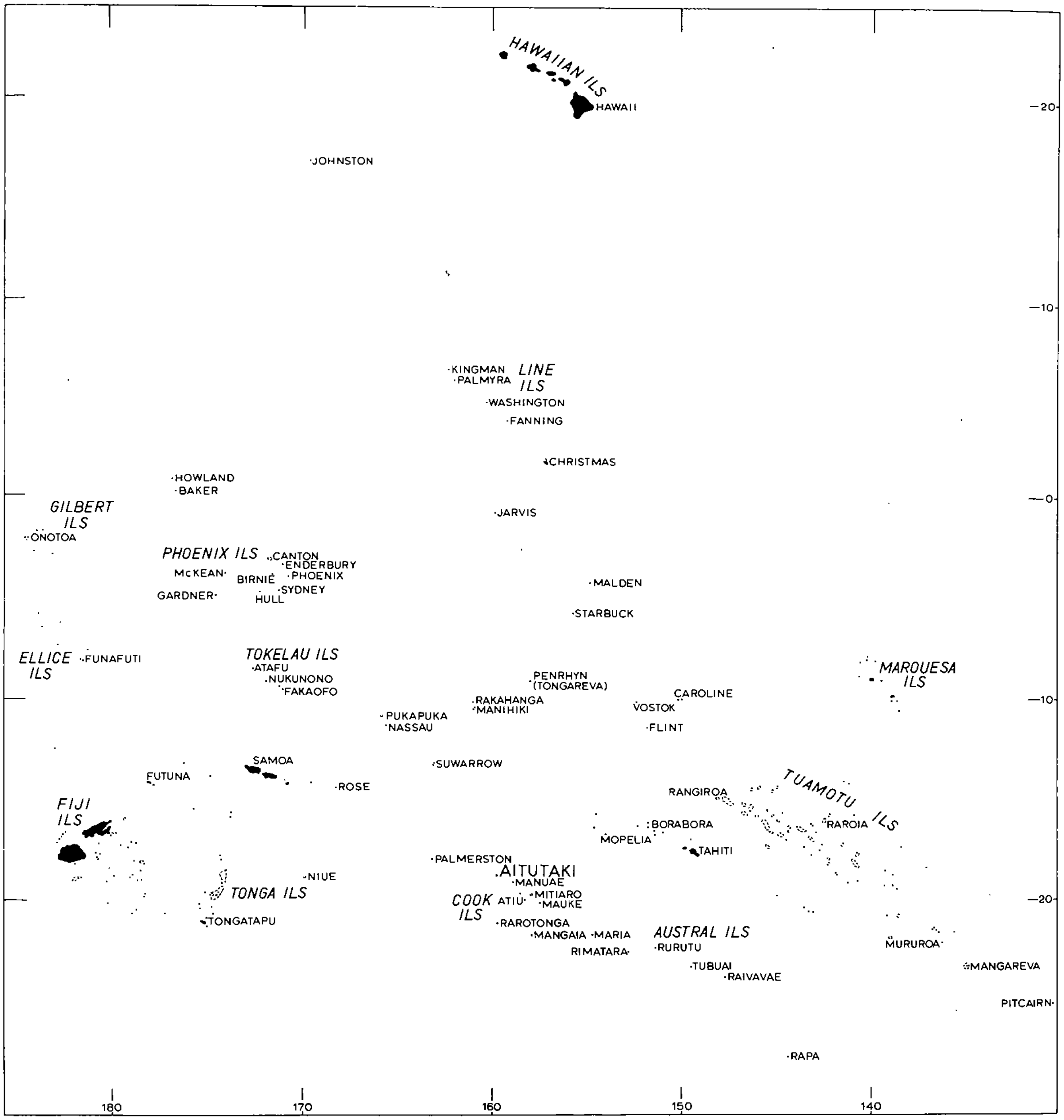


Figure 1. Location of Aitutaki in the central Pacific

Figure 2. Bathymetry of the southern Cook Islands, after Summerhayes (1967)

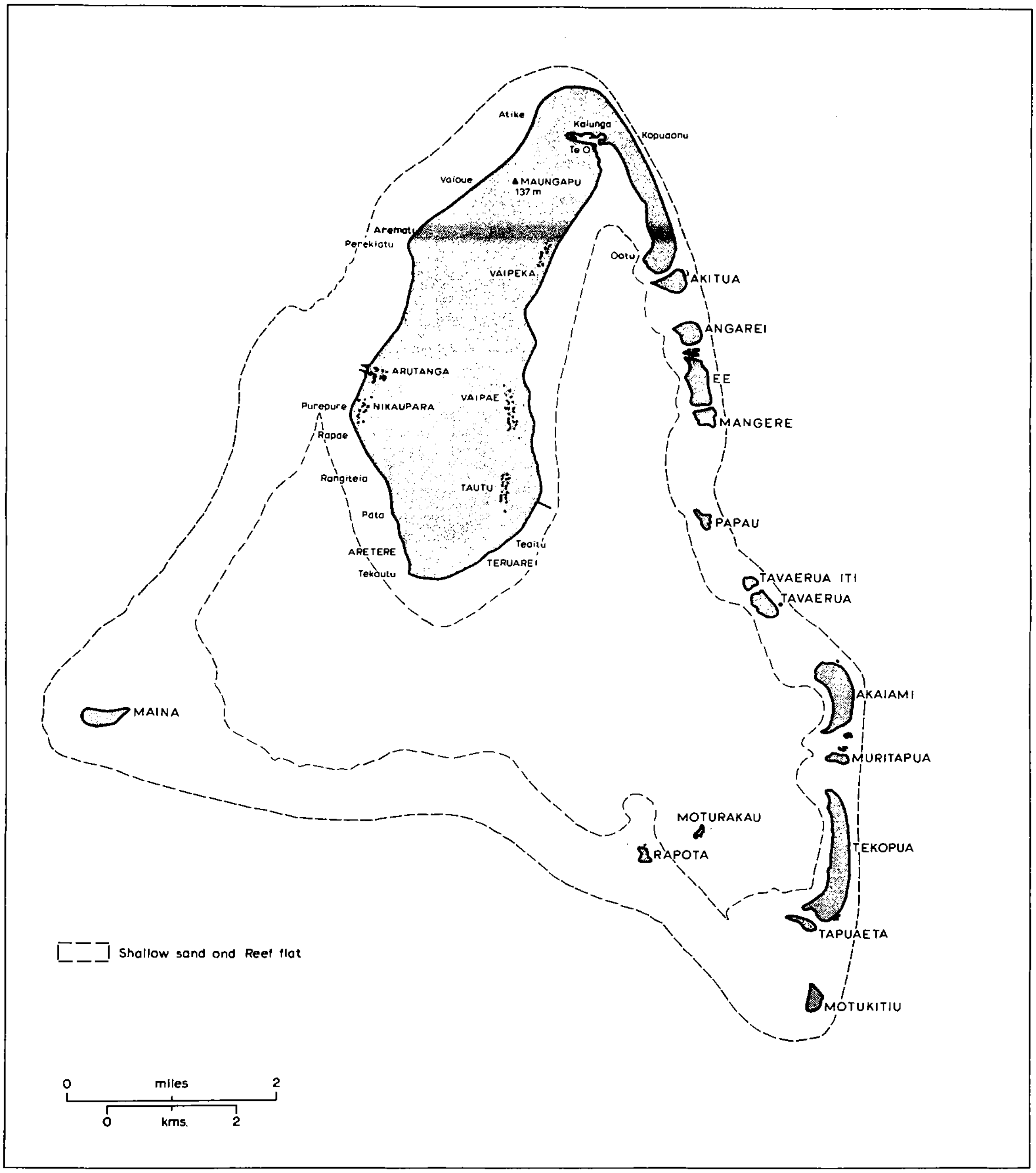


Figure 3. Aitutaki

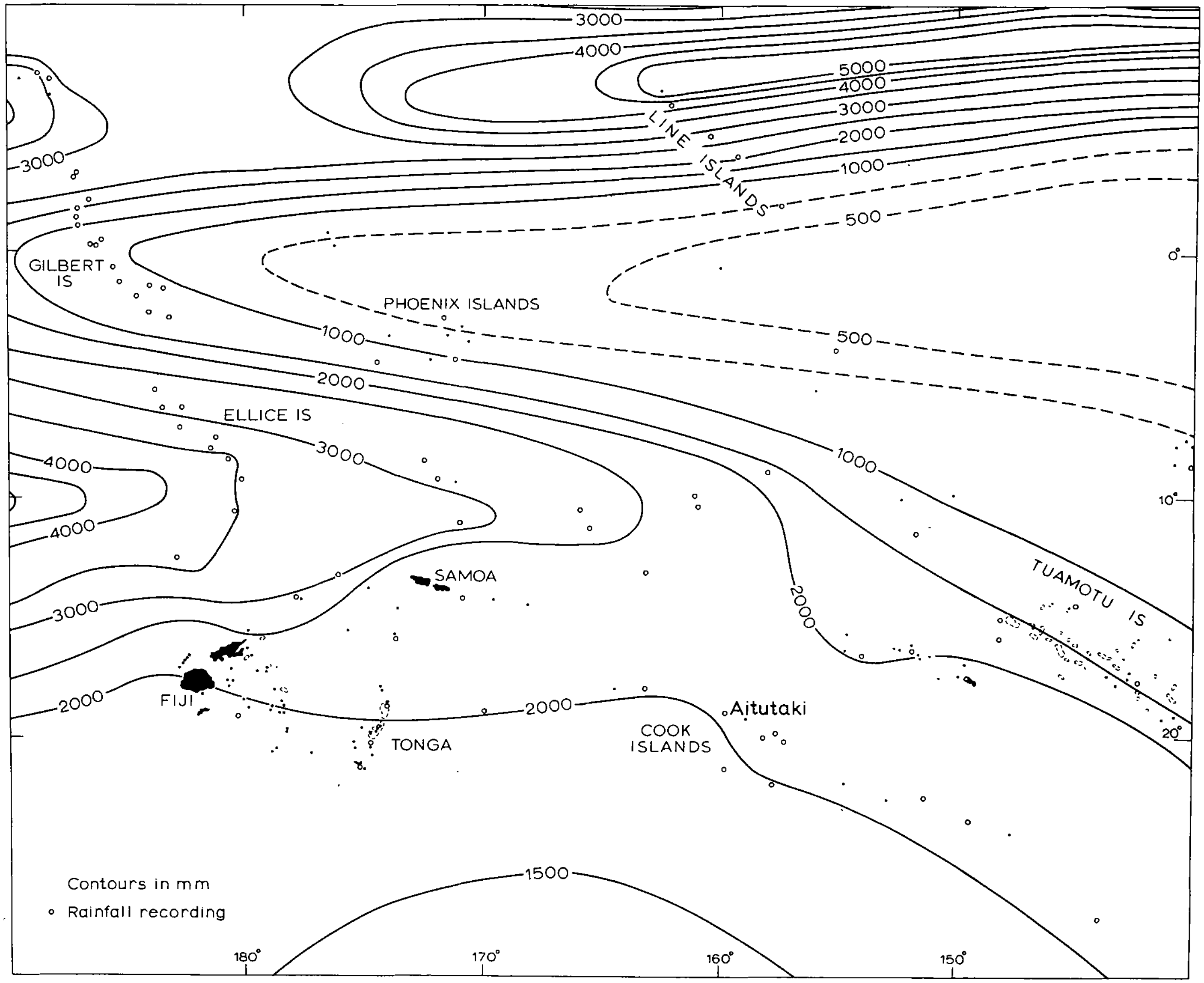


Figure 4. Rainfall distribution in the central Pacific, based on Taylor (1973)

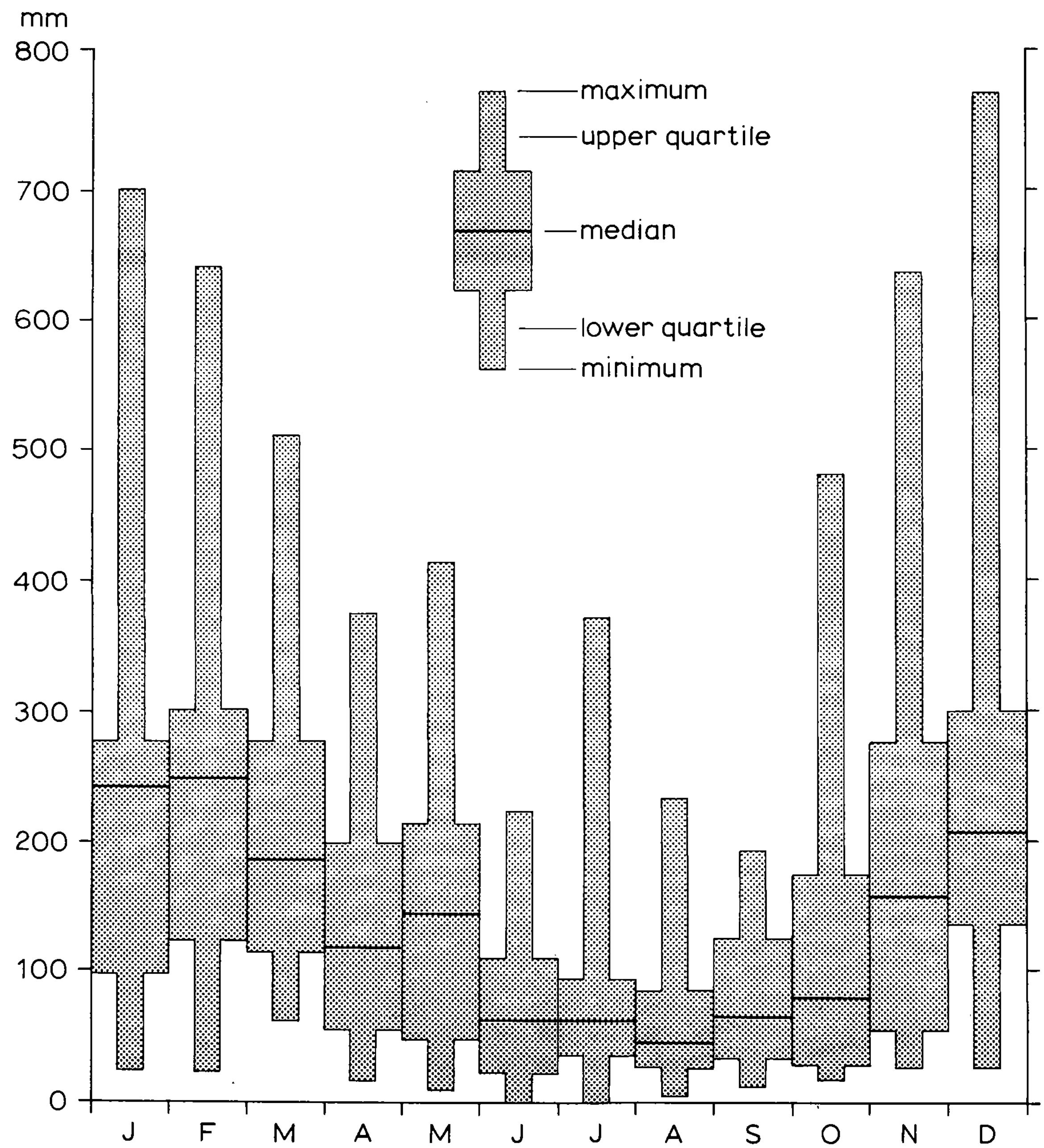


Figure 5. Monthly distribution of rainfall at Aitutaki, after Johnston (1967)

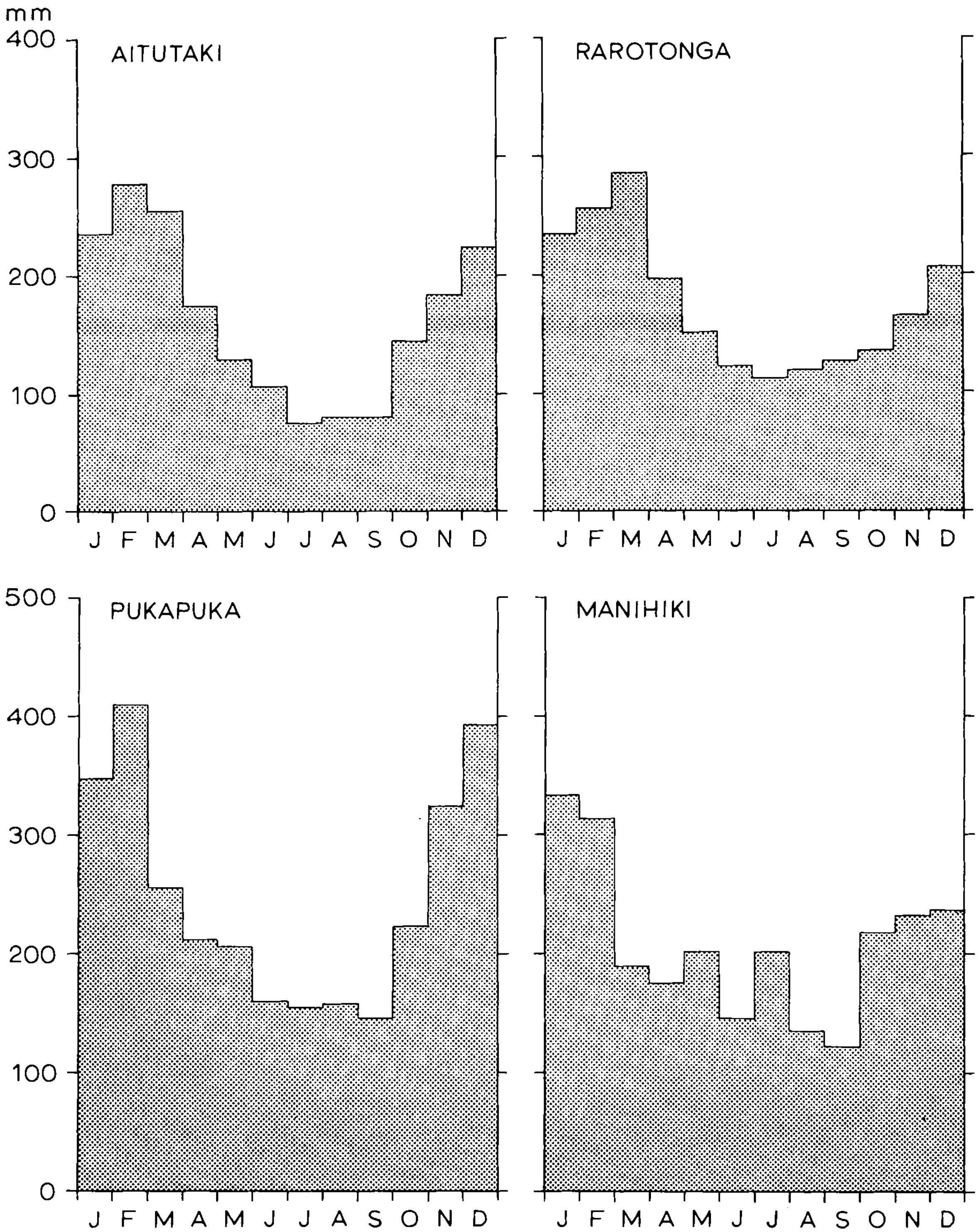


Figure 6. Monthly distribution of rainfall at Aitutaki, Rarotonga, Pukapuka and Manihiki

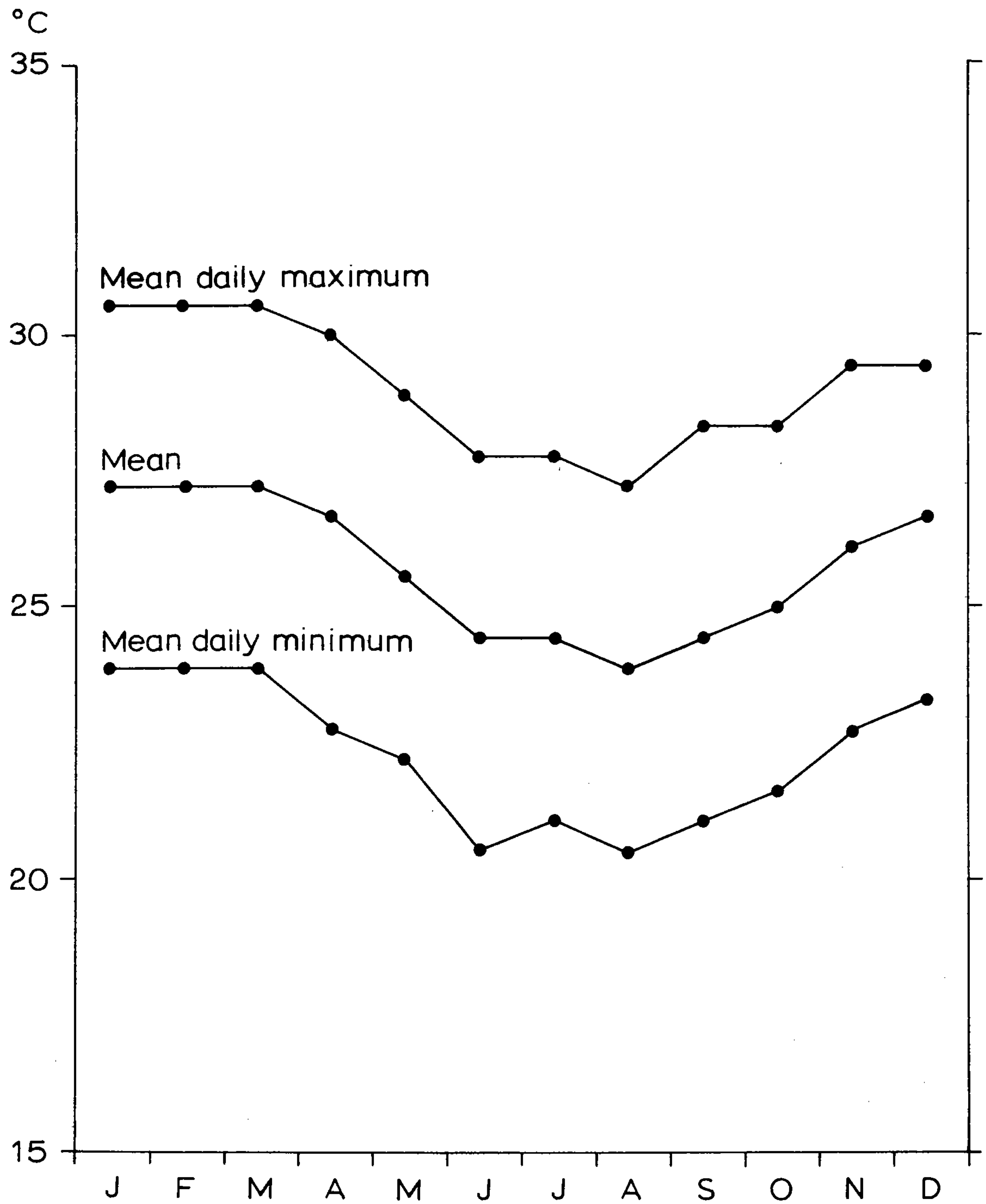


Figure 7. Monthly distribution of temperature at Aitutaki, after Johnston (1967)

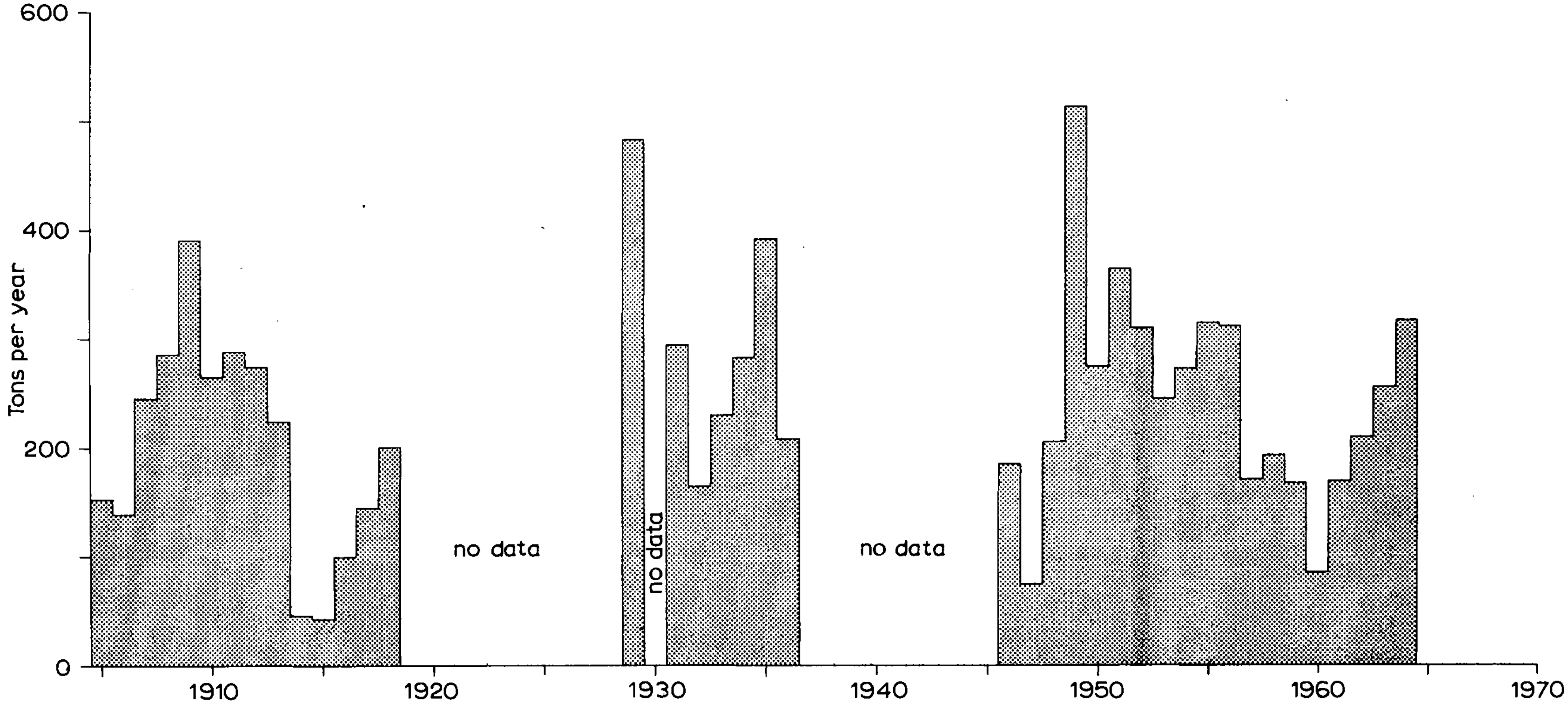
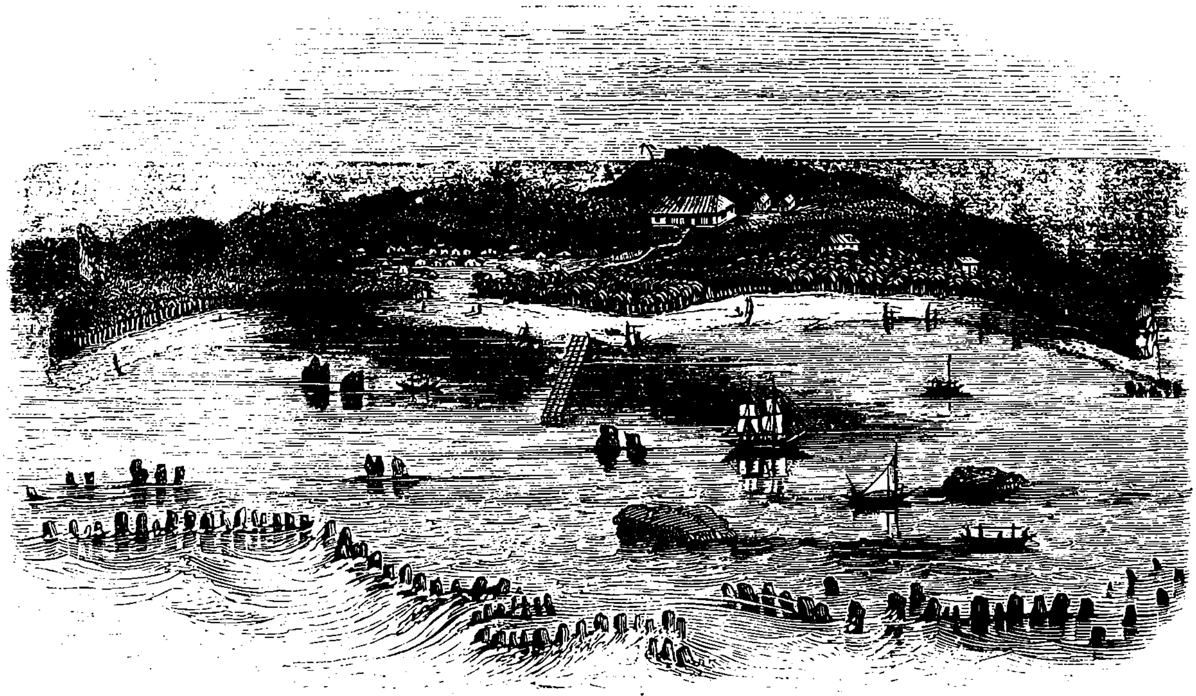
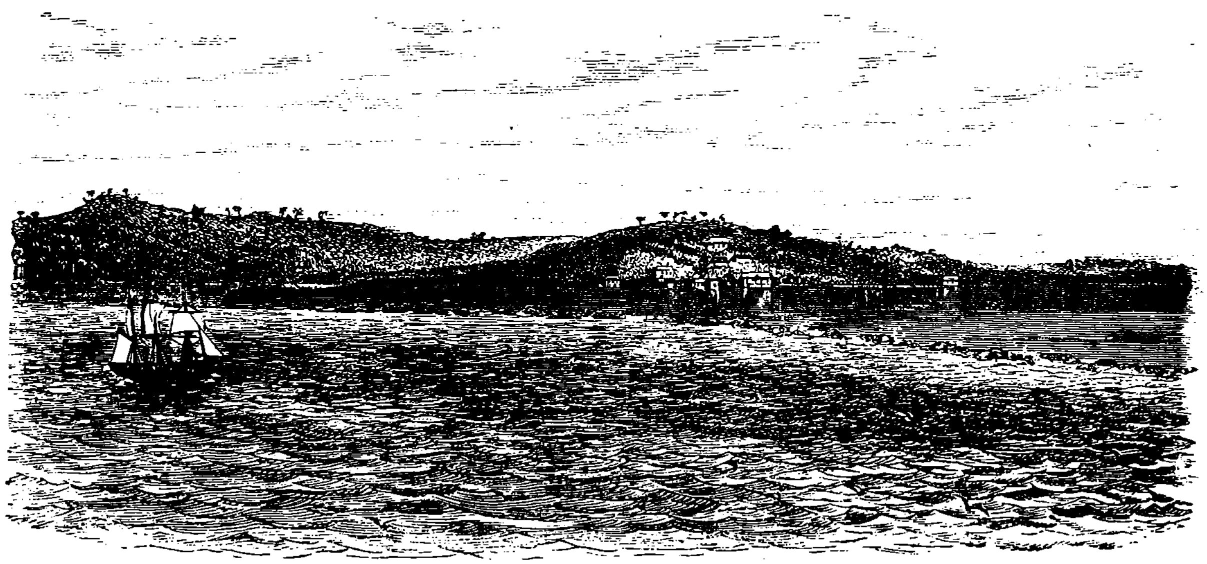


Figure 8. Copra exports from Aitutaki, after Johnston (1967).
Date to 1964 only.



1 Aitutaki in the nineteenth century (Gill, 1855, p.202)

2 Aitutaki in the nineteenth century (Gill, 1872, p.6)



2. ALMOST-ATOLL OF AITUTAKI: GEOMORPHOLOGY OF REEFS AND ISLANDS

D.R. Stoddart

"ALMOST-ATOLL": TERMINOLOGY

Charles Darwin (1837, 1842), in his initial classification of reefs, distinguished three types--fringing, barrier and atoll reefs--which he arranged in a developmental sequence controlled by subsidence of the reef foundations and concurrent upgrowth of the reef itself. The characteristics of fringing and barrier reefs were not rigorously defined, and later workers, notably Davis (1928) and Tayama (1952), introduced both intermediate terms and end-members in Darwin's sequence (Steers and Stoddart, 1974).

The term "almost-atoll" was introduced by Davis (1920; 1928, p. 7) for situations where "the lagoons of certain barrier reefs are so little occupied by islands that their reefs almost become atolls. Reefs of this kind will be called almost-atolls." No precise limits were set on the size of the volcanic residual in relation to the peripheral reef in so defining the term. Tayama (1952, p. 221) used the term in Davis's sense for "an intermediate type of [i.e. between] barrier reef and atoll. There is a central island as in the barrier reef, but it is much smaller than the lagoon". He later stated that "the area of the central island is extremely small when compared to the area occupied by the lagoon" (1952, p. 241). Both Davis and Tayama cite Truk in the Carolines as an example. Davis (1928, pp. 375-382), in the only systematic treatment of almost-atolls, also included Mangareva, Clipperton, Aitutaki, and several reefs near Fiji and New Guinea as examples; all meet Tayama's size criterion. By implication reef-encircled high islands such as Ponape and Bora-Bora should be classed as barrier-reef islands rather than almost-atolls.

Two points must be made about this nomenclature. First, the genetic implications of "almost-atoll" are considerably stronger than for the now more neutral descriptive terms of barrier reef and atoll. Davis (1920) laid great stress on the shoreline characteristics (presence of embayments, absence of cliffing) of the residual islets of almost-atolls, and inferred that rates of subsidence are greater than the rate of subaerial degradation of such islets. As Sachet (1962, p. 3) notes, however, a wide variety of islands have been included in the class of almost-atolls, and they "may have nothing in common beyond the fact that they include both coral and volcanic features."

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It seems useful to retain the term, however, defined descriptively in Tayama's sense, while noting that in some cases (though probably few) the mode of origin of the features may not be that proposed by the originators of the term.

Second, however, unnecessary confusion has been introduced by the use of the term with a different meaning and by the introduction of redundant new terms for the forms covered by the original definition of almost-atoll. The confusion is made worse by the fact that some of these new terms have previously been used in the literature with a different meaning.

Wiens (1962, p. 100) uses the term almost-atoll for volcanoes which have subsided so rapidly that their reefs were drowned, or which were submerged without corals being established on them. He apparently broadens the term to include guyots. Almost-atoll is thus used for features which almost became, or had the potential to become, atolls, but failed to do so. Genetic terminology such as this is always dangerous, and descriptive terms already exist for the features referred to.

A redundant synonym for almost-atoll is the term "near-atoll" introduced by Stearns (1946, p. 251) and adopted for Aitutaki by Wood and Hay (1970, p. 36). This has no advantage over the earlier term, and has the disadvantage that it has been applied to atolls parts of the rim of which do not carry surface reefs. Fairbridge (1950, p. 345) used it for incompletely closed annular reefs, and MacNeil (1954, pp. 395-396) for atolls with "very large reefless segments," when "their foundations are closed figures capable of supporting reef across the unfilled gap, whereas if the platforms are curved or U-shaped and the reef covers their top completely, they should be called table reefs." MacNeil complicated the matter, moreover, by using "semiatoll" synonymously with near-atoll (1954, p. 395), although Fairbridge (1950, p. 359) had already used "semi-atoll" sensu MacNeil's table reef. The term semi-atoll had been used by Agassiz as early as 1894 (p. 146) for curved, horseshoe-shaped and semi-circular reefs such as those of Campeche Bank. Features to which the term semi-atoll has been applied by Fairbridge had also been termed "pseudo atolls" by Agassiz (1898, 105), in the sense of atoll-shaped reefs which had not developed in the Darwinian manner. This is a particularly unfortunate term, for it has been used for reefs with the same plan-form as atolls but in shallow rather than oceanic waters (the "pseudo-atoll" of Molengraaff, 1930, p. 56, equivalent to the "bank atoll" of Davis, 1928, p. 19, and the "shelf atoll" of Fairbridge, 1950, p. 342), for annular features superficially resembling atolls but lacking coral reefs (the "pseudatoll" of Verrill, 1900, p. 313, and "pseudoatoll" of Newell and Rigby, 1957, pp. 25, 45), and even as a synonym for micro-atoll (the "pseudoatoll" of Mergner, 1971, p. 154). This leads, however, to even more confused aspects of terminology.

We conclude that "almost-atoll" should be retained as a descriptive term as defined by Davis and Tayama, and that the use of "near-atoll" as a synonym be abandoned. The value of terms such as "semi-atoll" and "pseudo-atoll" needs close examination and more rigorous definition before being generally accepted. It is in Davis's and Tayama's sense that this paper examines the geomorphology of the almost-atoll of Aitutaki. Of all the almost-atolls listed by Davis in 1928 only Clipperton has recently been studied in detail (Sachet, 1962a, 1962b, 1962c), though there the volcanic residual is a minute pinnacle compared with that at Aitutaki. Comparison is probably more appropriate in the case of Aitutaki with atolls recently studied in the Tuamotu Archipelago (Mururoa: Chevalier et al., 1969; Raroia: Newell, 1956; Rangiroa: Stoddart, 1969) and the Society Islands (Mopelia: Guilcher et al., 1969), and with the barrier-island of Bora-Bora (Guilcher et al., 1969).

REEFS

Morphology

The gross features of Aitutaki have been described in the previous chapter. The detailed bathymetric mapping by Summerhayes and Kibblewhite (1966) shows that the island consists of a roughly circular cone rising from depths of more than 4 km, and capped by a triangular reef with low volcanic islands (Figures 9 and 10). Aitutaki lies at the northwestern end of a line of similar cones which includes the limestone-capped volcanoes of Mauke, Mitiaro and Atiu, the sea-level atoll of Manuae, and the submerged Eclipse Seamount rising to -1.75 km. The highest point on the main volcanic island of Aitutaki reaches 119 m; two small volcanic islands are located near the southern reef of the almost-atoll, but all the other small islets are of clastic reef material. Volcanic rocks underlie the eastern reefs at shallow depth (Hochstein, 1967).

Bathymetric data indicate that reef slopes outside the reef edge are steep along the south side of the almost-atoll, intermediate on the west side, and more gentle on the east where the 250 m isobath is located 1-3 km from the reef edge (giving a mean angle of 5-14°). The only sector of the reef to have been surveyed in detail (by H.M.N.Z.S. Lachlan in 1961) is that off Arutanga on the northwest coast (Figure 11). This shows a fairly well marked shelf or terrace at a depth of 10-20 m, extending outwards for about 200 m from the reef edge, with a marked steepening to seaward. This may be the equivalent of the "ten fathom terrace" described from the Marshall Islands by Emery et al. (1954) and from other Pacific areas including the Tuamotus (Newell, 1956, pp. 334-335). It is not known whether it is a common feature round the atoll. Groove and spur topography is not conspicuous on the upper seaward slopes of the reefs.

The sides of the triangle formed by the Aitutaki reefs are 13-15 km long, and the total length of the peripheral reefs is 45 km. The reefs are mostly 600-1000 m wide, with a maximum of 1700 m. This compares with mean and maximum widths at Mopelia of 1000 and 1500 m and at Bora-Bora of 1500 and 2000 m. Tuamotu reefs are also comparatively narrow in spite of the great size of many of the atolls: widths at Raroia range from 500-700 to 800-1250 m and at Rangiroa from 320-650 to 750-1100 m. The triangular form of the Aitutaki reefs must reflect patterns in the volcanic basement; Wood and Hay (1970) suggest that minor irregularities and re-entrants in the surface reefs may result from slumping and collapse of reef limestones. There are no deep passes or channels through the peripheral reefs, a situation in common with that of atolls in the northern Cooks, and water exchange between lagoon and ocean is hence entirely over the peripheral reef flats, and consequently mainly from the east at high tide.

Zonation

The reefs differ markedly in character on different sides of the almost-atoll, as would be expected in a trade wind location. Representative transects have been described by Stoddart and Pillai (1973) and fuller details are given by Pillai and Stoddart (*in litt.*); we here summarise features of geomorphic significance.

The eastern (windward) reef is continuous and forms a rock flat 0.6-1 km wide, much of the surface of which is occupied by detrital reef islands. The level of the flat is higher opposite islands and lower between them, where scouring may occur. Conversely the flat is generally narrower where occupied by islands and wider where not, because of the development of submarine sand deltas between islands on the lagoon slope. The lagoon reef edge is thus lobate in plan in contrast to the straighter seaward edge. Though little of the reef flat dries at low water, it is not an area of active reef construction. Corals grow in rock-floored moats near the seaward margin of the flat, and in deeper, more sheltered areas between islands, but they grow on planed rock surfaces and are not genetically related to the reef limestone on which they stand. A typical transect (Plate 3) at Kopuaono, Ootu, shows the following main physiographic zones:

(a) algal rim, 40 m wide, standing 0.6 m above the general level of the reef flat and emersed by up to 15 cm at low water spring tides (Plates 4-5). The rim is deeply dissected by surge channels at least 2 m deep at their heads. It is coated with crustose *Porolithon*, a turf of filamentous algae, and larger algae such as *Sargassum* and *Turbinaria*. Corals are limited to encrustations on the seaward side of the rim and small colonies on the sides of surge channels. They are mainly species of *Acropora* and *Pocillopora* and the hydrozoan *Millepora*.

(b) zone of green algae on the inner part of the algal rim, 5-10 m wide.

(c) inner slope of the algal rim, 15 m wide, covered with encrusting pink algae and Turbinaria, and with a smooth surface.

(d) moat, 75-85 m wide, 0.3-0.5 m deep at low water spring tides and 1 m deep at high springs. The moat has an eroded and hummocky rock floor, with little sand and gravel, and with scattered colonies and patches of coral, including large microatolls of Porites lutea.

(e) narrow rippled sand zone at the inner edge of the moat, 5 m wide, passing to the island beach.

The western reefs are 0.8-1.7 km wide and in the north abut against the main volcanic island. The reef flat is deeper in this northern sector than on the eastern reefs. Well-defined surge channels are absent, or are broad and irregular features. Wood and Hay (1970, 39) have suggested that irregularities in the reef edge result from localised slumping. The flat increases in depth from the land towards the sea where a narrow constructional barrier of corals rises from depths of 3-4 m. In the south the wide and rather deep reef flat is absent, and the reef is formed by coalescing coral colonies with sinuous intersecting channels between, rising from a general level of 3-4 m. In the north a typical transect at Vaioue, where the flat is 900 m wide, shows the following zones:

(a) reef edge, irregularly dentate with surge channels without an algal ridge, formed by coalescing coral colonies and rubble forming an openwork structure superficially bound with pink encrusting algae. Conspicuous organisms include encrusting Acropora, soft corals and Turbinaria.

(b) outer flat, coral colonies, mostly ramose Acropora, with deep winding channels 2 m deep between.

(c) main reef flat, 500 m wide, a sandy surface with coalescing and anastomosing linear coral patches, dead on their upper surfaces and rimmed with Millepora but with living corals on their sides.

(d) an inner zone, 50-100 m wide, of mainly dead corals, including living microatolls 1-2 m in diameter of Porites lutea, covered with bushy Turbinaria on their upper surfaces.

(e) mainland beach.

Devaney and Randall (1973) examined the seaward slope of the western reefs in the south, from depths of 3 to 35 m. They found that 80-90 per cent of the corals on the slope were dead, and considered it "very possible" that this resulted from an Acanthaster infestation, though no starfish were seen.

Reef blocks are common on and near the reef edge in the north (Plate 6). They are up to 2 m in diameter and consist of single coral colonies or more often fragments of reef limestone detached from the reef. Coral colonies in the blocks are often inverted and there is no doubt of the storm origin of these features. There is a further cluster of blocks near the southwest point. Black Rock, midway along the west reef, is a mass of storm-tossed coral conglomerate 15 m long and 3 m high, located about 50 m back from the reef edge.

The southern reefs average 0.8 km in width; there is no algal rim. Much of the width of the reef flat consists of a sand flat 1-3 m deep, with constructional reef corals forming an open framework interrupted by pools (Plate 7). These reef patches coalesce and become more continuous towards the seaward edge. The reefs are protected from both the Trades and presumably also hurricane waves; there are no large storm blocks and much delicate coral growth. Tridacna maxima is very abundant on these reefs, modifying coral growth forms, weakening limestone structures, and forming the basis of a major local food-gathering industry (Gill, 1885, p. 153).

LAGOON

Morphology

The lagoon of Aitutaki forms a triangle interrupted in the north by the main volcanic island, with arms of the lagoon extending northwards to east and west of it. The total area of the lagoon is 50 sq km.

Early charts (e.g. Army Map Service 1:50,000, 1942) showed depths of $3\frac{1}{2}$-$4\frac{1}{2}$ fathoms (6.4-8.2 m) in the western part of the lagoon, 2-3 fathoms (3.7-5.5 m) in the northeast, and 2-4 fathoms (3.7-7.3 m) in the southeast. A maximum depth of 6 fathoms (11 m) was recorded close inshore at Akaiami. During the Eclipse Expedition Summerhayes (1971) prepared a first bathymetric map of the lagoon based on 48 wire-line soundings fixed by prismatic compass; this shows a trough along the eastern half of the lagoon with depths greater than 20 feet (6.1 m) and a maximum depth of 36 feet (11 m). In the southwest of the lagoon the floor slopes inwards from the reefs towards the main island, with maximum depths of ca 20 feet (6.1 m).

In 1969 a bathymetric survey was carried out using a Marconi Offshore 500 echosounder. 86.5 km of echotraverses were completed, together with 108 line soundings; positions were fixed by horizontal sextant angles mainly on the eastern reef islands mapped from air photographs. The location of the traverses and soundings is shown in Figure 12 and the resulting bathymetric chart in Figure 13. The lagoon comprises two separate basins each more than 6 m deep. The deepest part of the lagoon is found in narrow channels, visible on air photographs, between reef patches in the northeastern arm, between the main island and Mangers, where depths of up to 10.5 m are found. These depressions have the appearance of arcuate scourholes rather than karst sinkholes, but comment on their origin must at present be speculative. The greater part of the lagoon is considerably shallower: 75 per cent is less than 4.5 m deep. We did not locate the areas of deeper lagoon (greater than 9 m) west of Akaiami reported by previous surveys.

On its eastern side the lagoon terminates abruptly against the steep wall of the eastern reef, which is rapidly aggrading as fresh sediment is swept across the reef-flat to form inter-island lobes on the lagoon margin. The foreslopes of these lobes are the steepest parts of the lagoon slope. The main island is surrounded by a platform 0.75-1 km in width, which dries for about half its width at low spring tides; the outer slopes of this platform are also steep. Elsewhere, on the south and west sides of the lagoon, the marginal slopes are much less clearly defined, being formed by an iregular and intricate coral framework with little sediment accumulation and no continuous lagoon slope.

The Aitutaki lagoon is thus exceptionally shallow, both by comparison with lagoons of atolls as a class and with those of atolls in the central and eastern Pacific. Thus in the northern Cooks, maximum lagoon depths are 64 m at Manihiki, 66 m at Penrhyn and 80 m at Suwarrow (Wood and Hay, 1970), and in the Tuamotus 55 m at Raroia and 63 m at Rangiroa; all of these are large atolls. But Mopelia, with a lagoon approximately half as large (26 sq km) as that of Aitutaki, has a maximum depth of 40 m, and the same maximum depth is found in the lagoon of Bora-Bora (Guilcher _et al._, 1969).

Two factors could help to account for lagoon shallowness at Aitutaki: infilling with sediment, and reef growth. There are no deep channels through the peripheral reefs of Aitutaki, and hence export of sediment from the lagoon must be small. 38 linear km of peripheral reef are supplying sediment to the lagoon, a ratio of 1 km of reef to 1.3 sq km of lagoon. This compares with 1:2.5 at Eniwetok, 1:2.6 at Raroia, 1:6.0 at Bikini, 1:6.8 at Rongelap, and 1:6.8 at Rangiroa. The inferred relatively rapid filling of the lagoon by sediment at Aitutaki is probably increased by the frequency of hurricanes capable of transporting sediment lagoonward. The presence of a volcanic island on the margin of the lagoon, although shedding sediment, is not thought to be a significant factor in lagoon filling.

The role of reef growth is difficult to assess. Small reef patches are abundant in the southwest and south of the lagoon, though less common in the northeast and extreme southeast. It is unusual for there to be so many small patch reefs in a lagoon with no deep entrances and presumed high rates of sedimentation, and also surprising that although so abundant the patches have in general not coalesced to form substantial constructional features. At several points around the lagoon margins, particularly near Maina and along the east rim, the patches are being buried by marginal sediments. Many of the patch reefs close to the main island, particularly in the turbid water of the northeast arm, are dead. These were formerly covered with Lobophyllia communities and it is possible that death resulted from predation by Acanthaster. Devaney and Randall (1973) found up to 90 per cent of branching corals dead on patch reefs in the northwestern arm, and ascribed this to an advancing front of Acanthaster, though only small numbers of starfish were seen.

Large surface reefs are not common in the lagoon, except in the southeast, where Summerhayes (1971) has already drawn attention to the irregular ridges, visible on air photographs, extending from the main island towards Maina. These are flat-topped, steep-sided ridges with abundant coral growth on their sides; because of their continuity across the lagoon they make navigation from east to west difficult. Summerhayes (1971, p. 359) on the evidence of their pattern suggests that these ridges are coral reefs which began growing on the gravels of dendritic streams which drained the highlands during glacial low sea levels.

Sediments

One hundred and fourteen sediment samples were taken in the lagoon during the 1969 Expedition; of these 20 were dredge samples and the rest grab samples (Figures 14-15). In addition, 93 sediment samples were taken on transects normal to the shore of the main island to determine trends in the distribution of non-calcareous constituents. Results of the sediment work will not be presented here, though Gibbs considers the infauna of the lagoon floor later in this Bulletin. Three main facies can be distinguished: (1) mixed terrigenous-calcareous poorly sorted sands from the shallow shelf around the main island; (2) moderate to well-sorted medium to coarse sands of the reef flats and reef islands; (3) generally poorly sorted fine silty calcareous sands with areas of coarser sands on the lagoon floor. The lagoon floor sediments are highly variable because of the abundance of reef patches.

At Aitutaki, as elsewhere (e.g. Bora-Bora, Mayotte, New Georgia), the terrigenous component is localized near the volcanic island, and the lagoon floor deposits are almost entirely calcareous. Insoluble residues are low even on the beaches of the main island, in spite of Agassiz's (1903, p. 170) statement that these sands are mainly volcanic. As in other lagoons lacking deep passes, e.g. Diego Garcia, patches of fine sediment are found in enclosed basins even at shallow depth. Detailed analyses of the sediments and their distribution patterns will be reported elsewhere.

REEF ISLANDS

Morphology

There are two types of reef island on Aitutaki: motus and sand cays. "Motu" was introduced as a technical term by Newell (1961, pp. 102-3; also Danielsson, 1954, p. 94) for atoll islands, especially those of Tuamotuan atolls. He initially used the term synonymously for sand and gravel cays, but since there is a considerable difference in form and origin between islands of the Tuamotu type and simple sand cays, it is appropriate to differentiate the two types by the use of the terms motu and cay (Stoddart and Steers, 1974).

Motus are restricted to the eastern reef rim, where there are twelve separate islands, from Akitua in the north to Motukitiu in the south. The Ootu peninsula in the north, though adjoining the main island, can in many respects be considered as simply the longest and largest of the motus (it is 3 km long, with an area of about 175 ha), though its morphology has been obscured by airstrip construction. The other islands are generally of similar width, transverse to the reef edge (300-400 m), but vary in length from 150 to 2250 m. The ratio of longest to shortest dimension, as an index of shape, varies from 1.2 to 4.7, the larger islands (Ee, Akaiami, Tekopua) being more elongate. Table 6 gives dimensions of these islands and of the sand cay of Maina on the southwest reefs. The islands, together with the two small volcanic islets of Moturakau and Rapota, are described in the following chapter.

Similar restriction of islands to the eastern (windward) reef is found on Mopelia and Bora-Bora in the Society Islands (Guilcher _et al_., 1969), but it is not characteristic of atolls in the northern Cooks (Wood and Hay, 1970), nor is it well-marked among the atolls of the Tuamotus.

In a transect from the reef edge to lagoon shore, the following zones may be recognised on a typical motu at Aitutaki (Figure 16):

(a) reef edge with raised algal rim, 30-95 m wide.

(b) rock-floored moat, with a discontinuous carpet of sand and gravel and scattered coral communities; the moat is generally less than 1.5 m deep and is 70-150 m wide.

(c) conglomerate platform, up to 0.5 m above high water level, up to 95 m wide but averaging 50 m.

(d) sheets of rubble, gravel and sand forming the seaward sides of the motus, with occasional large boulders; this zone is usually 100-150 m wide and covered with a scrub of _Pemphis_ and _Suriana_.

Table 6. Dimensions of Aitutaki islands

Island	Width of reef rim	Width of moat	Total width of seaward reef flat	Maximum length of island	Maximum width of island	Width of conglomerate platform	Width of gravel spread	Area
	m	m	m	m	m	m	m	ha
Akitua	50	150	200	750	310	50	100	14.86
Angarei	65	90	155	480	400	40	187	13.07
Ee	50-85	130	170-210	975	410	50	50-430	29.21
Mangere	65	90	150	400	280	35-55	160	8.54
Papau	65	100	160	400	200	35-75	75	5.26
Tavaerua Iti	95	55	150	250	210	55	85	4.12
Tavaerua	65	70	120-150	500	290	55	130	12.47
Akaiami	35-90	125-150	190-250	1120	410	30-65	-	41.91
Muritapua	45	150	195	360	150	95	125	4.04
Tekopua	30-80	140	150-220	2250	480	65	-	71.29
Tapuaeta	-	-	-	570	210	-	-	5.96
Sand cay	-	-	-	175	75	-	-	0.95
Motukitiu	-	-	-	450	300	-	135	11.47
Moturakau	-	-	-	460	120	-	-	3.86
Maina	-	-	-	710	310	-	-	16.96

Rapota (no data).

(e) leeward sand area, the highest part of the motu, with a woodland vegetation.

(f) sand beaches and sand spits on the lagoon shore.

Two motus depart from this pattern. Akaiami and Tekopua, the largest islands, both have well-marked seaward beach ridges immediately overlying and in places obscuring the conglomerate platform: the wide rubble and gravel sheets are absent. The Ootu peninsula has a similar structure. These differences in morphology are reflected in the vegetation pattern on these islands.

Conglomerate platform

The conglomerate platform (Plates 8-14) consists of coarse and poorly sorted reef debris, mainly coral and molluscan shell material, tightly cemented in a sandy matrix. The upper surface of the platform lies up to 0.5 m above high water mark, but is constantly wetted by spray; depressions on its surface carry standing water. The horizontal surface is black in colour and rough-textured, except where wave action has recently detached blocks of material from it, when the scars are white. At lower levels the surface becomes yellow and then white, and also becomes smoother. The edges of the platform are vertical or undercut, and waves break against them with some force on a rising tide. In plan the edge of the platform is usually very irregular, with promontories and long straight or angular channels extending back towards the island. Sectors of the platform may become detached by these channels to form separate outcrops. Mostly these are small, but in some cases, as between Akaiami and Muritapua, there are substantial isolated areas of platform with no island sediments and either unvegetated or with a few Pemphis bushes. These remnants suggest that the platform was formerly more extensive, and that some islands, notably Angarei, Ee and Mangere, were formerly continuous. The conglomerate platform does not outcrop on the lagoon shores of islands, and only extends lagoonward along the sides of inter-island channels for 50-100 m.

Very similar conglomerate platforms were described at Raroia in the Tuamotus by Newell (1956). These platforms (pakokota), rising to 0.5-1 m above mean high water, are found on the seaward shores of islands both on the windward and the leeward sides of the atoll. Newell's diagrams (1956, figures 6B, 6C, 6E and 7A) show features directly comparable to those of the Aitutaki motus, i.e. wide seaward conglomerate platforms, extensive seaward rubble and gravel sheets, and a dry-land area of sediments on the lagoon side. Such situations are, however, less common at Raroia than cases where a narrow conglomerate platform is overtopped by a high seaward beach ridge, as at Tekopua, Akaiami and Ootu on Aitutaki. Seaward beach ridges are also more common on Rangiroa than are gravel sheets

(Stoddart, 1969). A second point of difference between Aitutaki and the Tuamotus is that in the latter the conglomerate platform is of much greater lateral extent on the reef flats than the motus themselves (Newell, 1956, pl. 32-34), while on Aitutaki the areas of platform are more closely related to the size and location of the motus. At Rangiroa also the platforms, though less well developed on their seaward sides, are extensive *between* islands (Stoddart, 1969, p. 9). A minor difference noted by Newell (1956, pp. 330-332) is that the Raroia platforms are unvegetated, whereas at Rangiroa and also at Aitutaki, while more exposed areas are bare, the inner sections support a scrub of *Pemphis* and *Suriana*.

At Aitutaki the conglomerate is everywhere a clastic rock and not an elevated reef rock: it does not contain any reef corals in the position of growth but only broken and worn coral fragments and mollusc shells. The constituent material is poorly sorted and variable in size, and there are no structures suggesting submarine deposition. At Raroia, Newell (1956, p. 332) found that *pakokota* is "clearly bioclastic throughout and does not contain *in situ* reef material. It is not an elevated platform of planation, a reef flat, but it is a depositional surface ... /which/ could have been formed at or near the existing sea level"; a similar conclusion was reached at Rangiroa (Stoddart, 1969, p. 22). Superficially similar conglomerate ledges on reef islands of Bora-Bora and Mopelia, Society Islands, however, have been found by Guilcher *et al.* (1969, pp. 26-28) to consist largely of reef corals in the position of growth overlain in places by conglomerate of the Aitutaki and Tuamotuan type; these ledges reach about 1 m above present sea level. Conglomerate platforms 10-200 m wide and 0.6-1.3 m above mean high water springs are also described from Mururoa (Chevalier *et al.* 1968, pp. 17-25); these too are bioclastic and have no *in situ* reef material, but Chevalier quotes dates of 3000-4000 yr B.P. and interprets them in terms of a Holocene higher stand of the sea. Elsewhere he considers the *feo* of Tuamotu atolls to be a dissected conglomerate platform (Chevalier, 1973, pp. 118-119). Conglomerate ledges have also been described from islands in the Carolines and Marshalls, west Pacific, and interpreted as clastic rocks, by Shepard *et al.* (1967) and Curray *et al.* (1970). These Micronesian platforms have flat upper surfaces standing at up to 1.2 m above the present reef flats, are submerged at high tide, and contain no growth-position corals.

An important constituent of the Aitutaki conglomerates are valves of the clam *Tridacna maxima* Röding. Two samples were taken for carbon-14 dating: sample F-52 from the seaward platform at the south end of Akaiami, and sample F-56 from the platform on the seaward side of Muritapua; both valves were tightly cemented in the upper part of the conglomerate. The results were as follows:

Table 7. Conglomerate platform carbon-14 dates

Sample number	Elevation, m	Analysis number	Age
F-52	0.5	GaK-3496	2040±90
F-56	0.4	GaK-3500	160±80

Source: dating by Dr K. Kigoshi, Gakushuin University

These dates indicate the recency of the material composing the platforms and hence of the features themselves; they are compared with dates from similar features elsewhere in the Pacific in the following section.

Beachrock

Beachrock (Plates 15-16) is uncommon on Aitutaki, except on the sand cay of Maina, where rather weakly cemented single ledges of rock outcrop in the low intertidal on several sides of the island. The rock is sandy, with valves of *Tridacna maxima*. On the motus, there is a long line of older beachrock on the leeward shore of Tapuaeta, and in places beachrock caps the upper surface of the conglomerate platform. This is best seen on Tekopua, where there is a high seaward beach ridge: layers of seaward-dipping sandy beachrock are well exposed near the south end of the island. Similar cases of beachrock overlying conglomerate are reported by Guilcher *et al*. (1969) from Mopelia. Elsewhere some of the conglomerate outcrops themselves resemble beachrock (e.g. on Motukitiu), and it may be difficult to distinguish true beachrock from sandy conglomerate in such circumstances. Beachrock standing on the conglomerate is clearly younger than it. Two samples of modern beachrock from Maina, F-57 from the north shore and F-58 from the south, were dated by carbon-14:

Table 8. Beachrock carbon-14 dates

Sample number	Elevation	Analysis number	^{14}C	Age
F-57	Intertidal	GaK-3501	9.35±1.1%	modern; post-bomb?
F-58	Intertidal	GaK-3502	4.5±0.9%	modern

Source: dating by Dr K. Kogoshi, Gakushuin University

Rubble and gravel sheets and reef blocks

The wide areas of low-lying rubble and gravel on the seaward sides of most motus form the most distinctive and unusual features of the Aitutaki islands. The sediments are poorly sorted and very variable in composition, in places rubble, elsewhere coarse sand and gravel. In some areas, e.g. the unvegetated gravel sheets 100 m wide on Motukitiu, the material is fresh and white, but even where scrub-covered it is light-coloured and appears relatively recent. Thus coral heads in the rubble have not yet disintegrated through weathering. Reef blocks up to 1.5 m in height and 2 m in longest dimension are common (Plates 17-18), not only on the shore but also inland in the scrub on several islands, notably Ee, Papau and Muritapua. These consist both of single coral colonies and blocks of reef rock containing many smaller colonies. The reef blocks are loose boulders, uncemented at the base, generally still white in colour, and clearly storm-deposited. Both rubble and gravel sheets and the reef blocks are best simply interpreted as formed by hurricanes. It is possible that the storms responsible for these features on the northern islands (the Ee group) were different from those in the south (Motukitiu), and that the lateral extent of the effects of any single storm is limited. The implication is that where severe hurricane effects have not recently been felt, normal seaward beach ridges survive (at Ootu, Akaiami and Tekopua): this would explain the close juxtaposition of very different types of islands.

Island sediments

The sediments on the lee sides of the motus, under woodland, are mainly sand, with cobbles, gravel, and patches of rubble. Sandy beaches are frequently scattered with coral boulders and patches of rubble, and it is clear that normal processes of sediment accretion are interspersed with hurricane events. This is confirmed by two types of evidence. First, sections in the island sediments, as at Papau, show successive soil horizons buried by fresh layers of gravel and sand 10-20 cm thick, clearly derived from individual storm events. Similar evidence of storm accretion is recorded by Newell (1956, p. 337) in pits at Garumaoa, Raroia, where carbon-14 dates for the lower humic horizons range from 800 to 1730 yr B.P. Second, samples of *Tridacna maxima* from island sediments were taken at Muritapua for carbon-14 dating. Sample F-53 was from the seaward edge of the coconut woodland, approximately in the centre of the island. Sample F-54 was under *Pemphis* scrub near the northwest corner of the coconut woodland, close to the lagoon shore, elevation about 2 m. Sample F-55 was from an old beach ridge within the woodland, midway between the first two samples. The dates are as follows:

Table 9. Island sediment carbon-14 dates

Sample number	Analysis number	Age
F-53	GaK-3497	Modern
F-54	GaK-3498	100±80
F-55	GaK-3499	470±80

Source: dating by Dr K. Kigoshi, Gakushuin University

The conglomerate platform sample on this island gave a date of 160±80 yr. Clearly the surface sediments and features of these islands are young, and storms are capable at the present time of depositing material not only on the shores but across the surface of the island. The approximate age-equivalence of the sediments and the conglomerate platform material is also interesting, suggesting that the platform is a contemporary feature related to present island sedimentation, rather than an inherited or fossil feature formed in the past.

Other island features

Other island features may be briefly noted. Beaches consist of well sorted sands and fine gravels of coral, algal and molluscan debris. In contrast to atolls in the Tuamotus, Foraminifera are an unimportant constituent. Beaches are narrow, except in sheltered crescentic bays such as those of leeward Akaiami and Tekopua, and many beaches are being eroded. This may be a seasonal phenomenon, but exposure of roots and apparent truncation of vegetation patterns suggests that it is more extensive in some areas. The main areas of aggradation on the islands are on sand spits at the northwest and southwest leeward points, especially on the larger islands, and at the leeward end of smaller islands such as Akitua and Tapuaeta. Calcareous sand tails are also found on the volcanic islets of Moturakau and Rapota. Some of these features may be followed into much wider submarine sand lobes aggrading on the lagoon reef slope. Sand dunes are curiously uncommon in such a trade wind location. Low dunes are found on the southern end of the Ootu peninsula, but not elsewhere. This contrasts with Tuamotuan atolls such as Rangiroa, where dunes up to 10 m high are found on the lagoon coasts of western reef islands (Stoddart, 1969, 14).

Channels between islands, especially between Mangere, Ee and Angarei, have many of the characteristics of Tuamotuan hoa (Chevalier, 1969; Stoddart, 1969). They appear to have been formed by the dissection of previously more extensive land. Patches of island conglomerate extend across their seaward entrances, and they often deepen lagoonward by tidal scour.

Marsh areas are uncommon on the islands. There is one small area of Cladium marsh on Akitua, but otherwise no marshes or even internal depressions. Their absence presumably results from the importance of hurricane activity transporting sediments across island surfaces and the unimportance of marginal beach ridges. Attention may be called to the intertidal basins of silty sand in the northeastern arm of the lagoon, between the Ootu Peninsula and the mainland. These are unvegetated and occupied by meandering tidal channels. They resemble the barachois described from central Indian Ocean atolls, where, too, mangroves, which might otherwise colonise such situations, are absent (Stoddart, 1971). They are not, however, found on the reef islands.

SEA-LEVEL CHANGE AND THE AITUTAKI REEFS

In placing Aitutaki in the wider context of Pacific reef evolution, the following main points need to be considered: (1) the outer slope of the reefs is bevelled at 10 to 25 m depth; (2) the present reef flats are rocky abrasion surfaces, not growth features, at least on the windward side; (3) reef islands are being eroded on their seaward shores, exposing conglomerate platforms, and channels are being cut through some larger islands; (4) there is no unequivocal raised reef in the position of growth; (5) conglomerate platforms and beachrock yield recent dates, as do island sediments; (6) hurricanes are clearly important both as agents of deposition and erosion on the islands. This evidence suggests that the reef flats of Aitutaki are old features, pre-dating the present sea-stand and possibly last interglacial in origin, thinly veneered by modern reef growth, and that the islands are recent accumulations on them, formed mainly during and continually being changed by severe hurricanes. In a regional context the main problems of interpretation of the evolution of the Aitutaki forms are the local absence of makatea, the apparent absence of raised Holocene reefs, and the significance of the conglomerate platforms.

The Makatea problem

The southern Cook Islands are a classic location for makatea, elevated karst-eroded limestone caps encircling residual volcanic mountains on the islands of Mangaia, Atiu, Mauke and Mitiaro. On Mangaia the central volcanic island rises to 169 m and the makatea rim to 55-70 m; on Atiu the elevations respectively are 72 and 20-39 m; on Mauke 27.5 and 18 m; and on Mitiaro 9 m and 6-12 m (Marshall, 1927, 1930; Wood and Hey, 1970). Between the volcanic residual and the makatea rim there is a swampy depression, and at one time there was much discussion over whether this represents an original lagoon, with the makatea rim an old barrier reef (Davis, 1928; Marshall, 1929), or whether it is a karst-erosional feature formed by run-off from the central hills (Chubb, 1927; Hoffmeister, 1930). It is now clear that the makatea limestones of the type-island, Mangaia, are of Miocene age and are largely non-reef in composition, and that the topography is not an original topography as Marshall and Davis supposed (Hoffmeister and Ladd, 1935; Wood and Hey, 1970, pp. 27-36).

On Rarotonga there is no ring of makatea; but a small outcrop of limestone is found on the north side of Ngatangiia Harbour, at Matavera, and on the islet of Motutapu (Stoddart, 1972). On Aitutaki there is no makatea at all. Aitutaki is separated from the makatea islands by the atoll of Manuae, but nevertheless the absence of evidence for positive movements on an island which could be as old as early Tertiary (Wood and Hey, 1970) is surprising.

Evidence is also reported from the makatea islands for the existence of erosional bevels on the volcanic rocks, and benches and notches on the limestones. These are said to be at similar altitudes on different islands in the southern Cooks, with equivalent benches and alluvial deposits on volcanic rocks of Rarotonga and Aitutaki, and to indicate Pleistocene high sea-level stands (Wood and Hey, 1970); Table 10 lists the main levels identified. Schofield (1959) found comparable levels at Niue, and, from the literature, claimed accordance with benches and notches on Eua, Tonga (Schofield, 1967) and in the Lau Islands, Fiji (Schofield, 1971). The analysis is carried further by Ward et al. (1971), who assume that the levels on Mangai are true eustatic levels, and use additional data from South Carolina and New South Wales to establish both a sequence and an absolute chronology for Pleistocene high sea levels. It should perhaps be stated that no satisfactory detailed field evidence of the extent, altitude and nature of the Mangaia features has ever been published, and the attempt to erect a Pleistocene chronology on this basis seems premature, if not bizarre. Further, the field evidence at Aitutaki does not, to me, satisfactorily indicate the existence of raised marine features, or, indeed, of any raised features of chronological significance at all.

In the interpretation of the modern reefs the lower shoreline features claimed in the Cooks are of greater importance. A shoreline at 1 m of Holocene age and a 2-3 m shoreline of last interglacial age are claimed for Aitutaki and Mangaia (Table 5). The Mangaia 2-3 m feature is based on uranium-series ages of 90,000±20,000 and 110,000±50,000 yr obtained by Veeh (1966, p. 3383) for samples at +2 m from a reef terrace up to 3-10 m high. This terrace is equivalent to raised reefs up to 5 m above low tide at Anaa and Niau Atolls in the Tuamotus

Table 10. Elevations (m) of raised platforms and notches in the Cook Islands

Mangaia	Mauke	Rarotonga	Aitutaki	Inferred Age
70			?76	Antepenultimate interglacial
52-55			?55	Penultimate interglacial
34-38			35	
23		21-23	18-21	Last interglacial
12-15	12	12	12	
5	4.6	6		
3			2-2.7	
1		1	1	?Holocene

Source: Wood and Hay, 1970, 76

(representative of the widespread _feo_ of Tuamotuan atolls, present on Rangiroa though absent from Raroia), dated at between 110 ± 20 and $160 \pm 40 \times 10^3$ yr B.P. and with an 8 m reef terrace round Makatea Island from which a sample at 3 m yields dates of 100 ± 20 and $140 \pm 30 \times 10^3$ yr B.P. (Veeh, 1965, 1966). The outcrop of _makatea_ on Rarotonga is probably of the same age as the Mangaian and Tuamotuan samples dated by Veeh: Schofield (1970) obtained a carbon-14 age of $28{,}200 \pm 850$ yr on this outcrop, but this, like the dates for similar raised reef at Te Ava Vaka, Rarotonga, of >43,400 quoted by Wood and Hay (1970) and >48,900 yr quoted by Schofield (1970), is probably too low: Thom (1973) has discussed the general difficulties of accepting carbon-14 dates in this age range. The Rarotonga limestone is similar to that of western Indian Ocean raised reefs assigned to the last interglacial by Veeh (1966), and similar dates have subsequently been obtained at other sites by Thomson and Walton (1972). There is, therefore, wide evidence, much of it from the southern Cooks and the Tuamotus, for a last interglacial stand of the sea at about +5 to +10 m above the present (cf. Lalou _et al_., 1971).

It would be surprising if there were not some evidence of this stand on present sea-level atolls in the central and east Pacific. Wood and Hay (1970, pp. 57-64) refer to low outcrops, often beneath recent conglomerates, of well-cemented dark "reef rock" on several atolls in the northern Cooks (such as Pukapuka, Penrhyn, Manihiki and Suwarrow), which may be of similar age. There is, however, no _direct_ evidence for this stand at Aitutaki, other than in the planed-rock reef flats, which may be bevelling reef limestones of last interglacial age. There is no _makatea_, or _feo_, or similar deposits, above the present sea level.

Recent high sea levels?

Is there evidence at Aitutaki of higher sea levels _since_ the last interglacial? Two types of evidence have been cited. First, Shepard (1961, p. 34) states that he "observed an elevated reef at two feet above sea level at Aitutaki" but that the outcrop was not dated. The location of this reef was not given. In 1969 the whole coastline of Aitutaki was traversed, both of the main island and of all the smaller islands, and no raised reef was found. Shepard must have interpreted the conglomerate platform as a raised reef, but, as has been described above, it is an entirely clastic rock. Second, Wood and Hay (1970, p. 39) refer to "beach deposits such as coral sand, partly cemented conglomerates, and lithified beach rock" which "form two levels 2-3 ft (1 m) and 7-9 ft (2-2.7 m) above high tide level around Aitutaki." The only deposits corresponding to the second of these levels are the low sand flats around the main island and the upper surfaces of the reef islands; the lower level presumably refers to the conglomerate platforms of the motus. Wood and Hay note that the "past sea levels represented by these deposits may have been little higher than at present, and are almost certainly Holocene in age." In describing similar conglomerate benches on atolls in the northern Cooks they also comment: "They are not remains of a former higher sea level, and no conclusive evidence for a postglacial high sea level was found" (Wood and Hay, 1970, p. 56); this refers specifically to conglomerates on Pukapuka and Suwarrow Atolls.

It is clear that the nature and origin of the conglomerate platforms is central to any interpretation of the development of the present reefs and motus on islands such as Aitutaki. Comparable benches have been described in the southeast Pacific at Raroia (Newell, 1956), Rangiroa (Stoddart, 1969), Bora-Bora (Veeh, 1965; Guilcher et al., 1969), and Mopelia (Guilcher et al., 1969), as well as in the Cook Islands, and at many locations in the western Pacific (in the Carolines and Marshalls) and the north Pacific (in the leeward Hawaiian Islands).

At Mopelia, 600 km east of Aitutaki, and at Bora-Bora, the bench is described as partly a clastic conglomerate, and partly a raised reef in the position of growth. A sample of in situ reef material at +0.8 m on Mopelia is dated at 3450±130 yr B.P., and a sample of conglomerate, possibly raised reef, at +0.8 to +1 m at Bora-Bora at 2250±130 yr B.P. (Guilcher et al., 1969, p. 30). Morphologically the outcrops resemble those of Aitutaki.

Ten dates are available for samples from conglomerate ledges at up to +1.2 m at Truk, three atolls in the Carolines, and three in the Marshalls. The dates range from 1270±95 to 4350±110 yr B.P., but half cluster in the range 2500-3000 yr B.P. The ledges have flat upper surfaces, are submerged at high tide (and are hence lower than those in the Cooks and Tuamotus), and contain no corals in the position of growth. Like the Aitutaki platforms, they are interpreted as cemented rubble ramparts built during storms and subsequently eroded (Shepard et al., 1967; Curray et al., 1970). Curray et al. discuss the age-clustering of the dates. This could result either from a slight transgression or a change in the rate of transgression at about 3000 B.P., aiding sediment accumulation; or it could indicate a period of stormier conditions at about this time; or it could result from sampling bias. Further evidence for increased storminess in the period 3650±125 to 4980±150 yr B.P., though inferential, comes from the composition of rocks underlying the windward reef flat at Eniwetok Atoll (Buddemeier et al., in litt.). The older Aitutaki conglomerate platform date of 2040±90 yr B.P. is consonant with this pattern of Pacific conglomerate dates.

Conversely, superficially similar rock ledges, forming platforms 2-10 m wide standing at 0.5-0.75 m above low tide, at Midway and Kure Atolls, have been interpreted as true reef rocks, not cemented rubble, by Gross et al. (1969); dates range from 1230±250 to 2420±300 yr B.P. Tracey (1968) quotes carbon-14 dates on *in situ* corals at up to 1 m above present reef-flat levels from Guam, Midway, Bikini and Ifaluk of 1230±250 to 4050±300 yr B.P., mostly clustering in the range 2000-3000 yr B.P. Additional good evidence of a Recent relative high sea level comes from the Pacific equatorial islands, where Tracey (1972) has identified clear recent reef features at 1 m above present level on Enderbury (2150 and 2650 yr B.P.), Jarvis (1230, 1800, 1980 and 2800 yr B.P.), Starbuck (3950 yr B.P.) and Malden (3550 yr B.P. with a much older reefrock below). Finally, sequences of dates from northeast Brazil and from New Caledonia indicate at least local transgressions to +3 m at about 3500 yr B.P. and to +2 m at 2250 yr B.P. (Delibrias and Laborel, 1971; Coudray and Delibrias, 1972).

Some dates are also available within this range from Rarotonga. Schofield (1967a, 1970, 1971; Schofield and Suggate, 1971) describes beach deposits (Aroa Sands) up to 7.6 m above present sea level and overlying Pleistocene reef or *makatea*; modern beach ridges have a maximum elevation of 3.4 m above low tide. Aroa Sands samples yield dates as follows: +1.5 m, 3510±50 yr B.P.; 2.3 m, 2470 yr B.P.; 4.3 m, 1235±57 yr B.P. Schofield also notes a raised reef at Avarua, Rarotonga, at 1 m above low tide level, with a date of 2030±60 yr B.P., and interprets these data as indicating Holocene eustatic high stands of the sea.

There are thus substantial problems in the interpretation of reef and island features at Aitutaki. The *local* evidence indicates that the conglomerate platforms are storm rubble deposits which are continually accreting and eroding. A similar interpretation is reached for conglomerates in the Carolines and Marshalls by Curray *et al*. (1970). Newell (1956) also found the platforms at Raroia to consist of cemented rubble, though these do stand at a higher level than those of the west Pacific, and, according to Newell, indicate a slight regional uplift. The origins of such conglomerate platforms have been discussed by Newell (1961) and Newell and Bloom (1970), and their conclusions are similar to those reached at Aitutaki. But there is an increasing and impressive body of evidence in radiocarbon dates, many from central Pacific reefs, suggesting a slight transgression in the period 1000-4000 yr B.P. If this transgression was real, it would be helpful in explaining the presence of islands and platforms on the Aitutaki reefs, and might also explain the present state of shore erosion, island retreat and channel-cutting on reef islands, but at Aitutaki at least it is not a *necessary* component of the explanation.

CONCLUSION

From this survey of the main characteristics of the reefs and reef islands of Aitutaki it will be apparent that the distinctive characteristics of the geomorphology of this almost-atoll arise almost entirely from its location in a hurricane belt, and that the fact that a volcanic island emerges through the reefs has remarkably little influence on either morphology or sediments of the surrounding area. The fact that Aitutaki is an almost-atoll rather than a true atoll is of little significance in an analysis of the present reef features.

Agassiz, who made the first field observations on the geomorphology of the Aitutaki reefs, completely misinterpreted them. Erroneously identifying storm blocks on the reef edge as "volcanic negroheads," he argued that:

> "This group is an excellent example of a volcanic rock flat upon which corals are growing. The formation of the underlying base can be traced, as volcanic outliers crop out at many places on the barrier reef. Aitutaki shows, perhaps as plainly as any other volcanic island we have visited, the manner in which the lagoon and barrier reef flats have been formed from the denudation and erosion of the volcanic mass which once occupied the area indicated by the outer edge of the barrier reef" (Agassiz, 1903, 170).

It is unnecessary to refute this argument, which Agassiz (1898) also proposed for features as large as the Great Barrier Reef of Australia, in any detail. Apart from Rapota and Moturakau, the volcanic outliers he refers to are all blackened storm-deposited reef blocks; the reef flats themselves are all of reef limestone and not abraded basalt; and the high cliffs which, as Davis (1928) forcibly argued, must have resulted from marine erosion on this scale, are absent from both the main island (there is only one small area of steep coast, near Teaitu) and from the volcanic islets.

All the evidence indicates that the almost-atoll of Aitutaki has developed by a process of subsidence and reef upgrowth as Darwin's theory indicates, and that the details of reef geomorphology here, as elsewhere, result from the effects of sea-level fluctuations in the Pleistocene and Recent, in the long term, and of repeated hurricanes in the short term.

REFERENCES

Agassiz, A. 1894. A reconnaissance of the Bahamas and of the elevated reefs of Cuba in the steam yacht "Wild Duck", January to April, 1893. Bull. Mus. comp. Zool. Harv. 26(1): 1-203, 46 pl.

---------- 1898. A visit to the Great Barrier Reef of Australia in the steamer "Croydon", during April and May, 1896. Bull. Mus. comp. Zool. Harv. 28(4): 95-148.

Agassiz, A. 1903. Reports on the scientific results of the expedition to the tropical Pacific, in charge of Alexander Agassiz, by the U.S. Fish Commission Steamer 'Albatross', from August 1899, to March 1900, Commander Jefferson F. Moser, U.S.N., commanding. IV. The coral reefs of the tropical Pacific. Mem. Mus. comp. Zool. Harv. 28: i-xxxiii, 1-410, 238 pl.

Buddemeier, R.W., Smith, S.V. and Kinzie, R.A., III. In litt. Holocene windward reef flat history, Eniwetok Atoll.

Chevalier, J.-P. 1969. Observations sur les chenaux incomplets appelés hoa dans les atolls des Tuamotu. Symposium on Corals and Coral Reefs (Marine Biological Association of India, Mandapam Camp, January 1969), Abstracts of Papers: 27.

Chevalier, J.-P. 1973. Geomorphology and geology of coral reefs in French Polynesia. Biology and geology of coral reefs, O.A. Jones and R. Endean, eds. (New York: Academic Press), Vol.1, Geology, Part I: 113-141.

Chevalier, J.-P., Denizot, M., Mougin, J.-L., Plessis, Y. and Salvat, B. 1968. Etude géomorphologique et bionomique de l'atoll de Mururoa (Tuamotu). Cah. Pacif. 12: 1-144, 24 pl.

Chubb, L.J. 1927. Mangaia and Rurutu: a comparison between two Pacific islands. Geol. Mag. 64: 518-522.

Coudray, J. and Delibrias, G. 1972. Variations du niveau marin au-dessus de l'actuel en Nouvelle-Calédonie depuis 6000 ans. C. r. hebd. Séanc. Acad. Sci., Paris, 275: 2623-2626.

Curray, J.R., Shepard, F.P. and Veeh, H.H. 1970. Late Quaternary sea-level studies in Micronesia: CARMARSEL Expedition. Bull. geol. Soc. Am. 81: 1865-1880.

Danielsson, B. 1954. Native topographical terms in Raroia, Tuamotus. Atoll Res. Bull. 32: 92-96.

Darwin, C.R. 1837. On certain areas of elevation and subsidence in the Pacific and Indian Oceans, as deduced from the study of coral formations. Proc. geol. Soc. Lond. 2: 552-554.

---------- 1842. The structure and distribution of coral reefs. London: Smith, Elder and Co. xii, 214 pp.

Davis, W.M. 1920. The small islands of almost-atolls. Nature, Lond. 105: 292-293.

---------- 1928. The coral reef problem. Spec. Publs Am. geogr. Soc. 9: 1-596.

Delibrias, C. and Laborel, J. 1971. Recent variations of the sea level along the Brazilian coast. Quaternaria, 14: 45-49.

Devaney, D.M. and Randall, J.E. 1973. Investigations of Acanthaster planci in southeastern Polynesia during 1970-1971. Atoll Res. Bull. 169: 1-21.

Emery, K.O., Tracey, J.I., Jr. and Ladd, H.S. 1954. Geology of Bikini and nearby atolls. U.S. geol. Surv. Prof. Pap. 260-A: 1-265.

Fairbridge, R.W. 1950. Recent and Pleistocene coral reefs of Australia. J. Geol. 58: 330-401.

Gross, M.G., Milliman, J.D., Tracey, J.I., Jr. and Ladd, H.S. 1969. Marine geology of Kure and Midway Atolls, Hawaii: a preliminary report. Pacif. Sci. 23: 17-25.

Guilcher, A., Berthois, L., Doumenge, F., Michel, A., Saint-Requier, A. and Arnold, R. 1969. Les récifs et lagons coralliens de Mopelia et de Bora-Bora (Iles de la Société). Mem. Off. Rech. scient. tech. Outre-Mer, 38: 1-103.

Hochstein, M.P. 1967. Seismic measurements in the Cook Islands, southwest Pacific Ocean. N.Z. J. Geol. Geophys. 10: 1499-1521.

Hoffmeister, J.E. and Ladd, H.S. 1935. The foundations of atolls: a discussion. J. Geol. 43: 653-665.

Lalou, C., Duplessy, J.-C. and Nguyen Huu Van. 1971. Données géochronologiques actuelles sur les niveaux des mers et la paléoclimatologie de l'interglaciaire Riss-Würm. Rev. Géog. phys. Gémorph. dynam. 13: 447-462.

MacNeil, F.S. 1954. Organic reefs and banks and associated detrital sediments. Am. J. Sci. 252: 385-401.

Marshall, P. 1927. Geology of Mangaia (Cook Islands). Bishop Mus. Bull. 36: 1-48.

---------- 1929. Mangaia and Rurutu - a comparison between two Pacific islands. Geol. Mag. 66: 385-389.

---------- 1930. Geology of Rarotonga and Atiu. Bishop Mus. Bull. 72: 1-75.

Mergner, H. 1971. Structure, ecology and zonation of Red Sea reefs (in comparison with South Indian and Jamaican reefs). Symp. zool. Soc. Lond. 28: 141-161.

Molengraaff, G.A.F. 1930. The coral reefs in the East Indian Archipelago, their distribution and mode of development. Proc. 4th Pacif. Sci. Congr. 2A: 55-89.

Newell, N.D. 1956. Geological reconnaissance of Raroia (Kon Tiki) Atoll, Tuamotu Archipelago. Bull. Am. Mus. nat. Hist. 109: 311-372.

Newell, N.D. 1961. Recent terraces of tropical limestone shores. Z. Geomorph., N.F. Supplbd. 3: 87-106.

Newell, N.D. and Bloom, A.L. 1970. The reef flat and 'two-meter eustatic terrace' of some Pacific atolls. Bull. geol. Soc. Am. 81: 1881-1894.

Newell, N.D. and Rigby, J.K. 1957. Geological studies on the Great Bahama Bank. Spec. Publs Soc. econ. Palaeont. Miner., Tulsa, 5: 15-72.

Pillai, C.S.G. and Stoddart, D.R. In litt. Hermatypic corals from the Cook Islands.

Sachet, M.-H. 1962a. Geography and land ecology of Clipperton Island. Atoll Res. Bull. 86: 1-115.

---------- 1962b. Monographie physique et biologique de l'Ile Clipperton. Annls Inst. Océanogr. 40(1): 1-107, 12 pl.

---------- 1962c. Flora and vegetation of Clipperton Island. Proc. Calif. Acad. Sci. (4) 31: 249-307.

Schofield, J.C. 1959. The geology and hydrology of Niue Island, south Pacific. Bull. N.Z. geol. Surv., n.s. 62: 1-28.

---------- 1966. Evidence for Quaternary sea-levels from the Cook Islands and the effect of density changes on post-glacial sea-level rise. Proc. 11th Pacific Sci. Congr., 4 (Abstracts of Papers, Geological Sciences).

---------- 1967a. 1. Post glacial sea-level maxima a function of salinity? 2. Pleistocene sea-level evidence from the Cook Islands. J. Geosciences Osaka City Univ. 10: 115-120.

---------- 1967b. Notes on the geology of the Tongan Islands. N.Z. J. Geol. Geophys. 10: 1424-1428.

---------- 1970. Notes on late Quaternary sea levels, Fiji and Rarotonga. N.Z. J. Geol. Geophys. 13: 199-206.

---------- 1971. Notes on high sea-level evidence from Lau Islands, southwest Pacific. N.Z. J. Geol. Geophys. 14: 240-241.

Schofield, J.C. and Suggate, R.P. 1971. Late Quaternary sea level records of the southwest Pacific. Quaternaria, 14: 243-253.

Shepard, F.P. 1961. Sea level rise during the past 20,000 years. Z. Geomorph., N.F. Supplbd. 3: 30-38.

Shepard, F.P., Curray, J.R., Newman, W.A., Bloom, A.L. Newell, N.D., Tracey, J.I., Jr. and Veeh, H.H. 1967. Holocene changes in sea level: evidence in Micronesia. Science, N.Y. 157: 542-544.

Stearns, H.T. 1946. An integration of coral reef hypotheses. Am. J. Sci. 244: 245-262.

Steers, J.A. and Stoddart, D.R. In press. The origin of fringing reefs, barrier reefs, and atolls. In O.A. Jones and R. Endean, eds.: Geology of coral reefs (New York: Academic Press).

Stoddart, D.R. 1969. Reconnaissance geomorphology of Rangiroa Atoll, Tuamotu Archipelago, with list of vascular flora of Rangiroa by M.-H. Sachet. Atoll Res. Bull. 125: 1-44.

---------- 1971. Geomorphology of Diego Garcia Atoll. Atoll Res. Bull. 149: 7-26.

---------- 1972. Reef islands of Rarotonga, with list of vascular flora by F.R. Fosberg. Atoll Res. Bull. 160: 1-14.

Stoddart, D.R. and Pillai, C.S.G. 1973. Coral reefs and reef corals in the Cook Islands, South Pacific. Oceanography of the South Pacific 1972, R. Fraser, ed. (Wellington: New Zealand National Commission for UNESCO): pp. 475-483.

Stoddart, D.R. and Steers, J.A. 1974. Nature and origin of reef islands. In O.A. Jones and R. Endean, eds.: Geology of coral reefs (New York: Academic Press).

Summerhayes, C.P. 1971. Lagoonal sedimentation at Aitutaki and Manuae in the Cook Islands: a reconnaissance survey. N.Z. J. Geol. Geophys. 14: 351-363.

Summerhayes, C.P. and Kibblewhite, A.C. 1966. Aitutaki provisional bathymetry. New Zealand Oceanographic Institute Chart, Island Series, 1:200,000.

Tayama, R. 1952. Coral reefs in the South Seas. Bull. hydrograph. Office (Japan), 11: 1-292.

Thom, B. 1973. The dilemma of high interstadial sea levels during the last glaciation. Progr. Geog. 5: 167-231.

Thomson, J. and Walton, A. 1972. Redetermination of chronology of Aldabra Atoll by $^{230}Th/^{234}U$ dating. Nature, Lond. 240: 145-146.

Tracey, J.I., Jr. 1968. Reef features of Caroline and Marshall Islands. U.S. geol. Surv. Prof. Pap. 600-A: 80.

Tracey, J.I., Jr. 1972. Holocene emergent reefs in the central Pacific. Abstr. 2nd natn. Conf. Am. Quatern. Assoc. (December 1972): 51-52.

Veeh, H.H. 1965. Thorium-230/Uranium-238 and Uranium-234/Uranium-238 ages of elevated Pleistocene coral reefs and their geological implications. Ph.D. thesis, University of California at San Diego. 91 pp.

---------- 1966. Th^{230}/U^{238} and U^{234}/U^{238} ages of Pleistocene high sea level stands. J. geophys. Res. 71: 3379-3386.

Verrill, A.E. 1900. Notes on the geology of the Bermudas. Am. J. Sci. 159: 313-340.

Ward, W.T., Ross, P.J. and Colquhoun, D.J. 1971. Interglacial high sea levels - an absolute chronology derived from shoreline elevations. Palaeogeog. Palaeoclimatol. Palaeoecol. 9: 77-99.

Wiens, H.J. 1962. Atoll environment and ecology. New Haven: Yale University Press. xxii, 532 pp.

Wood, B.L. and Hay, R.F. 1970. Geology of the Cook Islands. Bull. N.Z. geol. Surv., n.s. 82: 1-103.

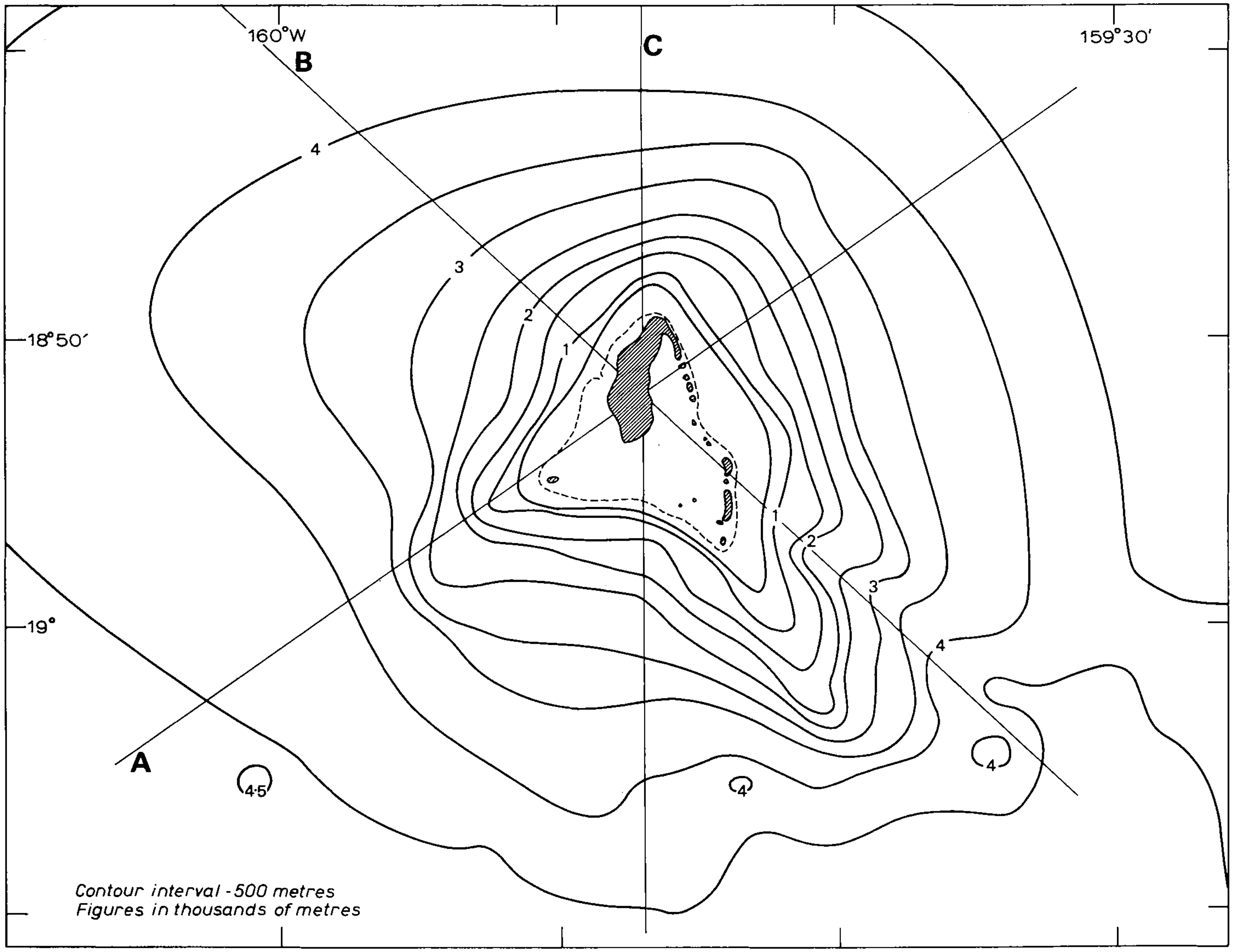


Figure 9. Regional bathymetry of Aitutaki, after Summerhayes and Kibblewhite (1966)

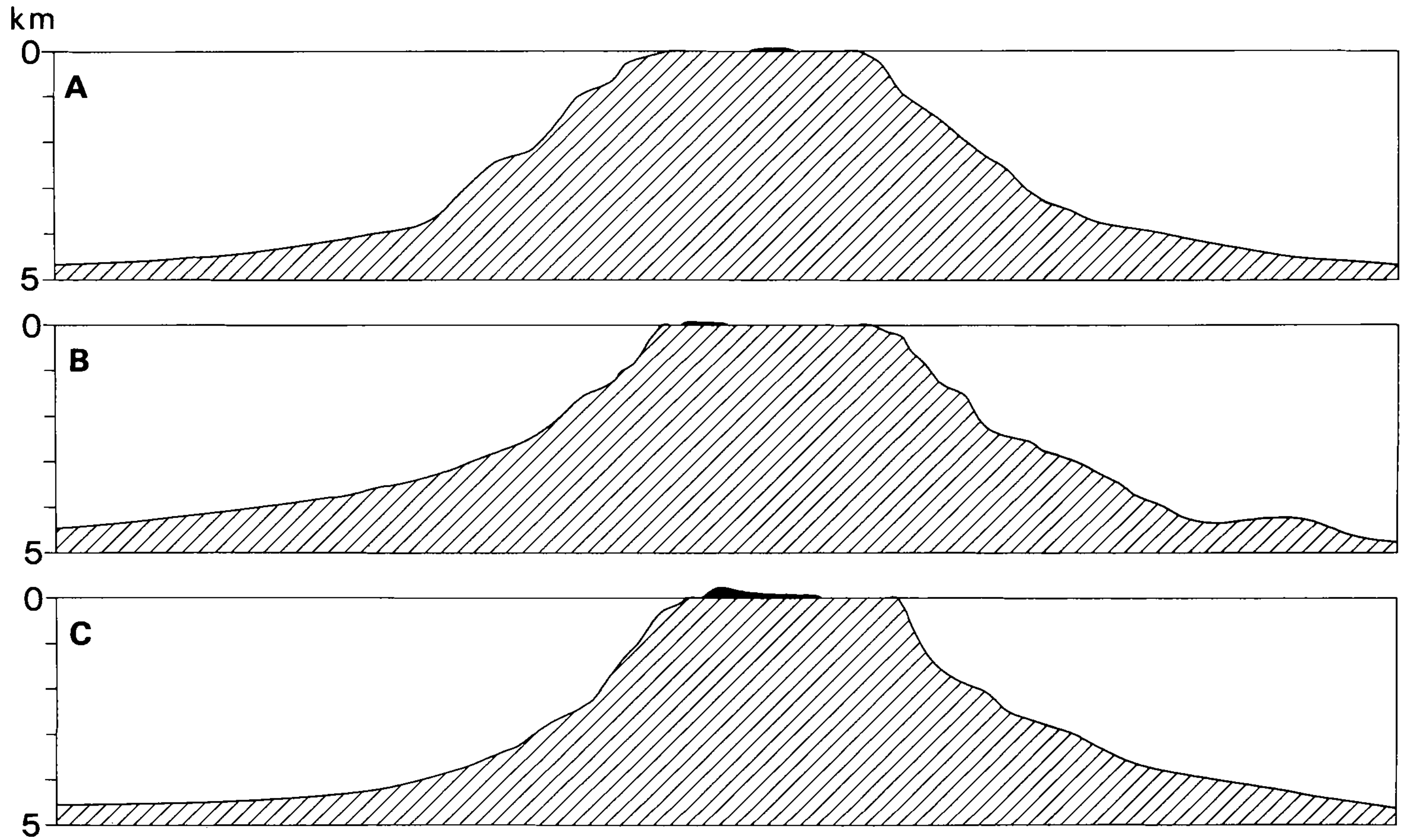


Figure 10. Bathymetric profiles of Aitutaki, from Summerhayes and Kibblewhite (1966)

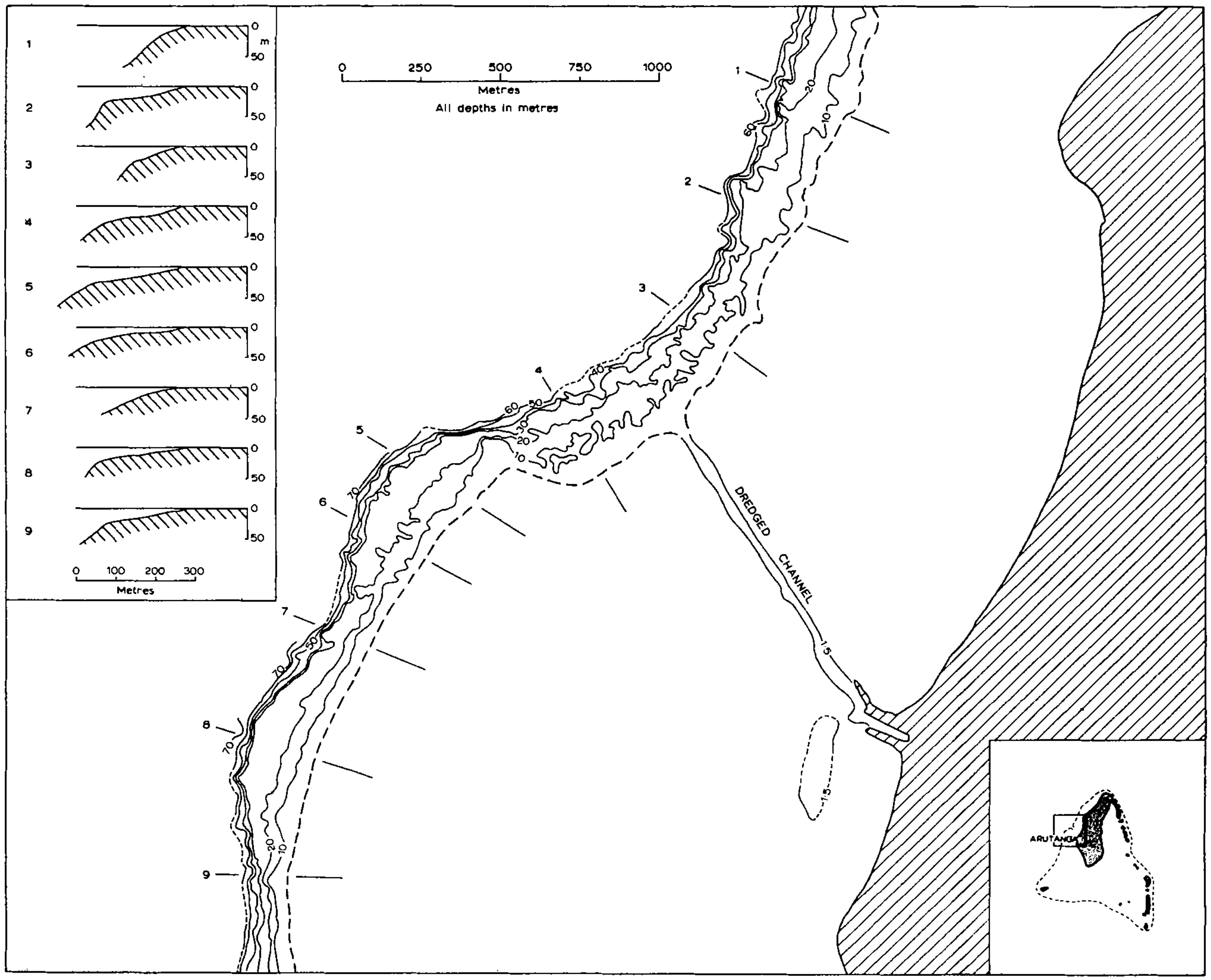


Figure 11. Bathymetry of the reef near Arutanga, surveyed by H.M.N.Z.S. Lachlan

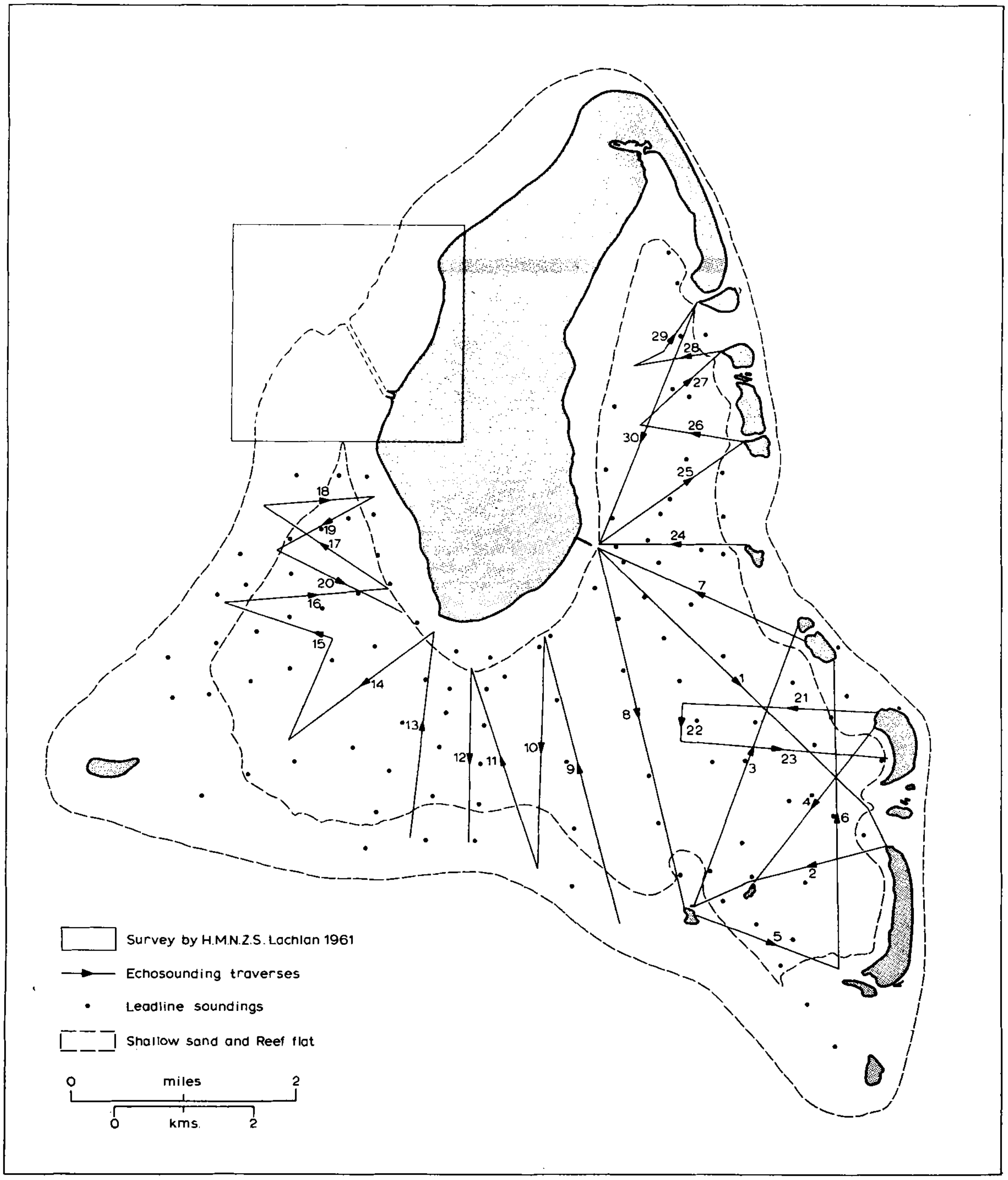


Figure 12. Location of echotraverses and soundings in the Aitutaki lagoon, 1969

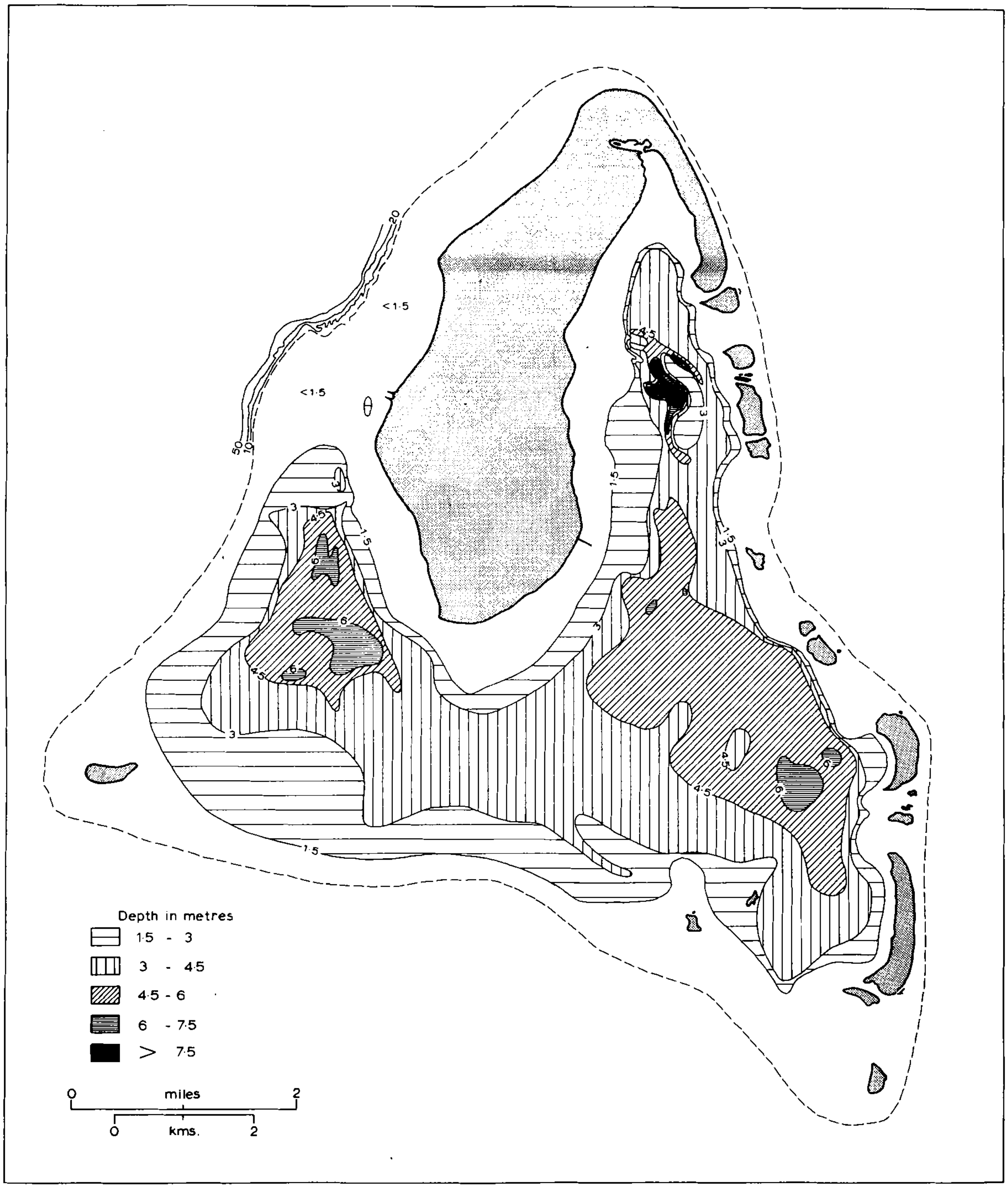


Figure 13. Bathymetry of the Aitutaki lagoon

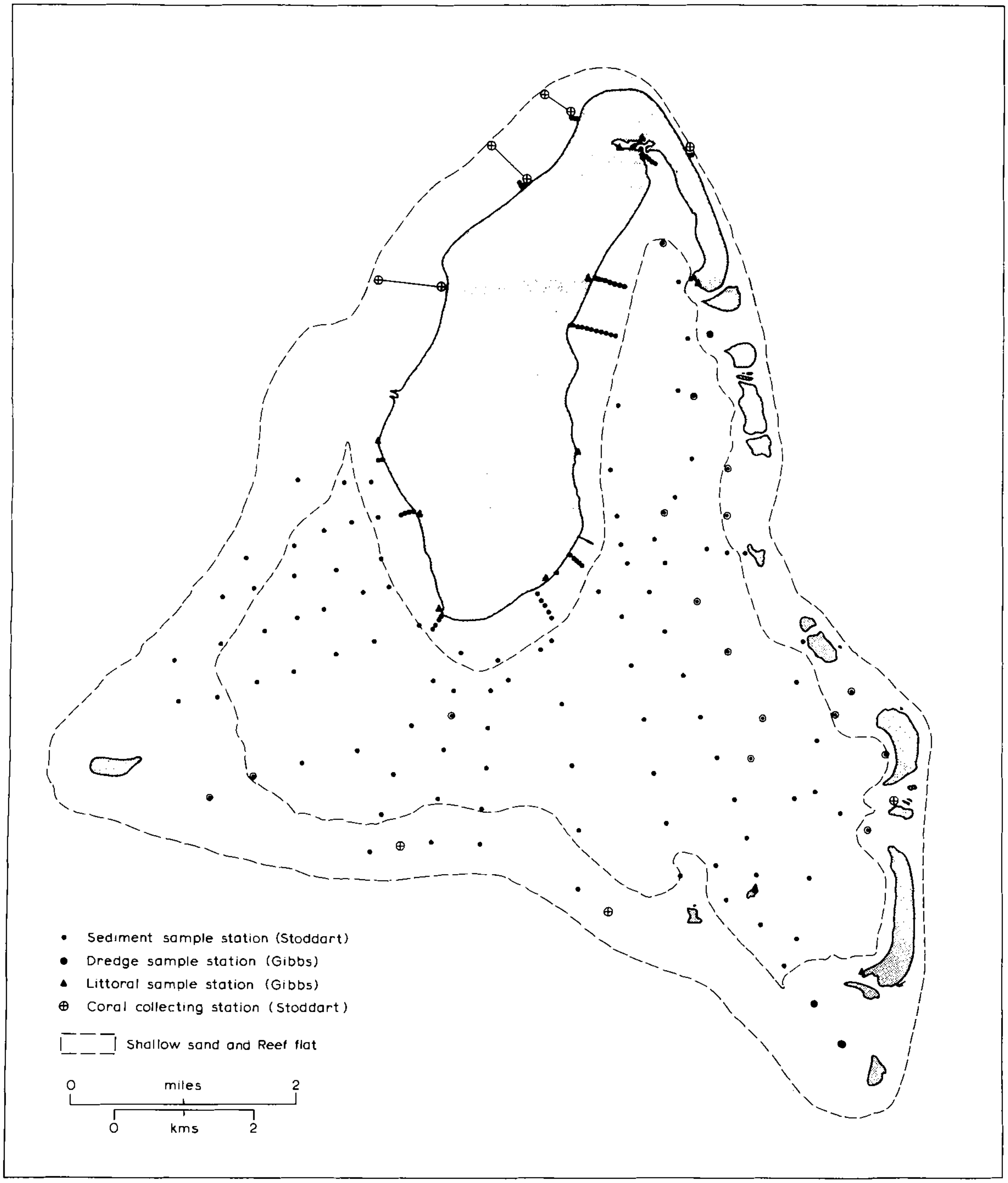


Figure 14. Types of sediment samples in the Aitutaki lagoon and on the reefs

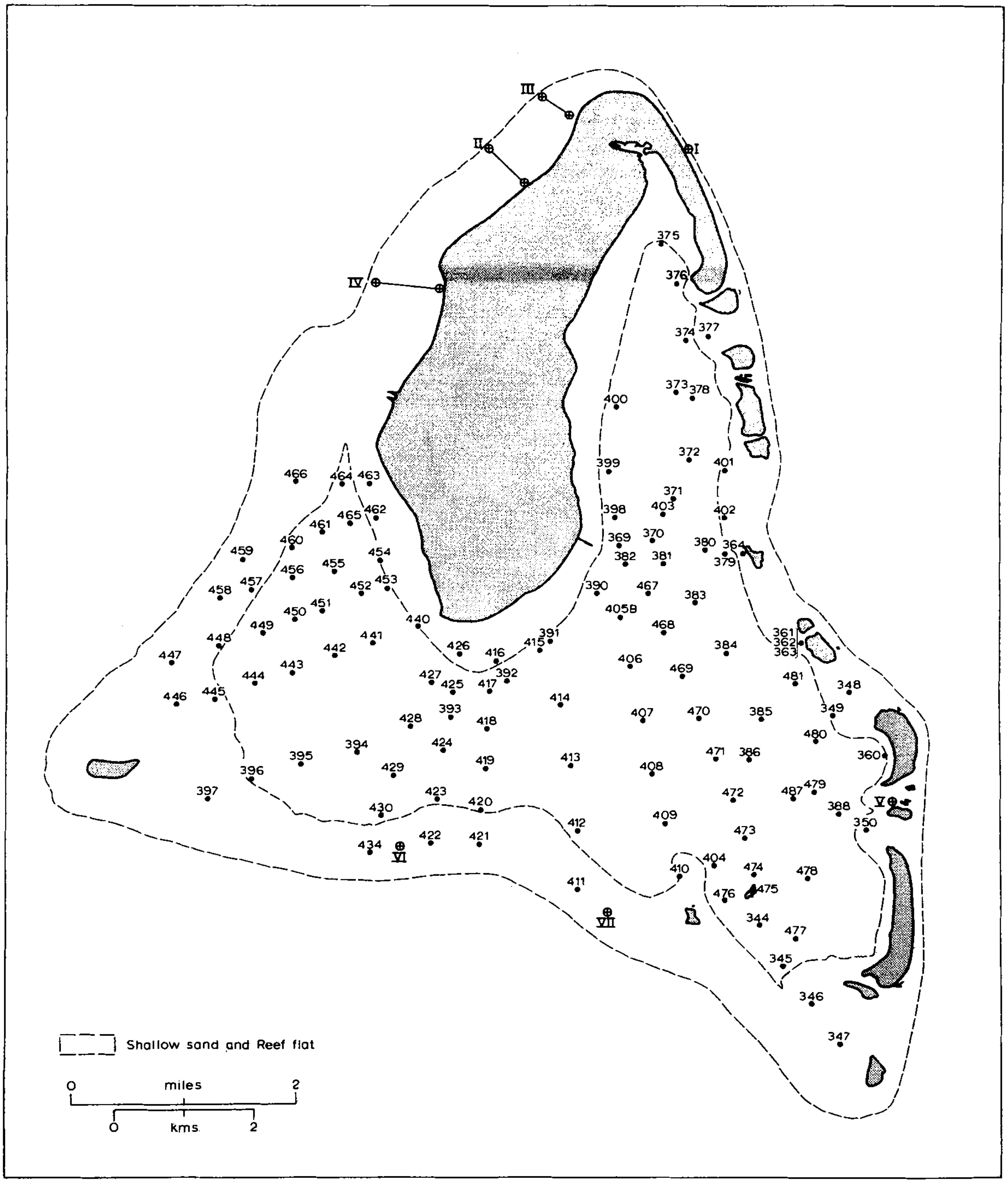


Figure 15. Sediment samples, Aitutaki lagoon

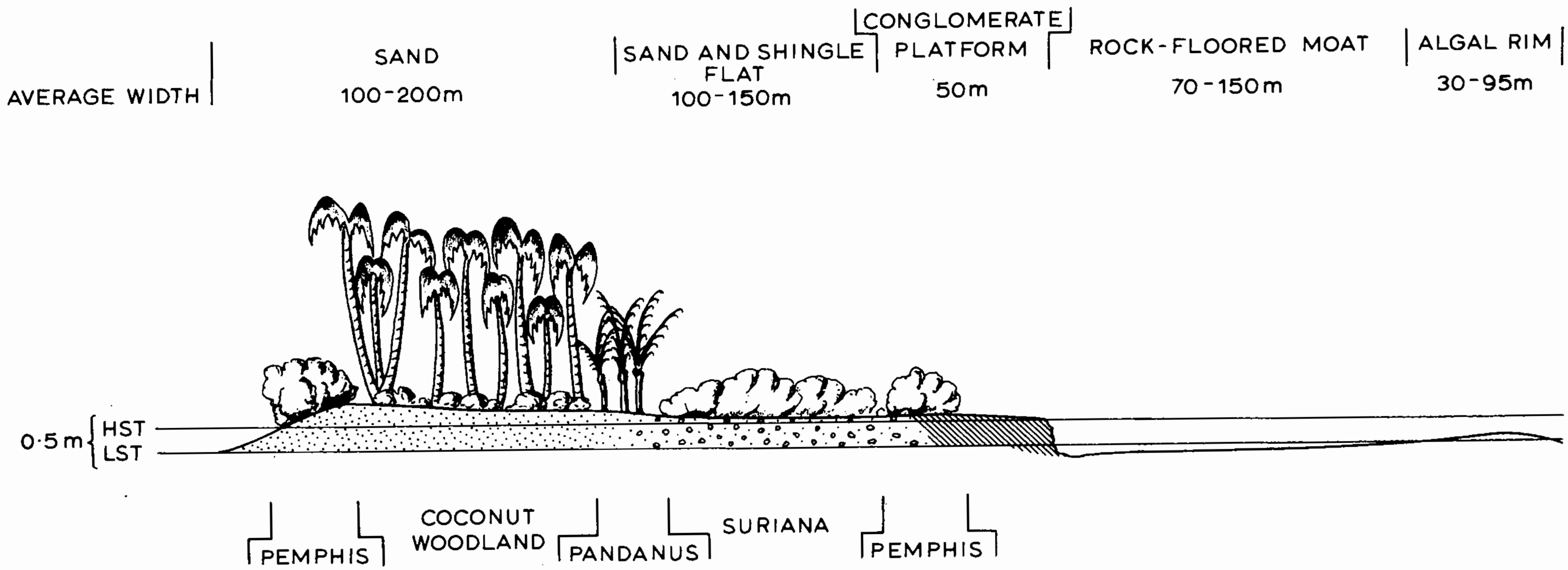


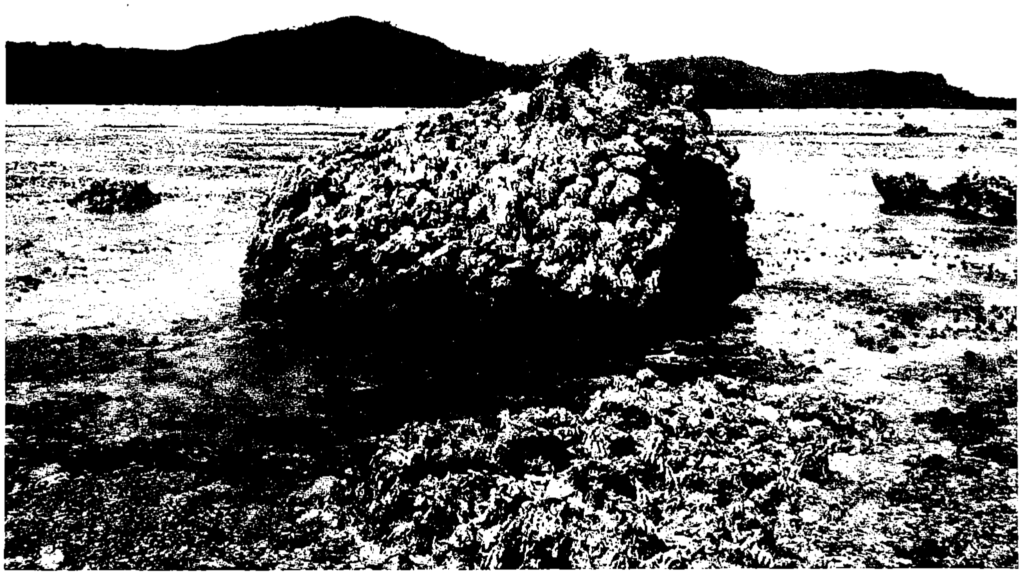
Figure 16. Schematic profile of an eastern reef motu

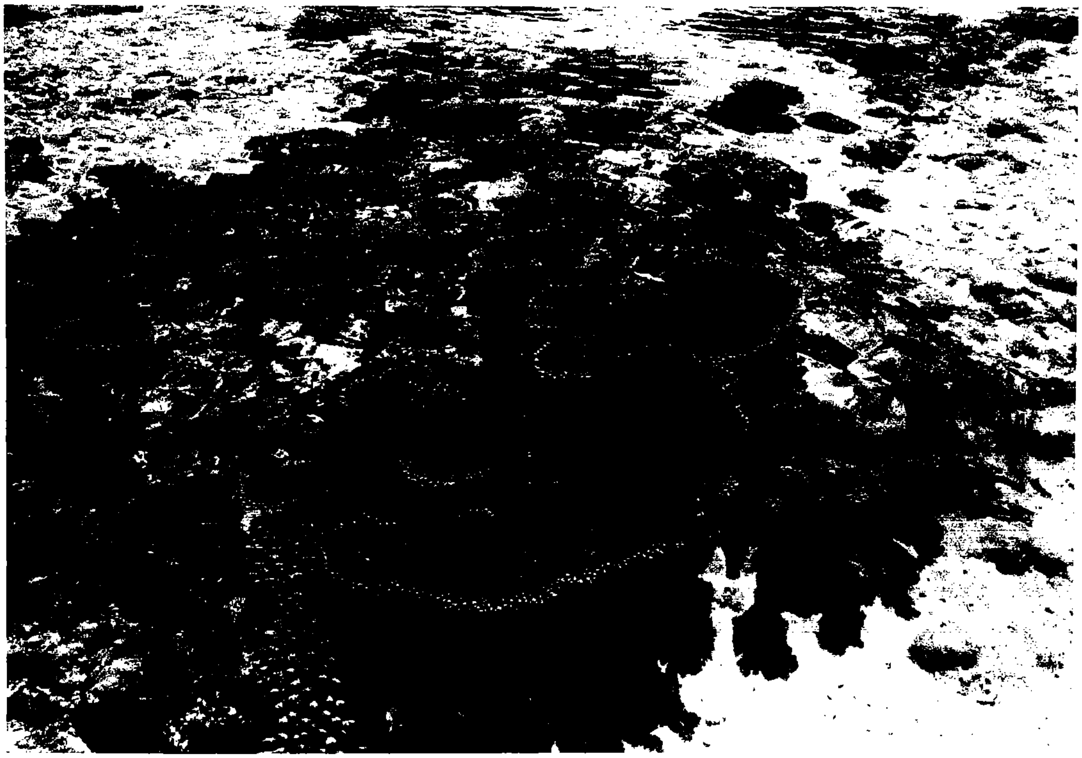
3 Reef edge at Ootu, looking south

4 Surge channel in the reef edge at Ootu

5 Algal ridge at Ootu

6 Reef block on the reef edge at Atike, northwest coast. Note the inverted corals in the block.





7 Acropora on the southern reefs near Station VII

8 Conglomerate platform on Angarei, view south

9 Conglomerate platform on Ee, view south

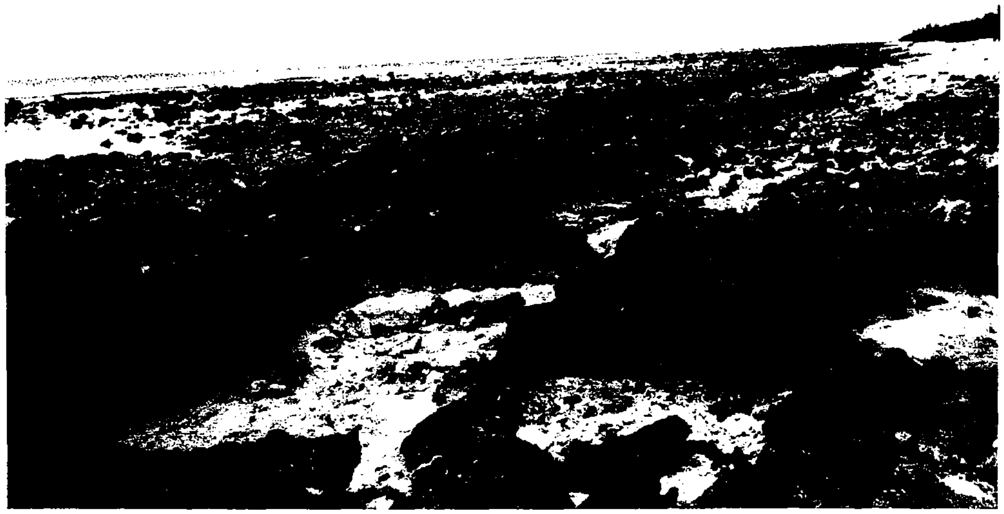
10 Conglomerate platform on Mangere, view north

11 Conglomerate platform, north end of Tavaerua, view south

12 Conglomerate platform, north end of Tekopua, view north

13 Detail of conglomerate platform, Ootu

14 Detail of conglomerate platform, Muritapua



15 Beachrock overlying conglomerate platform, southern end of Keopua

16 Beachrock on the north shore of Maina

17 Inverted reef block, seaward coast of Muritapua

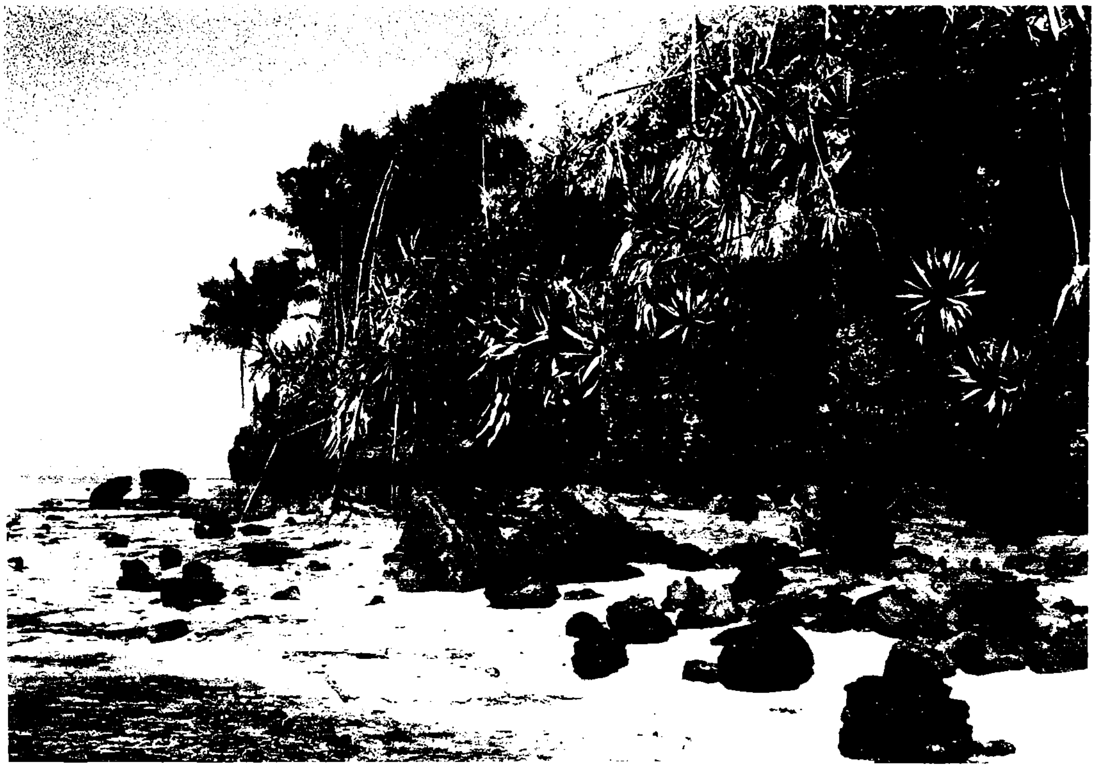
18 Reef block on the seaward coast of Papau

19 Motus from the mainland shore at Vaipeka

20 Sandy lee shore on Akaiami, view south

21 Rubble on the north shore of Angarei

22 Eroded beach section showing humic horizons, north shore of Papau



23 Cliffed west coast of Moturakau, with Furcraea

24 Leeward shore of Rapota

25 South shore of Rapota

3. REEF ISLANDS OF AITUTAKI

D.R. Stoddart

This chapter describes the main physiographic features and the vegetation patterns of the smaller islands of Aitutaki (Plates 19 and 34). Of the sixteen islands, fifteen were mapped by compass traverse and pacing and maps based on these surveys are presented here. All are detrital reef islands (motus) with the exception of one volcanic island, Moturakau; the other volcanic island, Rapota, could not be mapped using the traverse method because of its rugged shoreline topography. In addition to the islands, this account also includes the Ootu peninsula which joins the main island of Aitutaki at its northern end but which in many respects closely resembles the motus. For interpretations of the data presented here, reference should be made to Chapters 2 and 5. The very dissimilar reef islands of Rarotonga have been described elsewhere (Stoddart, 1972).

Ootu (Plates 3-5 and 13)

The Ootu peninsula, entirely composed of carbonate sediments, extends for 3.25 km along the eastern reefs from its junction with the main volcanic island. Its mean width is about 400 m, with a minimum of 250 m; at its widest, near the junction with the main island, it reaches 750 m in width. If separate, it would have been the largest of the Aitutaki motus; Tekopua, the largest, is 2.25 km long. The seaward beach crest rises 2-3 m above high water, and the surface slopes gently to the lagoon; there are no dunes except at the southern point. According to Hochstein (1967), seismic refraction measurements show the reef sediments under Ootu to be 13-20 m thick.

Because of its connection with the main island the peninsula has undergone considerable alteration by man. Two intersecting runways, respectively 1800 and 1500 m long, were constructed during World War II and are still in use. Their construction entailed levelling of the land and clearing of the vegetation adjacent to them. The only woodland remaining is along the lagoon shore and south of the main runway, where there is a less disturbed area approximately 600 m long and 450 m wide. Elsewhere the vegetation is periodically cleared and is restricted to low shrubs, herbs and grasses.

The main vegetation seaward of the main runway is Scaevola scrub 1-1.5 m tall, with similar shrubs and occasionally trees (3-5 m tall) of Tournefortia. The most frequent tree is Pandanus, 3-5 m tall, with Morinda citrifolia, and shrubby trees

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of Guettarda speciosa and Hibiscus tiliaceus, all cut back from time to time. Much of the ground surface is bare sand with Cassytha filiformis, large erect Portulaca, Heliotropium anomalum, Euphorbia hirta, and several grasses and sedges (Dactyloctenium aegyptium, Cenchrus echinatus, Cynodon dactylon, Fimbristylis cymosa, Cyperus javanicus). The seaward beach is mainly coarse sand with patches of gravel; the outpost vegetation comprises Ipomoea pes-caprae and Triumfetta procumbens. In places near the airstrip there are extensive patches, now relict, of introduced decorative plants such as Gaillardia.

South of the airstrip there is a denser scrub, with Euphorbia chamissonis and Corchorus torresianus up to 1 m tall and occasional small trees of Tournefortia, Guettarda, Morinda, Hibiscus, Leucaena insularum, and, rarely, Pisonia. Capparis is found occasionally; this species is not common at Aitutaki.

Between the scrub and the lagoon shore is a taller woodland, dominated by trees 12-15 m tall of Pisonia grandis, with Hibiscus tiliaceus, Morinda citrifolia, Guettarda speciosa, and coconuts. The ground cover is very sparse, and much of the surface is covered with leaves and coconuts. Groves of Pandanus tectorius occur in the woodland, with trunks up to 3 m tall before branching. Coconut woodland extends along the lagoon side of the Pisonia-Hibiscus woodland. The trees are 15 m tall and there is little undergrowth. There are some massive trees 10 m tall of Guettarda speciosa, and occasional Casuarina. Further north, on the lagoon side of the airstrip, there is a scrub woodland of Hibiscus, Guettarda and Scaevola, with Triumfetta and Vigna, and along the shore itself, extending to the waterline, a belt of Pemphis acidula with Sophora and Suriana. Some swampy depressions near the lagoon shore are unvegetated.

The southern shore of the peninsula has low dunes with Pemphis, Tournefortia and Scaevola, and a ground cover of Fimbristylis and Cyperus. Colubrina asiatica is common in the nearshore scrub.

The vegetation of Ootu is characteristic of the motus in the presence of such species as Scaevola and Tournefortia and of trees such as Guettarda and especially Pisonia. Several species are common on the peninsula, however, but are not found on the motus. These are mostly grasses (Dactyloctenium aegyptium, Cynodon dactylon, Cenchrus echinatus), sedges (Cyperus javanicus), and herbs, often cultivated and weedy species (Spermacoce suffrutescens, Euphorbia hirta, Mimosa pudica, Solanum nigrum, Datura metel, Momordica, Gaillardia).

Akitua (Figure 17)

Akitua is the northernmost of the motus, separated from the southern end of the Ootu peninsula by a channel less than 2 m deep. The island is triangular, 750 m long and up to 310 m wide.

The seaward coast is lined by a discontinuous and irregular conglomerate platform with a maximum exposed width of 50 m; the platform is generally mantled by a recent rubble spread of about the same width. Beaches on the north and south sides are narrow, with overhanging vegetation in places and some cliffing. The only extensive area of unvegetated sand is a lagoonward sand spit 200 m long.

Pemphis scrub forms a zone 50 m on the seaward side of the island, and a narrow fringe along the north and south shores. This is replaced by Suriana scrub on the northeast shore inland of the conglomerate platform. A mixed scrub, dominated by Scaevola but with Tournefortia, Sophora, Suriana, Pemphis, and low trees of Guettarda, is extensive at the west end and in the north.

The centre of the island is covered with Cocos-Guettarda woodland with Morinda, Leucaena and Pandanus. The woodland is open and there is a well-developed shrub layer beneath. This includes Timonius polygama, Corchorus torresianus, Sida rhombifolia and Euphorbia chamissonis. Ground cover is also luxuriant, comprising grasses and sedges (Cenchrus echinatus, Fimbristylis cymosa), fern (Polypodium), and herbs and vines (Ipomoea pes-caprae, I. macrantha, Cassytha filiformis, Triumfetta procumbens, Emilia sonchifolia, Boerhavia repens, Bidens pilosa). Several of these species (e.g. Cenchrus) are uncommon or absent on other motus and are present on Akitua because of its proximity to Ootu: some are only found at the point where the path from Ootu reaches the beach crest.

The only other woodland consists of clumps of Casuarina at the west end and along the south shore. Both Hibiscus and Hernandia are absent. One vegetation type is represented only on Akitua of the Aitutaki motus: a sedge marsh occupying a depression with standing water, and dominated by Cladium jamaicense 2-2.5 m tall.

Angarei (Figure 18, Plates 8 and 21)

Angarei, Ee and Mangere form a group of very similar islands separated by narrow channels and which probably originally formed a single entity. Ee is the largest, and the two islands to north and south closely resemble each other. Angarei has maximum dimensions of 480 and 400 m. It consists of rubble, cobbles and gravel, with unusually narrow lagoon beaches overhung with vegetation. There is a conglomerate platform up to 40 m wide along the seaward coast.

The vegetation is clearly zoned. Pemphis scrub forms a zone up to 50 m wide along the seaward side, and also extends as a narrow fringe around the leeward shores. Few other plants, apart from outpost Triumfetta and Vigna, are found in this zone. Inland of the Pemphis is a zone of Suriana scrub up to 125 m wide with occasional Tournefortia shrubs. The Suriana is less dense than the Pemphis; the sand beneath is bare, except for trailing Cassytha and occasional Heliotropium. Much of the centre of the island is occupied by a scrub 1-1.5 m tall of Scaevola, with Euphorbia chamissonis and occasional trees of Morinda, Guettarda and Pandanus 2-3 m tall.

Woodland is confined to an area of coconuts and a grove of Casuarina on the northwest side of the island. The coconuts occur with Morinda, Guettarda, and the shrubs Colubrina asiatica and Corchorus torresianus; a single Hernandia seedling was seen. The Casuarina grove is also open and mixed with Guettarda and shrubby Scaevola and Euphorbia chamissonis, with Fimbristylis on bare sand.

Ee (Figure 19, Plates 9 and 28)

The third largest of the Aitutaki motus, and probably formerly connected with Angarei and Mangere to north and south, Ee is 975 m long, parallel to the reef edge, and up to 410 m wide. A conglomerate platform lines the whole of the seaward coast of this rectangular island; it varies in width from 10 to 50 m. The inner parts of the platform are mantled with rubble and boulders: much rubble extends back into the Pemphis zone, and there are boulders 1-1.5 m in diameter even in the woodland. Beaches are very narrow all round the island, and vegetation reaches the sea along most of the lagoon coast.

Pemphis extends almost continuously around the island's shores, as a narrow strip on the lagoon shore and as a zone up to 30 m wide on the seaward side; it is also present along the north and south shores. The most extensive vegetation type is, however, Suriana scrub, extending across the greater part of the island towards its northern and southern ends, and elsewhere forming a zone 50-60 m wide. The scrub is generally 2-3 m tall, and reaches a maximum of 4 m. Other species present include Euphorbia chamissonis and Cassytha filiformis. Further inland other shrubs become more common, including Sophora, Scaevola, and Colubrina, the latter 3-4 m tall. Under this taller scrub is a sparse ground cover of Euphorbia, Fimbristylis and Cassytha.

There are three main types of woodland on the island. Cocos-Guettarda woodland occupies a compact area about 250 m in diameter, with several smaller groves. The trees of Guettarda reach 10 m in height, Pandanus 7 m, and tall shrubs of Colubrina 5 m. Other shrubs in the more open woodland include Scaevola, Suriana and Euphorbia, with Fimbristylis on otherwise bare ground. In the more dense and deeply-shaded woodland, Scaevola is absent and is replaced by Timonius polygama; there are many young coconuts as well as Guettarda and Pandanus. Juvenile Hibiscus is present, and, rarely, individual trees of Pisonia. This woodland is margined by a zone of Pandanus and Guettarda.

No other plants grow in this zone, and the ground is deeply covered with trash of *Pandanus* leaves. The third woodland type comprises *Casuarina* groves on the lagoon shore. Low *Scaevola*, *Suriana* and *Euphorbia* are found in these open groves, with *Heliotropium*, grasses, *Triumfetta* and *Vigna*. One *Leucaena* tree was seen.

Mangere (Figure 20, Plate 10)

A small island south of Ee, with maximum length and breadth of about 350 m, Mangere comprises a seaward continuous conglomerate platform 35-55 m wide, a rubble spread, and a leeward sandy area. Beaches are almost non-existent on the lee side, where vegetation reaches the sea.

The vegetation consists mainly of low scrub with a leeward area of coconut woodland. *Pemphis* forms a zone up to 30 m wide on the seaward side of the island, and a narrow fringe on the lagoon shores. The most extensive scrub is dominated by *Suriana maritima*, in a zone up to 130 m wide, replaced inland by a more mixed scrub, dominated by *Scaevola*, with *Tournefortia* and some *Pemphis*, *Guettarda* and *Pandanus*. Most of the scrub is 2-3 m tall; some of the seaward *Pemphis* reaches 4 m. The coconut woodland is distinctly taller, with much *Guettarda* up to 8 m. Other trees include *Pandanus* and *Leucaena*. In more open areas there is extensive scrub beneath the trees, mainly *Scaevola* about 1 m tall but in places reaching 2 m, and *Timonius polygama* reaching 2.5 m. *Euphorbia chamissonis* forms a lower dwarf scrub, and other plants beneath the woodland include *Fimbristylis*, *Triumfetta* and *Tacca*. *Polypodium* is common in more deeply shaded places. The narrow leeward beaches have an outpost vegetation of *Ipomoea* and *Vigna* with *Heliotropium* and occasional *Tournefortia*.

Papau (Figure 21, Plates 18 and 22)

Papau is a small isolated island, rather irregularly shaped, 400 m long and 200 m wide, with a discontinuous dissected conglomerate platforms 35-75 m wide on its seaward side. Coral rubble and boulders are scattered along the seaward shore, but sand and gravel beaches are better developed here than on the islands to the north. The rubble includes large boulders of *Porites* 1.5 m in diameter. Large blocks, many of them more than 1 m in diameter, are found well inland as well as on the shore. The island reaches a height of 2-2.5 m above sea-level. On the north coast the shore is being eroded, revealing a sequence of soil horizons covered by storm sands and gravels. The sequence is:

Surface	
Humic pebbly sand with roots	13 cm
White fine sand	15 cm
Dark humic sand with roots	5 cm
White fine sand	10 cm
Black humic sand with roots	13 cm
Coarse gravel	18 cm
Fine white sand to beach	100 cm +

For so small an island the vegetation is of some interest. The usual z ne of Pemphis is here narrow and discontinuous on the seaward side, with an average width of only 10 m. There is some indication that its width has been reduced by shore retreat. The Suriana zone, with some Sophora, has a more normal width of up to 130 m. On the leeward side there is an area of coconut-Guettarda woodland 8-15 m tall. Other trees include Pandanus, low Morinda, and Leucaena. Shrubs beneath the woodland are Timonius polygama, Scaevola (to 1.5 m), Sophora, and Euphorbia chamissonis, with on the surface Stenotaphrum, Fimbristylis, Portulaca, Cassytha and Lepidium bidentatum. Within the coconut woodland is an area of tall, closed-canopy broadleaf woodland, consisting mainly of Pisonia grandis, Hernandia and Guettarda. The ground surface in this woodland is mainly covered with trash, with Triumfetta and Polypodium, and occasional Tacca and sedges. There is some leeward beach scrub of Scaevola and Tournefortia, with Heliotropium and Ipomoea.

Tavaerua Iti (Figure 22)

A small island immediately north of Tavaerua, Tavaerua Iti is rather regularly shaped, 250 m in maximum length (transverse to the reef) and 210 m wide. The reef edge lies 120 m to seaward. The outer 60 m of the reef platform comprises a boulder zone, the inner 60 m a moat 0.5-1 m deep. The outer 45 m of the moat is sand-flored, but the inner part is bare rock, with outliers of the conglomerate platform near shore. Small patches of the conglomerate platform extend between the two islands, and it is possible that they were formerly connected. On the seaward side of the island the conglomerate platform is low and dissected, with an irregular outline; it is unusually narrow (a few metres wide), except where it extends lagoonward along the north and south shores. Assuming its continuity beneath the seaward rubble spread with Pemphis, its maximum width is about 55 m. The island is mainly formed of coral rubble, with narrow leeward beaches, and a lobe of coarse sand on the northern side.

About one-third of the island is wooded, and the rest is covered with scrub. Pemphis forms a continuous zone on the seaward side, up to 25 m wide and 2 m tall. Inside this there is a zone of Suriana, also 2 m tall but with a maximum width of about 60 m. Towards the sea this is fairly pure, but inland it becomes more open, with Euphorbia chamissonis, Triumfetta procumbens, Vigna marina and Ipomoea macrantha. The transition between the scrub and the woodland is formed by a dense thicket of Pandanus fringing the taller coconut woodland on its seaward side. The latter includes tall Guettarda and Pandanus, juvenile Hibiscus, Timonius polygama up to 5 m tall, Euphorbia chamissonis, Tacca, and, on the ground, Boerhavia, Fimbristylis, grasses and Polypodium. The leeward beaches are fringed by mixed woodland of Pandanus and Guettarda, a grove of Casuarina 6 m tall, Scaevola and Euphorbia chamissonis, and outpost Heliotropium. There is evidence of burning of the vegetation, especially of Pandanus thickets.

Tavaerua (Figure 23, Plate 11)

Tavaerua closely resembles Taverua Iti, but is larger: the island is 290 m wide and 500 m long. The conglomerate platform on the seaward side is intricately dissected, with promontories and deep inlets and many separate outliers. It reaches 30 m in width but much of it is only a few metres wide. It does not extend far lagoonward on the north and south coasts. The leeward beaches are sandy, and in the south over 10 m wide; on the lagoon shore there is some erosion and cliffing, and patches of gravel and rubble.

The seaward Pemphis zone, 50 m wide, has shrubs up to 5 m tall. The Suriana zone within, 80 m wide, is rather lower. About half of the island is occupied by coconut-Guettarda woodland, with Pandanus. In spite of the size of the woodland there are no other big trees. Pandanus forms an exclusive thicket round the seaward side of the woodland, at the junction with the Suriana scrub. In the woodland there are seedlings of Morinda, young Guettarda 2-5 m tall, dense Scaevola scrub up to 1.5 m tall, Timonius polygama commonly reaching 1-2 m, and Euphorbia chamissonis. Cassytha is present but is not common. On the lagoon coast there is a tall scrub of Suriana (up to 3 m tall), Tournefortia (to 2 m) and Timonius, with Euphorbia chamissonis, Triumfetta, Heliotropium and Fimbristylis. The ground surface is higher along the lagoon side, and falls towards the seaward margin of the woodland to the rubble and gravel spreads under the seaward scrub.

Akaiami (Figure 24, Plates 20 and 27

The second largest of the motus, Akaiami was formerly used as a base for the Solent flying-boat service, and resthouses, refuelling depot and customs building were erected there (Wood and Hay, 1970, p. 37). Little trace now remains of these, though there are remnants of old jetties on the lagoon shore. The island is 1120 m long and up to 410 m wide. Unlike most of the other motus it has a prominent seaward beach ridge of gravel and cobbles, and for much of the seaward shore this overlies and obscures the conglomerate platform. Where exposed this is 30-65 m wide, and dissected by inlets. There is an extensive separate remnant of the platform south of the island. Wide sand beaches extend round the leeward side of the island; the lagoon beach ridge is 0.6 m high and 50 m wide, and the interior of the island is somewhat lower. There is a small exposure of near-shore beach rock on the south coast.

Unusually, Pemphis scrub is not well developed on the seaward side of the island: it forms a narrow fringe in the north of the island, and a zone 10 m wide in the south, where the conglomerate platform is widest; it is absent along much of the seaward beach ridge, and is most extensive at the southwest point. Suriana scrub too is weakly developed: it forms a narrow zone on the seaward beach ridge, with outpost Heliotropium, Euphorbia chamissonis, Triumfetta and grasses. The place of Pemphis and Suriana is taken by Scaevola scrub, forming a zone up to 30 m wide and 1 m tall, with occasional Tournefortia to 2 m, along the seaward side. Euphorbia chamissonis and Capparis cordifolia are also present. This scrub terminates landward in a zone of tall massed Pandanus at the fringe of the coconut woodland.

In more open parts of the woodland there are trees of Morinda up to 6 m tall and of Guettarda up to 8 m. Timonius and Euphorbia chamissonis are common low shrubs, with Tacca, Vigna, Fimbristylis and grasses on the ground. Thomson (1968) has described fertiliser experiments on coconuts in the southern part of the island. He found that of 247 palms aged 2-75 years only 67 were bearing nuts, 27 were beyond bearing age, and the rest were unproductive and too crowded. Yield was only 10.7 nuts per bearing palm. With different fertilisers on 0.75 acre experimental plots he obtained yields of 23.9-47.8 nuts per tree. Elsewhere the woodland is more dense and the ground more shaded. Morinda and Guettarda are both much lower, and Polypodium replaces the sedges and grasses on the ground. Near the seaward margin of the woodland Guettarda increases in density until it forms a zone 3-5 m wide immediately inland of the Pandanus fringe, normally about 10 m wide.

Muritapua (Figure 25, Plates 14, 17 and 29)

Muritapua is a small island between Akaiami and Tekopua, 360 m long transverse to the reef edge, and 150 m wide. It has a very irregular seaward conglomerate platform up to 95 m wide, which is scattered with large boulders, mostly of single coral colonies; one of Porites measures 2 x 1.7 x 1.5 m. Most of the surface of the island is formed of gravel and cobbles, with sand beaches on the leeward side, in places formed of mainly Halimeda sand.

The seaward Pemphis zone, up to 50 m wide, is well-developed, with standing in prominent windrows oriented at 280°. Pemphis also occurs intermittently round the lee shores, with Heliotropium and occasional Scaevola. Many of the Pemphis bushes are covered with Cassytha. The most extensive vegetation type is Suriana scrub, surrounding the small central area of woodland on all sides except the north where it is replaced by Scaevola. The scrub contains low Scaevola, some Pemphis, Euphorbia chamissonis and juvenile Pandanus, with Ipomoea macrantha, Triumfetta and grasses on the largely bare ground surface. Cassytha is common, especially on Scaevola. The main area of coconut woodland is only 100 m in diameter, with trees 8-12 m tall. There are patches of Euphorbia and Scaevola beneath the trees, with a sparse ground cover of Triumfetta, Tacca, Fimbristylis, grasses and Polypodium. The surface under the woodland is irregular, with old beach ridges and coral blocks up to 0.6 m long scattered over the gravel and cobbles. Seaward of the coconut woodland is a fringe of Guettarda, 6-7 m tall, with some Pandanus.

Tekopua (Figure 26, Plates 12, 15 and 30)

Tekopua is the largest of the motus, 2250 m long parallel to the reef edge, with an average width of 300 m and a maximum width of 480 m. The seaward reef flat is 150-200 m wide, and consists mostly of a rock-floored moat up to 1 m deep with a higher algal rim. The seaward coast of the island is lined by a continuous conglomerate platform, undissected in the north but crenulate and irregular in the south, with a maximum width of 65 m. In places the conglomerate platform comprises parallel ridges with pronounced seaward dip and landward-facing scarps; some of these are composed of sand rather than gravel and are probably beach rocks. The inlets in the conglomerate platform contain high densities of Holothuria atra, with up to 20 per sq m.

As at Akaiami the conglomerate platform is overlain by a pronounced seaward beach ridge rather than by a flat rubble spread, and the usual Pemphis scrub zone is absent. Pemphis is present only as tall spreading open-branched shrubs on the south coast. Suriana forms a continuous zone along the seaward side, up to 65 m wide, with few other species represented apart from occasional Tournefortia and Pemphis. Low Suriana, with Scaevola, Tournefortia, and in the south Sophora, also forms a narrow fringe on the lagoon shore. Most of the island is covered with a dense coconut woodland. Other trees present include very common Guettarda; tall Hernandia, especially towards the south; Leucaena; Morinda; and trees of Tournefortia 12-14 m tall. These latter are now overtopped by coconuts and Hernandia and are not reproducing. They are more common on the seaward side of the woodland, and may indicate a recent extension of the coconuts. Juvenile trees and low shrubs beneath the woodland include Pipturus argenteus, Timonius polygama, Colubrina asiatica, Hernandia, Sophora, Scaevola, and Euphorbia chamissonis.

Tacca is common, and Capparis is present. The coconuts are more actively managed in the north of the island, where the undergrowth is burned and the ground is largely bare apart from scattered Vigna, Heliotropium, Tacca, Euphorbia and grasses. Elsewhere the woodland is much more dense, and grades into a mixed coconut-Pandanus-Guettarda thicket. Towards the south there is an area of pure Pisonia woodland measuring 520 x 200 m, with tall trees 3-4 m apart, growing on a rubble surface covered with rotting trunks and other trash. Pisonia trees up to 20 m tall are also found in the adjacent coconut woodland, with Morinda, Guettarda and Pandanus and an undercover of Euphorbia. At the southwest point there is a developing sandspit with a zonation of vegetation types outwards from the coconut woodland of: low Scaevola with Cassytha and Euphorbia; tall Pemphis; low Suriana. Apart from clumps of Fimbristylis and some Cenchrus the ground surface is bare.

Terrestrial invertebrates were collected on Tekopua during the Expedition by Wise (1971, pp. 58-60).

Tapuaeta (Figure 27, Plate 33)

Tapuaeta is a small island south of Tekopua, from which it is separated by a deeply scoured channel opening lagoonwards. The island is aligned transverse to the reef-edge, and is 570 m long and up to 210 m wide. It is entirely built of sand, with its surface standing about 1.5 m above sea level. The beaches are sandy, except for cliffed eroded sectors on the north, east and south shores. Beach rock outcrops at several places, with a prominent line 160 m long extending offshore to the southwest.

Coastal scrub comprises mainly Pemphis in the east, with elsewhere Scaevola and Tournefortia with Sophora. These all form a narrow fringe round a mixed woodland dominated by coconuts which covers most of the island. A dense woodland of coconut and Guettarda, floored with coconut trash and Polypodium, becomes more open to the west, where juvenile coconuts 3-4 m tall are scattered through a scrub of Scaevola and Euphorbia with juvenile Pandanus, Guettarda and Morinda, and, on the ground, Tacca, Vigna, Portulaca, sedges and grasses. Towards the east the coconuts are taller and closer, with massive trees of Hernandia sonora and Guettarda. There is an understorey of Hernandia seedlings, Hibiscus tiliaceus and Morinda, and a ground layer of Vigna, Cassytha and Euphorbia. Trees of Pisonia grandis are present in this woodland, but they do not form a distinct vegetation type.

The island is uninhabited, but there are wild pigs in the woodland.

Sand cay south of Tapuaeta (Figure 28)

A small sand cay south of Tapuaeta is 190 m long and up to 70 m wide. It is entirely built of sand. The vegetation is restricted to a low scrub of Suriana maritima, with two low bushes of Tournefortia. There is no conglomerate platform and no beach rock.

Motukitiu (Figure 29, Plates 26 and 31)

Motukitiu is the southernmost island on the eastern reef. It is 450 m long and 300 m wide, with a narrow seaward conglomerate platform or ledge covered by a wide spread of largely unvegetated fresh gravel and cobbles up to 100 m wide.

There are patches of wind-sheared Pemphis mostly less than 2 m tall, with the largest shrubs reaching 3 m, forming a zone up to 40 m in width, on the northern part of this gravel spread, close to the sea, but the most extensive scrub is formed by Suriana maritima. This forms a zone up to 95 m wide, occupying about one-third the width of the island, with shrubs rising inland to a height of 4 m. The Suriana is mainly a pure stand with scattered Tournefortia. In pioneer situations seaward of the Suriana zone, on the rubble flat, there are low bushes of Suriana and Scaevola 1-2 m apart and numerous seedlings of Heliotropium anomalum. The Suriana zone passes landward through a fringe of Pandanus and Guettarda into coconut woodland. This averages 100 m in width. Guettarda and Pipturus are common under the coconuts, Morinda is rather rare. The ground cover comprises Boerhavia tetrandra, Triumfetta procumbens, Ipomoea macrantha, Vigna marina, grasses and Polypodium. Capparis cordifolia is present but rare. On the lagoon coast there is a wide sand beach, with Scaevola up to 2 m tall, Polypodium, grasses and sedges, and outpost Triumfetta and Heliotropium. Low shrubby trees of Cordia are present on the beach crest in the north.

Wise (1971, pp. 58-60) collected terrestrial invertebrates on Motukitiu in 1969.

Moturakau (Figure 30, Plate 23)

One of the two small volcanic islets on the southern reef rim, Moturakau is 460 m long in a north-south direction and 120 m wide. The core of the island is a steep ridge of volcanic rocks 160 m long on the east side of the island, extended in an abrasion platform cut in volcanic rocks for 100 m to the south. Wood and Hay (1970, p. 38) describe the volcanic rocks as comprising 9 m of well-bedded agglomerate containing palagonitic ash, angular basalt and coral fragments, mostly dipping 10° toward the west. Carbonate sands extend the island to the west and south of this volcanic core.

The vegetation is very different from that of the other reef islands. On the west side of the ridge, on volcanic soil, is a dense woodland of Calophyllum inophyllum 40-50 m wide, with Guettarda, Morinda, Leucaena and some Hibiscus tiliaceus. Calophyllum is not found on the normal reef islands. The woodland is deeply shaded, and ferns are plentiful on the ground and boles of trees. This woodland is surrounded by a coconut-Hibiscus woodland, especially towards the southern point. Under the trees there is some low Scaevola, together with Vigna marina and grasses. The steep eastern slope of the volcanic ridge is vegetated with tall Fourcraea and some Hibiscus, with Polypodium in crevices, and also tall Pandanus tectorius. There are vines of Abrus precatorius over the bare rock. Beach vegetation on the leeward side is more typically that of the motus, with patches of Sophora and Pemphis, and outpost Ipomoea pes-caprae and Vigna, but no Suriana or Tournefortia.

The island was formerly used as a leper colony but is now uninhabited. Magnetic samples were collected here during the 1969 Expedition by Lumb and Carrington (1971).

Rapota (Plates 24 and 25)

The main island consists of a rounded hill of basalt surrounded by large basalt boulders, which form the shorelines. These boulders are set in a calcareous matrix up to about 1.5 m above sea level on the south coast. Marshall (1930, p. 40) recorded nephelinite and basalt from this island. Wood and Hay (1970, p. 38) record 1.8 m of "flow-banded nephelinite ... on a subhorizontal weathered zone in porphyritic limburgite. The weathered zone is 6 to 8 in thick (15-20 cm) and yellowish brown in colour. Also present in agglomerate on Rapota Island are pebbles of trachyte and phonolite, presumably erupted during a late stage in the volcanic history of Aitutaki."

The island is covered with a dense woodland of Calophyllum inophyllum with tall trees of Hernandia, Cocos, Casuarina and Morinda, with Pandanus, Hibiscus and Thespesia. The ground cover consists of Polypodium, Tacca, Vigna marina, Abrus precatorius and grasses. Two small islets offshore also have trees of Calophyllum, Pandanus and Cocos; that to the north also has Guettarda, Thespesia and Scaevola, and that to the east Hibiscus and Pemphis. Otherwise Rapota lacks some of the most common plants of the motus. Mature trees of Erythrina variegata and Mangifera indica suggest that the island was formerly inhabited.

Magnetic samples were collected here during the 1969 Expedition (Lumb and Carrington, 1971), and also terrestrial invertebrates (Wise, 1971, pp. 58-60).

Maina (Figure 31, Plate 16)

Maina is a true sand cay located near the southwestern reef point of Aitutaki. It is a sandy island 710 m long and 310 m in maximum width. There is no counterpart of the conglomerate platforms of the eastern motus, but beach rock is widely if discontinuously exposed along the foot of beaches. These latter are exceptionally wide for Aitutaki, reaching 40 m in the southwest.

Most of the island is covered with a tall open scrub. At the eastern end and along the north shore this comprises Scaevola (1-1.5 m tall) and Tournefortia with Guettarda. The scrub is rather open and the ground surface bare except for Fimbristylis and Cassytha. The western end of the island is occupied by a scrub 1.5-2 m tall of Suriana maritima with occasional Tournefortia reaching 2 m. Other shrubs such as Scaevola and Colubrina are also present, but patchily. The ground surface is again rather bare, with Cassytha, grasses, Portulaca, and some Euphorbia chamissonis. The open coconut woodland near the centre of the island includes Hibiscus and Pandanus; shrubs such as Scaevola and Colubrina; and, on the surface, mainly Triumfetta, Heliotropium and Cassytha, with Tacca, Portulaca, Euphorbia, Polypodium and grasses.

The island is uninhabited, but there is a light tower on the south coast, erected in 1954. Wise (1971, pp. 58-60) collected terrestrial invertebrates here during the 1969 Expedition.

REFERENCES

Hochstein, M.P. 1967. Seismic measurements in the Cook Islands, southwest Pacific Ocean. N.Z. J. Geol. Geophys. 10: 1499-1521.

Lumb, J.T. and Carrington, L. 1971. Magnetic surveys in the south-west Pacific and rock sampling for magnetic studies in the Cook Islands. Bull. R. Soc. N.Z. 8: 81-89.

Marshall, P. 1930. Geology of Rarotonga and Atiu. Bishop Mus. Bull. 72: 1-75.

Stoddart, D.R. 1972. Reef islands of Rarotonga, with List of vascular flora by F.R. Fosberg. Atoll Res. Bull. 160: 1-14.

Thomson, R.W.F. 1968. Spacing and nutrition of Cocos nucifera under atoll conditions in the Cook Islands. Oléagineux, 23: 449-451.

Wise, K.A.J. 1971. A preliminary report on the terrestrial invertebrate fauna of the Cook Islands, collected during the Cook Bicentenary Expedition, 1969. Bull. R. Soc. N.Z. 8: 55-64.

Wood, B.L. and Hay, R.F. 1970. Geology of the Cook Islands. Bull. N.Z. geol. Surv., n.s. 82: 1-103.

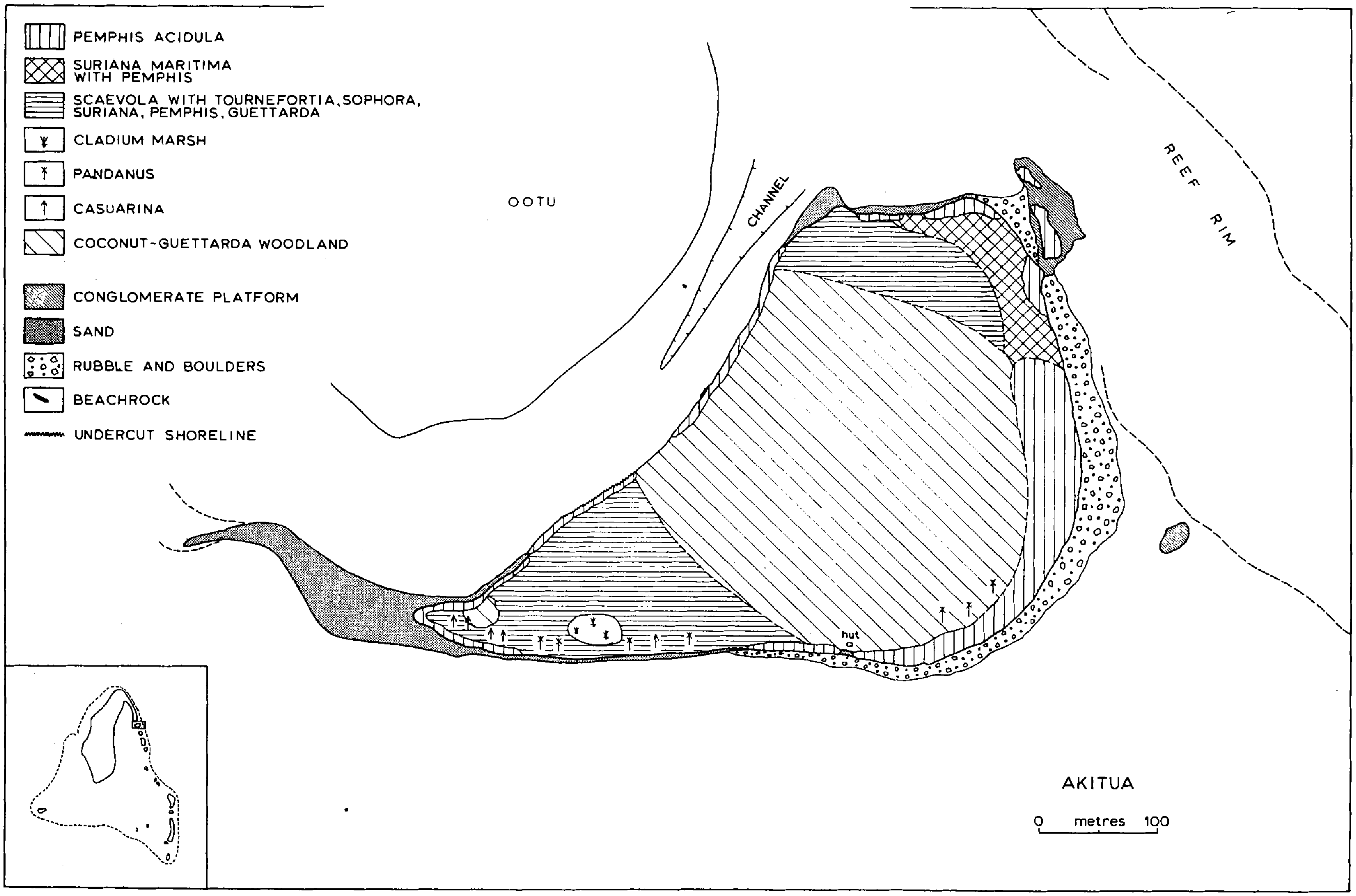


Figure 17. Akitua

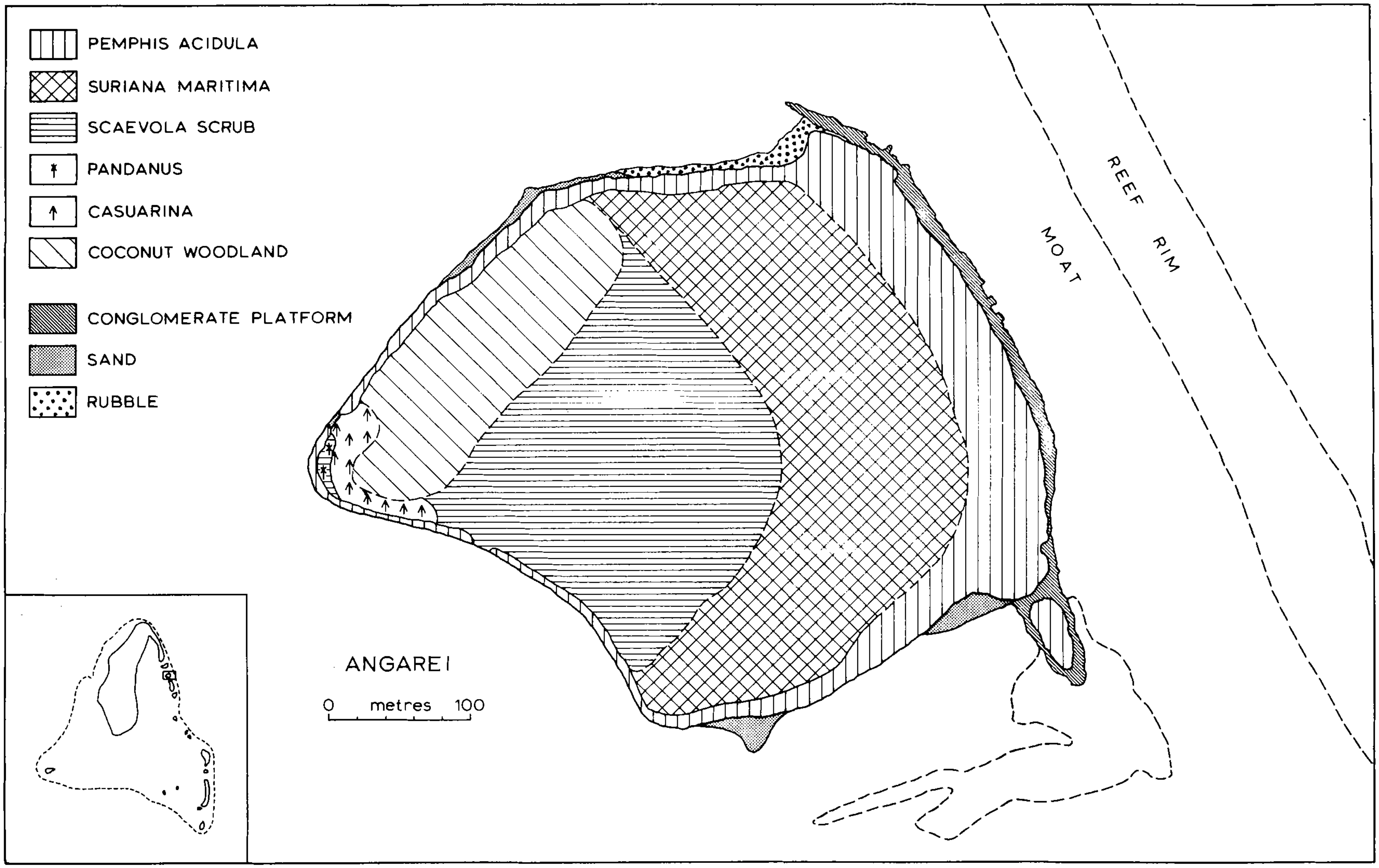


Figure 18. Angarei

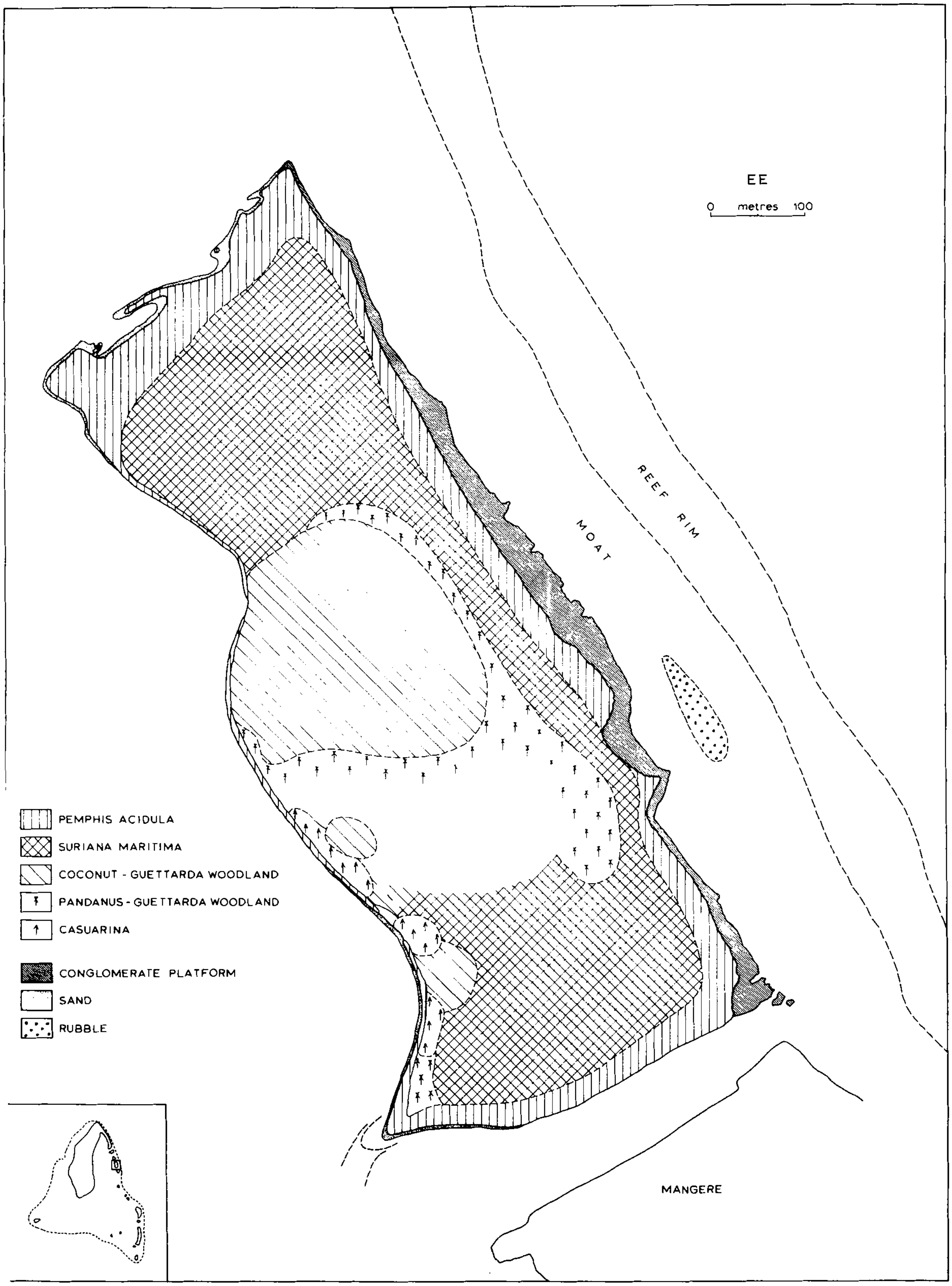

EE
0 metres 100
REEF RIM
MOAT
MANGERE
PEMPHIS ACIDULA
SURIANA MARITIMA
COCONUT - GUETTARDA WOODLAND
PANDANUS - GUETTARDA WOODLAND
CASUARINA
CONGLOMERATE PLATFORM
SAND
RUBBLE

Figure 19. Ee

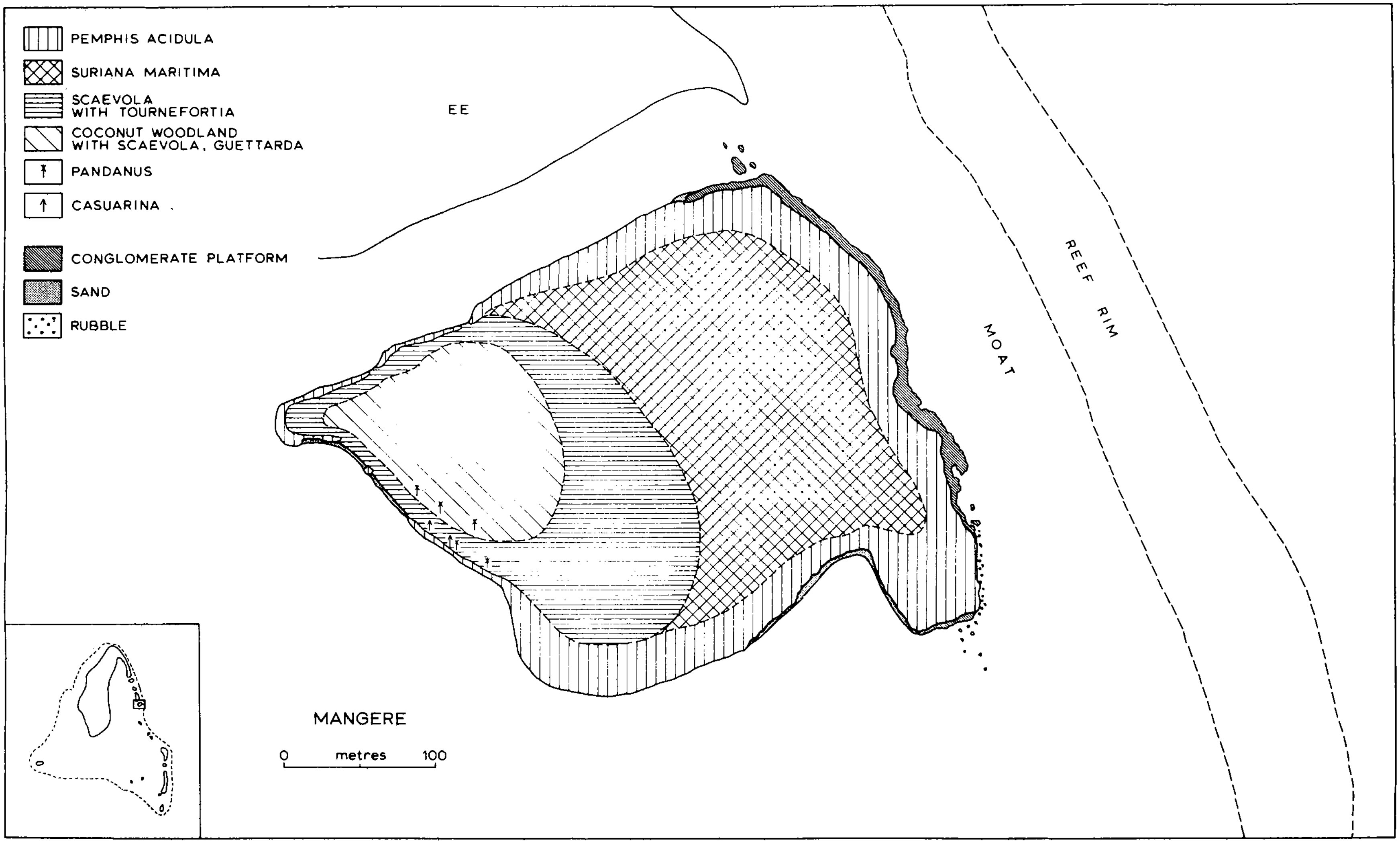


Figure 20. Mangere

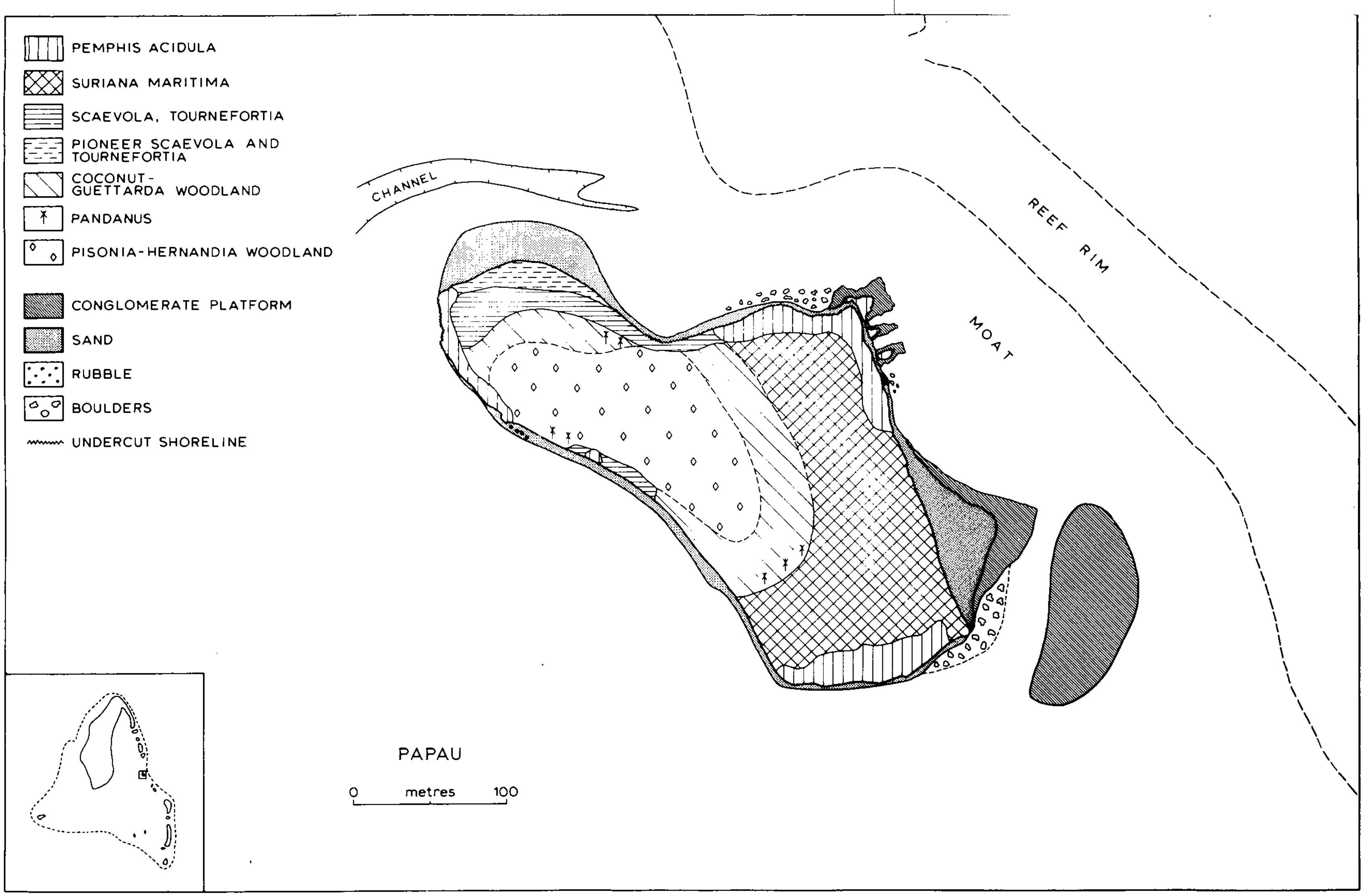
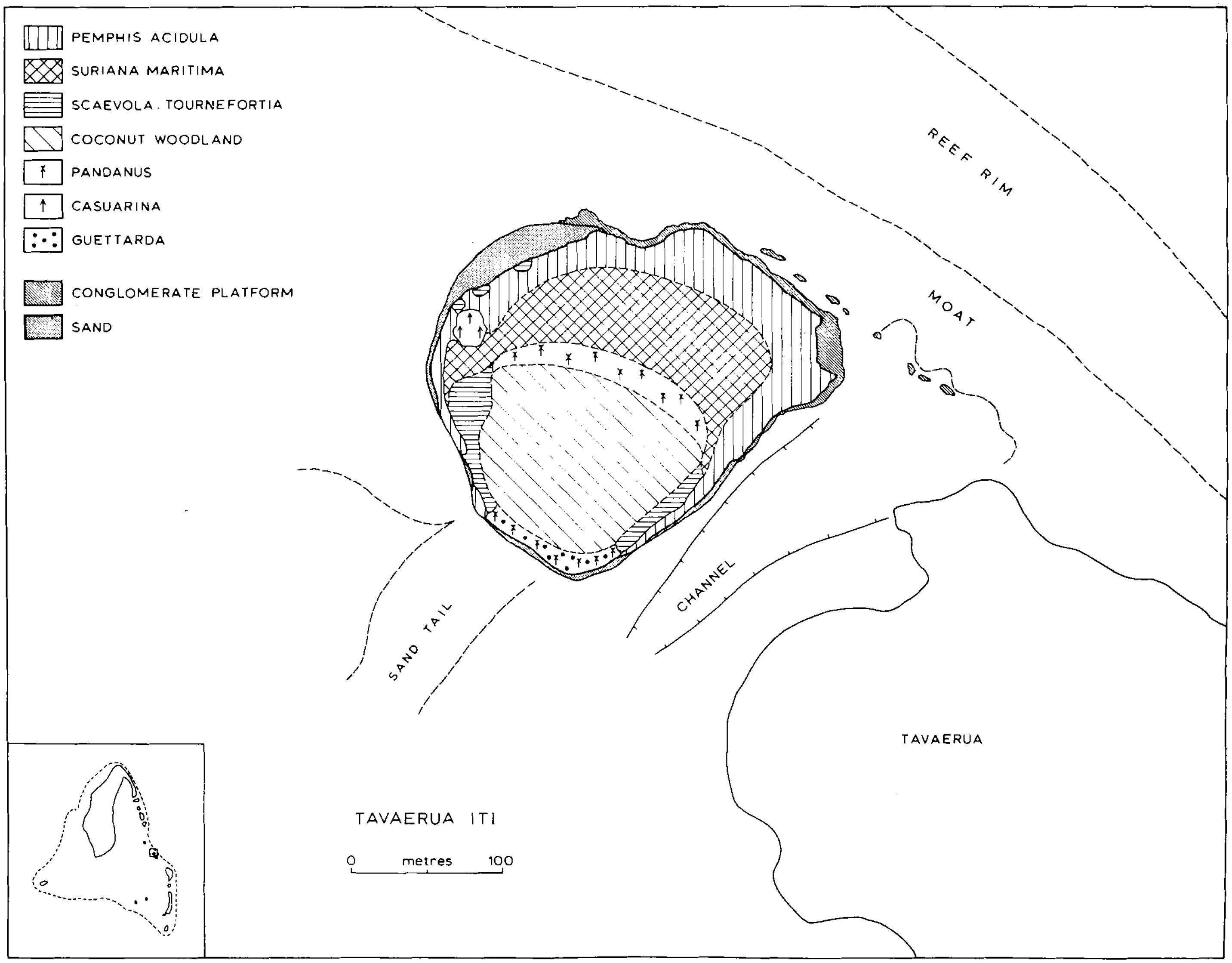


Figure 21. Papau


PEMPHIS ACIDULA
SURIANA MARITIMA
SCAEVOLA. TOURNEFORTIA
COCONUT WOODLAND
PANDANUS
CASUARINA
GUETTARDA
CONGLOMERATE PLATFORM
SAND
REEF RIM
MOAT
CHANNEL
SAND TAIL
TAVAERUA
TAVAERUA ITI
0 metres 100

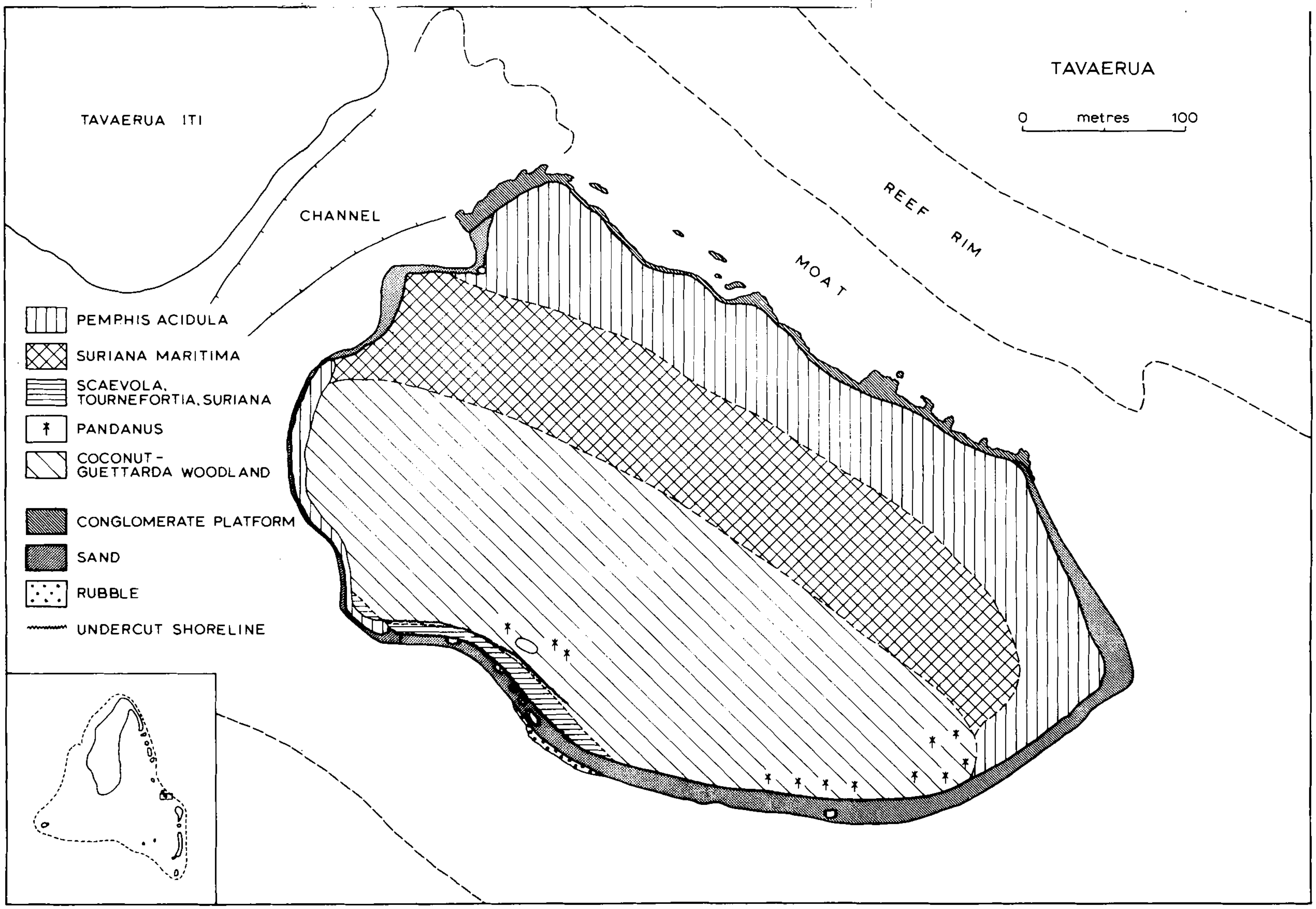


Figure 23. Tavaerua

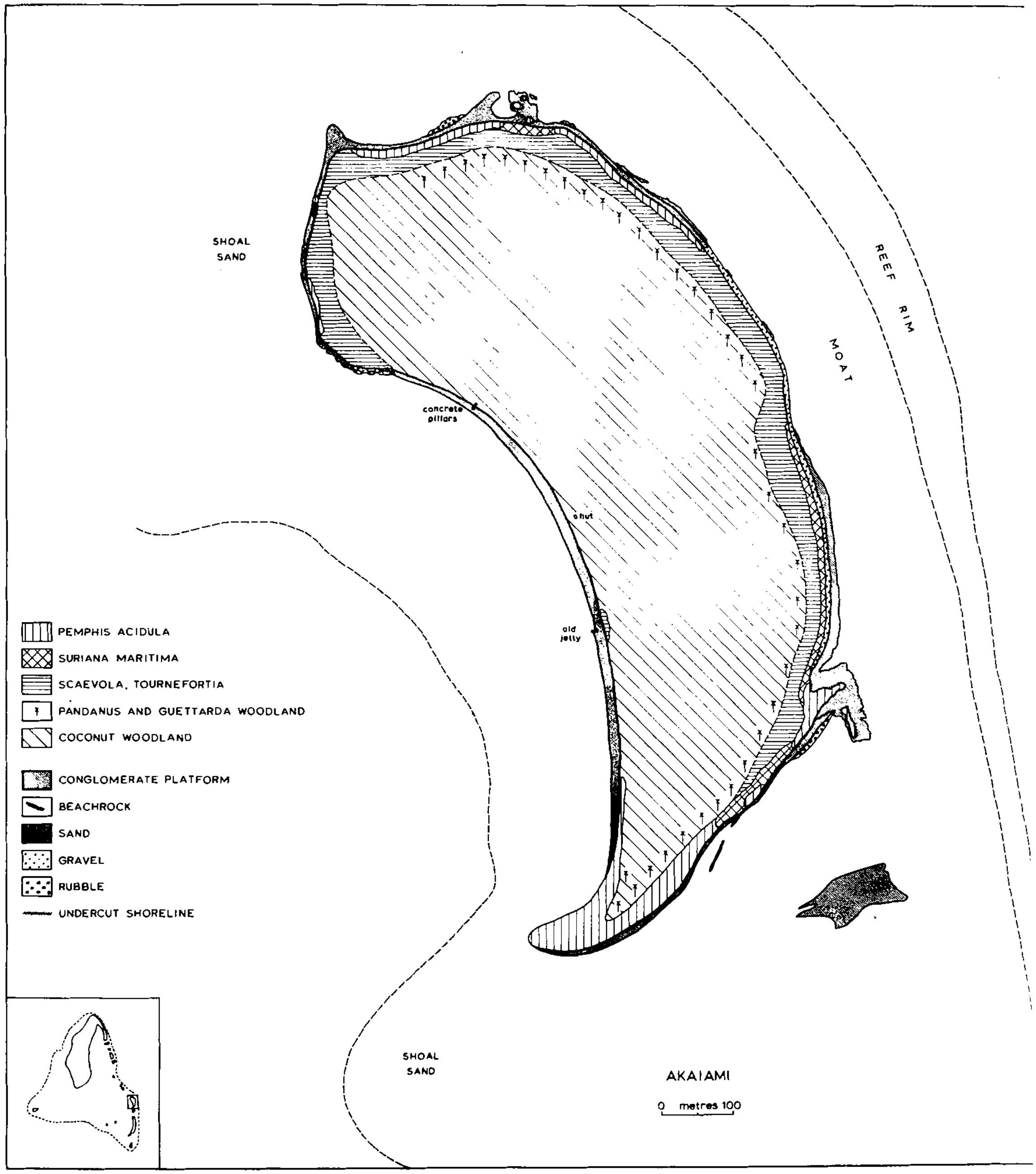


Figure 24. Akaiami

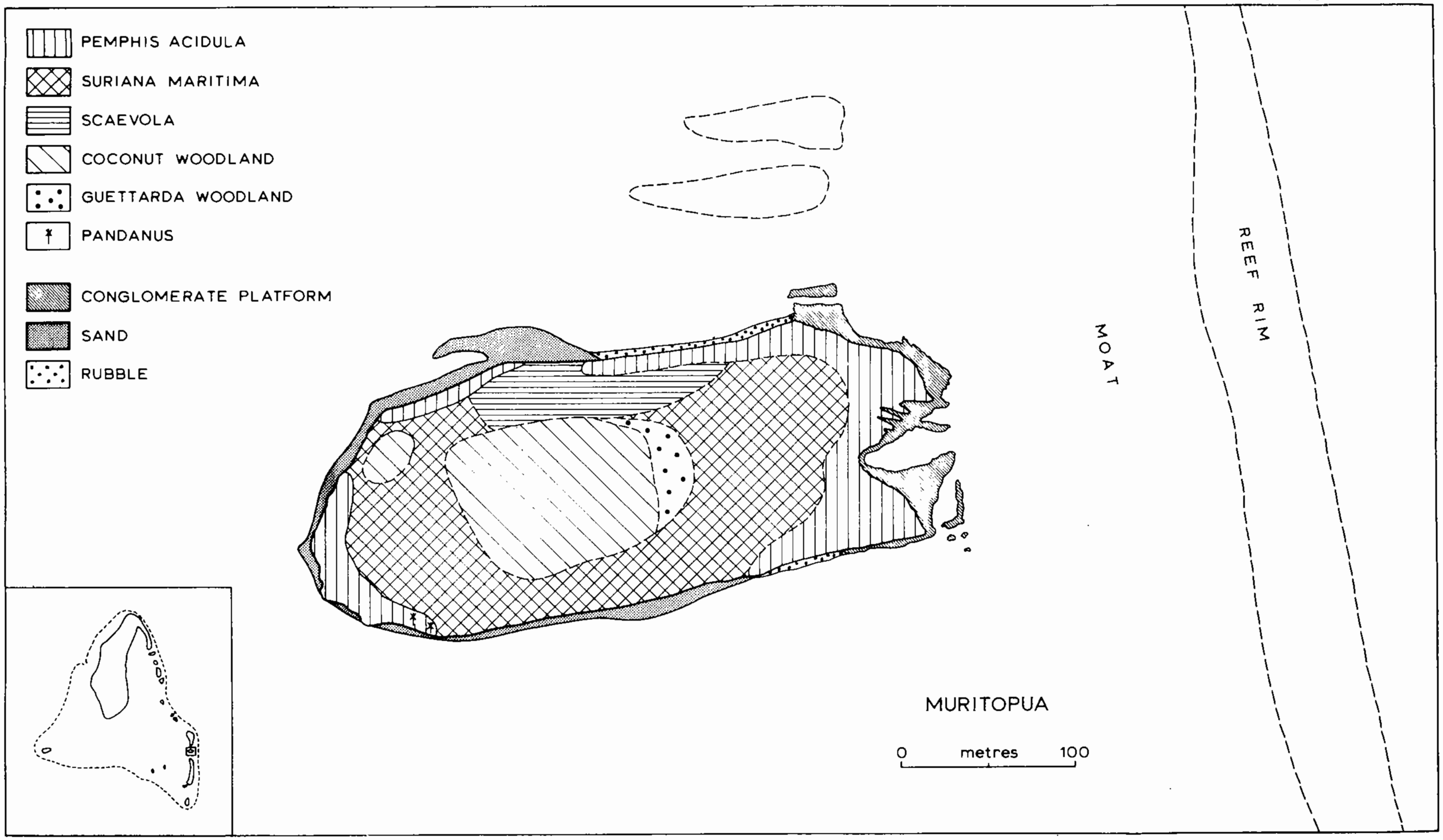


Figure 25. Muritapua

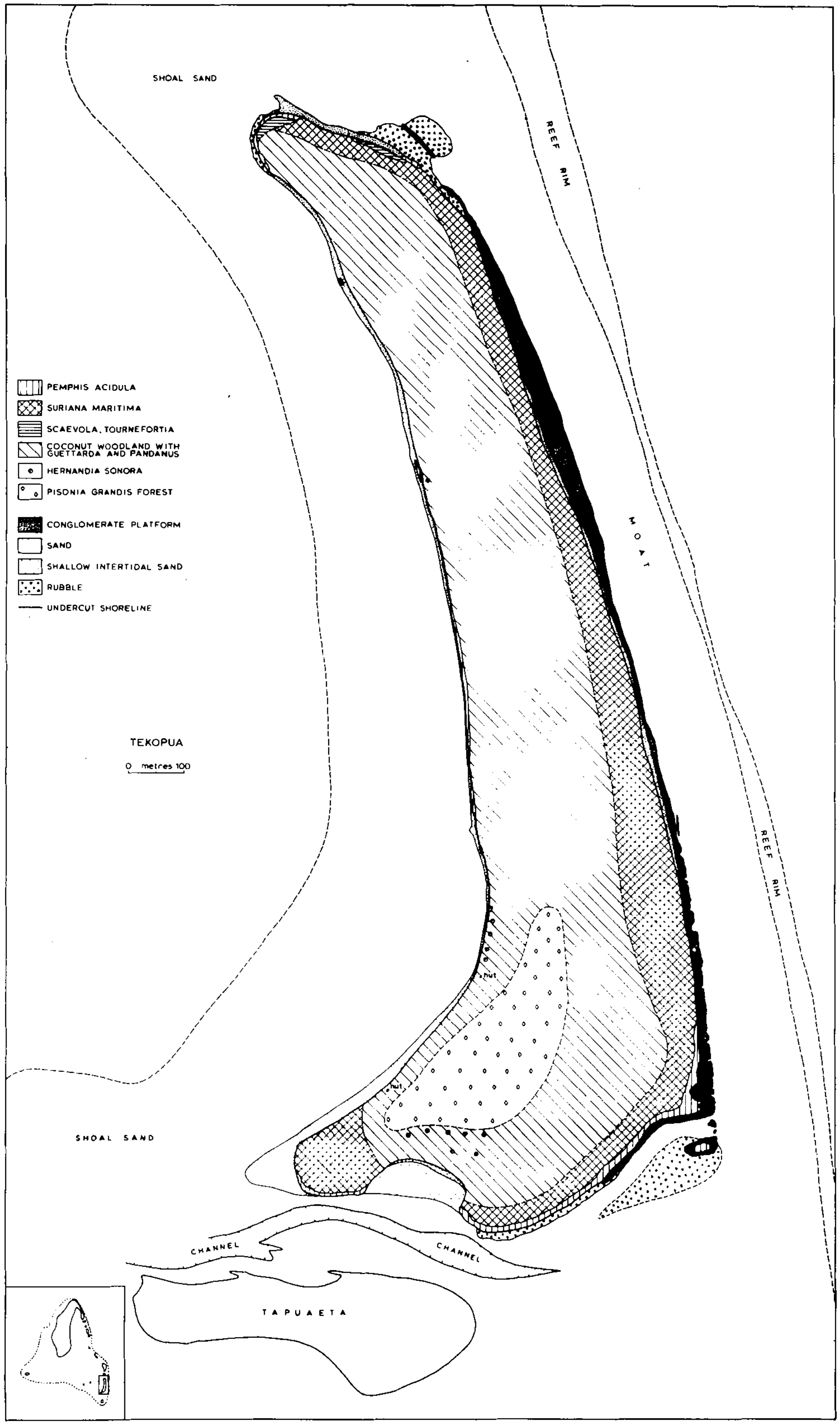


Figure 26. Tekopua

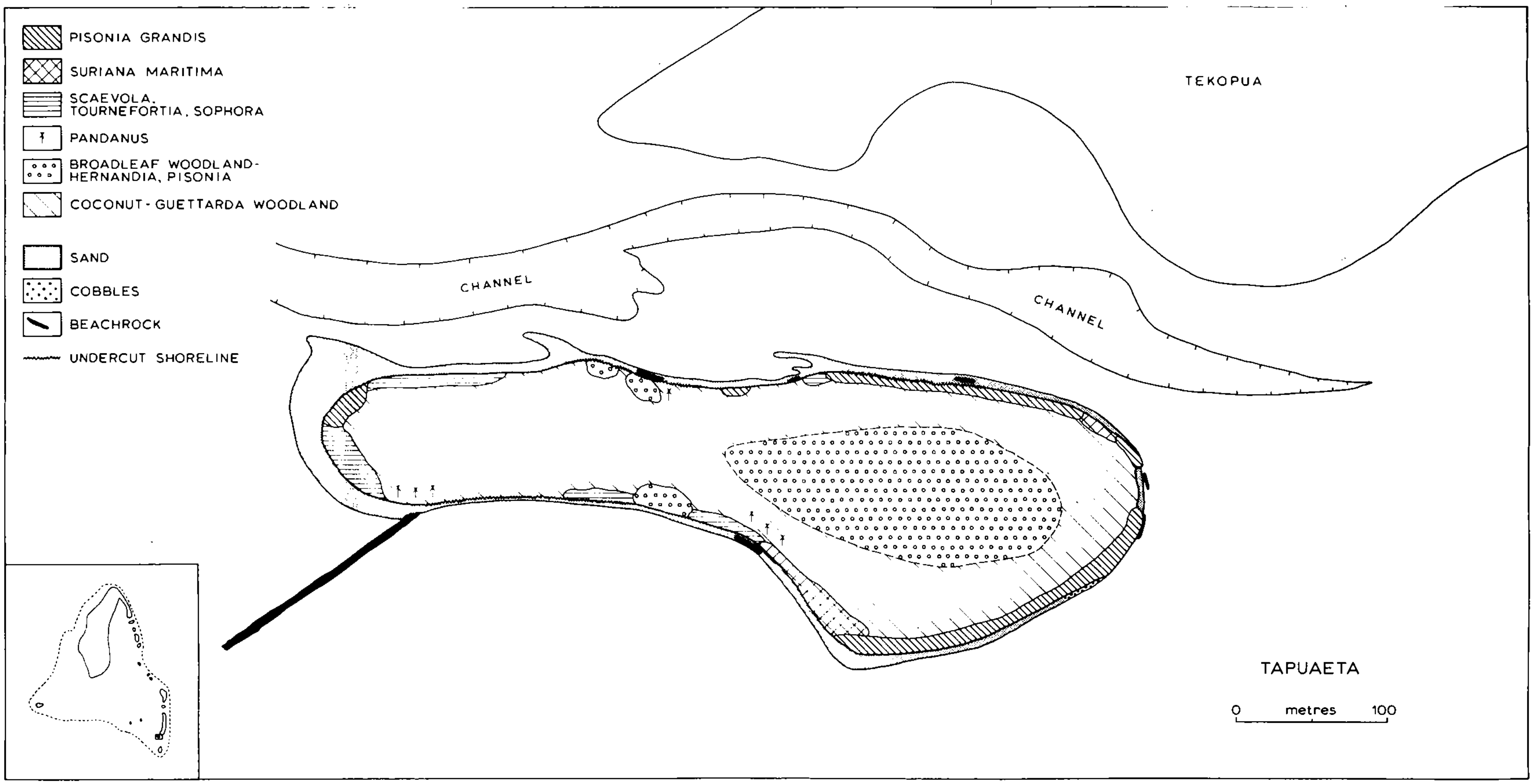
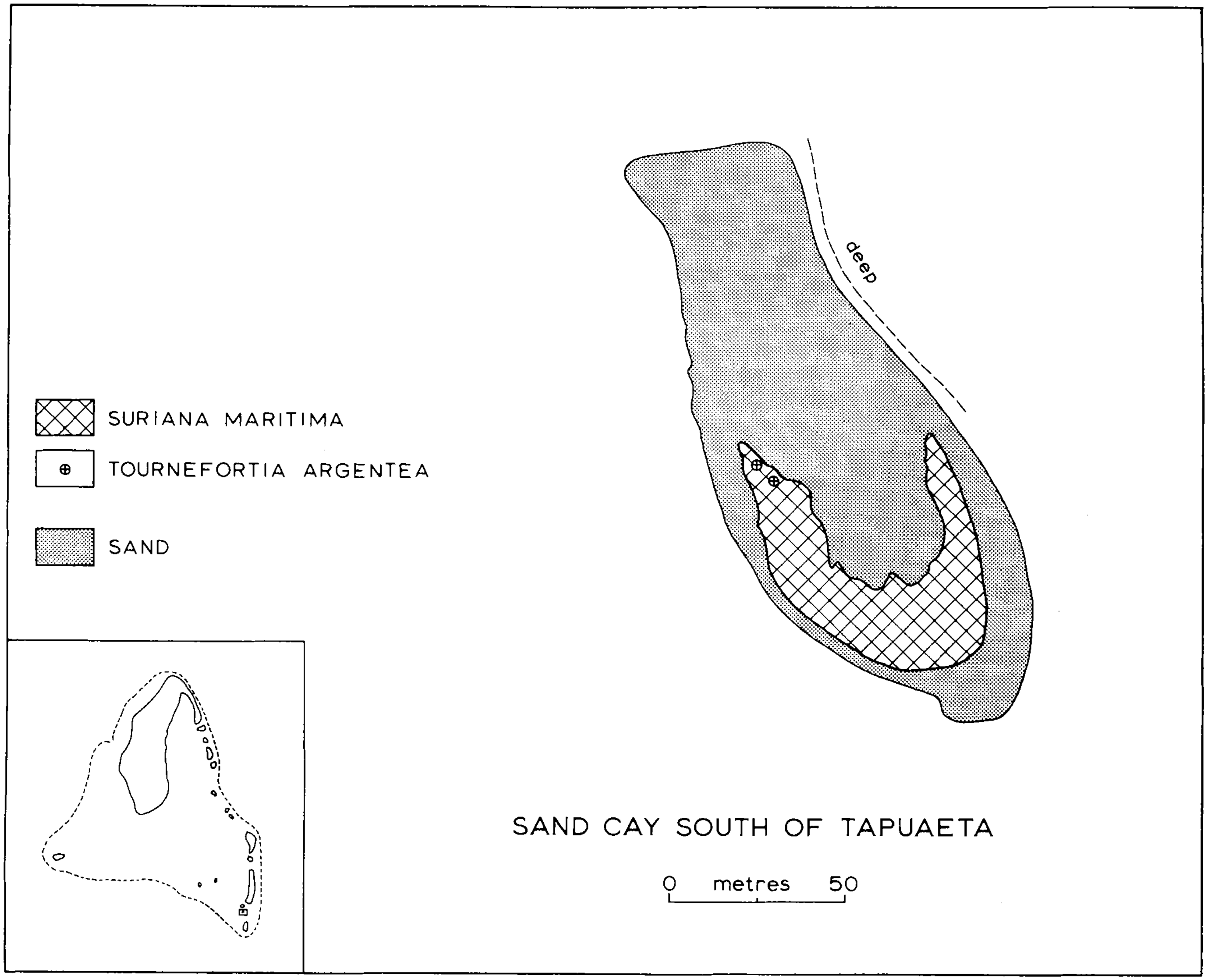


Figure 27. Tapuaeta


SURIANA MARITIMA
TOURNEFORTIA ARGENTEA
SAND
deep
SAND CAY SOUTH OF TAPUAETA
0 metres 50

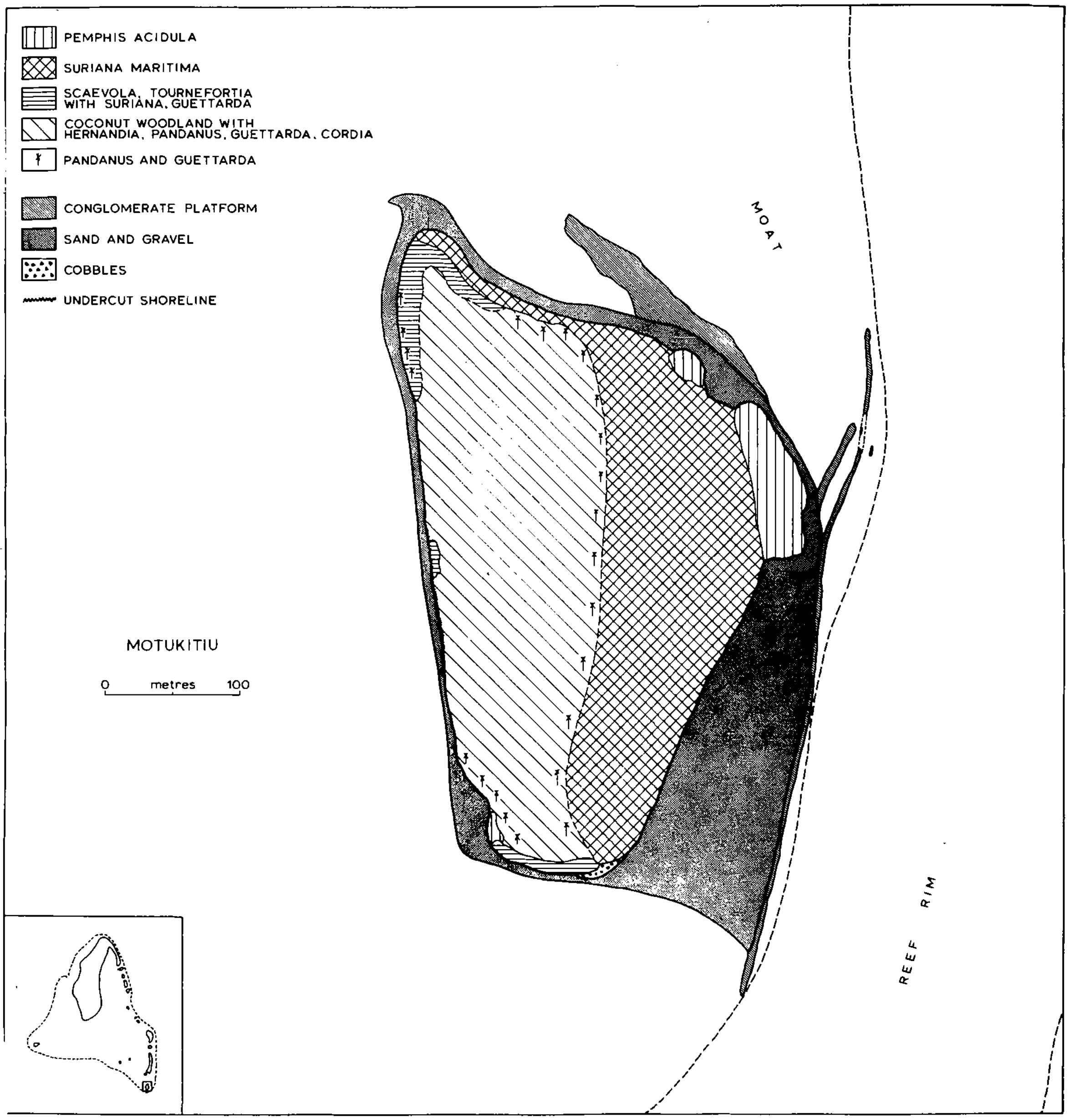


Figure 29. Motukitiu

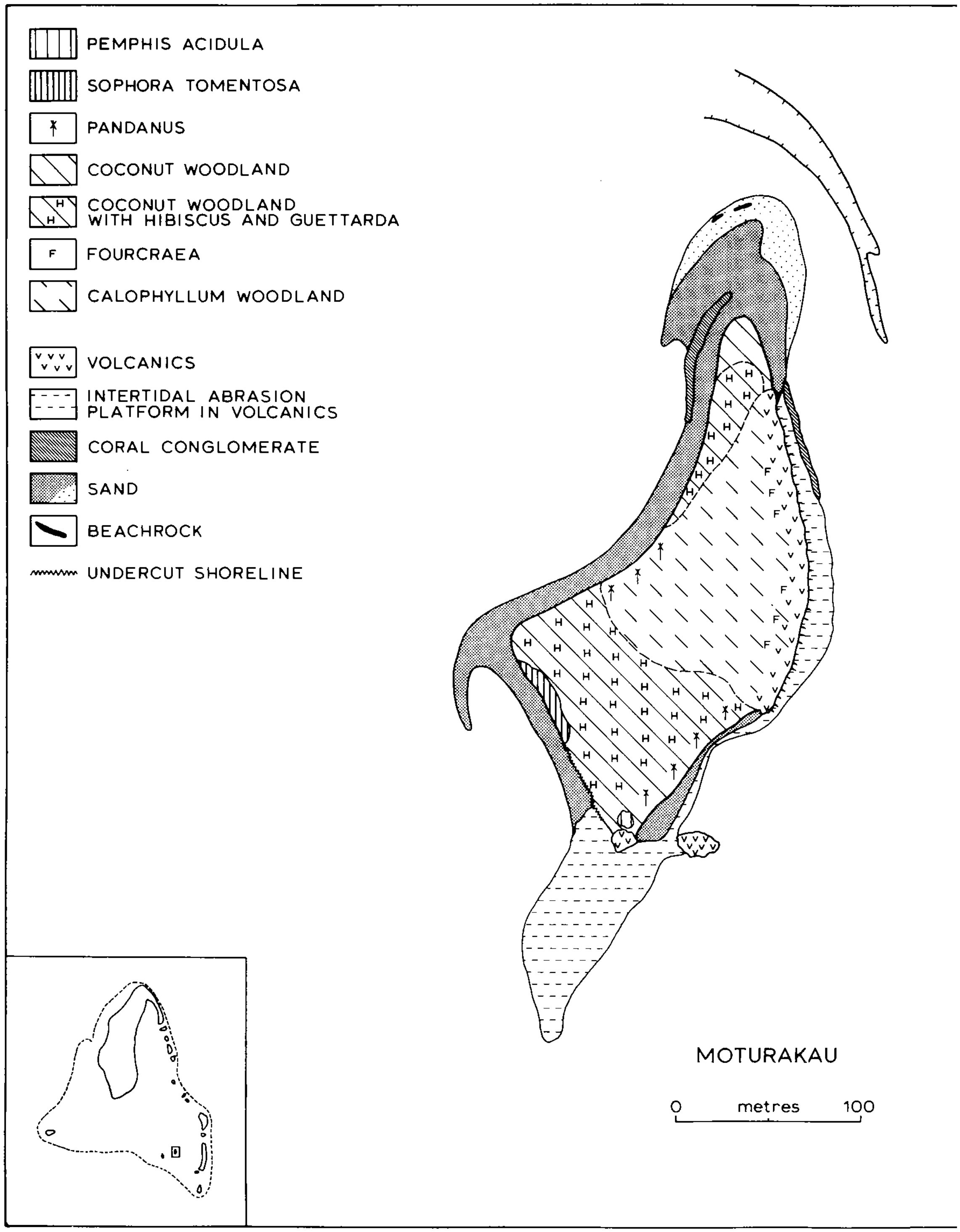


Figure 30. Moturakau

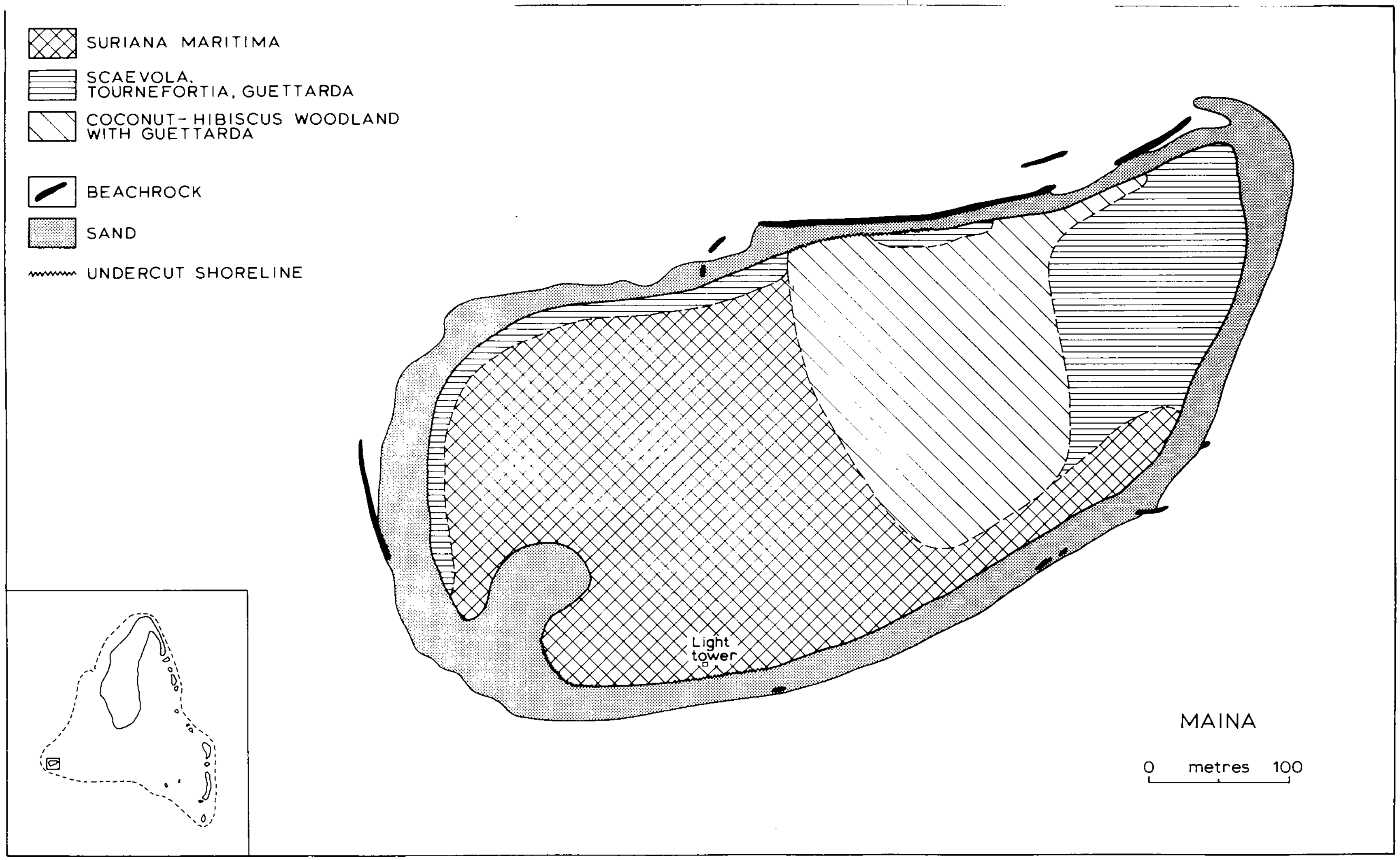


Figure 31. Maina

4. VASCULAR PLANTS OF AITUTAKI

F.R. Fosberg

Cheeseman (1903) and Wilder (1931) have published floras of Rarotonga, and Philipson (1971) has commented on collections made on that island in 1969. No list has previously been published for Aitutaki. Ferns collected on Aitutaki in 1969 are included in the treatment of ferns of the Cook Islands by Brownlie and Philipson (1971). The following list is mainly of plants collected on the main island of Aitutaki, but some plants from the reef islands are included; it may be compared with the list of plants from the reef islands of Rarotonga published by Fosberg (1972). Collecting localities are shown in Figure 32. Plants marked + are considered indigenous, those marked ∅ are considered aboriginal introductions, and those marked * recent introductions.

PSILOTACEAE

+ _Psilotum nudum_ (L.) Beauv.
Teaitu, _Stoddart 2332_ (US, CANTY, BISH).

POLYPODIACEAE

+ _Nephrolepis hirsutula_ (Forst.f.) Presl
Vaipae, _Stoddart 2230_ (US, CANTY); Anaunga, _Stoddart 2266_ (US, CANTY).

+ _Polypodium scolopendria_ Burm.f.
Akitua, _Stoddart 2223_ (US, CANTY).

+ _Thelypteris forsteri_ Mort. (?)
Anaunga, _Stoddart 2265_ (US, CANTY); Aretere, _Stoddart 2333_ (US, CANTY).

ARAUCARIACEAE

* _Araucaria heterophylla_ (Salisb.) Franco
Aremati, _Stoddart 2298_ (US, CANTY, BISH).

PANDANACEAE

+ _Pandanus tectorius_ Park.
Ootu, _Stoddart 2225_ (US).

GRAMINEAE

* _Cenchrus echinatus_ L.
Ootu, _Stoddart 2210_ (US, CANTY).

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* Coix lachryma-jobi L.
Vaipae, Stoddart 2245 (US, CANTY, BISH).

* Cynodon dactylon (L.) Pers.
Ootu, Stoddart 2192 (US, CANTY).

* Dactyloctenium aegyptium (L.) Willd.
Ootu, Stoddart 2191 (US, CANTY).

* Digitaria ciliaris (Retz.) Krel.
Ootu, Stoddart 2193 (US, CANTY).

ø Echinochloa colonum (L.) Beauv.
Vaipae, Stoddart 2227 (US), Stoddart 2242 (US, CANTY, BISH).

* Panicum maximum Jacq.
Vaipae, Stoddart 2235 (US, CANTY, BISH).

\+ Panicum reptans var. marquesensis (Brown) Fosb.
Anaunga, Stoddart 2267 (US, CANTY, BISH).

\+ Paspalum distichum L.
Arutanga, Stoddart 2292 (US).

ø Paspalum orbiculare Forst.
Vaipae, Stoddart 2242a (US).

* Sorghum bicolor (L.) Moench
Maungapu Hill, Stoddart 2276 (US, CANTY, BISH).

* Sporobolus africanus (Poir.) Robyns and Tourn.
Anaunga, Stoddart 2264 (US, CANTY, BISH); Maungapu Hill, Stoddart 2283 (US, CANTY).

\+ Stenotaphrum micranthum (Desv.) Hubb.
Papau, Stoddart 2346 (US, CANTY, BISH).

CYPERACEAE

\+ Cladium jamaicense Crantz
Akitua, Stoddart 2218 (US, CANTY, BISH).

* Cyperus alternifolius L.
Arutanga, Stoddart 2289 (US, CANTY, BISH); Rangiteia-Pata, Stoddart 2319 (US, CANTY, BISH).

* Cyperus brevifolius (Rottb.) Hassk.
Vaipae, Stoddart 2241 (US).

\+ Cyperus javanicus Houtt.
Ootu, Stoddart 2178 (US, CANTY, BISH).

* Cyperus cyperoides (L.) O.Ktze.
Vaipae, Stoddart 2226 (US, CANTY); Rangiteia-Pata, Stoddart 2320 (US).

\+ Fimbristylis cymosa R.Br.
Ootu, Stoddart 2180 (US, CANTY), Stoddart 2187 (US, CANTY, BISH); Rangiteia-Pata, Stoddart 2321 (US, CANTY).

PALMAE

ø Cocos nucifera L.
Widespread on main island and on all reef islands.

ARACEAE

ø Colocasia esculenta (L.) Schott
Stoddart, sight; main island.

* Xanthosoma sagittifolia (L.) Schott (?)
Aretea, Stoddart 2314 (US, CANTY).

COMMELINACEAE

* Commelina diffusa Burm.f.
Rangiteia-Pata, Stoddart 2325 (US).

LILIACEAE

* Gloriosa superba L.
Arutanga, Stoddart 2285 (US, CANTY).

AMARYLLIDACEAE

* Crinum procerum Carey
Teaitu, Stoddart 2316 (US, CANTY).

AGAVACEAE

ø Cordyline fruticosa (L.) Chev.
Maungapu Hill, Stoddart 2295 (US, CANTY).

* Furcraea probably F. foetida L.
Moturakau, Stoddart, sight.

TACCACEAE

ø Tacca leontopetaloides (L.) O.Ktze.
Teaitu, Stoddart 2331 (US, CANTY); Tapuaeta, Stoddart 2343 (US).

MUSACEAE

ø Musa sp.
Stoddart, sight.

CANNACEAE

* Canna indica L.
Vaipae, Stoddart 2255 (US, CANTY, BISH).

CASUARINACEAE

+ Casuarina equisetifolia L.
Ootu, Stoddart 2179 (US, CANTY, BISH).

URTICACEAE

+ Pipturus argenteus (Forst.f.) Wedd.
Motukitiu, Stoddart 2340 (US, CANTY, BISH).

MORACEAE

ø Artocarpus altilis (Park.) Fosb.
Aretea, Stoddart 2312 (US).

Ficus sp.
Arutanga-Aretea road, Stoddart, sight.

NYCTAGINACEAE

+ Boerhavia repens L.
Akitua, Stoddart 2222 (US, CANTY, BISH).

+ Boerhavia tetrandra Forst. (?)
Motukitiu, Stoddart 2342 (US, CANTY, BISH); Taverua Iti, Stoddart 2345 (US, CANTY, BISH).

+ Pisonia grandis R.Br.
Ootu, Stoddart 2174 (US, CANTY).

AMARANTHACEAE

+ Achyranthes canescens R.Br.
Motukitiu, Stoddart 2341 (US, CANTY, BISH).

PORTULACACEAE

* Portulaca oleracea L. (?)
Ootu, Stoddart 2196 (US, CANTY, BISH).

LAURACEAE

+ Cassytha filiformis L.
Ootu, Stoddart 2177 (US, CANTY).

* Persea americana L.
Aretea, Stoddart 2315 (US, CANTY, BISH).

HERNANDIACEAE

+ Hernandia sonora L.
Teruarei, Stoddart 2261 (US, CANTY).

CAPPARIDACEAE

+ Capparis cordifolia Lam.
Ootu, Stoddart 2297 (US, CANTY).

CRUCIFERAE

+ Lepidium bidentatum Montin
Papau, Stoddart 2347 (US, CANTY, BISH).

LEGUMINOSAE

* Abrus precatorius L.
Rangiteia-Pata, Stoddart 2329 (US, CANTY); Aremati, Stoddart 2306 (US).

* Acacia farnesiana (L.) Willd.
0 Arutanga, Stoddart 2304 (US, CANTY, BISH).

* Adenanthera pavonina L.
Vaipae, Stoddart 2330 (US).

* Alysicarpus vaginalis (L.) DC.
Rangiteia-Pata, Stoddart 2326 (US).

* Bauhinia monandra Kurz (?)
Vaipae, Stoddart 2337 (US, CANTY, BISH).

* Caesalpinia pulcherrima (L.) Sw.
Arutanga, Stoddart 2290 (US, CANTY, BISH).

+ Canavalia cathartica Thouars
Vaipae, Stoddart 2238 (US).

* Crotalaria pallida Ait.
Ootu, Stoddart 2183 (US, CANTY, BISH); Maungapu Hill, Stoddart 2277 (US, CANTY).

* Derris elliptica Benth.
Teaitu, Stoddart 2318 (US, CANTY).

* Delonix regia (Bojer) Raf.
Arutanga, Stoddart, sight; mentioned by Tamashiro (1964).

ø Erythrina variegata var. orientalis (L.) Merr.
Vaipeka, Stoddart 2339 (US, CANTY, BISH).

* Indigofera suffruticosa Mill.
Vaipae, Stoddart 2247 (US, CANTY, BISH).

ø Inocarpus fagifer (Park.) Fosb.
Teaitu, Stoddart 2317 (US, CANTY, BISH).

+ Leucaena insularum (Lam.) Dän.
Ootu, Stoddart 2175 (US, CANTY), Stoddart 2203 (US, CANTY, BISH).

* Mimosa pudica L.
Ootu, Stoddart 2212 (US).

+ Mucuna gigantea (Willd.) DC.
Arutanga, Stoddart 2303 (US, CANTY, BISH).

+ Sophora tomentosa L.
Ootu, Stoddart 2185 (US, CANTY, BISH), Stoddart 2190 (US, CANTY).

+ Vigna marina (Burm.) Merr.
Ootu, Stoddart 2184 (US, CANTY).

RUTACEAE

* Citrus sp.
Main island, Stoddart, sight.

SURIANACEAE

+ Suriana maritima L.
Ootu, Stoddart 2204 (US, CANTY, BISH).

ANACARDIACEAE

* Mangifera indica L.
Vaipae, Stoddart 2229 (US, CANTY, BISH).

EUPHORBIACEAE

* Acalypha godseffiana Mast.
Arutanga, Stoddart 2288 (US, CANTY, BISH).

* Acalypha wilkesiana var. circinata M.-A.
Aretea, Stoddart 2310 (US, CANTY, BISH).

ø Aleurites moluccana (L.) Willd.
Vaipae, Stoddart 2239 (US, CANTY, BISH); Rangiteia-Pata, Stoddart 2323 (US).

+ Euphorbia chamissonis (Kl. and Gke.) Boiss
Ootu, Stoddart 2200 (US, CANTY, BISH).

* Euphorbia hirta L.
Ootu, Stoddart 2211 (US); Maungapu Hill, Stoddart 2282 (US).

* Manihot esculenta Crantz
Arutea, Stoddart 2307 (US, CANTY, BISH).

RHAMNACEAE

+ Colubrina asiatica (L.) O.Ktze.
Ootu, Stoddart 2182 (US, CANTY, BISH).

TILIACEAE

+ Corchorus torresianus Gaud.
Ootu, Stoddart 2173 (US, CANTY, BISH).

+ Triumfetta procumbens Forst.
Ootu, Stoddart 2195 (US, CANTY, BISH).

* Triumfetta rhomboidea Jacq.
Vaipae, Stoddart 2243 (US, CANTY, BISH); Maungapu Hill, Stoddart 2278 (US, CANTY).

MALVACEAE

ø Hibiscus tiliaceus L.
Vaipae, Stoddart 2251 (US, CANTY); Teruarei, Stoddart 2260 (US).

* Hibiscus (ornamental hybrid)
Vaipae, Stoddart 2240 (US, CANTY, BISH).

* Sida rhombifolia L.
Akitua, Stoddart 2220 (US, CANTY); Vaipae, Stoddart 2234 (US, CANTY, BISH).

ø Thespesia populnea (L.) Sol. ex Correa
Rapota, Stoddart, sight.

BOMBACACEAE

* Ceiba pentandra (L.) Gaertn.
Arutanga, Stoddart 2291 (US).

GUTTIFERAE

+ Calophyllum inophyllum L.
Teruarei, Stoddart 2262 (US, CANTY, BISH).

CARICACEAE

* Carica papaya L.
Perekiatu, Stoddart 2286 (US, CANTY, BISH).

PASSIFLORACEAE

* Passiflora rubra L.
Vaipae, Stoddart 2244 (US, CANTY).

CUCURBITACEAE

* Cucurbita maxima Duch. (?)
Vaipae, Stoddart 2246 (US, CANTY, BISH).

* Luffa cylindrica (L.) Roem.
Teruarei, Stoddart 2259 (US, CANTY, BISH); Rangiteia-Pata, Stoddart 2322 (US, CANTY).

* Momordica charantia L.
Ootu, Stoddart 2199 (US, CANTY).

LYTHRACEAE

+ Pemphis acidula Forst.
Ootu, Stoddart 2181 (US, CANTY, BISH).

LECYTHIDACEAE

+ Barringtonia asiatica (L.) Kurz
Aretea, Stoddart 2308 (US, CANTY, BISH).

MYRTACEAE

* Eugenia uniflora L.
Aretea, Stoddart 2309 (US, CANTY, BISH).

* Eugenia jambos L.
Aretea, Stoddart 2311 (US, CANTY, BISH).

ONAGRACEAE

ø Ludwigia octovalvis (Jacq.) Raven
Vaipae, Stoddart 2250 (US, CANTY, BISH).

OLEACEAE

* Jasminum officinale var. grandiflorum (L.) Kobuski
Vaipae, Stoddart 2254 (US, CANTY, BISH).

APOCYNACEAE

* Allamanda cathartica L.
Vaipae, Stoddart 2299 (US).

* Catharanthus roseus (L.) G. Don
Vaipae, Stoddart 2253 (US, CANTY, BISH).

* *Nerium oleander* var. *indicum* (Mill.) Deg. and Greenw.
Arutanga, *Stoddart 2302* (US, CANTY).

* *Tabernaemontana divaricata* (L.) R.Br.
Vaipae, *Stoddart 2257* (US, CANTY, BISH).

CONVOLVULACEAE

ø *Ipomoea batatas* (L.) Lam.
Main island, Stoddart, sight.

\+ *Ipomoea indica* (Burm.) Merr.
Vaipeka, *Stoddart 2338* (US, CANTY, BISH).

\+ *Ipomoea littoralis* BL. (?)
Aremati, *Stoddart 2305* (US, CANTY, BISH).

\+ *Ipomoea macrantha* R. and S.
Ootu, *Stoddart 2188* (US); Akitua, *Stoddart 2224* (US, CANTY, BISH).

\+ *Ipomoea pes-caprae* subsp. *brasiliensis* (L.) Ooststr.
Ootu, *Stoddart 2208* (US, CANTY, BISH).

BORAGINACEAE

\+ *Cordia subcordata* Lam.
Akitua, *Stoddart 2219* (US, CANTY, BISH).

\+ *Heliotropium anomalum* H. and A.
Ootu, *Stoddart 2213* (US, CANTY, BISH).

\+ *Tournefortia argentea* L.f.
Ootu, *Stoddart 2214* (US).

VERBENACEAE

* *Clerodendrum speciosissimum* Van Geert
Vaipae, *Stoddart 2256* (US, CANTY, BISH).

* *Stachytarpheta urticifolia* Sims
Vaipae, *Stoddart 2236* (US, CANTY, BISH).

LABIATAE

* *Coleus scutellarioides* L.
Rangiteia-Pata, *Stoddart 2324* (US, CANTY).

* *Leonurus sibiricus* L.
Aretea, *Stoddart 2313* (US, CANTY, BISH).

* *Ocimum suave* Willd.
Vaipae, *Stoddart 2258* (US, CANTY, BISH); Maungapu Hill, *Stoddart 2293* (US, CANTY, BISH).

* Salvia occidentalis L.
Vaipae, Stoddart 2233 (US, CANTY, BISH); Maungapu Hill, Stoddart 2284 (US).

SOLANACEAE

* Capsicum frutescens L.
Vaipae, Stoddart 2248 (US, CANTY, BISH).

* Datura metel L.
Ootu, Stoddart 2207 (US); Arutanga, Stoddart 2287 (US, CANTY, BISH).

* Solanum lycopersicum L.
Vaipae, Stoddart 2228 (US).

ø Solanum nigrum var. americanum (Mill.) O.E.Sch.
Ootu, Stoddart 2198 (US, CANTY, BISH); Vaipae, Stoddart 2249 (US, CANTY, BISH).

SCROPHULARIACEAE

+ Lindernia crustacea (L.) F.Muell. (?)
Rangiteia-Pata, Stoddart 2327 (US).

BIGNONIACEAE

* Spathodea campanulata Beauv.
Anaunga, Stoddart 2268 (US, CANTY, BISH).

RUBIACEAE

+ Guettarda speciosa L.
Ootu, Stoddart 2189 (US, CANTY, BISH).

ø Morinda citrifolia L.
Ootu, Stoddart 2206 (US, CANTY, BISH).

* Spermacoce suffrutescens Jacq.
Ootu, Stoddart 2201 (US, CANTY).

+ Timonius polygama (Forst.) Rob.
Ootu, Stoddart 2176 (US, CANTY, BISH); Akitua, Stoddart 2221 (US, CANTY, BISH); Tavaerua Iti, Stoddart 2344 (US, CANTY).

CAMPANULACEAE

* Hippobroma longiflora (L.) G.Don
Main island, south point, Stoddart 2263 (US, CANTY, BISH

GOODENIACEAE

+ Scaevola taccada var. tuamotuensis St J.
 Ootu, Stoddart 2186 (US, CANTY, BISH).

COMPOSITAE

* Ageratum conyzoides L.
 Vaipae, Stoddart 2231 (US, CANTY); Maungapu Hill, Stoddart 2294 (US, CANTY, BISH).

* Bidens pilosa L.
 Ootu, Stoddart 2202 (US, CANTY, BISH); Vaipae, Stoddart 2232 (US, CANTY); Maungapu Hill, Stoddart 2281 (US, CANTY).

* Eclipta prostrata (L.) Hassls.
 Rangiteia-Pata, Stoddart 2328 (US, CANTY, BISH).

ø Emilia sonchifolia (L.) DC.
 Ootu, Stoddart 2194 (US, CANTY); Vaipae, Stoddart 2252 (US, CANTY, BISH); Maungapu Hill, Stoddart 2279 (US, CANTY, BISH).

* Gaillardia pulchella var. picta (Sweet) Gray
 Ootu, Stoddart 2205 (US, CANTY, BISH), Stoddart 2209 (US, CANTY, BISH).

* Sonchus oleraceus L.
 Ootu, Stoddart 2197 (US, CANTY, BISH).

* Tagetes erecta L.
 Vaipae, Stoddart 2301 (US, CANTY).

* Tagetes patula L. (?)
 Vaipae, Stoddart 2300 (US).

* Tithonia diversifolia (Hemsl.) A. Gray
 Vaipae, Stoddart 2237 (US, CANTY, BISH).

* Vernonia cinerea (L.) Less.
 Maungapu Hill, Stoddart 2280 (US).

REFERENCES

Brownlie, G. and Philipson, W.R. 1971. Pteridophyta of the southern Cook Group. Pacif. Sci. 25: 502-511.

Cheeseman, T.F. 1903. The flora of Rarotonga, the chief island of the Cook Group. Trans. Linn. Soc. Lond. (1) 6: 261-313.

Fosberg, F.R. 1972. List of vascular flora /Reef islands of Rarotonga/. Atoll Res. Bull. 160: 9-14.

Philipson, W.R. 1971. Floristics of Rarotonga. Bull. R. Soc. N.Z. 8: 49-54.

Tamashiro, M. 1964. Observations on the larval ecology of Aedes (Stegomyia) polynesiensis Marks on Aitutaki, southern Cook Islands. World Health Organization Report WHO/EB2/22, 7 October 1964, 29 pp.

Wilder, G.P. 1931. Flora of Rarotonga. Bishop Mus. Bull. 86: 1-113.

ADDENDUM

The specimens Stoddart 2264 and 2283, referred on pages 74, 117 and 122 to Sporobolus africanus are in all probability Sporobolus fertilis (Steud.) Clayton, though the species in the S. indicus complex are extremely difficult to distinguish satisfactorily. - F.R.F.

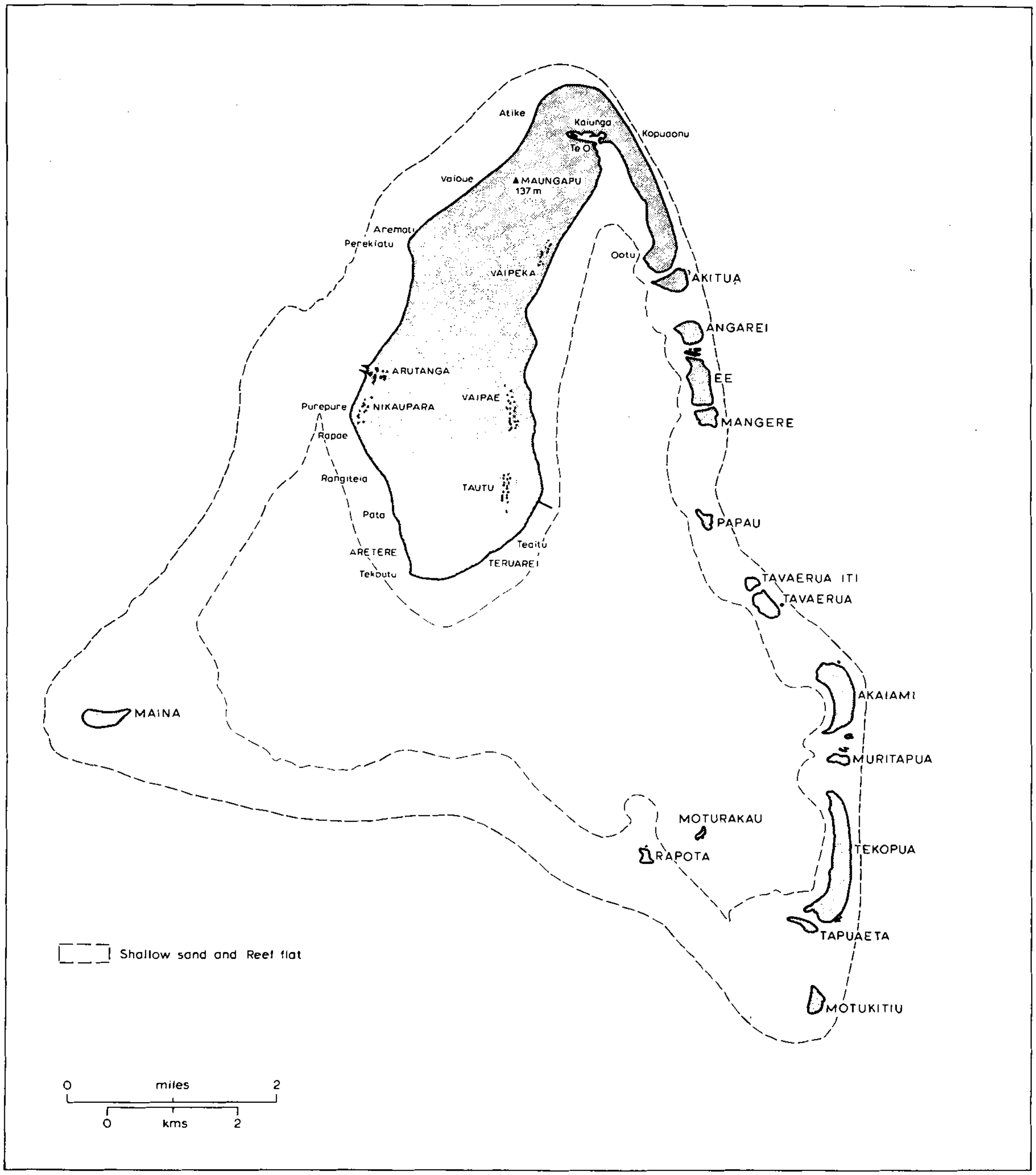

Figure 32. Aitutaki plants: collecting localities

5. BRYOPHYTES FROM THE COOK ISLANDS

C.C. Townsend

Calymperes tenerum C.M.
Aitutaki: Maungapu Hill, Stoddart 2296 (K); Teruarei, Stoddart 2336 (K).

Calymperes volkensii Broth.
Rarotonga: Oneroa, Stoddart 2101 (K).

Brachymenium indicum (Doz. and Molle.) Bosch and Lac.
Aitutaki: Akitua, Stoddart 2216 (K); Te O, Stoddart 2271 (sterile, probably this species) (K).

Ectropothecium sp.
Rarotonga: Oneroa, Stoddart 2102 (K).

6. VEGETATION AND FLORISTICS OF THE AITUTAKI MOTUS

D.R. Stoddart

The vegetation of the Aitutaki reef islands is of interest for several reasons. First, Aitutaki is remotely located in the central Pacific on a diversity gradient extending from the densely vegetated and floristically diverse atolls of the Carolines and southern Marshalls to isolated and depauperate islands such as Clipperton. The gradient effects should be apparent at Aitutaki in the absence of species restricted to the western Pacific (notably the mangroves and the seagrasses, but also many species of broadleaf trees). Second, the comparatively low floristic diversity will mean that certain species will be more important components of the vegetation than they are elsewhere. This is the case with shrubs such as Timonius polygama, abundant at Aitutaki and at Mopelia and throughout the Tuamotus to Henderson Island; and with Euphorbia chamissonis, though this has a wider distribution. Third, the unusual geomorphology of the motus, with stormswept seaward gravel spreads and conglomerate platforms and relatively small sand areas, should influence the type and distribution of the vegetation units present. And fourth, the range of size of the motus should have implications for the MacArthur and Wilson theory of island biogeography; the presence of a high island immediately adjacent to the motus adds a further factor to the analysis of area, distance and ecological diversity.

In this paper, we first consider the floristics of the motus, in terms both of biogeography and of island size and floristic diversity, and then discuss the vegetation units, emphasizing the place of Aitutaki in general Pacific distribution patterns, and noting the absence of certain widespread types which might have been expected in this location. The discussion covers only the vascular plants listed in the accompanying paper by F.R. Fosberg, and does not extend to either marine algae or to terrestrial algae, fungi, lichens, liverworts and mosses.

FLORISTICS OF THE MOTUS

Size of the flora

During the 1969 Expedition 72 numbers of plants (including 3 mosses and lichens) were collected on the Rarotonga reef islands, and 183 (including 14 mosses, liverworts, fungi, lichens and blue-green algae) at Aitutaki. The Rarotonga vascular plants are reported by Fosberg in Stoddart and Fosberg (1972), those from Aitutaki by Fosberg in this Bulletin.

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Of the total of ca 140 species recorded at Aitutaki, 80 or 57 per cent are only found on the main island and not on the motus. 62 species are recorded from the smaller islands, including the Ootu peninsula. Excluding the volcanic islets of Rapota and Moturakau and also the much-disturbed Ootu peninsula the number of species recorded from the motus is 45 (32 per cent). This compares with 41 species from the three Rarotonga reef islands. Only 26 species are common to the two lists, however: 19 Aitutaki motu species are missing from the Rarotonga islands, and 15 Rarotonga species are not recorded from the Aitutaki islands. Some of the missing species, where they do occur, are extremely common; their absence is further discussed below.

The 45 Aitutaki motu species comprise a flora comparable in size with that of other central and east Pacific atolls (Table 11). At least 50 per cent of the species can be considered indigenous, and this indigenous flora is intermediate in size between those of remote, small or dry islands such as Clipperton, Vostok and Flint, and large, wet or more accessible atolls such as Jaluit, Arno, Kapingamarangi and Onotoa. The number of species is similar to that for atolls in the Society and Tuamotu Islands: the nearest atoll for which a comparable list is available is Mopelia in the Societies (Sachet, in litt.).

Composition of the flora

The Cook Islands, by their remote location in the central Pacific, lack many species common on west Pacific atolls the ranges of which terminate in Tonga, Fiji or Samoa. Van Balgoo (1960, p.410) has clearly shown the magnitude of the floristic demarcation between Tonga and the Cooks when considering the total floras of these groups: in Tonga 104 genera are of 'western' affinity (Palaeotropical, Malaysian-Australian, Australian) compared with 41 such genera in the Cooks. Philipson (1971) has reinforced this conclusion with an analysis of the affinities of the woody species of Rarotonga, though clearly Pacific and pan-tropical components are more important in the strand flora.

15 tree species have been recorded from the Aitutaki islands, 4 of them only from the volcanic islets. Only 8 species are common: *Cocos*, *Guettarda*, *Pandanus*, *Morinda*, *Casuarina*, *Hernandia*, *Leucaena* and *Pisonia*. *Hibiscus* is widely distributed but rare, in sharp contrast to its abundance on the main island. The rarity of three species (*Calophyllum inophyllum*, *Cordia subcordata*, *Thespesia populnea*) is striking when compared with their wide distribution and abundance on other Pacific islands. Thus *Thespesia*, important on atolls such as Kapingamarangi, forms trees 20 m tall as close to Aitutaki as Penrhyn and Manihiki in the northern Cooks (Linton 1933). Both *Pandanus* and *Cordia* are also absent from the reef islands of Rarotonga. Other common western Pacific atoll

species which are absent from the reef islands are:

Allophylus timorensis Common on Arno and Kapingamarangi, forms a major woodland type in the southern Marshalls.

Barringtonia asiatica Present on mainland Rarotonga and Aitutaki, and on the Aitutaki volcanic islets.

Intsia bijuga Common on Arno and other Marshalls atolls; reaches its eastern limit in Tonga and Samoa (Yuncker, 1959).

Neiosperma oppositifolia Important woodland type in the Marshalls and extends to the Line Islands; absent in the Tokelaus.

Premna obtusifolia Common in western Pacific atolls and high islands eastward to Marquesas and Henderson.

Soulamea amara Common at Kapingamarangi and in most western Pacific atolls.

Of particular significance is the absence of mangroves from the Cook Islands. Six species in the genera Rhizophora, Bruguiera, Lumnitzera and Xylocarpus are recorded from Tonga (Yuncker, 1959) and three from Samoa in the genera Rhizophora, Bruguiera and Xylocarpus (Setchell, 1924). They are also absent from the Society Islands and the Tuamotus and other eastern and northern Pacific atolls, including the Tokelaus (though introduced in Hawaii and Tahiti). Their absence indicates an important vegetational and sedimentary difference between the Cooks and the islands of the west Pacific.

14 species of shrubs are present on the Aitutaki islets, 3 being uncommon recent introductions and the rest widespread and mostly abundant. Some of these shrubs are geographically extensive (Pemphis, Suriana, Tournefortia, Sophora, Scaevola), others are regionally restricted (Timonius polygama). Some are inexplicably absent from the Rarotonga reef islands though present and indeed abundant at Aitutaki: these include Pemphis, Timonius, Pipturus and Corchorus torresianus. Absent from both the Rarotonga and Aitutaki islands are Euphorbia atoto (common on Rangiroa and Raroia in the Tuamotus but here replaced by E. chamissonis) and Pluchea carolinensis (extensive, though recently introduced, in low scrub at Christmas Island).

At least 34 species of herbs are recorded from the Aitutaki motus, with an additional 13 from the Rarotonga reef islands. Of these only 10 are common: Stenotaphrum micranthum (exotic), Fimbristylis cymosa, Heliotropium anomalum, Polypodium scolopendria, Triumfetta procumbens, Cassytha filiformis, Vigna marina and Tacca leontopetaloides (exotic) are found on most motus. There are curious differences between the Rarotonga and Aitutaki lists. Thus Sesuvium portulacastrum, present on Rarotonga, is absent not only from the motus but also from the main island of Aitutaki, in spite of its wide distribution through the Line Islands and its importance as a vegetation type at Christmas Island (Christophersen, 1927; Jenkin and Foale, 1968). Other species present on Rarotonga but not the Aitutaki islands include Asplenium nidus, Davallia solida, Thuarea involuta, Peperomia species, Portulaca lutea, Canavali[a] sericea, Stachytarpheta urticifolia (exotic), Vitex trifolia, Sonchus oleraceus (exotic) and Wedelia biflora.

Particularly interesting is the absence, with the mangroves, of the sea grasses. Species of Syringodium, Diplanthera (=Halodule), and Halophila are recorded from Tonga by Yuncker (1959), but there are no records from the Cooks. Halophila is present in Samoa (Setchell, 1924), Tahiti and Hawaii and may be more widely distributed in the central Pacific than the other sea grasses, but it was not seen in the Cooks in 1969. The absence of this group, as with the mangrov[es] has important sedimentological implications: in consequence Aitutaki and the other Cook atolls more closely resemble the Tuamotus than the reefs of the western Pacific.

Species numbers on the motus

Table 12 gives the area and total numbers of species of vascular plants, classified as trees, shrubs and herbs, for each of the Aitutaki motus, together with the volcanic islets of Moturakau and Rapota and the Ootu peninsula. Data for the three reef islands of Rarotonga which are appended (from Stoddart and Fosberg, 1972) show similar values to those of Aitutaki. The motus have individual floras of 16-25 species each; the largest islands, Tekopua and Akaiami, have 25 and 22 species respectively. The only island to diverge markedly from the general pattern is the small sand cay south of Tapuaeta, with 5 species, while Ootu, a peninsula not a motu, much disturbed by man, has 42 species.

These data are of interest by comparison with those for the islets of Kapingamarangi Atoll, Caroline Islands, determined by Niering (1956). The Kapingamarangi data indicated a constant number of species per island for islands less than 1.4 ha (3.5 acre) in area, with a rapid rise in species numbers with increasing island area above this size. Wiens (1962) suggested that the threshold size is related to the smallest area of land which can support a permanent freshwater lens. The Kapingamarangi data were subsequently used by MacArthur and Wilson (1963; 1967, pp.30-32) in their theory of island biogeography relating the equilibrium level of an island biota to distance from source area (controlling immigration rate) and island size (controlling extinction rate).

The Aitutaki data raise two significant issues concerning the MacArthur and Wilson model and the Kapingamarangi data. First, can a similar control of number of species by island size be demonstrated for Aitutaki, where all except one of the islands lies above the 1.4 ha threshold (Aitutaki and Kapingamarangi have approximately the same annual rainfall of 2000 mm/yr), and where the largest Aitutaki motu is twice as large as Kapingamarangi's? MacArthur and Wilson's theory in fact predicts that the species-area relationship will be more marked in distant islands such as Aitutaki than in near islands such as Kapingamarangi, assuming that the source region in both cases is in the western Pacific. Second, whether or not this relationship exists, what is the effect of the existence of a 'species-reservoir' on the main volcanic island of Aitutaki, with between 4 and 9 times as many species as on individual motus, less than 8 km distant from the farthest of them?

Tables 13-15 document the distribution of trees, shrubs and herbs on the Aitutaki motus, volcanic islets and Ootu peninsula. The tables are based on sight records supplemented by collections made during the surveying of the islands. It is probable that some grasses have been systematically unrecognised in the field, but the other groups are thought to be reasonably complete. It should be noted that these tables are not directly comparable with those of Niering (1956), who classifies Tournefortia and Pemphis as trees and Euphorbia chamissonis as a herb; trees of Tournefortia are found at Aitutaki but this species is usually, and Pemphis is always, a shrub at Aitutaki, and Euphorbia too seems more appropriately termed a dwarf shrub than a herb. Figures 33 and 34, however, show direct comparisons, using Niering's classification, of the Aitutaki and Kapingamarangi data, in terms of numbers of species of trees, shrubs and herbs, and total numbers of species, against island area, and also in terms of the proportion of the number of species in each class for all islands.

It is clear that the close association between species number and island area for the Kapingamarangi islands does not exist on Aitutaki. There is a slight positive relationship between number of species and log area over the size range 4-71 ha but the scatter of points is considerable, and the mean number of species per island (21.1) over this size range is close to that for both small and large islands. There is reasonable agreement between the Kapingamarangi and Aitutaki data for small islands (approximately 27 and 21 species per island at 4 ha) but marked divergence at larger island sizes, with the largest Kapingamarangi islands having 2-3 times as many species as Aitutaki islands of equivalent size. Note that 16 (50 per cent) of the Kapingamarangi islands are smaller than 1 ha in area, compared with 1 at Aitutaki; the species number for this latter (5) is rather low by comparison with Kapingamarangi islands of the same size. It is evident, then, that the influence of island area is masked at Aitutaki when considering total numbers of species.

The influence of size for the two groups of islands can also be compared for the groups of trees, shrubs and herbs. At Kapingamarangi the number of tree species increases over the size range 0.16-32 ha from 5 to 17; while at Aitutaki, ignoring the smallest islet, the number is relatively invariant at about 7.5 species over the range 3.8-71 ha. At Kapingamarangi the number of shrub species is fairly constant at 1-3 up to 2 ha and then increases slightly to 5 species or more; at Aitutaki the number is variable but averages about 4 species over the size range. The most spectacular increase in species number with area is seen with herbs at Kapingamarangi: from 2.5 on islands of 1 ha to more than 20 (on one island 35) on islands larger than 10 ha. In this case it is clear that the diversity of the herb flora makes a major contribution to the general curve for all species derived by Niering. At Aitutaki, on the other hand, there is only a weak trend, from rather less than 10 to rather more than 10 species per island in the range 3.8-71 ha.

These differences in trend between groups of plants mean that the floras of large islands have a different composition from those of small ones on Kapingamarangi, but this is not the case on Aitutaki. Figure 2, plotting trees, shrubs and herbs as a percentage of the total flora for each island shows that on Kapingamarangi the proportion of trees decreases from about 80 to about 40 per cent with increasing island size; shrubs remain constant at about 20 per cent; and herbs increase from about 10 to about 60 per cent. On Aitutaki trees are fairly constant at 35 per cent, shrubs at 20 per cent, and herbs at 45 per cent.

In interpreting the species-area relationship, therefore, we need to consider not only the total size but also the composition of the island floras. Consider a series of islets on an atoll or almost-atoll such as Kapingamarangi or Aitutaki. The smallest islets will normally support a strand flora of grasses, sedges, vines and other herbs, with beach-crest shrubs and in some cases trees. The plants capable of surviving in such environments are limited in number and many are of pantropical or at least Indo-Pacific distribution. On large inhabited islands much of the area will have been cleared during the last few centuries for coconut plantations. This will have had the following effects. (1) The number of tree species will have been reduced on larger islands with the eradication of certain vegetation types. This is illustrated by the disappearance of _Barringtonia_, _Calophyllum_, _Pisonia_ and _Cordia_ from many islands. (2) The number of shrub species will probably remain the same, partly because there is probably an upper limit to the number of such species which can be successfully established on such islands, even if artificially introduced, but also because the native shrubs of beach crest, gravel spread and conglomerate platform areas are unlikely to be cleared for economic reasons and survive even on islands severely disturbed by man. (3) With the establishment of plantations and increasing human activity the number of herb species, especially widespread weedy species, will increase, as a result both of deliberate and inadvertent introduction and also because clearing prepares substrates for colonisation and reduces competition from already established species; the effect will be greater on larger islands.

This explanatory scheme is consonant with the Kapingamarangi data, and it perhaps needs to be stressed that on many Pacific atolls we are no longer dealing simply with patterns resulting from natural immigration and extinction, but with vegetation actively managed by man: or, as Hatheway (1953, 6) put it for Arno Atoll, with people and plants rather than flora and habitat.

Does the scheme apply to the Aitutaki motus? Large areas on the bigger motus are covered with coconut woodland, now the most extensive woodland vegetation. There is little doubt that Pisonia - and perhaps other species such as Cordia and Hibiscus - were formerly more extensive. With their removal from some islands a reduction in tree species diversity can be inferred. The number and identity of shrub species is monotonously regular on all the islands: large areas covered with Pemphis and Suriana, and smaller contributions by Tournefortia, Scaevola, Sophora, Euphorbia, Timonius and Corchorus. However, unlike the situation on Kapingamarangi, the herb flora (including weeds) does not markedly increase on the larger islands, in spite of their clearance for coconuts: there is no doubt that a major reason why there is no simple increase in total size of flora with island size on Aitutaki is because the herb component is relatively invariant with size.

Why is this so? If Aitutaki were an atoll, situated in the central Pacific, then it could be argued that immigration was reduced because of the distance from source areas to the west, in Tonga and Fiji. To some extent such an explanation must partially account for the smaller floras of the Cooks, the Tuamotus and other central and east Pacific atolls compared with the Carolines and the Marshalls. But there is at Aitutaki a reservoir of weedy species on the main volcanic island immediately adjacent to the motus. Many species, not only weeds, which are elsewhere common on atoll islands, are widespread on this volcanic island but are absent from the motus. They include ferns (Nephrolepis hirsutula), grasses (Dactyloctenium aegyptium and several others), sedges (several Cyperus species), Portulaca oleracea, Abrus precatorius, Canavalia cathartica, Caesalpinia, Euphorbia hirta, Barringtonia asiatica, Ipomoea littoralis, Stachytarpheta urticifolia, Spermacoce suffrutescens, and Vernonia cinerea. Making allowance for the fact that some motu species may have been overlooked (and this is particularly true of sterile grasses such as Lepturus and Paspalum, it is astonishing that many of these species have not established themselves on the islands. The presence of some of them, such as Calophyllum and Abrus, on the volcanic islets in the south suggests the operation of an ecological control.

The list would be longer if it included certain species recorded from the motus but which cannot be said to have established themselves. Akitua, which can be reached on foot from the mainland at Ootu, has three herb species (Bidens pilosa, Emilia sonchifolia, Boerhavia repens) not otherwise recorded from the motus, plus, where the path from Ootu reaches the beach, a patch of Cenchrus echinatus. Cenchrus is also recorded at the landing stage on Tekopua, but on no other motu; yet it is common on the mainland and on the Ootu peninsula.

Thus whatever limits the establishment of these species on the motus, it is not lack of colonising material from the Aitutaki "reservoir", and it has nothing to do with isolation in the central Pacific. It seems rather that the present vegetation of the islands has some property or character which inhibits the colonisation, establishment and spread of new species, even of weeds in coconut plantations. This has been noted before, for example in the case of the localisation of weeds such as Mimosa pudica near the landing stage at Diego Garcia Atoll, an intensively managed coconut plantation (Stoddart, 1971, 141), and similar observations have been made by Bayliss Smith (in preparation) at Ontong Java Atoll and by Parham (1971, p.593) in the Tokelau Islands. The processes of colonization by sea- and wind-transported propagules are certainly continuing and important on reef islands, and recent work on the British Honduras cays has shown that extinction and floristic change is more widespread than hitherto suspecte(even over short periods of years and in the absence of catastrophic storms, but it nevertheless appears unlikely that thes(processes account for the present levels of species numbers on the Aitutaki motus, and doubtful that their operation as envisaged by MacArthur and Wilson gives a sufficient explanation o: species numbers on the Kapingamarangi islands.

Niering's Kapingamarangi data have recently been re-analysed by Whitehead and Jones (1969). Their analysis, which breaks down the total species numbers into groups of recent introductions, strand species, and non-strand species, is particularly apposite to this discussion. They argue that on small islands, lacking a freshwater lens (i.e. less than 1.5 ha), the flora consists only of salt-tolerant strand species, limited in number by the size of the available "species pool" in this category and hence not greatly affected by island area They also found that there are no recent introductions on islands of less than 1.6 ha in area. As a result, smaller islands have 7-8 species each and larger islands 12-14. Above the freshwater lens threshold, however, there is a rapid increase in the number of non-strand, salt-intolerant species, with numbers closely related to island area. It is these species, they argue, which control the overall species-area relationship found by Niering. Whitehead and Jones (1969, p.176) suggest that most of the species in both strand and non-strand categories are drift-dispersed. Unfortunately they do not list the species placed by them in each category, apart from the coconut, which they classify (mis-classify?) as a strand species. By implication, however, they regard the dispersal of the non-strand species as a natural phenomenon. The do not consider the effect of human activities on species numbers, other than in terms of recent introductions. Hence, while clarifying some aspects of the MacArthur and Wilson analysis of the Kapingamarangi data, they do not make it possible to explain in terms of their model the divergent situations at Kapingamarangi and at Aitutaki.

The presence of the volcanic island at Aitutaki affects the floras of the motus other than by serving as a reservoir of weeds and other plants from which they may be colonised. The inhabitants can utilise the fertile volcanic soils rather than cultivate the carbonate sands of the motus. Breadfruit and taro, of common atoll crops, are unknown on the motus; the Polynesian Chestnut *Inocarpus fagiferus* is only found on the main island, as are *Citrus* species, *Persea americana*, *Musa* species, *Sorghum*, *Capsicum*, *Solanum* species, and other food crops; useful trees such as *Ceiba pentandra* are similarly distributed, as are decoratives such as *Crinum*, *Canna*, *Catharanthus*, *Gloriosa superba*, *Tagetes*, and many others. *Carica papaya* is found on the motus only on Akitua, although common on the main island. In effect, therefore, although heavily affected by human activities, the motus are islands lacking human populations, settlements and cultivation. Apart from coconuts the only food plant on the motus is the Polynesian Arrowroot *Tacca leontopetaloides*, which is rather uncommon on the main island. Had there been settlements on the motus, especially on the larger islands of Akaiami and Tekopua, many of these species would have been locally introduced and cultivated and the species numbers would have approached closer to those of Kapingamarangi islands of equivalent size. It would be interesting to test this inference by comparison with inhabited true atolls in the Cook Islands, such as Manihiki, Penrhyn and Palmerston, and with an uninhabited atoll such as Suwarrow. Similarly the Aitutaki patterns should resemble those of other reef-encircled high islands such as Bora-Bora.

VEGETATION OF THE MOTUS

The following accounts of the main vegetation units, arranged by scrub types, woodland types, and herb types, are derived from the surveys and descriptions of the individual islands previously described. The vegetation units recognised follow those of Fosberg (1953, in press). Particular attention is given to the geographical relationships of the units described. This discussion is followed by brief notes on vegetation units absent from the Aitutaki motus though important on other Pacific atolls.

Pemphis Scrub (Plates 28 and 29)

Pemphis acidula commonly forms a narrow zone of scrub on the seaward sides of motus, varying in width from 10 m at Papau, 25-30 m on Ee, Mangere and Tavaerua Iti, 40 m at Motukitiu, to 50 m at Akitua, Angarei, Tavaerua and Muritapua. The scrub consists of shrubs up to 2 m tall, often wind-sheared and aligned in windrows oriented slightly north of west. Pemphis is the characteristic outpost species on the surface of the conglomerate platform. The shrubs are openly branched and lack the height and density of Pemphis scrub on some other atolls such as Aldabra. On islands where the conglomerate platform is much reduced and the seaward coast is formed by a sand and gravel ridge, Pemphis is rare (Tekopua, Akaiami). It is also poorly developed on the seaward side of Papau, possibly because it has been destroyed by rapid beach retreat. On lagoon shores, mainly on sand, Pemphis often forms a narrow belt, often of taller shrubs (e.g. on Ee, Mangere, Angarei, Akitua, Muritapua); in many cases these beaches are slightly retreating and the roots of the Pemphis are exposed to seawater Wiens (1959) and others have drawn attention to the common association of Pemphis with low rocky substrates, often without soil and subject to salt-water flooding and salt spray.

Pemphis scrub in such situations, on exposed rocky substrates, either of reef-rock (feo) or island conglomerates, is found throughout the Societies and Tuamotus, from Mopelia to Rangiroa, Raroia and Mururoa (Sachet, in litt.; Stoddart and Sachet, 1969; Doty, 1954; Chevalier et al., 1968). In many of the Tuamotu atolls, however, it is more common along channel between islands (hoa) than on seaward coasts, which are generally formed by high sand and gravel ridges rather than by wide horizontal conglomerate platforms. As a result Pemphis is probably less abundant as a vegetation type than on Aitutaki. Pemphis is also found on exposed rocky substrates in the Tokelaus (Parham, 1971) and at Funafuti (Hedley, 1896). In the Gilberts Moul (1957) reports it as a rampart scrub rather than on rocky substrates. In general it appears common in the southern and southeastern Polynesian atolls, though not recorde from some more remote locations such as Oeno (St John and Philipson, 1960). It is widely distributed in the northwest Pacific, but is not recorded from Kapingamarangi. It is widespread and extensive in the central and western Indian Ocean, though absent from Diego Garcia in the Chagos Archipelago. In spite of this wide distribution, it is remarkably absent from the central equatorial and central north Pacific islands: it is not recorded from Hawaii and the other Phoenix Islands*, Caroline, Flint, Vostok, Palmyra, Christmas, Washington, Fanning, Baker and Jarvis islands. Its absence from Christmas is especially noteworthy because of the large areas of terrain covered by similar low scrub communities (Jenkin and Foale, 1968). Pemphis extends through the northern Cooks at least to Penrhyn and Manihiki, where it reaches heights of 6-7 m (Linton 1933), and the reasons for its absence further north are not known.

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*Since this Bulletin was submitted, F.R. Fosberg and the writer found extensive stands of Pemphis on Hull Atoll, Phoenix Islan and a single individual on Canton. We have since found that Pemphis was collected by J.T. Arundel on Hull and was cited by Hemsley (1884), p.116.

In the Polynesian area Pemphis generally forms shrubs rather than trees, though a large tree is reported from Henderson (St John and Philipson, 1962) and trees are common in the Melanesian area and Marshall Islands.

The occurrence of Pemphis is thus subject to a primary biogeographic control, and to a secondary substrate and exposure control.

Suriana Scrub

Suriana maritima forms a scrub 1-2 m tall, in places reaching 2-3 m and exceptionally 4 m, on the seaward sides of islands, usually inland of the Pemphis zone. The scrub is open, with individual plants 1-2 m apart. It generally covers thin sand and gravel sheets, in contrast to the rocky substrates occupied by Pemphis. The area occupied by Suriana on Aitutaki islands appears to be dependent on the extent of such low-lying sand and gravel sheets. The width of the zone varies from 50-75 m on Akitua, Papau, Tavaerua Iti, Taverua, Muritapua and Tekkopua; 95 m on Motukitiu; 125-130 m on Angarei and Mangere; to a maximum of 50-430 m on Ee. On Tekopua, where Pemphis is weakly developed, Suriana forms a narrow fringe on the seaward beach crest, occupying a very different situation from that on other motus. Similarly on Akaiami, where a seaward gravel spread is also lacking, Suriana forms a narrow fringe on the seaward beach ridge. Ground cover beneath the scrub is sparse. In more exposed areas it is limited to Heliotropium anomalum and Cassytha filiformis with seedling Tournefortia argentea and Suriana. In more inland areas Fimbristylis, Triumfetta procumbens, Ipomoea macrantha and Euphorbia chamissonis are present. Few other shrub species are represented; in inland sites they include Colubrina asiatica and Scaevola taccada (e.g. on Ee and Papau) and to seaward Tournefortia argentea. There is little admixture with Pemphis, though since Suriana stands are often surrounded on their seaward sides by a fringe of Pemphis the area of the latter may appear larger than it actually is. The two species, physiognomically so similar, can be readily distinguished from a distance by the yellow-green colour of Suriana foliage and the blue-grey green of Pemphis.

Suriana scrub occurs in a very different situation on Maina. Here it forms an open scrub 1.5-2 m tall in the interior of a sand cay. The scrub includes Tournefortia shrubs to 2 m tall and some Scaevola taccada, and a patchy ground cover of Cassytha, Triumfetta and Euphorbia chamissonis.

Suriana maritima is pan-tropical in distribution, but usually occupies a rather different situation to that on the Aitutaki motus. It is frequently extensive on lagoonal mudflats, as at Canton and Christmas in the central Pacific (Hatheway, 1955; Jenkin and Foale, 1968), but is rare on the seaward sides of islands. At Canton it is also found "in slab areas and less often in sandy areas swept by waves during violent storms"

(Degener and Gillaspy, 1955), and both here and at Christmas it occupies areas elsewhere characterised by Pemphis acidula. At Raroia, Tuamotus, where it occurs outside the Pemphis zone, Suriana extends out onto the conglomerate platforms and bare beach rock, situations normally occupied by Pemphis (Doty, 1954, p.33; Doty and Morrison, 1954, p.16). Suriana may also form a rampart scrub on seaward beach ridges, as on Akaiami and Tekopua at Aitutaki. Similarly at Rangiroa, Tuamotus, it forms a beach-crest hedge on seaward shores in the absence of Scaevol (Stoddart and Sachet, 1969, p.28), and it is also so distribute on Caroline Atoll (Clapp and Sibley, 1971). Finally it also forms extensive inland stands on sand cays, as at Maina, and is thus described from Alacran, Gulf of Mexico (Fosberg, 1962), and from Christmas Island.

In spite of its wide geographic distribution, Suriana is, like Pemphis, curiously unrecorded from a number of islands, while on others it is rare and fails to form distinctive vegetation units. It is not recorded, for example, from the Tokelaus (Parham, 1971), nor from Fanning, Jarvis, Washington and Baker islands (Christopherson, 1927), nor from Palmyra (Dawson, 1959), though it is common throughout the Australs and the Tuamotus (Brown, 1931). It is present but not common on Onotoa in the Gilberts (Moul, 1957) and present but rare at Jaluit in the Marshalls (Fosberg and Sachet, 1962) though common on other Marshall atolls, e.g. Likiep. Closer to Aitutaki, where it is so extensive, it is almost non-existent on the sand cays and absent from the mainland coast of Rarotonga; one single plant was seen there in 1969 (Stoddart and Fosberg, 1972). These differences suggest that further studies of the ecology of Suriana would be of interest. Fosberg (1974) notes that the species is tolerant of salt spray (though it is often seen dead in very exposed situations, presumably killed by salt laden wind: Stoddart, 1971, pl. 35 for an example from Diego Garcia); substrate conditions are probably also of importance.

Scaevola scrub (Plate 27)

Scaevola taccada forms three distinct vegetation types at Aitutaki: a narrow beach-crest scrub on exposed shores; an extensive more open scrub on sand flats; and an open scrub under coconut woodland.

At Aitutaki the beach-crest Scaevola hedges are rare, simply because of the absence of seaward beach ridges: such hedges are found on Tekopua and Akaiami, the only islands with well-developed seaward ridges. On nearby Rarotonga, the Scaevola hedge is common and extensive, up to 4 m tall, on seaward beaches of reef islands, both alone and with Tournefortia argentea (Stoddart, 1972). Elsewhere in the Indo-Pacific Scaevola is characteristic of such situations, often forming a scrub 3-5 m tall, as for example at Diego Garcia (Stoddart, 1971); in the Marshalls (Taylor, 1950; Hatheway, 1953; Fosberg and Sachet, 1962); the Gilberts (Moul, 1957); the Ellice Island

(Hedley, 1896); and the Tokelaus (Parham, 1971). It appears to be less common through the Tuamotus, being not primarily a beach species at Raroia (Doty and Morrison, 1954, p.42), and is absent from Oeno. As a beach-crest scrub it is more common on seaward than on lagoon shores, and is often wind-sheared in consequence; where it does occur on lagoon shores the shrubs are taller and more open with a vertical rather than sloping profile; but unlike Pemphis and Tournefortia, Scaevola rarely becomes a tree. In the northern Cooks, Linton (1933) refers to dominantly lagoon-shore Scaevola at Penrhyn and Manihiki, and low Scaevola occupies lagoon flats at Christmas Island (Jenkin and Foale, 1968).

Inland Scaevola is extensive on several Aitutaki islands, especially Maina and Akitua, where it forms a zone up to 200 m wide between the Suriana scrub and the main woodland area. On Akaiami, Mangere and Angarei it forms a scrub 1-1.5 m tall, with occasional Tournefortia, Pandanus, Guettarda, and Euphorbia chamissonis. Cassytha is locally common, though nowhere reaching the smothering density seen on Scaevola on some Indian Ocean islands (e.g. Assumption: Stoddart et al., 1970, 127). The ground surface is bare with some Fimbristylis. Similar extensive inland scrub is described from Canton (Hatheway, 1955) and Diego Garcia (Stoddart, 1971).

Scaevola under coconuts is less extensively developed on Aitutaki. On Taverua it forms an open scrub up to 1.5 m tall, and similar low open scrub with many other species present has been described from many other Indo-Pacific atolls.

Tournefortia scrub

Tournefortia argentea, though widespread, is a less common component of atoll vegetation than Suriana, Pemphis or Scaevola. It characteristically occurs either as a beach scrub or as an inland scrub-forest. Its Caribbean counterpart, T. gnaphalodes, though smaller, occurs more commonly as a seaward-beach scrub, but never forms trees.

On Aitutaki Tournefortia is not common. It occurs with Scaevola in beach scrub on Mangere and Maina, and probably because of the nature of island topography is more common on channel and lagoon than on seaward shores. In the northern Cooks, on Penrhyn and Manihiki, Tournefortia up to 6 m tall is said to form the main beach scrub (Linton, 1933), and it is characteristic of exposed seaward beaches in the Tokelaus (Parham, 1971) and in the Tuamotus: at Raroia it forms bushes 2-3 m in diameter and height, with a root radius of 40 m (Doty and Morrison, 1953). In the Line Islands, in the absence of Pemphis and Suriana, it is an important beach scrub at Washington, Fanning, Christmas and Palmyra, on lagoon shores as well as seaward shores (Christopherson, 1927; Dawson, 1959).

Inland scrub-forest of Tournefortia is also widespread in the Pacific, though often now found only as relict patches. It is indeed the main woody vegetation at Pokak, Marshall Islands (Fosberg, 1955), at Gaferut, Caroline Islands (Niering, 1961), at Oeno, Tuamotus (St John and Philipson, 1960) and on Ducie. Groves are also described from Wake, Christmas, Palmyra, Fannin (reaching 12-15 m), Canton and Caroline Atolls. Plants in thes groves have well-developed trunks and form gnarled trees rather than shrubs.

Tournefortia seedlings are intolerant of shade, and when mature trees are found under coconut woodland (as on Tekopua), it is presumed that they pre-date the plantation.

Pandanus woodland

At Aitutaki *Pandanus* forms a narrow zone between Coconut-*Guettarda* woodland and low scrub to seaward. On Tavaerua Iti it forms a dense exclusive zone, while on Ee it might more properly be termed a *Pandanus*-*Guettarda* woodland. In pure stands of *Pandanus* the ground is covered with dead leaves and no other plants grow. The more mixed type on Aitutaki is equivalent to Parham's (1971) *Pandanus*-*Guettarda* facies in the Tokelaus, though in the latter many other species (*Cordia*, *Hernandia*, *Morinda*) are also present.

Pisonia woodland (Plate 33)

Relatively small stands of *Pisonia grandis* are found on some Aitutaki motus, the largest covering 10 ha on Tekopua and 4.6 ha on Tapuaeta. On Tekopua the trees are 20 m tall and 3-4 m apart; other tree species, including *Cocos*, *Guettarda*, *Pandanus* and *Morinda* are also present. On Tapuaeta the woodland is more open, with *Hernandia* and *Hibiscus* as well as *Cocos* *Guettarda* and *Morinda*. There is little undergrowth beneath the *Pisonia* woodland. *Pisonia* is also found, in a mixed *Pisonia*-*Hernandia* woodland, on Papau, and, as scattered trees only, on the Ootu peninsula.

It is possible that *Pisonia* woodland was more extensive before the spread of coconut woodland at Aitutaki. Certainly the trees do not compare in dimensions with those reported from the northern Cooks: Linton (1933) describes trees 23 m tall and 1 m in diameter at Penrhyn and Manihiki. *Pisonia* is the sole tree forming woodland on Vostok (Clapp and Sibley, 1971b), and it forms "magnificent stands" at Palmyra (Dawson, 1959, 14) and on atolls westward through the Marshall Islands and in the Indian Ocean. Agassiz reports *Pisonia* forests from many island which now have mainly coconut plantations.

Hernandia woodland

Hernandia sonora is a component of woodland on some of the Aitutaki motus, especially those such as Tapuaeta and Papau with stands of *Pisonia*. It may formerly have been more extensive. Aitutaki is close to the eastern limits of the range of this pantropical species. It is absent from the Tuamotus (though recorded from Mopelia and Tetiaroa in the Societies) and from Palmyra and Christmas Islands in the Line Islands, but is widespread in the Marshalls and other Micronesian and Melanesian areas, where it often forms very large trees.

Guettarda woodland

With Pandanus, Guettarda frequently forms a transitional zone between seaward scrub and coconut woodland on Aitutaki motus. The trees are up to 7 m tall (exceptionally reaching 10 m on Akaiami) and are located on the fringe of the higher leeward sand area rather than on the low sand and gravel sheets of the seaward sides of the islands. Doty (1954, p.28) has suggested that Guettarda is an indicator of the outer edge of the freshwater lens on islands, and also that since it is tolerant of shade it is widely distributed over the surface of islands beneath coconut woodland.

By comparison with the Tuamotus, where it forms the main native woodland on Raroia and Rangiroa (Doty and Morrison, 1954; Stoddart and Sachet, 1969), often in association with Tournefortia and Pandanus, Guettarda is weakly represented at Aitutaki. At Penrhyn and Manihiki in the northern Cooks there are trees of Guettarda 10 m tall; this is the maximum height of trees on Aitutaki (Linton, 1933). The species is absent from the Line Islands, and an introduction at Palmyra proved unsuccessful (Christophersen, 1927; Dawson, 1959).

Although Guettarda is widespread on the Aitutaki motus it is completely absent from the main volcanic island, with the exception of the Ootu Peninsula, which itself is simply a large motu attached to the main island: the first trees of Guettarda found are those at the northern end of the peninsula, with the transition from volcanic to calcareous soils. Guettarda is present on the two southern volcanic islets of Rapota and Moturakau, but on areas of calcareous sand rather than on volcanic substrates.

Casuarina woodland

Groves of Casuarina equisetifolia, presumably introduced, are found on leeward sandy areas of some motus, notably Ee and Angarei. The stands are not large and there is a ground vegetation of Scaevola taccada and Euphorbia chamissonis. Casuarina is also locally common on the main volcanic island.

Calophyllum woodland

Calophyllum inophyllum is absent from the motus and is found only on the volcanic islets of Moturakau and Rapota. On Moturakau it forms a dense canopy, with Hibiscus, Guettarda, Morinda and Leucaena; on Rapota it is associated with Pandanus. Its absence from the motus is surprising. Linton (1933) records trees 15 m tall on Manihiki in the northern Cooks but stated that it had been destroyed by man at Penrhyn. In the Tokelaus also it may have been removed by man, primarily for firewood. There are scattered trees on most of the Tuamotu atolls, but the Cook Islands are near the eastern limit of its range and it may have been introduced there. Nowhere on Aitutaki does i form the massive trees overhanging lagoon shores, characterist of many west Pacific and central Indian Ocean atolls (e.g. Kapingamarangi, Diego Garcia).

Coconut woodland (Plate 31)

Coconut woodland is the dominant woodland vegetation on the motus and has been so for at least a century (Gill, 1876, 1885). Only on Akaiami, where cultivation experiments are in progress (Thomson, 1968), are regular plantations maintained; elsewhere the woodland varies from a relatively clear woodland with little undergrowth, as on parts of Tekopua, to a mixed woodland of crowded coconut palms of different ages intermixed with broadleaf trees. Most of the mature coconuts are 8-10 m tall, though some are higher; the common broadleaf trees include Guettarda (to 10 m), Morinda (to 6 m), Pandanus (to 7 m Leucaena, Pipturus argenteus, and occasionally Tournefortia and tall Hernandia. There is usually a shrub layer of Timonius polygama (1-2 m), Scaevola (1 m), Corchorus torresianus, Euphorbia chamissonis, and, rather rarely, tall Tacca leontopetaloides. The ground layer is highly variable, with Opomoea, Tournefortia, Boerhavia, Portulaca, grasses, sedges, and ferns; the latter are mainly Polypodium scolopendria. Asplenium nidus common in the wetter atolls of the Line and Marshall Islands and characteristic of dense woodland in the Tokelaus (Dawson, 1959; Parham, 1971), is absent, as is Psilotum nudum. Perhaps the most striking characteristic of the Aitutaki coconut woodland is the restricted composition of the weedy ground layer: few of the many weeds of the main volcanic island are present on the motus, even though some, such as Stachytarpheta, are elsewhere abundant on such islands even where there is no local reservoir such as the main Aitutaki island provides; while others, such as Cenchrus, are found only on one or two motus near landing stages and have failed to spread and establish themselves.

Cladium marsh

There is one area of Cladium jamaicense marsh on Akitua, forming a dense stand up to 2.5 m tall. This species was not collected on other motus, where there are no similar habitats. It surrounds inland marshes at Avatoru and Tereiao, Rangiroa Atoll, in the Tuamotus (Stoddart and Sachet, 1969, pp.28-29, pl. 13), and may be relatively common in the region. It is common on Tetiaroa in what appear to be ancient abandoned taro marshes.

Pioneer beach communities (Plate 26)

Because of the geomorphology of the motus, pioneer beach communities of herbs, vines and grasses are largely limited to lagoon shores and especially to sandspits on the lagoon sides of islands adjacent to channels. The outpost species are mainly Vigna marina, Triumfetta procumbens and Ipomoea, with Fimbristylis and Heliotropium anomalum. As on other atolls these scattered outpost species can be followed inland through a regular zonation to coconut woodland: on Aitutaki the zonation includes scrub species such as Euphorbia chamissonis, Timonius polygama, juvenile Scaevola, Tournefortia, Suriana and Pemphis, and woodland species such as Guettarda, Pandanus and coconuts. The succession is well seen on the spit at the south end of Tekopua, and on leeward beaches of Ee, Mangere, Papau, Tavaerua and Tavaerua Iti. In many lagoon and channel areas, however, the beaches are narrow and cliffed, and the outpost species are absent. These herbaceous pioneer communities on sandy substrates are of very small extent by comparison with the pioneer scrub species, Pemphis and Suriana, on the seaward conglomerate platforms and gravel sheets of the motus.

ABSENT VEGETATION TYPES

By comparison with other Pacific atolls described in recent years, the Aitutaki motus lack a number of well-marked vegetation units. These fall into two categories: anthropogenic types common elsewhere but absent from the motus because cultivation is concentrated on the main volcanic island, and types absent for biogeographical reasons because of the remote location of the Cook Islands in the central Pacific.

Absent anthropogenic vegetation types

Breadfruit (Artocarpus altilis) groves are completely absent from the motus, though individual trees are common on the main island. On wetter atolls such as Kapingamarangi and Arno the groves reach heights of 20-30 m (Niering, 1956; Hatheway, 1953). Fosberg (1949) has suggested that the location of breadfruit is controlled by groundwater salinity; islands such as Akaiami and Tekopua on Aitutaki would certainly be large enough for this tree to be grown.

Pits for the cultivation of root crops such as Cyrtosperma chamissonis, Colocasia esculenta and Xanthosoma sagittifolia are prominent and in some cases extensive features of atoll islands in the western Pacific, forming the puraka pits of Kapingamarangi, the babai pits of Onotoa, and the yaraj pits of Arno (Niering, 1956; Moul, 1957; Hatheway, 1953). These pits are found on the main island of Aitutaki but on none of the motus. That they would have been dug on the motus had it not been for the existence of alternative food sources is indicated by their presence on Pukapuka and Palmerston Atolls in the northern Cooks (Wood and Hay, 1970, p.65).

Other absent vegetation types

The absence of mangroves and of sea-grasses in the Cooks has already been noted. This is perhaps the most obvious cause of contrast with the reefs and islands of Tonga and islands to the west and of similarity with the Tuamotus and islands to the east. The place of the former is taken on mainland shores of Aitutaki, and on the protected shores of Ngatangiia Harbour on Rarotonga, by dense thickets of Hibiscus tiliaceus, and elsewhe by a continuous saturated sward of Paspalum and other grasses.

The absence of Calophyllum and Barringtonia woodland from the motus has also been noted. Calophyllum is present on reef islands elsewhere in the Cooks, and Barringtonia is common on Aitutaki itself. If either ever existed on the motus they may have been cut for firewood; but the existence of Calophyllum woodland on the southern volcanic islets suggests that this is not the true explanation and that the species was never important on the motus.

Cordia subcordata woodland is also absent from the motus, though the species is found on Akitua. It is common in the Tokelaus, forms the main native woodland on Canton and Caroline Atolls (Hatheway, 1953, 3; Clapp and Sibley, 1971b), but is "almost rare" at Raroia in the Tuamotus (Doty, 1954, p.26). Yet in the northern Cooks, at Penrhyn and Manihiki, it is reported to form trees 15-25 m tall and up to 0.6 m in diameter (Linton, 1933).

Certain fleshy herbaceous vegetation types are also absent Portulaca is curiously rare and nowhere on the motus forms a vegetation unit, though at Canton (a much drier atoll), for example, it forms the most extensive vegetation (Hatheway, 1954 p.6). Sesuvium portulacastrum is unrecorded from Aitutaki, though present on the reef islands of Rarotonga; Wilder (1931) however noted it as rare at the latter island. At Christmas Island and in the Phoenix Islands Sesuvium mats are extensive (Jenkin and Foale, 1968). The species is absent from the Tokelaus and the Marshalls, but present in Phoenix, Wake, and Hawaii, and its distribution might merit further study. Other herbaceous vegetation units unrepresented or weakly represented on the Aitutaki motus include grasses such as Lepturus and Sporobolus (which also is absent from the Marshall Islands); and the Ipomoea-Wedelia-Stachytarpheta type often widespread under coconuts. For further details of these types, see the accounts by Fosberg (1953, 1974).

ACKNOWLEDGEMENT

I thank F.R. Fosberg and M.-H. Sachet for detailed comments on this chapter.

Table 11. Size of Pacific atoll floras

Group	Atoll	Number of species (number of indigenous species in brackets)		Source
Marshalls	Ailuk	56	(26)	Fosberg 1955
	Arno	125	(40)	Hatheway 1953
	Bikini	41		Taylor 1950
	Eniwetok	100	(33)	St John 1960
	Jaluit	288	(60)	Fosberg and Sachet 1962
	Jemo	34	(17)	Fosberg 1955
	Kwajalein	89	(25)	Fosberg 1955, 1959
	Lae	61	(35)	Fosberg 1955, 1959
	Likiep	91	(31)	Fosberg 1955, 1959
	Pokak	9		Fosberg 1955
	Rongelap	42		Taylor 1950, Fosberg 1959
	Taka	23	(18)	Fosberg 1955
	Ujae	61	(32)	Fosberg 1955, 1959
	Ujelang	50	(29)	Fosberg 1955, 1959
	Utirik	55	(26)	Fosberg 1955, 1959
	Wotho	40	(28)	Fosberg 1955, 1959
Solomons	Ontong Java	150	(58)	Bayliss-Smith 1973
Carolines	Ant	58		Glassman 1953
	Kapingamarangi	99	(43)	Niering 1962
	Namonuito	94		Stone 1959
	Pingelap	78		St John 1948
	Puluwat	42		Niering 1961
Gilberts	Onotoa	60	(50)	Moul 1957
	Tabiteuea	45		Luomala 1953

Table 11 continued

Group	Atoll	Number of species (number of indigenous species in brackets)		Source
	Tarawa	109	(28)	Catala 1957
Ellice	Funafuti	55		Maiden 1904
Tokelaus	Fakaofo	40		Parham 1971
	Nukunono	55	(35)	Parham 1971
Phoenix	Canton	164	(14)	Degener and Gillaspy 1955
Line	Christmas	41		Chock and Hamilton 1962
	Palmyra	64		Dawson 1959
Cooks	Aitutaki (motus)	45		This paper
	Manihiki	22		Cranwell 1933
	Rarotonga (motus)	41		Stoddart and Fosberg 1972
Societies	Mopelia	78		Sachet in litt.
Tuamotus	Oeno	17	(14)	St John and Philipson 1960
	Mururoa	26		Chevalier et al. 1968
	Rangiroa	121	(39)	Stoddart and Sachet 1969
	Raroia	135	(54)	Doty 1954
Hawaii	Kure	42	(23)	Lamoureux 1961, Clay 1961
	Laysan	38	(27)	Lamoureux 1963, Tsuda 1965
Others	Rose	4		Sachet 1954
	Caroline	35		Clapp and Sibley 1971a
	Flint	36	(13)	St John and Fosberg 1937
	Vostok	2		Clapp and Sibley 1971b
	Clipperton	31	(14)	Sachet 1962
	Wake	94	(20)	Fosberg 1959b, Fosberg and Sachet 1969

Table 12. Numbers of species of vascular plants on Aitutaki and Rarotonga islands

Island	Area ha	Tree species	Shrub species	Herb species	Total number of species
AITUTAKI					
Ootu	ca 175	8	12	22	42
Akitua	14.9	8	9	12	29
Angarei	13.1	6	8	6	20
Ee	29.2	7	7	7	21
Mangere	8.5	5	6	8	19
Papau	5.3	8	7	10	25
Tavaerua Iti	4.1	5	7	10	22
Tavaerua	12.5	4	6	8	18
Akaiami	41.9	5	9	8	22
Muritapua	4.0	3	5	8	16
Tekopua	71.3	7	10	9	26
Tapuaeta	6.0	7	8	6	21
Sand cay	1.0	1	3	1	5
Motukitiu	11.5	5	8	10	23
Moturakau	3.9	7	3	6	16
Rapota	-	11	3	6	20
Maina	17.0	4	5	10	19
RAROTONGA					
Motutapu	11.0	7	3	14	24
Oneroa	10.6	8	6	6	20
Koromiri	3.0	6	3	8	17

Table 13. Distribution of tree species on Aitutaki motus

	Tapueta cay	Muritapua	Tavaerua Iti	Papau	Tapuaeta	Mangere	Motukitiu	Tavaerua	Angarei	Akitua	Maina	Ee	Akaiami	Tekopua	Ootu	Moturakau	Rapota	Total
Cocos nucifera	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	17
Guettarda speciosa		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	16
Pandanus tectorius		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	16
Morinda citrifolia				x	x		x	x	x	x			x	x	x	x	x	11
Casuarina equisetifolia			x	x		x			x	x		x		x	x		x	9
Hibiscus tiliaceus			x		x						x	x	x		x	x	x	8
Hernandia sonora				x	x		x		x					x			x	6
Leucaena insularum				x		x				x		x			x	x		6
Pisonia grandis				x	x							x		x	x			5
Calophyllum inophyllum																x	x	2
Carica papaya										x								1
Cordia subcordata										x								1
Erythrina variegata																	x	1
Mangifera indica																	x	1
Thespesia populnea																	x	1
Total	1	3	5	8	7	5	5	4	6	8	4	7	5	7	8	7	11	

Table 14. Distribution of shrub species on Aitutaki motus

	Tapuaeta cay	Muritapua	Tavaerua Iti	Papau	Tapuaeta	Mangere	Motukitiu	Taverua	Angarei	Akitua	Maina	Ee	Akaiami	Tekopua	Ootu	Moturakau	Rapota	Total
Scaevola taccada	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	17
Pemphis acidula		x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	15
Suriana maritima	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			15
Tournefortia argentea	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	16
Euphorbia chamissonis		x	x	x	x	x	x	x	x	x	x	x	x	x	x			14
Timonius polygama			x	x		x		x	x	x		x	x	x	x			10
Sophora tomentosa				x	x					x		x	x	x	x	x		8
Colubrina asiatica					x		x		x		x		x	x	x			7
Capparis cordifolia							x						x	x	x			4
Pipturus argenteus			x		x		x							x				4
Corchorus torresianus									x	x					x			3
Sida rhombifolia										x								1
Solanum nigrum															x			1
Crotalaria pallida															x			1
Total	3	5	7	7	8	6	8	6	8	9	5	7	9	10	12	3	3	

Table 15. Distribution of herb species on Aitutaki motus

	Tapuaeta cay	Muritapua	Taverua Iti	Papau	Tapuaeta	Mangere	Motukitiu	Tavaerua	Angarei	Akitua	Maina	Ee	Akaiami	Tekopua	Ootu	Moturakau	Rapota	Total
Stenotaphrum micranthum		x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	15
Fimbristylis cymosa		x	x	x	x	x	x	x	x	x	x	x	x	x	x			14
Heliotropium anomalum	x	x	x	x		x	x	x	x		x	x	x	x	x			13
Polypodium scolopendria		x	x	x	x	x	x	x		x	x	x		x		x	x	13
Triumfetta procumbens		x	x	x	x	x	x	x	x	x	x	x			x			12
Cassytha filiformis		x		x			x	x	x	x	x	x	x	x	x			11
Vigna marina			x			x	x	x	x			x	x	x	x	x	x	11
Tacca leontopetaloides		x	x	x	x	x		x			x		x	x			x	10
Ipomoea pes-caprae				x		x				x					x	x	x	6
Ipomoea macrantha		x	x				x			x	x				x			6
Lepidium bidentatum				x							x		x	x				4
Portulaca oleracea				x	x						x				x			4
Cenchrus echinatus										x				x	x			3
Abrus precatorius																x	x	2
Boerhavia tetrandra			x				x											2
Bidens pilosa										x					x			2
Emilia sonchifolia										x					x			2
Digitaria ciliaris			x												x			2

Table 15 continued

	Tapuaeta cay	Muritapua	Taverua Iti	Papau	Tapuaeta	Mangere	Motukitiu	Tavaerua	Angarei	Akitua	Maina	Ee	Akaiami	Tekopua	Ootu	Moturakau	Rapota	Total
Achyranthes velutina							x											1
Boerhavia repens										x								1
Cladium jamaicense										x								1
Sporobolus												x						1
Vernonia cinerea																x		1
Unident. grass													x					1
Total	1	8	10	10	6	8	10	8	6	12	10	7	8	9	22*	6	6	

*includes 10 additional species not listed here

REFERENCES

Balgooy, M.M.J. 1960. Preliminary plant-geographical analysis of the Pacific, as based on the distribution of phanerogam genera. Blumea 10: 385-430.

Bayliss-Smith, T.P. 1973. Ecosystem and economic system of Ontong Java Atoll, Solomon Islands. Cambridge University Ph.D. thesis.

Brown, F.B.H. 1935. Flora of southeastern Polynesia. III. Dicotyledons. Bishop Mus. Bull. 130: 1-386.

Catala, R.L.A. 1957. Report on the Gilbert Islands: some aspects of human ecology. Atoll. Res. Bull. 59: 1-187.

Cheeseman, T.F. 1903. The flora of Rarotonga, the chief island of the Cook Group. Trans. Linn. Soc. Lond., (1) Bot., 6: 261-313.

Chevalier, J.-P., Denizot, M., Mougin, J.-L., Plessis, Y. and Salvat, B. 1968. Etude géomorphologique et bionomique de l'atoll de Mururoa (Tuamotu). Cah. Pacifique, 12: 1-144.

Chock, A.K. and Hamilton, D.C., Jr. 1962. Plants of Christmas Island. Atoll Res. Bull. 90: 1-7.

Christophersen, E. 1927. Vegetation of Pacific equatorial islands. Bishop Mus. Bull. 44: 1-79.

Clapp, R.B. and Sibley, F.C. 1971a. Notes on the vascular flora and terrestrial vertebrates of Caroline Atoll, southern Line Islands. Atoll Res. Bull. 145: 1-18.

Clapp, R.B. and Sibley, F.C. 1971b. The vascular flora and terrestrial vertebrates of Vostok Island, south-central Pacific. Atoll Res. Bull. 144: 1-10.

Clay, H.F. 1961. Narrative report of botanical fieldwork on Kure Island, 3 October 1959 to 9 October 1959. Atoll Res. Bull. 78: 1-4.

Cranwell, L.M. 1933. Flora of Manihiki, Cook Group. Rec. Auckland Inst. Mus. 1: 169-171.

Dawson, E.Y. 1959. Changes in Palmyra Atoll and its vegetation through the activities of man, 1913-1958. Pacific Naturalist, 1: 1-51.

Degener, O. and Gillaspy, E. 1955. Canton Island, south Pacific. Atoll Res. Bull. 41: 1-51.

Doty, M.S. 1954. Floristic and ecological notes on Raroia. Atoll Res. Bull. 33: 1-41.

Doty, M.S. and Morrison, J.P.E. 1954. Interrelationships of the organisms on Raroia aside from man. Atoll Res. Bull. 35: 1-61.

Fosberg, F.R. 1949. Atoll vegetation and salinity. Pacif. Sci. 3: 89-92.

---------- 1953. Vegetation of central Pacific atolls, a brief summary. Atoll Res. Bull. 23: 1-26.

---------- 1955. Northern Marshalls Expedition, 1951-1952. Land biota: Vascular plants. Atoll Res. Bull. 39: 1-22.

---------- 1959a. Additional records of phanerogams from the northern Marshall Islands. Atoll Res. Bull. 68: 1-9.

---------- 1959b. Vegetation and flora of Wake Island. Atoll Res. Bull. 67: 1-20.

---------- 1962. A brief survey of the cays of Arrecife Alacran, a Mexican atoll. Atoll Res. Bull. 93: 1-25.

---------- In press. Coral island vegetation. In O.A. Jones and R. Endean, eds.: Geology and Biology of Coral Reefs (London and New York: Academic Press).

Fosberg, F.R. and Sachet, M.-H. 1962. Vascular plants recorded from Jaluit Atoll. Atoll Res. Bull. 92: 1-39.

---------- 1969. Wake Island vegetation and flora, 1961-1963. Atoll Res. Bull. 123: 1-15.

Gill, W. Wyatt. 1876. Life in the southern isles; or, scenes and incidents in the South Pacific and New Guinea. London: Religious Tract Society. viii, 360 pp.

---------- 1885. Jottings from the Pacific. London: Religious Tract Society. 248 pp.

Glassman, S.F. 1953. New plant records from the eastern Caroline Islands, with a new comparative study of the native plant names. Pacif. Sci. 7: 291-311.

Hatheway, W.H. 1953. The land vegetation of Arno Atoll, Marshall Islands. Atoll Res. Bull. 16: 1-68.

---------- 1955. The natural vegetation of Canton Island, an equatorial Pacific atoll. Atoll Res. Bull. 43: 1-9.

Hedley, C. 1896. General account of the atoll of Funafuti. Mem. Aust. Mus. 3: 1-71.

Hemsley, W.B. 1884. Report on the botany of Juan Fernandez, the south-eastern Moluccas, and the Admiralty Islands. Sci. Rep. Voy. H.M.S. Challenger, Botany, 3: 1-333.

Jenkin, R.N. and Foale, M.A. 1968. An investigation of the coconut-growing potential of Christmas Island. Vol. 1. The environment and the plantations. Vol. 2. Appendices. Tolworth: Directorate of Overseas Surveys, Land Resource Study No. 4: 1-123, 1-113.

Lamoureux, C.H. 1961. Botanical observations on leeward Hawaiian atolls. Atoll Res. Bull. 79: 1-10.

---------- 1963. The flora and vegetation of Laysan Island. Atoll Res. Bull. 97: 1-14.

Linton, A.M. 1933. Notes on the vegetation of Penrhyn and Manihiki Islands. J. Polynes. Soc. 42: 300-307.

Luomala, K. 1953. Ethnobotany of the Gilbert Islands. Bishop Mus. Bull. 213: 1-129.

MacArthur, R.H. and Wilson, E.O. 1963. An equilibrium theory of insular zoogeography. Evolution, Lancaster, Pa., 17: 373-387.

---------- 1967. The theory of island biogeography. Princeton Princeton University Press. 203 pp.

Maiden, J.H. 1904. The botany of Funafuti, Ellice Group. Proc. Linn. Soc. N.S.W. 29: 539-556.

Moul, E.T. 1957. Preliminary report on the flora of Onotoa Atoll, Gilbert Islands. Atoll Res. Bull. 57: 1-48.

Niering, W.A. 1956. Bioecology of Kapingamarangi Atoll, Caroline Islands: terrestrial aspects. Atoll Res. Bull. 49: 1-32.

---------- 1961. Observations on Puluwat and Gaferut, Caroline Islands. I. List of plants noted on Puluwat Islet, Puluwat Atoll. II. Description of Gaferut Island. Atoll Res. Bull 76: 1-9.

---------- 1963. Terrestrial ecology of Kapingamarangi Atoll, Caroline Islands. Ecol. Monogr. 33: 131-160.

Parham, B.E.V. 1971. The vegetation of the Tokelau Islands with special reference to the plants of Nukunono Atoll. N.Z. J. Bot. 9: 576-609.

Philipson, W.R. 1971. Floristics of Rarotonga. Bull. R. Soc. N.Z. 8: 49-54.

Sachet, M.-H. 1954. A summary of information on Rose Atoll. Atoll Res. Bull. 29: 1-25.

Sachet, M.-H. 1962. Flora and vegetation of Clipperton Island. Proc. Calif. Acad. Sci. (4) 31: 249-307.

---------- in litt. Vascular plants of Mopelia Atoll, Society Islands.

Setchell, W.A. 1924. Vegetation of Tutuila Island. Pap. Dep. mar. Biol. Carnegie Instn Wash. 20: 1-188.

St John, H. 1948. Report on the flora of Pingelap Atoll, Caroline Islands, Micronesia, and observations on the vocabulary of the native inhabitants. Pacif. Sci. 2: 96-113.

---------- 1960. Flora of Eniwetok. Pacif. Sci. 14: 313-336.

St John, H. and Fosberg, F.R. 1937. Vegetation of Flint Island, central Pacific. Occ. Pap. Bernice P. Bishop Mus. 12 (24): 1-4.

St John, H. and Philipson, W.R. 1960. List of the flora of Oeno Atoll, Tuamotu Archipelago, south-central Pacific Ocean. Trans. R. Soc. N.Z. 88: 401-403.

---------- 1962. An account of the flora of Henderson Island, south Pacific Ocean. Trans. R. Soc. N.Z., Bot. 1: 175-194.

Stoddart, D.R. 1971. Land vegetation of Diego Garcia. Atoll Res. Bull. 149: 127-142.

Stoddart, D.R., Benson, C.W. and Peake, J.F. 1970. Ecological change and effects of phosphate mining on Assumption Island. Atoll Res. Bull. 136: 121-145.

Stoddart, D.R. and Fosberg, F.R. 1972. Reef islands of Rarotonga, with list of vascular flora. Atoll Res. Bull. 160: 1-14.

Stoddart, D.R. and Sachet, M.-H. 1969. Reconnaissance geomorphology of Rangiroa Atoll, Tuamotu Archipelago, with List of vascular flora of Rangiroa. Atoll Res. Bull. 125: 1-44.

Stone, B.C. 1959. The flora of Namonuito and the Hall Islands. Pacif. Sci. 13: 88-104.

Taylor, W.R. 1950. Plants of Bikini and other northern Marshall Islands. Univ. Michigan Stud., Sci. ser. 18: i-xv, 1-227.

Thomson, R.W.F. 1968. Spacing and nutrition of Cocos nucifera under atoll conditions in the Cook Islands. Oléagineux, 23: 449-451.

Tsuda, R.T. 1965. Marine algae from Laysan Island with additional notes on the vascular flora. Atoll Res. Bull. 110: 1-31.

Wiens, H.L. 1959. Atoll development and morphology. Ann. Ass. Am. Geogr. 49: 31-54.

Whitehead, D.R. and Jones, C.E. 1969. Small islands and the equilibrium theory of insular biogeography. Evolution, Lancaster, Pa. 23: 171-179.

Wilder, G.P. 1931. Flora of Rarotonga. Bishop Mus. Bull. 86: 1-113.

Wood, B.L. and Hay, R.F. 1970. Geology of the Cook Islands. Bull. N.Z. geol. Surv., n.s. 82: 1-103.

Yuncker, T.G. 1959. Plants of Tonga. Bishop Mus. Bull. 220: 1-283.

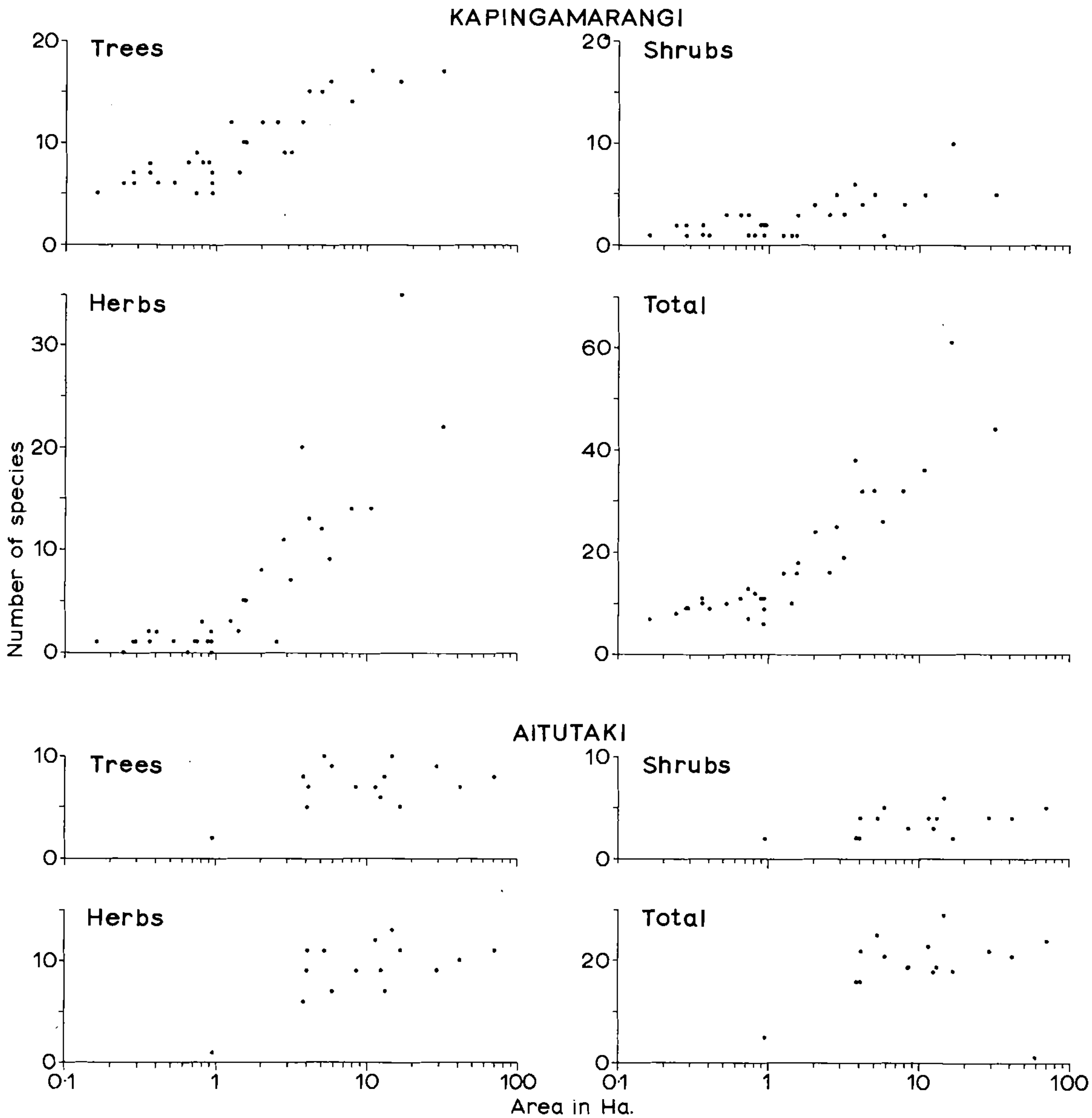


Figure 33. Numbers of species and island area for trees, shrubs and herbs at Kapingamarangi and Aitutaki

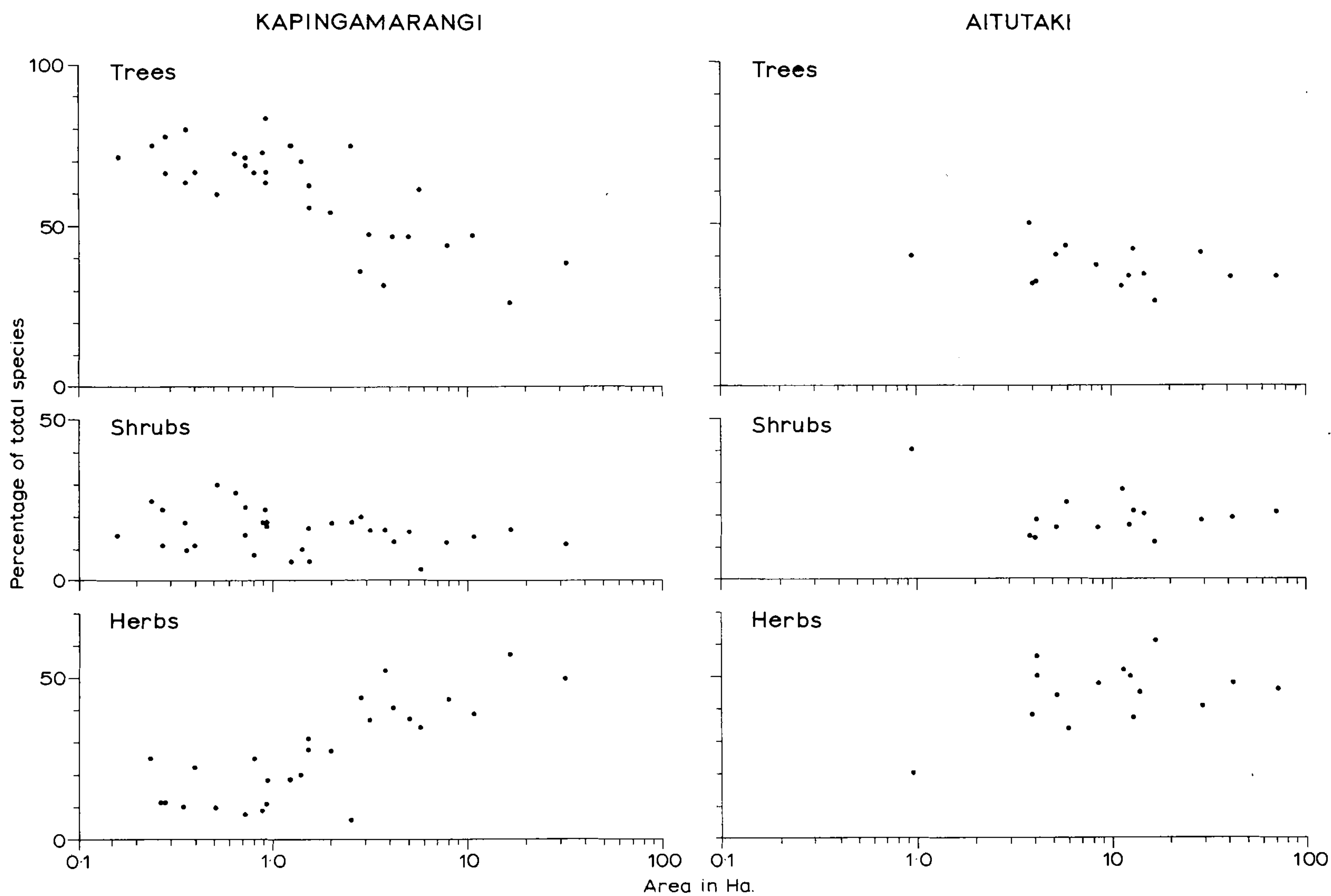


Figure 34. Numbers of species of trees, shrubs and herbs as percentages of total flora at Kapingamarangi and Aitutaki

26 Pioneer Heliotropium at Motukitiu

27 Scaevola scrub, north end of Akaiami

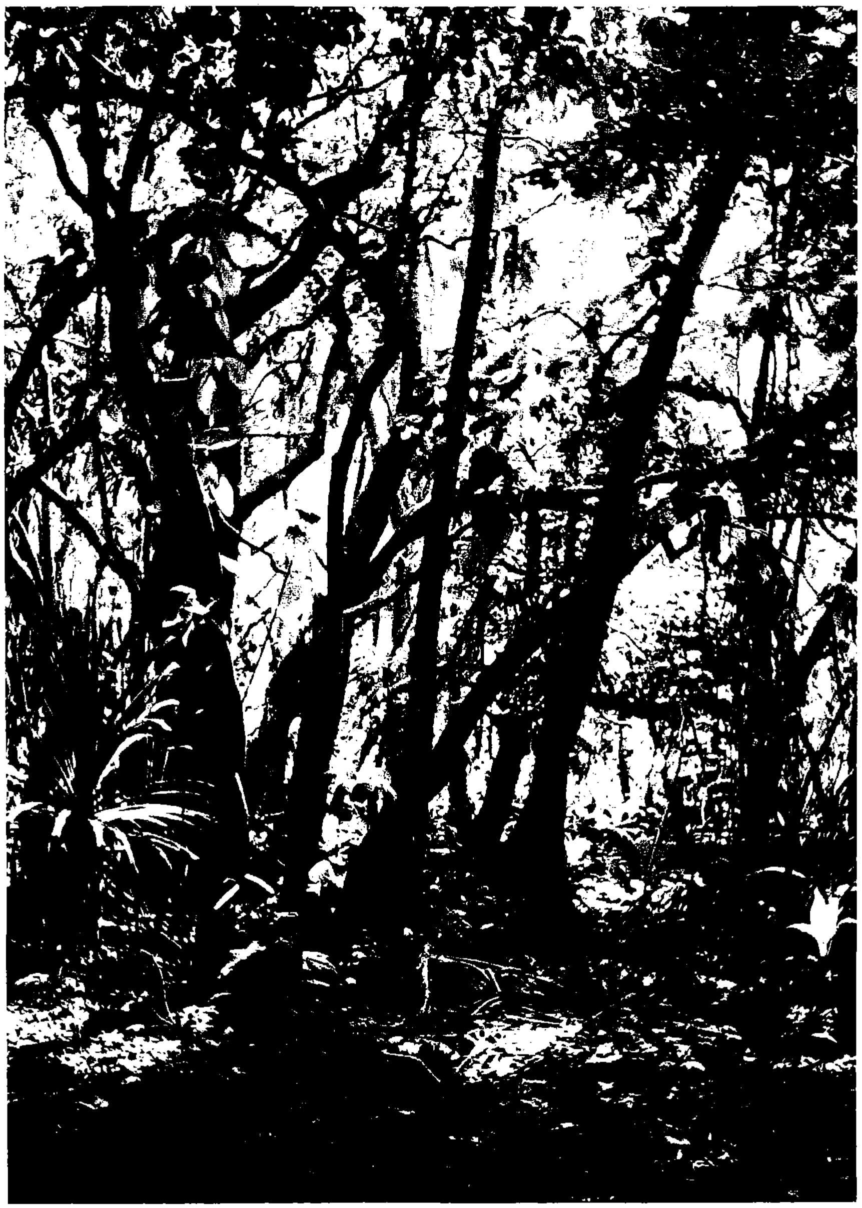
28 *Pemphis* scrub and leeward woodland at Ee

29 Pemphis scrub and leeward woodland at Muritapua

30 Mixed woodland at the south end of Tekopua

31 Coconut woodland on Motukitiu

32 Tacca on Akaiami in coconut woodland



33 Pisonia woodland on Tapueta

7. MAINLAND VEGETATION OF AITUTAKI

D.R. Stoddart

Though only incidental observations were made on the main island of Aitutaki, few observations on its vegetation have appeared in the literature since Bligh's notes in 1789, and this chapter therefore places on record notes on the vegetation types and their distribution, with emphasis on coastal areas. The greater part of Aitutaki is actively managed by man, and no areas escape human interference: the vegetation units described, therefore, are largely human artefacts, just as many of their component species have been introduced by man, either in pre-contact or more recent times.

The vegetation can conveniently be considered in categories defined by topography: (a) the coastal flat and beaches; (b) the slopes to higher ground, which in places reach the coast to form promontories or cliffs; (c) inland plateaux and rolling ground, largely cultivated and occupied by villages; and (d) hills, steep slopes and crags. Most information is available for the first of these categories, though collections and observations were made in all of them (Figure 35). Comparable types have been described from the lowlands of Rarotonga by Cheeseman (1903), Wilder (1931), and Philipson (1971).

COASTAL FLAT AND BEACHES

The coastal flat is discontinuously developed, being most extensive southwards from Nikaupara on the seaward coast and northwards from Vaipeka to Te O on the lagoon coast. Elsewhere it may be absent and basalt slopes reach directly to the sea. The coastal flat is an aggradation terrace of calcareous and volcanic sands, but even where the sands are dark coloured the calcium carbonate content is likely to be high.

Northwest coast

At Marutea the beach is exceptionally wide, reaching 50 m, with a zone of pioneer species (Triumfetta procumbens, Heliotropium anomalum, juvenile Casuarina) up to 35 m wide. The coastal flat is covered with an open woodland of Guettarda (9 m tall), Cocos, Hibiscus, trees of Tournefortia, and Pandanus, in a scrub of Scaevola taccada 1-1.5 m tall, with some Suriana and Sophora, and a ground cover of Triumfetta, Heliotropium, Ipomoea macrantha, and grasses (Sporobolus africanus, Panicum reptans). This sector may be regarded as the northern end of the Ootu peninsula, in effect a tied motu, rather than part of the mainland proper.

The coastal flat narrows southwards and the ground rises steeply from the sea to the crags of Maungapu Hill. At Vaiuoe there is a narrow beach, with a beach-crest zone of *Paspalum* 10 m wide, backed by a mixed woodland of coconut and *Casuarina* with *Hernandia* and *Hibiscus*. Other outpost species of scattere distribution along this sector include *Triumfetta*, and juvenile *Scaevola*, *Sophora*, *Hibiscus* and *Casuarina*. *Vigna marina* extend back into the woodland. The flat widens south of Perekiatu, bu consists of low-lying volcanics as well as aggradation deposits and it is continuously occupied by settlements from Perekiatu to Nikaupara.

Southwest coast

The coastal flat in this sector extends in shallow embayments between low rocky points or promontories; small streams flow out into the bays. Between Rapae and Rangiteia the coasta flat is 50-100 m wide and covered with coconut woodland with *Hibiscus* and *Hernandia*. Beginning here and becoming more continuous further south is a coastal fringe of *Casuarina* with some *Hibiscus* and *Calophyllum* and occasional *Pandanus*. The beach outpost vegetation consists of grasses and seedlings of *Suriana* and *Sophora*.

Between Rangiteia and Pata the flat is 90-100 m wide. It is again covered with coconut and *Hibiscus* woodland reaching about 15 m, with several other trees, including *Hernandia* (to 20 m), *Leucaena*, *Pandanus* and *Morinda citrifolia* (6-8 m), with, rarely, *Inocarpus fagifera*. The ground cover consists of *Fimbristylis cymosa*, *Cyperus*, *Hippobroma*, *Stachytarpheta*, *Mimosa pudica*, and *Sida rhombifolia*. Groves of *Pandanus* and *Casuarina* have little ground vegetation; near streams *Pandanus* grows luxuriantly with *Cyperus alternifolius* 1.5 m tall beneath. The beaches are narrow at the promontories (3 m wide) and wider (to 10 m) in the bays. The main beach vegetation is a meadow of *Paspalum* with *Fimbristylis*.

Southwards to Aretere the flat reaches a width of 120 m. There is a coastal fringe of *Casuarina*, then a zone 30-50 m wide of coconut-*Hibiscus* woodland with low *Casuarina*; and finally a zone of massive *Barringtonia* and *Hernandia* with ferns beneath. *Pandanus* and *Inocarpus* are also present. Ground cover in the coconut woodland consists of grasses, *Vigna marina* *Hippobroma*, and seedlings of *Sophora*. The grasses include *Cenchrus echinatus*. There is no beach in this sector: the edge of the coastal flat is cliffed and eroding, and *Casuarina* roots are exposed on the shore.

At Tekoutu Point there is a thicket of *Hibiscus*, passing back into a mixed woodland of *Cocos*, *Hernandia* and *Hibiscus*. The ground cover consists of *Cenchrus*, *Vigna*, *Triumfetta* and ferns; other trees present are *Guettarda*, *Casuarina* and *Pandanus*; and there are tall shrubs on the coast of *Sophora*, some 6 m tall. South of the point the erosion is replaced by aggradation. There is a wide lobe of recent sand, with pioneer

Ipomoea pes-caprae and Fimbristylis; grasses; a shrub zone of Scaevola and Sophora 1.5 m tall, with juvenile Casuarina; and on the coastal flat a mixed woodland of Cocos, Hibiscus, Leucaena, Casuarina, Pandanus and Guettarda.

Southeast coast

Approximately from Tekoutu to Teaitu the coastal flat has very similar characteristics: it is narrow, has a well-developed Casuarina fringe, and is covered with coconut woodland passing back into a broadleaf woodland. Immediately east of the point the flat is narrow and cliffed. The Casuarina fringe is 20 m wide, with occasional coastal Pandanus. Big trees of Hernandia reach the sea at one point, with spreading low branches. The coconut woodland contains occasional trees of Hernandia, Calophyllum and Leucaena. Sophora is the only shrub. The ground surface under the coconut woodland is mainly bare, with scattered Hippobroma, Triumfetta, Vernonia cinerea and Vigna marina. Ferns and Psilotum grow on coconut boles. Inland the coconut woodland is replaced by a Hibiscus woodland with Morinda and Pandanus.

At Vaiotango the coconut-Hibiscus-Guettarda woodland is about 100 m wide. Tall Scaevola (5 m) and Sophora grow near the shore, with Ipomoea indica, Hippobroma, Vigna and Triumfetta beneath the woodland. There are scattered tall trees of Calophyllum. Hibiscus and Pandanus are less important here than further south. Inland the woodland is replaced by Barringtonia and Guettarda, or Casuarina. At Vaiokora the Casuarina coastal fringe is re-established, and is here 20 m wide. The coconut woodland contains Calophyllum, Hibiscus, Leucaena, Morinda and Pandanus, with Scaevola, Sophora and Hippobroma. At Teruarei the Casuarina fringe is interrupted in places by Hernandia and some Pandanus. The coconut woodland is 70-85 m wide, with massive Hernandia and Calophyllum and much Morinda. The ground cover is again sparse, and is dominated by Hippobroma and Thelypteris forsteri. At Teaitu the Casuarina fringe is more continuous, with occasional trees of Hernandia, Guettarda and Barringtonia. Occasional Calophyllum and Barringtonia are found in the woodland of Cocos, Pandanus and Hernandia, with shrubs of Sophora and Scaevola and Hippobroma on the ground. These brief notes indicate the essential uniformity of vegetation in this sector.

Towards the Tautu jetty the coast erosion becomes less marked and the coastal flat widens to 100 m. The Casuarina fringe gives way to Hibiscus thicket and grass turf, with Hernandia and Pandanus on the flat. Pemphis, uncommon on most of the mainland coast, grows along the whole length of the old jetty.

East coast

North of the Tautu jetty the coastal flat is interrupted by a cliffy sector where volcanic rocks reach the coast, but it is resumed north of Vaipae. At Vaipae itself the flat is narrow but the coast is fringed by a very distinctive band, 10-15 m wide, of a wet Paspalum marsh with Echinochloa colonum and Cyperus cyperoides (Plate 36). Immediately inland of this is a thicket of Hibiscus and Pandanus, with ferns, intersected by almost tunnel-like paths leading to the village.

At Vaipeka the coastal flat has widened to 200-270 m (Plate 37). The Paspalum fringe is continuous at the seaward margin, and the flat itself is much lower than on the west side of the island. Shrubs of Pemphis and Hibiscus occur intermittently along the shore. The coconut woodland on the outer part of the flat is 40-50 m wide. There are trees of Hernandia and Hibiscus and occasional Morinda, with sedges beneath. It is more apparently a managed coconut plantation than that around the south coast. Moving north the flat widens to 300 m, and the coconut woodland to 60-70 m. Other trees noted include Casuarina, Pandanus, Morinda and occasional Calophyllum. At the northern end of the main island, at Te O, however, the flat narrows to 10-15 m and is then replaced by a low beach ridge separating the lagoon proper from the barachois (Plates 38 and 39). Pemphis covered with Cassytha and largely dead Hibiscus occur on the ridge. The barachois itself is unvegetated, excep for scattered islands covered with a scrub of Pemphis 2 and in places 3 m tall. Juvenile Casuarina, Cyperus and Fimbristylis were also seen on these islands. Pemphis scrub extends round the margins of the barachois and is continuous with that along the lagoon shore of the Ootu peninsula.

SLOPES TO HIGHER GROUND

The inner edge of the coastal flat is uniformly marked by a transition from coconut or broadleaf woodland to dense Hibiscus tiliaceus thicket. In the northwest this is narrow, because of the steepness of the ground. In the southwest, at Pata and Aretere the Hibiscus is less dense, with Morinda, Leucaena and Calophyllum: there is frequently a wet taro patch on the inner coastal flat at the junction with higher ground. A similar pattern extends round the south coast, with Hibiscus, Morinda and Pandanus thicket often separated from the flat by taro patches. On the lagoon coast at Vaipae the thicket is particularly dense, reaches a height of 8-9 m, and is composed of little but Hibiscus: this continues north to Te O.

In places the volcanic slopes reach the sea. On the west coast the largest such case is at Perekeiatu (Black Rocks). The margins of this spur support a woodland of Hernandia, Hibiscus and Casuarina, with some Pandanus. Small Scaevola bushes and Vigna marina form the beach vegetation. On the spur itself tall Calophyllum woodland reaches the sea. The vegetati is very similar to that of Moturakau and Rapota previously described.

Between Arutanga and Rapae volcanic rocks again reach the shore, and the coastal flat is narrow or non-existant. The slopes are covered with a thicket of Hibiscus 6-10 m tall, with a woodland of coconut, breadfruit and kapok behind. There is a narrow zone of Paspalum meadow along the foot of the Hibiscus zone. Ipomoea littoralis was collected beneath the Hibiscus. Low basalt points outcrop to the south, for example at Pata, but these are mainly inconspicuous. At Aretere, however, the point consists of basalt boulders 0.5 m in diameter. Dense Hibiscus thicket reaches the sea.

On the lagoon shore, north of Tautu jetty, the coastal flat narrows and disappears, and is replaced by a cliff up to 8 m high, with an intermittent sloping platform beneath up to 20 m wide, all cut in weathered red clays. Hibiscus and Calophyllum grow on the flat with massive Barringtonia, Calophyllum and Pandanus on the cliff and slopes above.

INLAND PLATEAUS

Most of the inland part of the main island consists of rolling ground 15-50 m above the sea. It is extensively cultivated and settled, and is either occupied by plantations of banana, citrus, and coconuts; groves of mango, breadfruit, Inocarpus, Eugenia jambos, and Carica; or secondary vegetation. Large areas are covered by Ocimum suave, and by a low scrub of Sida rhombifolia. Larger trees include old gnarled Hibiscus at Arutanga, tall Ceiba pentandra, and Hernandia up to 50 m high (most are 15-20 m). Calophyllum reaches 20 m, scattered massive Barringtonia 10-15 m, and at Vaipae there is a huge ancient banyan. There are dense local groves of Pandanus varieties (Plate 35) and Cordyline. All form a patchwork mosaic with cultivated useful and decorative plants. Useful trees include Aleurites moluccana, Persea americana, and Terminalia catappa, besides those already mentioned. The very wide variety of decorative trees includes Acacia farnesiana, Adenanthera pavonina, Araucaria heterophylla, Barringtonia asiatica, Bauhinia monandra, Caesalpinia pulcherrima, Delonix regia, Erythrina variegata, Plumeria, Poinsettia, Spathodea campanulata, and doubtless many others. Decorative shrubs, by no means confined to the villages proper, include Acalypha godseffiana, Acalypha wilkesiana, Bougainvillea, Clerodendrum speciosissimum, Crotalaria pallida, Hibiscus hybrids, Ocimum suave, Nerium indicum, Tabernaemontana divaricata, and again many others.

The greatest diversity, however, is in the introduced decorative and weedy herbaceous flora in this inland zone. Fosberg's list in this Bulletin includes over a dozen species in each category. Many food plants are also introduced; some are included in Fosberg's list; others are listed by Johnston (1967).

HILLS AND CRAGS

The main vegetation on the slopes of Maungapu Hill, the highest point on the island, consists of a grass, Sorghum bicolor, growing to 2 m, and a shrub reaching the same height, Crotalaria pallida (Plate 34). Other shrubs include Triumfetta rhomboidea and Sida rhombifolia. Coconuts rise to immediately below the summit. Before 1942, when they were cleared by troops building military installations, it is said they extended over the summit itself at 119 m. Weedy species now extend over the whole hill and no trace of native vegetation remains. These weeds include Mimosa pudica, which is very common, Vernonia cinerea, Sporobolus africanus, Dactyloctenium aegyptium, Passiflora rubra, Emilia sonchifolia, Euphorbia hirta, and Stachytarpheta urticifolia. It is clear that no areas of indigenous vegetation comparable to those of higher islands like Rarotonga survive on Aitutaki. Bligh's reference to "lawns" on the hills in the eighteenth century suggests that the process of transformation of the vegetation is an old one.

DISCUSSION

A few points of interest may be noted, particularly in contrasting the main island vegetation with that of the motus. Two tree species from the motus are absent from the main island (Pisonia grandis, Cordia subcordata), and one of the most common is restricted and relatively rare (Guettarda speciosa). Similarly the most common shrubs of the motus are absent from the main island. These include Corchorus torresianus, Timonius polygama and Euphorbia chamissonis. Capparis cordifolia is also absent. Scaevola, Suriana and Pemphis are restricted and uncommon, in sharp contrast to the motus, and only Sophora is more common on the main island than on the motus, of the plants characteristic of the latter. The absence on Aitutaki of Coccoloba uvifera, which is a common introduced tree on the coast of Rarotonga, may be noted. The marked disparity in numbers of weedy species between the mainland and the motus on Aitutaki has already been noted.

REFERENCES

Cheeseman, T.F. 1903. The flora of Rarotonga, the chief island of the Cook Group. Trans. Linn. Soc. Lond. (1) 6: 261-313.

Johnston, K.M. 1967. Village agriculture in Aitutaki, Cook Islands. Pacif. Viewpoint Monogr. 1: 1-122.

Philipson, W.R. 1971. Floristics of Rarotonga. Bull. R. Soc. N.Z. 8: 49-54.

Wilder, G.P. 1931. Flora of Rarotonga. Bishop Mus. Bull. 86: 1-113.

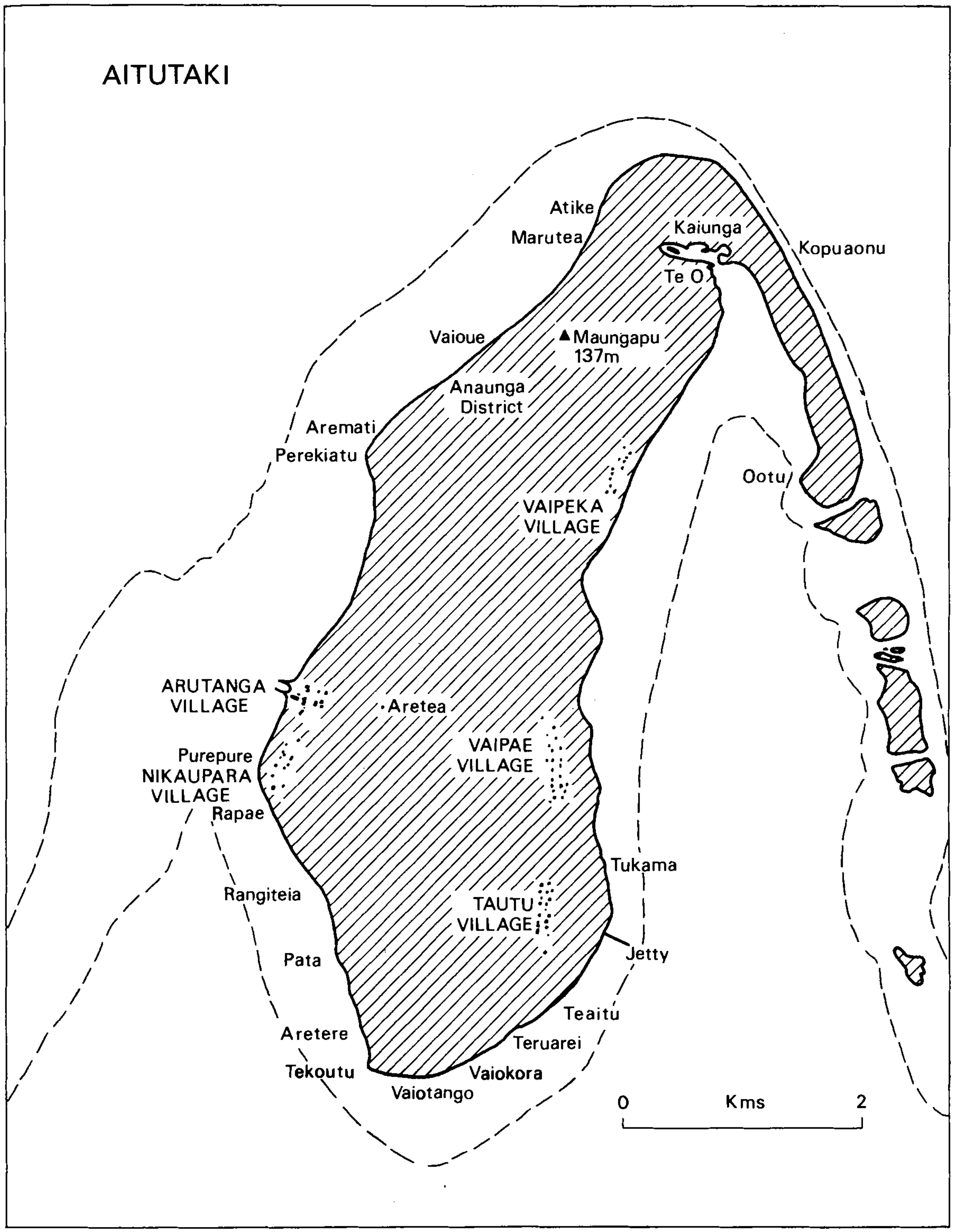


Figure 35. Aitutaki mainland vegetation localities

34 Motus and reef from Maungapu Hill; note the extent of cultivation on the mainland

35 Pandanus grove by the roadside, mainland near Vaioue

36 <u>Paspalum</u> marsh along the lagoon shore of the mainland near Vaipae

37 Sandy lagoon shore of the mainland between Vaipeka and Te O

38 Barachois at Te O

39 Barachois and lagoon beach ridge at Te O

8. SURVEY OF THE MACROFAUNA INHABITING LAGOON DEPOSITS ON AITUTAKI

P.E. Gibbs

INTRODUCTION

Whilst various aspects of the marine faunas of many of the remote islands in the Central Pacific have been investigated, few studies have been directed towards the benthic, soft-bottom communities inhabiting atoll lagoons. In recent years ecological surveys of the lagoon benthos, especially of the molluscs and echinoderms, have been carried out at a number of the Tuamotu atolls, notably Mururoa and Réao (see Chevalier *et al*, 1968; Renaud-Mornant *et al*, 1971; Salvat, 1967, 1971, 1972; Salvat and Renaud-Mornant, 1969) and these studies have demonstrated the great variability of the lagoon communities according to the atoll structure and related sedimentological processes. This chapter describes the composition and distribution of the macrofauna within the lagoon on Aitutaki in the southern Cook Islands, a survey of which was carried out in August-September, 1969, as part of the Cook Bicentenary Expedition, organised by the Royal Society of New Zealand.

Descriptions of Aitutaki (latitude 18° 51'45"S, longitude 159° 48'10"W) will be found in Gibbs *et al*. (1971), Stoddart (this Bulletin) and Summerhayes (1971). Briefly, Aitutaki is an almost-atoll with an area of about 100 km^2, approximately half of which is lagoon (Fig.36). Most of the lagoon is shallow, three quarters of its area being less than 4.5 m deep, and with a maximum depth of only 10.5 m. The tidal range at Aitutaki is small, about 0.5 m at springs.

Investigations were limited to the macrofauna, using this term in the sense of McIntyre (1971) i.e. comprising mainly the infauna of uncompacted sediments retained on a sieve of about 0.5 mm mesh. The positions of the stations sampled in the survey are shown in Fig.36. The littoral fauna was investigated at ten stations, eight around the mainland and two on the eastern reef at Ootu and Tekopua. At these stations the fauna was collected by digging and also sieving samples of sediment through 0.5 mm or 1.0 mm mesh. The bottom fauna of the lagoon was sampled at 20 stations, chiefly located in the eastern half of the lagoon, using a hand-operated naturalist dredge recovering 15-20 l of sediment. The infauna of these samples was separated by sieving through meshes of 0.5, 1.0 or 2.0 mm, the mesh size used depending on the sediment grade.

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The lagoon sediments are almost entirely calcareous; even on the shores of the mainland the non-calcareous fraction is small (Stoddart, 1975). Three main deposit zones may be distinguished within the lagoon: (i) the poorly-sorted silty sands forming the extensive intertidal flat and shallow shelf around the mainland (Stations 1-8); (ii) the well-sorted mediu to coarse sands, found around the reef islands and on the reef rim (Stations 10, L1-L9); and (iii) the poorly-sorted, fine sands, often with considerable admistures of silt, which cover the lagoon floor (Stations L10-L20).

FAUNA OF THE LITTORAL DEPOSITS

Mainland shore

Along the eastern shore of the mainland the broad sandfla that is exposed at low water springs for a distance of up to 400 m, was chiefly studied at Station 5 but similar observatio were made at Stations 4 and 6. A notable feature of this flat is the absence of seagrasses. The number of species found on this flat is relatively low (Table 16) and, for the most part, the fauna is sparse.

The surface-burrowing forms are chiefly gastropods, the commonest of which are Cerithium variegatum Quoy and Gaimard, Pyramidella acus (Gmelin) and Rhinoclavis asper (L.) - the latt being a characteristic lagoon species of Pacific Islands (Morrison, 1954). Less frequent are Natica gaultieriana Recluz Atys cylindrica (Helbling) and the bivalve (Gafrarium pectinatu (L.). The infauna is dominated by sedentary polychaetes, particularly the chaetopterid species Mesochaetopterus sagittarius (Claparède), Phyllochaetopterus elioti Crossland, and Spiochaetopterus costarum (Claparède), together with fewer individuals of Phyllochaetopterus brevitentaculata Hartmann-Schröder, Glycera lancadivae Schmarda, Armandia melanura Gravier, Dasybranchus caducus (Grube) and Malacoceros indicus (Fauvel). An errant polychaete, Marphysa macintoshi Crossland, and two deep-burrowing bivalves, Asaphis violascens (Forskål) and Quidnipagus palatum Iredale, mainly occur along the landwar edge of the flat where they penetrate cracks in the underlying clay-like rock. Species found under boulders lying on the sand surface include Siphonosoma cumanensé (Keferstein), Callianassa (Callichirus) sp. (near C. placida de Man), Alpheus spp., Calcinus latens (Randall), Clibanarius humilis (Dana) and Cypraea moneta (L.).

Over the outer (lagoonward) half of the flat the burrows of the large mantis shrimp Lysiosquilla maculata (Fabricius) are very conspicuous although from the surface indications, few burrows appeared to be occupied, a feature that could not be verified owing to the great depth to which this species burrows No specimens were captured by the author, the species being identified from a specimen (c.250 mm in length) purchased from a local fisherman. The deposit-feeder Holothuria atra Jaeger (see Bonham and Held, 1963) is fairly numerous in this area: many of these holothurians were examined for the commensal polynoid Gastrolepidia clavigera Schmarda but none of the latter were discovered despite the fact that this association is to be found on the outer reefs (see Gibbs, 1972). Crabs are frequently encountered ranging over the flat in shallow water; they include Calappa hepatica (L.), Thalamita admete (Herbst), Thalamita crenata (H. Milne Edwards), Metopograpsus thukuhar (Owen) and Percnon planissimum (Herbst), as well as several species of hermits, and probably all of these species are widespread in the lagoon. The largest of the lagoon crabs, Scylla serrata (Forskål), is generally trapped by local fishermen in nets laid in the muddier, northern part of the lagoon; the larger of two purchased specimens measures 20 cm across the carapace.

Along the landward edge of the flat, between the levels of about low water neaps and high water springs, the beach profile is steeper. In this narrow strip the ocypodid crabs Macrophthalmus (Macrophthalmus) convexus Stimpson and Uca tetragonon (Herbst) are common, the former extending from the upper levels of the flat to about mid-tide level and the latter from about mid-tide level up towards high water mark. Both species are found along the length of the eastern shore of the mainland but are commonest in the muddier deposits to the north, particularly in the backwater of Te O (Stations 7 and 8). On the other hand, the ghost crab Ocypode laevis Dana appears to be confined to the more southerly shoreline (e.g. Station 4) where it is found burrowing in moist sand at high water level. The land crab Cardisoma carnifex (Herbst) is found on the mainland but its distribution was not studied.

Along the lagoon shore of the mainland, in a narrow zone about mid-tide level, two spionid polychaetes dominate the infauna: these are Malacoceros indicus and Scolelepis (Scolelepis) squamata saipanensis Hartman, both of which form dense, often mixed, populations. Below this level, in the less silty deposits along the southern shoreline (Stations 2 and 3), the small opheliid Armandia melanura is frequently the only infaunal species but in patches Mesochaetopterus sagittarius occurs, its densely aggregated tubes often forming prominent, raised hummocks.

Special mention should be made of the polychaete Ceratonereis vaipekae Gibbs, a species described from the material of the present survey. This small nereid is very abundant amongst the Uca burrows at Te O (Station 8) and it is also found amongst the roots of shoreline grasses (at Station 6) often with the intertidal oligochaete Pontodrilus matsushimensis Iizuka. It seems likely that C. vaipakae is able to tolerate periods of lowered salinity since in these habitats brackish conditions must occur with surface run-off after heavy rainfall.

Reef shores

The fauna of the lagoon shores of the eastern reef was investigated at two localities, namely at Ootu (Station 9) where the intertidal flat is composed of silty, fine sand, and at the southern end of Tekopua Island where the littoral deposits are medium to coarse sands. The main difference between the fauna at these two localities and that of the mainlanc shore is the presence of the enteropneust Ptychodera flava Eschscholtz, the abundance of which is clearly indicated by the numerous faecal casts on the sand surface. However, apart fror this species, the fauna at Ootu is similar to that found on the flat of the mainland, with the three chaetopterids M. sagittar: P. elioti and S. costarum being the dominant elements of the infauna, except that here the surface burrowing gastropods are remarkably scarce, only one specimen of Pyramidella acus being found.

At Tekopua (Station 10) the infauna is again dominated by chaetopterids but the species are different, namely Phyllochaetopterus verrilli Treadwell and P. brevitentaculata. Apart frc P. flava, the remaining infauna is few in both species and individuals, perhaps the most striking being the two snake-eels Callechelys melanotaenia Bleeker and Leiuranus semicinctus (Lay & Bennett). However, the surface burrowers Strombus gibberulus gibbosus (Röding) and Rhinoclavis asper are common, together with hermits, including Calcinus elegans (H. Milne Edwards) and Aniculus aniculus (Fabricius).

FAUNA OF THE SUBLITTORAL DEPOSITS

Nine dredge hauls of the well-sorted medium to coarse sands found over the reef-rim (Stations L1-L9) were taken in depths of 1-2 m and 11 of the poorly-sorted finer deposits covering the lagoon floor (Stations L10-L20) in depths of 1-6 m (see Fig.36). The species taken in these samples are listed in Table 16. It should be noted that the distributions of the chaetopterid species are wider than the records suggest since empty or fragmentary tubes were present in most samples but cannot be identified with certainty.

Many of the species recorded from the intertidal zone are also widely distributed throughout the lagoon. The commonest of these include Glycera lancadivae, Nematonereis unicornis (Grube), Aonides oxycephala (Sars), Malacoceros indicus, chaetopterid spp., Dasybranchus caducus, Rhinoclavis asper, Strombus gibberulus gibbosus, Natica gaultieriana, Pupa sulcata (Gmelin), Atys cylindrica and Ptychodera flava. Of the total of about 70 species dredged in the lagoon, at least 46 species (chiefly molluscs (31) and polychaetes (10)) are recorded only from the sublittoral zone but the majority of these are known only from one or two stations.

Excluding those taken intertidally, the commoner sublittoral species (i.e. those taken at 4 or more stations) are relatively few in number. Characteristic species of the coarser, reef-rim deposits are *Strombus mutabilis* Swainson and the cephalochordate *Asymmetron lucayanum* Andrews, whilst *Lioconcha ornata* (Dillwyn) and *Glossobalanus* sp. appear to be characteristic of the finer deposits. On the other hand, the bivalves *Tellinella staurella* (Lam.) and *Arcopagia* (*Pinguitellina*) *robusta* (Hanley) do not appear to be so restricted in their distribution, both species being widespread throughout the sublittoral of the lagoon.

DISCUSSION

As mentioned above, surveys of the soft-bottom lagoon communities of only a few of the remote atolls in the Central Pacific have been made. A major interest in such surveys in this region obviously lies in obtaining records for defining the eastern limits of the distribution pattern of many shallow-water Indo-West-Pacific species. Although this aspect is fairly well documented for some groups, for example, brachyuran decapods (see Forest & Guinot, 1962) and molluscs (see Ranson, 1967), many other groups remain poorly known. Whilst the present survey has contributed many records towards a preliminary check-list of the Cook Islands marine fauna (see Gibbs *et al*, 1975), the primary aim in carrying out a survey of the Aitutaki lagoon was to obtain an estimate of the species diversity of the soft-bottom community.

The species composition of the soft-bottom community on Aitutaki is given in Table 16; its composition by group is as follows:

Polychaeta	27	Gastropoda	31
Oligochaeta	1	Pelecypoda	13
Sipuncula	1	Echinodermata	4
Phoronida	1	Cephalochordata	1
Stomatopoda	2	Enteropneusta	2
Decapoda	20+	Teleostei	3

Thus, from these preliminary data, the soft-bottom macrofauna of the lagoon is estimated at a total of about 100 species. The number of species represented in each of the three main deposit zones, i.e. the intertidal sand flat of the mainland, the reef rim, and the lagoon floor, are given in Table 17. These data show that the intertidal flat has fewer species than either of the other two zones chiefly because of the paucity of mollusc species. However, the fact that only 10 mollusc species were discovered on the intertidal flat could be a result of many of the sand-dwelling molluscs being highly regarded as food by the islanders, as noted by Banner (1952) for Onotoa Atoll, Gilbert Islands. Further, it should be mentioned that a number of species, notably terebrids and mitrids, represented in the Morgan Collection of mollusc shells (see Chapter 10 of this Bulletin) and collected at Aitutaki, were not found in the present survey.

Although data relating to species diversity and faunal composition of the soft-bottom benthos of other atoll lagoons are not available for comparison, several features of interest emerge in relating the present observations with those of the surveys of Tuamotu atolls. The most abundant molluscs on Aitutaki are Rhinoclavis asper, Strombus spp., Natica gaultieriana, Pupa sulcata, Tellinella staurella and Arcopagia (Pinguitellina) robusta; interestingly only the last-named species is included in the list of the 12 most abundant mollusc found by Salvat (1972) on Réao. On Réao, and other atolls (see Ranson, 1954; Salvat, 1967), Fragum fragum (L.) is the dominant mollusc, but on Aitutaki this species appears to be uncommon, only two live specimens being taken in the 20 dredge hauls. Also the Aitutaki fauna appears to lack any species of spatangoid: no specimens or traces of such forms as Rhinobrissus hemiasteroides A. Agassiz and Brissopsis luzonica (Gray) were discovered, although both of these species are common in the lagoon of Mururoa (Salvat & Renaud-Mornant, 1969). The widespread abundance of enteropneusts, particularly Ptychodera flava, except on the mainland shore, is a striking feature of the Aitutaki lagoon fauna: on other atolls that have been investigated this group appears to be less dominant. Whilst such differences in the relative abundance of species may be related to sedimentological processes and atoll structure (see Salvat, 1967), before comparative and regional analyses can be attempted, much faunistic data remains to be compiled both for individual atolls and atoll groups.

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REFERENCES

Banner, A.H. 1952. Preliminary report on marine biology study of Onotoa Atoll, Gilbert Islands. Part 1. Atoll Res. Bull 13: 1-42.

Bonham, K. & Held, E.E. 1963. Ecological observations on the sea cucumbers Holothuria atra and Holothuria leucospilota at Rongelap Atoll, Marshall Islands. Pacif. Sci., 17: 305-314.

Chevalier, J.-P., Denizot, M., Mougin, J.-L., Plessis, Y. & Salvat, B. 1968. Étude géomorphologique et bionomique de l'Atoll de Mururoa (Tuamotu). Cah. Pacif., 12: 1-144.

Forest, J. & Guinot, D. 1962. Remarques biogéographiques sur les crabes des archipels de la Société et des Tuamotu. Cah. Pacif., 4: 41-75.

Gibbs, P.E. 1972. Polychaete annelids from the Cook Islands. J. Zool., Lond., 168: 199-220.

Gibbs, P.E., Stoddart, D.R. & Vevers, H.G. 1971. Coral reefs and associated communities in the Cook Islands. Bull. R. Soc. N.Z., 8: 91-105.

Gibbs, P.E., Vevers, H.G. & Stoddart, D.R. 1975. Marine fauna of the Cook Islands: checklist of species collected during the Cook Bicentenary Expedition, 1969. Atoll Res. Bull. 190:133-148

McIntyre, A.D. 1971. Introduction: design of sampling programmes. In: Methods for the study of marine benthos, edited by N.A. Holme & A.D. McIntyre. IBP Handbook No. 16: 1-11.

Morrison, J.P.E. 1954. Animal ecology of Raroia Atoll, Tuamotus. Part 1. Ecological notes on the mollusks and other animals of Raroia. Atoll Res. Bull. 34: 1-18.

Ranson, G. 1954. Les eaux apparemment vertes, mais en réalité lactescentes du lagon de l'ile Anaa (Tuamotu). Bull. Lab. marit. Dinard, 40: 27-32.

---------- 1967. Contribution à la connaissance de la faune malacologique de l'Océanie. Cah. Pacif. 10: 85-135.

Renaud-Mornant, J.C., Salvat, B. & Bossy, C. 1971. Macrobenthos and meiobenthos from the closed lagoon of a Polynesian atoll. Maturei Vavao (Tuamotu). Biotropica, 3: 36-55.

Salvat, B. 1967. Importance de la faune malacologique dans les atolls Polynésiens. Cah. Pacif. 11: 6-49.

---------- 1971. Données bionomiques sur les peuplements benthiques à prédominance de mollusques, d'un lagon d'atoll fermé Polynésien. Haliotis, 1: 45-46.

---------- 1972. La faune benthique du lagon de l'Atoll de Réao (Tuamotu, Polynésie). Cah. Pacif. 16: 31-109.

Salvat, B. & Renaud-Mornant, J. 1969. Étude écologique du macrobenthos et du meiobenthos d'un fond sableux du lagon de Mururoa (Tuamotu - Polynésie). Cah. Pacif. 13: 159-179.

Stoddart, D.R. 1975. Almost-atoll of Aitutaki: geomorphology of reef and islands. Atoll Res. Bull. 190:31-57

Summerhayes, C.P. 1971. Lagoonal sedimentation at Aitutaki and Manuae in the Cook Islands: a reconnaissance survey. N.Z. J. Geol. Geophys. 14: 351-363.

Table 16 continued

SPECIES STATION	1	2	3	4	5	6	7	8	9	10	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19	L20
Myriochele sp.																												+		
Branchiomma cingulata (Grube)												+																		
Branchiomma picta (McIntosh)																					+									
Oligochaeta																														
Pontodrilus matsushimensis Iizuka					+	+	+																							
Sipuncula																														
Siphonosoma cumanense (Keferstein)					+																									
Phoronida																														
Phoronopsis harmeri Pixell									+			+	+															+		+
Crustacea[1]																														
Amphipod sp(p).											+			+				+												
Lysiosquilla maculata Fabricius					(+)	(+)			(+)																					
Heterosquilla sp.									+																					
Alpheus crassimanus Heller					+																									
Alpheid sp.															+															
Callianassa sp.					+																									
Aniculus aniculus (Fabricius)										+																				
Calcinus elegans (H. Milne Edwards)										+																				
Calcinus latens (Randall)					+																									
Clibanarius humilis (Dana)					+																									
Pagurid sp(p).													+	+																
Calappa hepatica (L.)					+				+																					
Macrophthalmus convexus Stimpson			+	+	+	+	+	+																						

Table 16. Aitutaki lagoon: list of species occurring in samples taken at littoral Stations 1-10 between high and low water levels and in samples dredged at Stations L1-L20 in depths of 1-6m (see Fig. 36)

SPECIES STATION	1	2	3	4	5	6	7	8	9	10	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19	L20
Polychaeta																														
Paleanotus debilis (Grube)										+																				
Eurythoë complanata (Pallas)															+															
Gyptis capensis (Day)										+		+		+												+				
Typosyllis regulata Imajima												+			+															+
Ceratonereis vaipekae Gibbs						+		+																						
Glycera lancadivae Schmarda	+	+	+		+				+			+	+	+		+		+		+	+	+	+	+	+	+	+	+	+	+
Marphysa macintoshi Crossland	+		+		+		+	+																						
Nematonereis unicornis (Grube)										+	+	+	+		+														+	+
Aonides oxycephala (Sars)												+			+		+										+			
Malacoceros indicus (Fauvel)	+	+	+	+	+	+	+	+	+																+	+	+	+		
Prionospio malmgreni Claparède																+		+								+		+		
Scolelepis aitutakii Gibbs										+																+			+	
Scolelepis squamata saipanensis (Hartman)	+	+		+	+																									
Spio filicornis (Müller)				+																										
Poecilochaetus tropicus Okuda																										+			+	
Mesochaetopterus sagittarius (Claparède)	+			+	+				+			+				+														
Phyllochaetopterus brevitentaculata Hart-Sch.					+					+	+	+	+		+	+				+			+							
Phyllochaetopterus elioti Crossland					+				+		+				+															
Phyllochaetopterus verrilli Treadwell										+	+	+			+	+					+								+	+
Spiochaetopterus costarum (Claparède)			+		+				+											+				+		+				
Armandia melanura Gravier	+	+	+	+	+																									
Polyophthalmus pictus (Dujardin)																					+							+		
Dasybranchus caducus (Grube)	+		+	+	+				+	+													+		+	+		+		
Myriochele haplosoma Gibbs																												+		+

Table 16 continued

SPECIES STATION	1	2	3	4	5	6	7	8	9	10	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19	L20
Eucithara pulchella (Reeve)													+																	
Clavus sp.[3]																				+										
Terebra affinis Gray													+																	
Pupa sulcata (Gmelin)										+						+			+		+	+					+	+	+	+
Bulla punctulata A.Adams															+															
Atys cylindrica (Helbling)					+										+	+		+		+	+	+	+				+			+
Atys naucum (L.)											+																			
Cylichna dentifera A.Adams[3]																+														
Pyramidella acus (Gmelin)					+				+		+		+																	
Pyramidella terebellum (Müller)																				+										
Otopleura auriscati (Holten)														+																
Stylocheilus longicauda (Quoy & Gaim.)															+															
Modiolus auriculatus (Krauss)					+							+																		
Fragum fragum (L.)																				+						+				
Fragum unedo (L.)																						+								+
Codakia punctata (L.)																			+											
Codakia divergens (Philippi)										+																				
Anodontia edentula (L.)																			+											
Lioconcha ornata (Dillwyn)																							+	+		+	+		+	
Gafrarium pectinatum (L.)					+																							+		
Asaphis violascens (Forskål)					+	+			+																					
Gari gari (L.)[3]																						+						+		+
Tellinella staurella (Lam.)											+					+			+	+		+	+						+	
Quidnipagus palatum Iredale				+	+																									
Arcopagia robusta (Hanley)											+			+		+	+				+	+	+		+	+		+	+	+

Table 16 continued

SPECIES STATION	1	2	3	4	5	6	7	8	9	10	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19	L20
Ocypode laevis Dana			+	+																										
Uca tetragonon (Herbst)			+	+	+	+	+	+																						
Brachyuran sp(p).											+				+															
Mollusca																														
Philippia radiata (Röding)[3]																					+									
Cerithium columna Sowerby															+				+		+									
Cerithium variegatum Quoy & Gaim.					+		+																							
Rhinoclavis asper (L.)					+					+	+	+	+		+	+			+	+										+
Bittium sp.[3]																														+
Triphora pavimenta (Laseron)																			+											
Strombus gibberulus gibbosus (Röd.)										+	+					+		+	+		+									
Strombus maculatus Sowerby															+													+		
Strombus mutabilis Swainson											+	+		+	+				+											
Natica areolata Recluz																														+
Natica bougei Sowerby											+	+														+				
Natica gualtieriana Recluz					+																+		+	+	+		+	+	+	
Cypraea annulus obvelata (Lam.)													+																	
Cypraea moneta L.					+																									
Engina histrio (Reeve)																			+											
Engina lauta (Reeve)																			+											
Nassarius graniferus (Kiener)																					+									
Vexillum tusum (Reeve)[3]																														+
Gibberula sp. cf. G.ros (Reeve)[3]																														+

Table 16 continued

SPECIES STATION	1	2	3	4	5	6	7	8	9	10	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19	L20
Echinodermata																														
Amphipholis squamata (Delle Chiaje)															+							+						+	+	+
Amphiodia sp. aff. A. individua Mort.																												+		
Chiridota hawaiiensis Fisher																													+	+
Holothuria atra Jaeger					+					+																				
Hemichordata																														
Ptychodera flava Eschscholtz									+	+	+	+	+		+	+	+		+	+	+	+	+	+	+	+	+		+	+
Glossobalanus sp.																							+	+	+	+	+	+	+	+
Cephalochordata																														
Asymmetron lucayanum Andrews													+	+	+	+														
Teleostei																														
Leiuranus semicinctus (Lay & Benn.)										+					+															
Callechelys melanotaenia Bleeker										+																				
Echelid sp.																					+									

[1]The portunid and grapsid crabs, which probably range widely within the lagoon have been omitted: these are Thalamita admete (Herbst), Thalamita crenata (H. Milne Edwards), Scylla serrata (Forskål), Metopograpsus thukuhar (Owen) and Percnon planissimum (Herbst).

[2]Burrows seen but specimens not collected.

[3]Mollusc species recorded only from empty shells.

Table 17. Comparison of the number of species represented in the three main deposit zones of the lagoon on Aitutaki

Zone / Group	Intertidal flat HWM-LWM Stations 3-8	Reef rim LWM-2m depth Stations 10, L1-L9	Lagoon floor 1-6m depth Stations L10-L2
Polychaeta	12	15	17
Crustacea[1]	9	6	1
Mollusca[2]	10	27	23
Other	3	7	7
Total	34	55	48

[1]Excluding portunids and grapsids - see Table 1

[2]Including trace (shell only) species

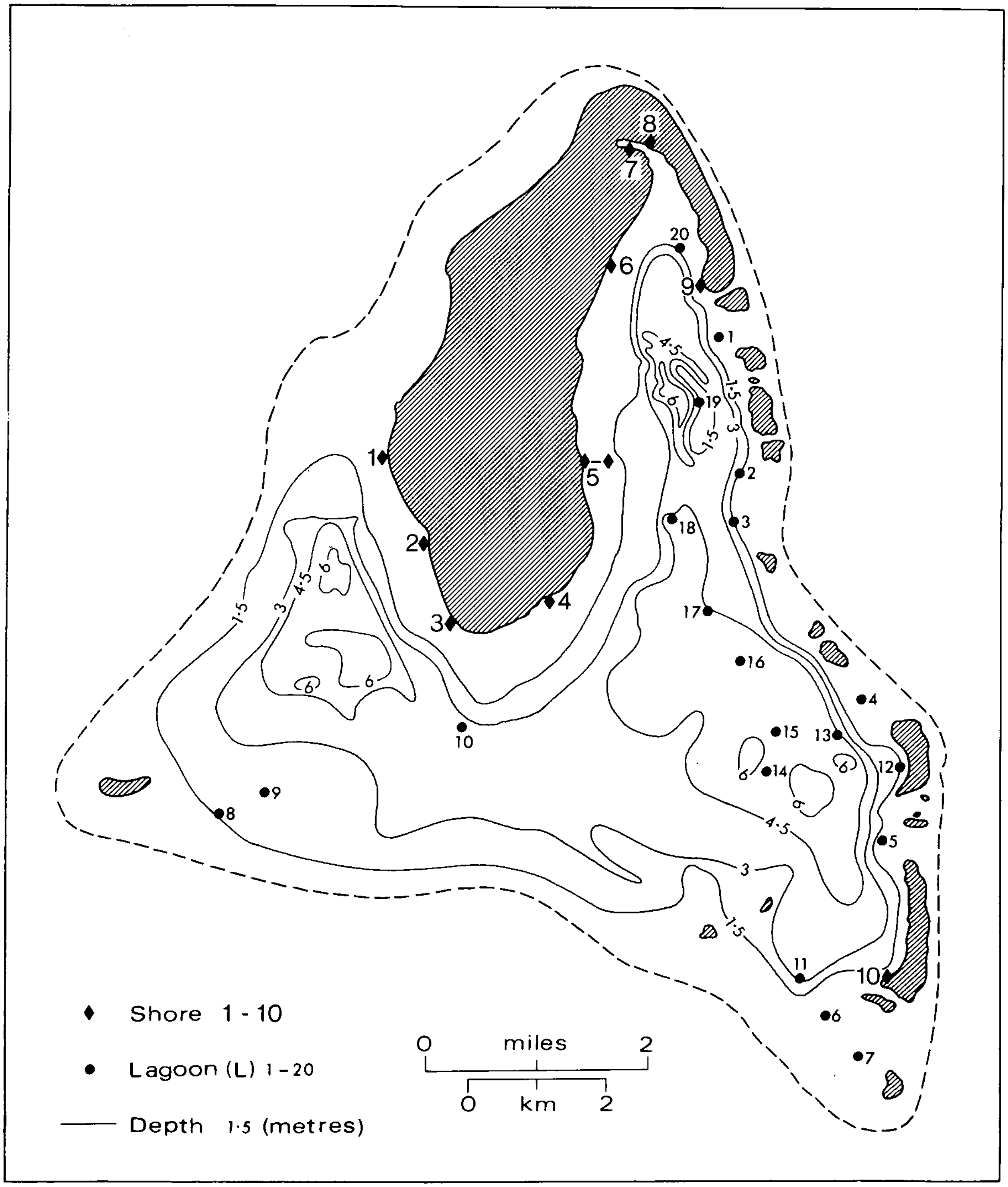

Figure 36. Map of Aitutaki showing lagoon bathymetry and location of sampling stations

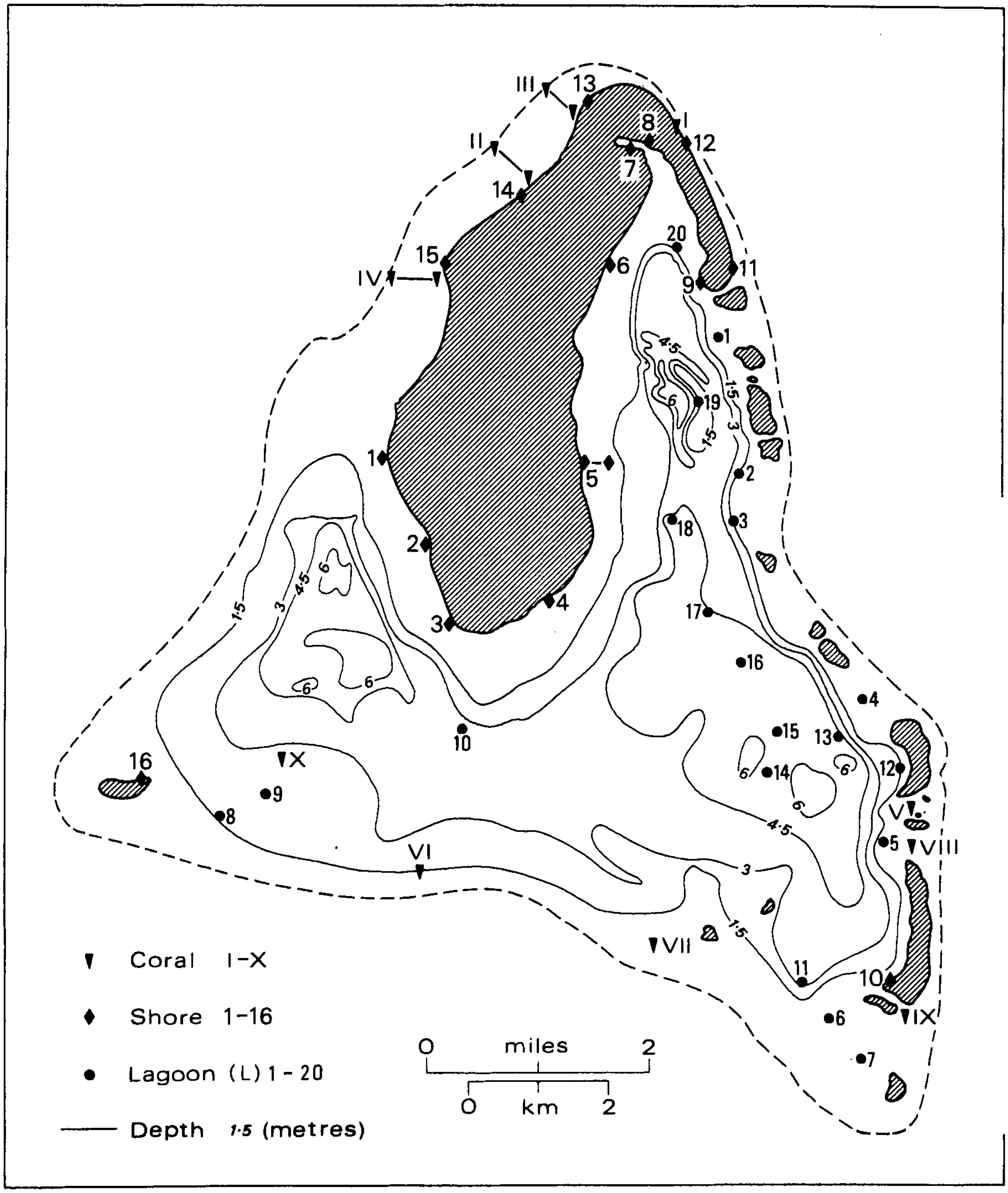

Figure 37. Map of Aitutaki showing positions of shore stations 1-16, dredge stations L1-L20, and coral collection areas I-X.

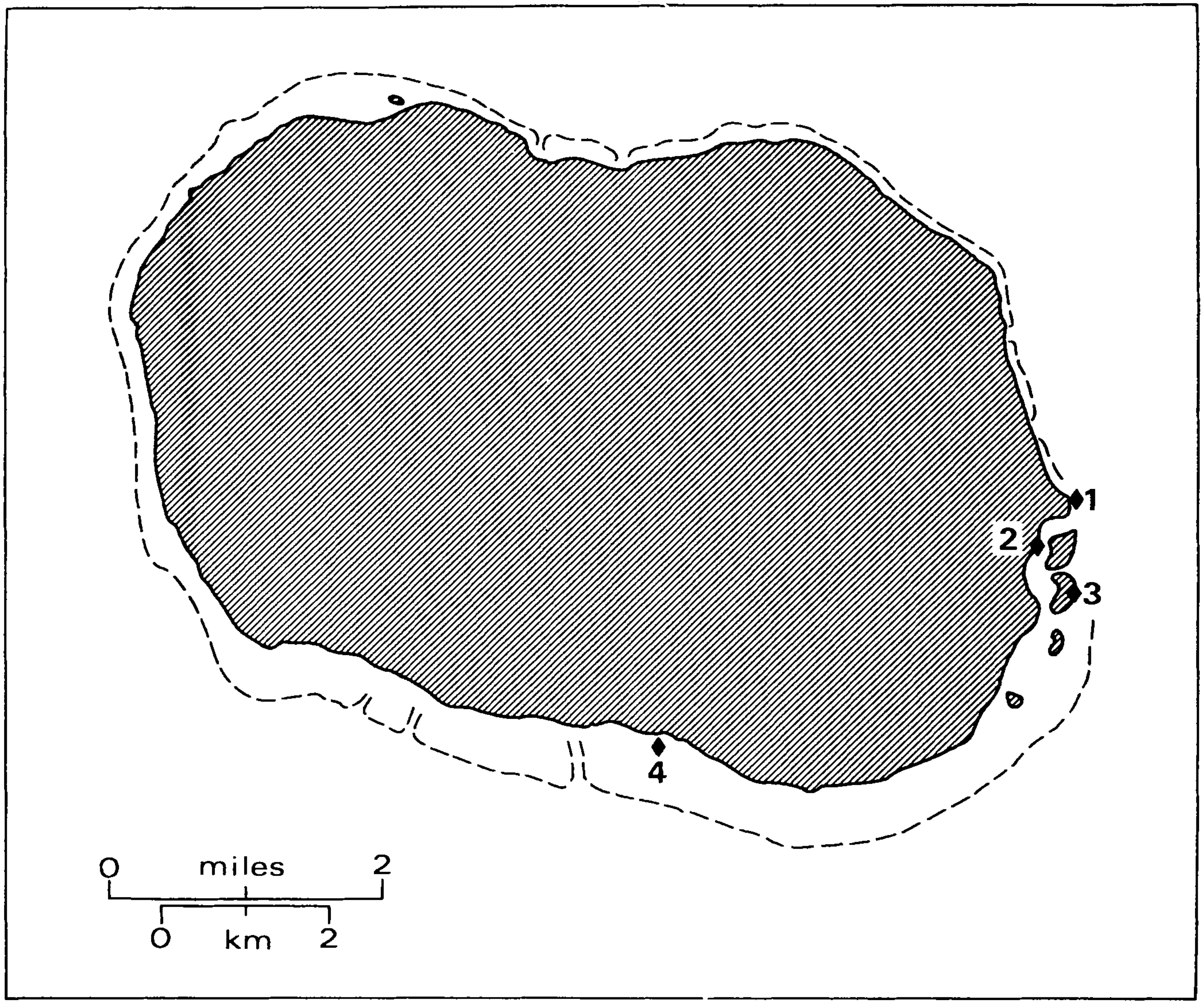

Figure 38. Map of Rarotonga showing locations of shore stations R1-R4

9. MARINE FAUNA OF THE COOK ISLANDS: CHECK-LIST OF SPECIES COLLECTED DURING THE COOK BICENTENARY EXPEDITION IN 1969

P.E. Gibbs, H.G. Vevers and D.R. Stoddart

INTRODUCTION

As part of the Cook Bicentenary Expedition in 1969, various aspects of the marine communities of the reef and lagoon environments on Aitutaki and Rarotonga in the southern Cook Islands were investigated. Descriptions of these surveys, carried out between 21 August and 26 September, and the study areas are given in Gibbs, Stoddart & Vevers (1971), Gibbs (1975) and Stoddart (1975a, 1975b). Some of the material resulting from these studies has already been described (see Gibbs, 1971; Pillai & Stoddart, In press; Stoddart & Pillai, 1973) but since it is doubtful whether all of the Expedition material will be utilized and/or recorded in future publications, it was considered advisable to bring together all of the species records in the form of a preliminary check-list of the marine fauna which would serve as a basis for further faunistic work in the Cook Islands.

This check-list of the marine fauna is based solely on the collections made on Aitutaki and Rarotonga during the 1969 Expedition: no attempt has been made to include species recorded previously from the Cook Islands although here attention may be drawn to the papers of Banner & Banner (1967), McKnight (1972) and Devaney (1973) who have dealt with the alpheid shrimps and echinoderms, and to the lists of corals, sipunculids, molluscs, crabs, echinoderms and fishes from Manihiki Atoll (in Bullivant and McCann, 1974). This check-list is, to a certain extent, selective in that because of the limited time available efforts were directed towards obtaining comprehensive collections of certain groups or communities and, as a result, the scleractinians and echinoderms as well as the macrofauna inhabiting the lagoon deposits on Aitutaki are well represented. However, apart from the corals and echinoderms, the reef fauna is known only from general collections. Consequently, the molluscs for example, with 92 species recorded, are probably poorly represented, considering that about 260 species are known from French Oceania (see Ranson, 1967) and that the atoll of Raroia (Tuamotus) alone may support over 600 species (Morrison, 1954). However the Expedition collection of molluscs is supplemented by the Morgan collection of Cook Islands mollusc shells now housed by the Cook Islands Library and Museum at Rarotonga (see Chapter 10 of this Bulletin). This valuable collection, containing over 200 species, deserves to be documented more fully by a group expert.

We wish to thank the Royal Society and the Royal Society of New Zealand for the opportunity to take part in the Cook Bicentenary Expedition. This check-list could not have been compiled without the kind assistance of many group experts: for identifying material in the Expedition collections we are most grateful to C.S.G. Pillai (Scleractinia), S.J. Edmonds (Sipuncula), C.C. Emig (Phoronopsis), J.C. Yaldwyn (most Crustacea, Xanthidae assisted by J.S. Garth), R.S.K. Barnes (Macrophthalmus), R.W. Ingle (Crustacea deposited in British Museum (Nat. Hist.)), W.O. Cernohorsky (most Mollusca), J.D. Taylor (Mollusca deposited in Brit. Mus. (Nat. Hist.)), A.M. Clark (Asteroidea, Ophioroidea, Echinoidea), F.W.E. Rowe (Holothuroidea), C. Burdon-Jones (Enteropneusta), J.H. Wickstead (Asymmetron) and G. Palmer (Teleostei).

The Expedition collections are composed of nearly 300 species comprising the following groups:

Scleractinia	57	Asteroidea	3
Polychaeta	38	Ophiuroidea	9
Oligochaeta	1	Echinoidea	2
Sipuncula	4	Holothuroidea	14
Phoronida	1	Hemichordata	2
Stomatopoda	3	Cephalochordata	1
Decapoda	55+	Teleostei	14
Gastropoda	71		
Pelecypoda	20	Total	295+
Cephalopoda	1		

This material has been deposited in the British Museum (Natural History) and the National Museum, Wellington. Most specimens of the Crustacea and Mollusca are placed in the National Museum, the remainder in the British Museum (Nat. Hist.): in the check-lists of these two groups, species deposited in the British Museum (Nat. Hist.) collections are marked * and where both museums have specimens the species is marked +. The collections of all other groups are deposited in the British Museum (Nat. Hist.).

In the check-list, for each species the stations at which specimens were taken are given. The positions of the stations on Aitutaki are shown in Fig. 37 and on Rarotonga in Fig. 38. The main habitats investigated at these stations are as follows

Aitutaki:	Stations	1 - 10	intertidal lagoon sand flat
		11 - 12	outer reef platform
		13 - 15	outer reef-chiefly coral heads
		16	beach rock
		L1 - L9	medium to coarse sand, 1-2m depth (dredge)
		L10 - L20	silty sand, 1-6m depth (dredge)

Rarotonga: Stations R1 + R3 : outer reef platform
R2 + R4 : intertidal sand flat

In addition to the above, corals were collected at 10 localities on Aitutaki (Fig. 1, Areas 1 - X) and at Station R3 on Rarotonga.

Check-list of species

Coelenterata

Scleractinia

The following coral species were collected in shallow water (0-3m depth):

Astrocoeniidae	
Stylocoeniella armata (Ehrenberg)	X
Thamnasteriidae	
Psammocora contigua (Esper)	R3
Psammocora (Plesioseris) haimeana Milne-Edwards & Haime	I II
Pocilloporidae	
Pocillopora brevicornis Lam.	I
Pocillopora damicornis (L.)	II IV V R3
Pocillopora ligulata Dana	II III
Pocillopora meandrina Dana var. nobilis Verrill	I IV VII R3
Pocillopora verrucosa (Ellis & Solander)	IV
Acroporidae	
Acropora corymbosa (Lam.)	R3
Acropora diversa (Brook)	R3
Acropora formosa (Dana)	V
Acropora humilis (Dana)	R3
Acropora hyacinthus (Dana)	VI
Acropora otteri Crossland	II
Acropora paniculata Verrill	II
Acropora rosaria (Dana)	II V
Acropora rotumana (Gardiner)	I
Acropora squarrosa (Ehrenberg)	V
Acropora surculosa (Dana)	I R3
Acropora variabilis Klunzinger	II
Astreopora listeri Bernard	I III
Montipora ehrenbergii Verrill	II IV
Montipora elschneri Vaughan	R3
Montipora gracilis Klunzinger	II
Montipora spumosa (Lam.)	IV
Montipora venosa (Ehrenberg)	III IV
Montipora sp. (?nov.)	II

Agariciidae	
Pavona varians Verrill	
Fungiidae	
Fungia (*Pleuractis*) *paumotensis* Stutchbury	X
Fungia (*Pleuractis*) *scutaria* Lam.	VI X
Fungia (*Verrillofungia*) *concinna* Verrill	II III VI VIII X
Herpolitha limax (Esper)	VI
Poritidae	
Porites lutea Milne-Edwards & Haime	I II III IV VII R3
Faviidae	
Cyphastrea chalcidicum (Forskal)	R3
Cyphastrea serailia (Forskal)	VI
Echinopora horrida Dana	VI
Favia favus (Forskal)	I VI VIII
Favia pallida (Dana)	VIII R3
Favia stelligera (Dana)	II VI VII X
Favites abdita (Ellis & Solander)	IX
Favites acuticollis (Ortmann)	I
Favites flexuosa (Dana)	VIII
Goniastrea benhami Vaughan	
Goniastrea pectinata (Ehrenberg)	III IV X
Hydnophora exesa (Pallas)	VII VIII
Hydnophora microconos (Lam.)	I II III IV R3
Leptastrea purpurea (Dana)	R3
Leptastrea transversa Klunzinger	III R3
Leptoria phrygia (Ellis & Solander)	I II III IV R3
Platygyra lamellina Ehrenberg	III IV VI R3
Plesiastrea lilli Wells	X
Plesiastrea versipora (Lam.)	I IV VIII IX R3
Oculinidae	
Galaxea clavus (Dana)	IV
Galaxea fascicularis (L.)	II IV
Mussidae	
Acanthastrea echinata (Dana)	I VI R3
Lobophyllia corymbosa (Forskal)	I III IV VI R3
Dendrophylliidae	
Turbinaria sp. cf. *veluta* Bernard	R3

Annelida

Polychaeta

Aphroditidae	
Gastrolepidia clavigera Schmarda	12 R1
Hololepidella nigropunctata (Horst)	12 R1

Palmyridae	
Paleanotus debilis (Grube)	10
Amphinomidae	
Eurythoë complanata (Pallas)	12 L5 R1
Phyllodocidae	
Phyllodoce pruvoti Fauvel	R1
Phyllodoce (Anaitides) madeirensis Langerhans	12
Hesionidae	
Gyptis capensis (Day)	10 L2 L4 L16
Hesione splendida Savigny	R1 R3
Leocrates chinensis Kinberg	R1
Syllidae	
Typosyllis regulata Imajima	L2 L5 L20 R3
Nereidae	
Ceratonereis vaipekae Gibbs	6 8
Perinereis cultrifera (Grube)	11 R3
Perinereis jascooki Gibbs	R3
Perinereis nigropunctata (Horst)	R3
Pseudonereis variegata (Grube)	R3
Glyceridae	
Glycera lancadivae Schmarda	1 2 3 5 9 11 L2 L3 L4 L6 L8 L10 L11 L12 L13 L14 L15 L16 L17 L18 L19 L20 R3 R4
Eunicidae	
Marphysa macintoshi Crossland	1 3 5 7 8
Nematonereis unicornis (Grube)	10 L1 L2 L3 L5 L19 L20
Spionidae	
Aonides oxycephala (Sars)	L2 L5 L7 L17
Malacoceros indicus (Fauvel)	1 2 3 4 5 6 7 8 9 L15 L16 L17 L18 R2 R4
Prionospio malmgreni Claparède	L6 L8 L16 L18
Scolelepis (Scolelepis) aitutakii Gibbs	10 L16 L19
Scolelepis (Scolelepis) squamata saipanensis (Hartman)	1 2 4 5
Spio filicornis (Muller)	4
Trochochaetidae	
Poecilochaetus tropicus Okuda	L16 L19

Chaetopteridae	
Mesochaetopterus sagittarius (Claparède)	1 5 9 L2 L6 R1 R4
Phyllochaetopterus brevitentaculata Hartmann-Schröder	5 10 L1 L2 L3 L5 L6 L10 L13
Phyllochaetopterus elioti Crossland	5 9 L1 L5
Phyllochaetopterus verrilli Treadwell	10 L1 L2 L5 L6 L11 L19 L20
Spiochaetopterus costarum costarum (Claparède)	3 5 9 L10 L14 L16 R4
Opheliidae	
Armandia melanura Gravier	1 2 3 4 5
Polyophthalmus pictus (Dujardin)	L11 L18
Capitellidae	
Dasybranchus caducus (Grube)	1 3 4 5 9 10 L13 L15 L16 L18 R2 R4
Oweniidae	
Myriochele haplosoma Gibbs	L18 L20
Myriochele sp.	L18
Sabellidae	
Branchiomma cingulata (Grube)	L2
Branchiomma picta (McIntosh)	L11 L19
Sabellastarte sanctijosephi (Gravier)	R1

Oligochaeta

Megascolecidae	
Pontodrilus matsushimensis Iizuka	5 6

Sipuncula

Sipunculidae	
Siphonosoma (Damosiphon) cumanense (Keferstein)	5 11 R3
Aspidosiphonidae	
Aspidosiphon elegans (Chamisso & Eysenhardt)	11
Phascolosomatidae	
Phascolosoma (Antillesoma) asser (Selenka & de Man)	12
Phascolosoma (Phascolosoma) albolineatum Baird	R3

Phoronida

Phoronopsis harmeri Pixell	9 L2 L3 L18 L20

Crustacea

Stomatopoda

*	*Gonodactylus chiragra* (Fabricius)	14		
	Lysiosquilla maculata (Fabricius)	9		
	Heterosquilla sp. (small)	9		

Decapoda

Caridea

	Hippolytidae			
*	*Thor* sp.	14		
	Alpheidae			
	Alpheus crassimanus Heller	5		
	Alpheus pacificus Dana	5		
+	*Alpheus* sp(p).	13	14	R3
*	*Arete* sp.	14		
	Athanas djiboutensis Coutiere	5		
	Palaemonidae			
*	*Coralliocaris* sp.	14		
	Gnathophyllidae			
*	*Gnathophyllum* sp.	14		

Thalassinidea

	Callianideidae			
	Callianidea typa H. Milne Edwards	R3		
	Callianassidae			
	Callianassa (*Callichirus*) sp. near *C. placida* de Man	5		

Paguridea

	Coenobitidae			
	Coenobita perlata H. Milne Edwards	10	16	
	Coenobita rugosa H. Milne Edwards	10		
	Paguridae			
	Aniculus aniculus (Fabricius)	10		
	Calcinus elegans (H. Milne Edwards)	10	12	
	Calcinus herbstii de Man	16		
	Calcinus latens (Randall)	5		
	Clibanarius humilis (Dana)	5		
	Dardanus deformis (H. Milne Edwards)	10		
	Dardanus scutellatus (H. Milne Edwards)	16		
+	Pagurid spp.	12	13	14

Galatheidea

Galatheidae	
*Galatheid sp(p).	13 14
Porcellanidae	
Petrolisthes lamarkii (Leach)	R3

Oxystomata

Calappidae	
Calappa hepatica (L.)	5 9

Oxyrhyncha

Majidae	
*Majid sp.	13 14

Brachyrhyncha

Portunidae	
Scylla serrata (Forskål)	northern lagoon
Thalamita admete (Herbst)	5
Thalamita crenata (H. Milne Edwards)	5 6 9
Thalamita edwardsi Borradaile	R3
* *Thalamita* sp.	13
Atelecyclidae	
Kraussia rugulosa (Krauss)	R3
Xanthidae	
Chlorodiella cytherea (Dana)	R3
Eriphia sebana (Shaw & Nodder)	10
Leptodius gracilis (Dana)	11 R3
Leptodius leptodon Forest & Guinot	11 R3
Leptodius sanguineus (H. Milne Edwards)	11 R3
Liomera bella (Dana)	R3
Liomera laevis (A. Milne Edwards)	R3
Lydia annulipes (H. Milne Edwards)	R3
Pilodius areolatus (H. Milne Edwards)	R3
Pilodius scabriculus Dana	R3
Pseudozius caystrus (Adams & White)	11 R3
Xanthias lamarkii (A. Milne Edwards)	R3
*Xanthid sp(p.).	12 13 14 15
Ocypodidae	
Macrophthalmus (*Macrophthalmus*) *convexus* Stimpson	3 4 5 6 7 R2
Ocypode laevis Dana	3 4
Uca tetragonon (Herbst)	3 4 6 7 R2

Grapsidae

Cyclograpsus sp. cf. *C. intermedium* Ortmann 11
Grapsus tenuicrustatus (Herbst) 10
Metopograpsus thukuhar (Owen) 5 R3
Pachygrapsus minutus A. Milne Edwards R3
Pachygrapsus plicatus (H. Milne Edwards) R3
Pachygrapsus sp. 15
Percnon planissimum (Herbst) 5

Gecarcinidae

\+ *Cardisoma carnifex* (Herbst) 6 R1

Hapalocarcinidae

*Hapalocarcinid sp. 13

Mollusca

Gastropoda

" indicates species known only from empty shells

Trochidae

\+ *Trochus* (*Tectus*) *niloticus* L. 12 15

Turbinidae

\+ *Astraea* (*Australium*) *rhodostoma* Lam. 12 R1
Turbo (*Marmarostoma*) *argyrostomus* L. 12
* *Turbo* (*Marmarostoma*) *setosus* Gmelin 12

Neritidae

Nerita plicata L. 2 16

Phenacolepadidae

Phenacolepis tenuisculpta Thiele R3

Vermetidae

Vermetus maximus (Sowerby) 12

Planaxidae

Planaxis (*Angiola*) *lineatus* (da Costa) (= *ineptus* Gould) 11

Cerithiidae

"*Bittium* sp. L20
Cerithium columna Sowerby 16 L5 L9 L11
* *Cerithium nodulosus* (Bruguière) 13
Cerithium (*Clypeomorus*) *rugosum* Wood 2 16
Cerithium (*Clypeomorus*) *variegatum* Quoy & Gaimard 5 7

	Cerithium (Conocerithium) egenum Gould	12
	Cerithium (Semivertagus) nesioticum Pilsbry & Vanatta	12
	Rhinoclavis asper L.	5 10 L1 L2 L3 L5 L6 L9 L10 L20
Triphoridae		
	Triphora pavimenta (Laserow)	L9
Architectonicidae		
	"Philippia radiata (Röding)	L11
Vanikoridae		
*	Vanikoro sp.	12
Hipponicidae		
	Hipponix conicus (Schumacher)	12
Females parasitic on Astraea rhodostoma and Turbo argyrostomus		
Strombidae		
	Strombus gibberulus gibbosus (Röding)	10 L1 L6 L8 L9 L11
	Strombus maculatus Sowerby	L5 L18
	Strombus mutabilis Swainson (juveniles)	L1 L2 L4 L5 L9
Naticidae		
	Natica areolata Recluz	L20
	Natica bougei Sowerby	L1 L2 L16
	Natica gualtieriana Reclux (= marochiensis of authors - non Gmelin)	5 L11 L13 L14 L15 L17 L18 L19
Cypraeidae		
+	Cypraea (Erosaria) caputserpentis L.	12 13
*	Cypraea (Erosaria) helvola L.	R1
*	Cypraea (Luria) isabella L.	R1
	Cypraea (Mauritia) maculifera (Schilder)	12
	Cypraea (Monetaria) annulus obvelata Lam.	L3
+	Cypraea (Monetaria) moneta L.	5 12 13 16
Cymatiidae		
	Cymatium nicobaricum (Röding) (juvenile)	16
*	Septa pilearis (L.)	13
Muricidae		
+	Drupa morum Röding	12
	Drupa ricinus (L.)	12

	Drupina grossularia (Röding)	12				
	Morula granulata (Duclos)	16				
+	*Morula uva* (Röding)	12	14			
	Thais armigera (Link)	12				
	Magilidae					
	Coralliophila violacea (Kiener)	12				
	Magilus antiquus (Montfort)	12				
	Pyrenidae					
*	*Pyrene* sp. cf. *spiculus* Duclos	14				
	Buccinidae					
*	*Cantharus* sp. (juvenile)	14				
	Engina (*Enginopsis*) *histrio* (Reeve)	L9				
	Engina (*Enginopsis*) *lauta* (Reeve)	L9				
	Nassariidae					
	Nassarius graniferus (Kiener)	L11				
	Fasciolariidae					
+	*Peristernia nassatula* (Lam.)	12	14			
	Mitridae					
*	*Mitra stictica* (Link)	R1				
	Mitra (*Strigatella*) *litterata* (Lam.)	16				
"	*Vexillum* (*Pusia*) *tusum* (Reeve)	L20				
	Marginellidae					
"	*Gibberula* sp. cf. *ros* (Reeve)	L20				
	Conidae					
*	*Conus catus* Hwass	R1				
+	*Conus chaldaeus* (Röding)	12	R1			
+	*Conus ebraeus* L.	12	16	R1		
*	*Conus lividus* Hwass	R1				
	Conus miliaris Hwass	12				
	Conus sponsalis Hwass	12				
	Turridae					
"	*Clavus* sp.	L10				
	Eucithara pulchella (Reeve)	L3				
	Terebridae					
	Terebra affinis Gray	L3				
	Acteonidae					
	Pupa sulcata (Gmelin)	10	L6	L9	L11	L12
		L17	L18	L19	L20	
	Bullidae					
	Bulla punctulata A. Adams	L5				

Atyidae	
Atys cylindrica (Helbling)	5 L5 L6 L8 L10 L11 L12 L13 L17 L20
Atys naucum (L.)	L1
Scaphandridae	
"Cylichna (Diniatys) dentifera A. Adams	L6
Pyramidellidae	
Otopleura auriscati (Holten)	L4
Pyramidella acus (Gmelin)	5 9 L2 L4
Pyramidella terebellum (Müller)	L10
Aplysiidae	
Stylocheilus longicauda (Quoy & Gaimard)	L5
Hexabranchidae	
Hexabranchus marginatus (Quoy & Gaimard)	5 (stranded)

Pelecypoda

Arcidae	
Arca arabica Philippi	12
Mytilidae	
Modiolus auriculatus (Krauss)	5 L2
* Lithophaga sp.	13
Pteriidae	
* Pinctada sp.	13
Pinnidae	
* Pinna muricatum L.	R1
Lucinidae	
Anodontia edentula (L.)	L9
Codakia punctata (L.)	L9
Codakia (Epicodakia) divergens (Philippi)	10
Chamidae	
Chama iostoma (Conrad)	12
Cardiidae	
Fragum fragum (L.)	L9 L10 L16
Fragum unedo (L.)	L12 L20
Tridacnidae	
+ Tridacna (Chametrachea) maxima (Röding)	12 13

Veneridae	
Gafrarium pectinatum (L.)	5 L18
* *Gafrarium* sp.	14
Lioconcha ornata (Dillwyn)	L13 L14 L16 L17 L19
Sanguinolariidae	
Asaphis violascens (Forskål)	5 6 9
"*Gari gari* (L.)	L12 L18 L20
Tellinidae	
Arcopagia (*Pinguitellina*) *robusta* (Hanley)	L1 L4 L6 L7 L11 L12 L13 L15 L16 L18 L19 L20
Quidnipagus palatum Iredale	4 5
Tellinella staurella (Lam.)	L2 L6 L9 L10 L12 L13 L19

Cephalopoda

Octopodidae	
Octopus sp. (large)	12

Echinodermata

Asteroidea

Ophidiasteridae	
Linckia multifora (Lam.)	R3
Asteropidae	
Asteropsis carinifera (Lam.)	R1
Acanthasteridae	
Acanthaster planci (L.)	12 II IV

Ophiuroidea

Amphiuridae	
Amphiodia sp. cf. *individua* Mortensen	L18
Amphipholis squamata (Delle Chiaje)	L5 L12 L18 L19 L20 R1
Ophiactidae	
Ophiactis savignyi Müller & Troschel	14
Ophiotrichidae	
Macrophiothrix longipeda (Lam.)	12 R1
Ophiocomidae	
Ophiarthrum elegans Peters	12 R1 R3
Ophiocoma dentata Müller & Troschel	12 R1
Ophiocoma erinaceus Müller & Troschel	12 13

Ophiocoma pica Müller & Troschel	12
Ophiocomella sexradia (Duncan)	13 14

Echinoidea

Echinometridae	
Echinometra mathaei (de Blainville)	12 13 R1
Heterocentrotus mammillatus (L.)	12

Holothuroidea

Holothuriidae	
Actinopyga mauritiana (Quoy & Gaimard)	13 R1
Holothuria (Halodeima) atra Jaeger	5 10 R1
Holothuria (Lessonothuria) pardalis Selenka	R3
Holothuria (Mertensiothuria) leucospilota Brandt	12 R1
Holothuria (Mertensiothuria) pervicax Selenka	R1
Holothuria (Platyperona) difficilis Semper	R1
Holothuria (Semperothuria) cinerascens (Brandt)	12 R1
Holothuria (Thymiosycia) hilla Lesson	12 R1
Holothuria (Thymiosycia) impatiens (Forskål)	13 R1
Stichopodidae	
Stichopus chloronotus Brandt	14 R1
Stichopus horreus Selenka	R1
Stichopus variegatus Semper	13
Synaptidae	
Euapta godeffroyi (Semper)	R1
Chiridotidae	
Chiridota hawaiiensis Fisher	11 L19 L20 R3

Hemichordata

Enteropneusta

Ptychodera flava Eschscholtz	9 10 L1 L2 L3 L5 L6 L7 L9 L10 L11 L12 L13 L14 L15 L16 L17 L19 L20
Glossobalanus sp.	L13 L14 L15 L16 L17 L18 L19 L20

Cephalochordata

Asymmetron lucayanum Andrews	L3	L4	L5	L6

Pisces

Teleostei

Congridae		
Conger cinereus cinereus Rüppell	R1	
Echelidae		
Echelid sp.	L11	
Ophichthyidae		
Callechelys melanotaenia Bleeker	10	
Leiuranus semicinctus (Lay & Bennett)	10	L5
Moringuidae		
Moringua macrocephala (Bleeker)	R1	
Muraenidae		
Gymnothorax richardsoni (Bleeker)	14	
Pseudechidna brummeri Bleeker	12	
Chromidae		
Chromis caeruleus (Cuvier)	14	
Dascyllus aruanus (L.)	14	
Eleotridae		
Asterropteryx semipunctatus Rüppell	14	
Eviota gymnocephala Weber	14	
Gobiidae		
Paragobiodon echinocephala (Rüppell)	14	
Zonogobius semidoliatus (Valenciennes)	14	
Scorpaenidae		
Sebastapistes bynoensis (Richardson)	R1	

REFERENCES

Banner, A.H. & Banner, D.M. 1967. Contributions to the knowledge of the alpheid shrimp of the Pacific Ocean, XI. Collections from the Cook and Society Islands. Occ. Pap. Bernice P. Bishop Mus., 23: 253-286.

Bullivant, J.S. & McCann, C. 1974. Contributions to the natural history of Manihiki Atoll, Cook Islands. Mem. N.Z. oceanogr. Inst. 31: 1-63.

Devaney, D.M. 1973. Zoogeography and faunal composition of south-eastern Polynesian asterozoan echinoderms. Oceanography of the South Pacific 1972, R. Fraser, ed. (Wellington: New Zealand National Commission for UNESCO): 357-366.

Gibbs, P.E. 1972. Polychaete annelids from the Cook Islands. J. Zool., Lond., 168: 199-220.

---------- 1975. Survey of the macrofauna inhabiting lagoon deposits on Aitutaki. Atoll Res. Bull. 190:123-131

Gibbs, P.E., Stoddart, D.R. & Vevers, H.G. 1971. Coral reefs and associated communities in the Cook Islands. Bull. R. Soc., N.Z., 8: 91-105.

McKnight, D.G. 1972. Echinoderms collected by the Cook Islands Eclipse Expedition 1965. N.Z. oceanogr. Inst. Rec., 1: 37-45.

Morrison, J.P.E. 1954. Animal ecology of Raroia Atoll, Tuamotus. Part 1. Ecological notes on the mollusks and other animals of Raroia. Atoll Res. Bull., 34: 1-18.

Pillai, C.S.G. & Stoddart, D.R. 1973. Hermatypic corals from the Cook Islands (in litt.).

Ranson, G. 1967. Contribution à la connaissance de la faune malacologique de l'Océanie. Cah. Pacif., 10: 85-135.

Stoddart, D.R. 1975a. Scientific studies in the Southern Cook Islands: background and bibliography. Atoll Res. Bull., 190:1-30

---------- 1975b. Almost-atoll of Aitutaki: geomorphology of reefs and islands. Atoll Res. Bull., 190:31-57

Stoddart, D.R. & Pillai, C.S.G. 1973. Coral reefs and reef corals in the Cook Islands, South Pacific. Oceanography of the South Pacific 1972, R. Fraser, ed. (Wellington: New Zealand National Commission for UNESCO): 475-483.

10. CHECKLIST OF THE MORGAN COLLECTION OF MOLLUSC SHELLS FROM THE COOK ISLANDS

This collection of shells was made by the late Judge H.J. Morgan, who was responsible for its arrangement and for the identifications. The collection is now housed by the Cook Islands Library and Museum at Rarotonga, where it is available for study. The arrangement of this list follows that of Judge Morgan, except that species in each genus are arranged alphabetically. Specimens marked * were dead when found, all others were living. The list is included here by permission of the Council of the Cook Islands Library and Museum and of the Rev. Bernard Thorogood. The collection as determined by Judge Morgan includes over 200 species, derived as follows: Rarotonga 110 species; Aitutaki 59; Atiu 50; Mauke 19; Pukapuka 10; Manihiki 8; Penrhyn 3; Suwarrow 2; Palmerston 1.

Cypraea amphiperas ovum Linnaeus
    Rarotonga: 66
C. annulus Linnaeus
    Rarotonga: 163-166
C. arabica Linnaeus
    Atiu: 68*-71*. Rarotonga: 67
C. bistrinotata Schilder
    Rarotonga: 1*-4*
C. carneola Linnaeus
    Aitutaki: 192. Rarotonga: 191, 193
C. caputserpentis Linnaeus
    Rarotonga: 115-119
C. cumingi Sowerby
    Atiu: 54*-56*
C. depressa Gray
    Manihiki: 92-94
C. dillwyni Schilder
    Mauke: 6*
C. eglantina Duclos?
    Aitutaki: 95
C. erosa Linnaeus
    Aitutaki: 99-101. Mauke: 102-103. Rarotonga: 98, 104
C. goodalli Sowerby
    Aitutaki: 50-52. Atiu: 53*?
C. helvola Linnaeus
    Atiu: 120, 123*, 124. Mauke: 122. Rarotonga: 121
C. histrio Gmelin
    Atiu: 89*. Manihiki: 90. Pukapuka: 91
C. imorata Gray
    Atiu: 38*-43*. Manihiki: 31*-37*
C. isabella Linnaeus
    Aitutaki: 22, 24, 26. Atiu: 14-17, 20-21, 27-28.
    Mauke: 23, 25, 29. Rarotonga, 18-19
C. lynx Linnaeus
    Aitutaki: 184-186

<u>Cypraea</u> <u>maculifera</u> Schilder
Atiu: 72-74, 79*-80*, 81, 82*-83*, 88*. Rarotonga: 75-78, 84*-87*
<u>C</u>. <u>mariae</u> Schilder
Rarotonga: 5*
<u>C</u>. <u>mauritiana</u> Linnaeus
Pukapuka: 57-64
<u>C</u>. <u>moneta</u> Linnaeus
Aitutaki: 143-156. Penrhyn: 135-142. Rarotonga: 157-162.
<u>C</u>. <u>nucleus</u> Linnaeus
Atiu: 7*-13*
<u>C</u>. <u>obvelata</u> Lamarck
Rarotonga: 167-173
<u>C</u>. <u>poraria</u> Linnaeus
Atiu: 125-130, 131*-134*
<u>C</u>. <u>schilderorum</u> Iredale
Aitutaki: 208-210. Atiu: 203-207, 211-212
<u>C</u>. <u>scurra</u> Gmelin
Mauke: 96*-97*
<u>C</u>. <u>subteres</u> Weinkauff
Mauke: 48*-49*
<u>C</u>. <u>talpa</u> Linnaeus
Rarotonga: 65
<u>C</u>. <u>teres</u> Gmelin
Mauke: 44*-45*, 46*?, 47*?
<u>C</u>. <u>testudinaria</u> Linnaeus
Rarotonga: 30
<u>C</u>. <u>tigris</u> Linnaeus
Pukapuka: 174-183
<u>C</u>. <u>ventriculus</u> Lamarck
Atiu: 194-195, 196*, 199-202. Pukapuka: 197-198
<u>C</u>. <u>vitellus</u> Linnaeus
Aitutaki: 187. Rarotonga: 188, 189*, 190

<u>Conus</u> <u>adamsoni</u> Broderip
Rarotonga: 263*-264*
<u>C</u>. <u>aristophanes</u> Sowerby
Rarotonga: 251-253
<u>C</u>. <u>auliculus</u> Linnaeus
Rarotonga: 216*
<u>C</u>. <u>auricomus</u> Hwass?
Rarotonga: 314*-315*
<u>C</u>. <u>bandanus</u> Hwass
Rarotonga: 228*
<u>C</u>. <u>capitaneus</u> Linnaeus
Rarotonga: 245*
<u>C</u>. <u>catus</u> Hwass
Rarotonga: 274-277
<u>C</u>. <u>chaldeus</u> Röding
Atiu: 294-299
<u>C</u>. <u>coronatus</u> Gmelin
Rarotonga: 247-250
<u>C</u>. <u>cylindraceus</u> Broderip and Sowerby
Aitutaki: 279*

<u>Conus distans</u> Hwass
Mauke: 313*. Rarotonga: 213-215
<u>C. ebraeus</u> Linnaeus
Atiu: 284-286
<u>C. eburneus</u> Hwass
Aitutaki: 226, 243. Rarotonga: 225, 227, 241-242
<u>C. episcopus</u> Hwass
Atiu: 235. Rarotonga: 229*
<u>C. flavidus</u> Lamarck
Aitutaki: 304. Rarotonga: 305-309
<u>C. frigidus</u> Reeve?
Rarotonga: 303
<u>C. geographus</u> Linnaeus
Penrhyn: 217*
<u>C. glans</u> Hwass
Atiu: 293*
<u>C. imperialis</u> Linnaeus
Rarotonga: 222-224
<u>C. leopardus</u> Röding
Rarotonga: 218, 220, 828. No location: 221
<u>C. litoglyphus</u> Hwass
Aitutaki: 244*
<u>C. lividus</u> Hwass
Rarotonga: 261-262
<u>C. miles</u> Linnaeus
Atiu: 288-292
<u>C. miliaris</u> Hwass
Rarotonga: 268-273
<u>C. mitratus</u> Hwass
Aitutaki: 301*. Rarotonga: 302*?
<u>C. musicus</u> Hwass
Rarotonga: 254
<u>C. nussatella</u> Linnaeus
Atiu: 278*
<u>C. pertusus</u> Hwass
Mauke: 310*
<u>C. pulicarius</u> Hwass
Rarotonga: 239-240, 255*, 256-257
<u>C. rattus</u> Hwass
Rarotonga: 280-283, 300
<u>C. retifer</u> Menke
Atiu: 265-267
<u>C. sanguinolentus</u> Quoy and Gaimard
Rarotonga: 258-260
<u>C. scabriusculus</u> Dillwyn
Mauke: 312*
<u>C. sponsalis</u> Hwass
Rarotonga: 311, 316-324
<u>C. tessulatus</u> Born
Aitutaki: 237-238
<u>C. textile</u> Linnaeus
Rarotonga: 246*
<u>C. tulipa</u> Linnaeus
Atiu: 234. Mauke: 230*-232*. Rarotonga: 233

Conus vexillum Gmelin
Rarotonga: 219*
C. vitulinus Hwass
Atiu: 236

Cypraecassis rufa Linnaeus
Pukapuka: 829-830

Charonia tritonis Linnaeus
Rarotonga: 835

Terebra affinis Gray
Aitutaki: 349-360
T. bablonia Lamarck
Rarotonga: 361
T. dimidiata Linnaeus
Aitutaki: 335. Rarotonga: 333-334, 336-337
T. genulata Linnaeus
Aitutaki: 345. Rarotonga: 344, 346-348
T. guttata Röding
Rarotonga: 340
T. maculata Linnaeus
Aitutaki: 341. Rarotonga: 331-332, 342-343
T. subulata Linnaeus
Aitutaki: 325-330, 338-339

Mitra ambigua Swainson
Aitutaki: 383*
M. circumerina Lamarck
Manihiki: 369*
M. coffea Schubert and Wagner
Atiu: 386-388. Mauke: 385
M. colombelliformis Kiener
Aitutaki: 370-371. Rarotonga: 372-373
M. conovula Quoy and Gaimard
Aitutaki: 380. Mauke: 379
M. ferruginea Lamarck
Rarotonga: 374*
M. genulata Gmelin
Aitutaki: 375-376, 378*. Rarotonga: 377
M. litterata Lamarck
Rarotonga: 397-401
M. mitra Linnaeus
Aitutaki: 389, 390
M. nodosa Swainson
Atiu: 392-396
M. nucea Gmelin
Aitutaki: 384
M. paupucula Linnaeus
Aitutaki: 382. Rarotonga: 381
M. tuberosa Reeve
Rarotonga: 391
M. stictica Link
Atiu: 367. Rarotonga: 366, 368

Mitra sp.
Aitutaki: 362*-365*. Atiu: 402*-405*

Harpa _amouretta_ Röding
Pukapuka: 409*. Rarotonga: 407-408
_H._ _conoidalis_ Lamarck
Rarotonga: 406

Vasum _armatum_ Broderip
Pukapuka: 410, 411*
Vasum sp.
Atiu: 412-420

Patella sp.
Mauke: 421*-445*

Nerita _albicilla_ Linnaeus
Rarotonga: 451*-453*
_N._ _plicata_ Linnaeus
Rarotonga: 454*-457*
_N._ _polita_ Linnaeus
Rarotonga: 447*-450*
Nerita sp.
Atiu: 458*-460*. Rarotonga: 461*

Echinella _bellula_
Aitutaki: 462, ?463-472

Melarapha _obesa_
Atiu: 473-479

Architectonica sp.
Rarotonga: 480*-481*

Modulas _tectum_ Gmelin
Rarotonga: 482

Janthina _violacea_ Röding
Atiu: 485*-486*. Manihiki: 483*-484*

Vanikoro _ligata_ Recluz
Aitutaki: 487-496

Epitomium sp.
Rarotonga: 497*-498*

Trochus _niloticus_ Philippi?
Aitutaki: 831-832. Pukapuka: 503*
Trochus sp.?
Atiu: 502. Rarotonga: 499-501

Stomatia sp.?
Atiu: 504*

<u>Turbo</u> <u>petholatus</u> Linnaeus
Rarotonga: 506*
<u>T</u>. <u>setosus</u> Gmelin
Rarotonga: 508-509
<u>Turbo</u> sp.
Atiu: 505*. Rarotonga: 507

<u>Astrea</u> <u>astralium</u>?
Rarotonga: 510-511
<u>Astrea</u> sp.
Mauke: 512*-513*

<u>Cerithium</u> <u>nodulosum</u> Bruguiere
Rarotonga: 541-542
<u>C</u>. <u>rhinoclavis</u> <u>kochi</u> Philippi?
Rarotonga: 522-523
<u>C</u>. <u>sinensis</u> Gmelin
Rarotonga: 543-544
<u>Cerithium</u> sp.
Aitutaki: 524-540. Rarotonga: 514-521

<u>Strombus</u> <u>dentatus</u> Linnaeus?
Rarotonga: 547
<u>S</u>. <u>gibberulus</u> <u>gibberulus</u> Röding
Rarotonga: 548-568
<u>S</u>. <u>mutabilis</u> Swainson
Rarotonga: 545-546
<u>S</u>. <u>thersites</u> Swainson
Rarotonga: 569*, 836*

<u>Polinices</u> <u>melanostoma</u> Gmelin
Aitutaki: 570-578
<u>P</u>. <u>simiae</u> Deshayes?
Aitutaki: 580. Rarotonga: 579

<u>Natica</u> sp.
Aitutaki: 581-593

<u>Casmaria</u> <u>erinaceus</u> <u>kalosmodix</u> Melvill
Mauke: 594. Rarotonga: 595-596

<u>Cymatium</u> <u>muricinum</u> Röding
Rarotonga: 597-598, 599*, 600
<u>C</u>. <u>nicobaricum</u> Röding
Atiu: 605. Rarotonga: 606
<u>C</u>. <u>pileare</u> Linnaeus
Rarotonga: 603-604
<u>C</u>. <u>rübeculum</u> Linnaeus
Aitutaki: 601-602

<u>Columbraria</u> sp.
Aitutaki: 607*-609*

Bursa bufolia Gmelin
Atiu: 610. Rarotonga: 611
B. gruentata Sowerby?
Mauke: 622*-623*
B. lampas Linnaeus
Rarotonga: 833
Bursa sp.
Rarotonga: 612-613, 614*

Tonna perdix Linnaeus
Rarotonga: 615-617

Malea pomum Linnaeus
Aitutaki: 618-620, 621*

Drupa albolabris Blainville
Rarotonga: 629-632
D. grossularia Röding
Atiu: 625-628
D. hystrix Linnaeus
Atiu: 637-641
D. morum Röding
Rarotonga: 633-634, 636
D. ricinus Linnaeus
Rarotonga: 624
D. rubucaesium Röding
Rarotonga: 642*-643*
Drupa sp.
Aitutaki: 644. Manihiki: 645

Coralliophila bulbiformis Conrad
Rarotonga: 690*
C. erosa Gmelin
Aitutaki: 635*
C. violacea Kiener
Rarotonga: 687-689

Thais affinis Reeve
Atiu: 650-651
T. armigera Röding
Aitutaki: 655. Atiu: 652-654
T. intermedia Kiener
Atiu: 658-659
T. tuberosa Röding
Atiu: 656-657

Nassa serta Bruguiere
Rarotonga: 660-664

Morula nodus St Vincent
Atiu: 665, 668. Rarotonga: 666-667, 669-670, 674
M. ochrostoma Blainville
Atiu: 677

Morula tuberculata Blainville
Atiu: 671-673
Morula sp.
Aitutaki: 675*-676*

Vexilla vexillum Gmelin
Rarotonga: 678*-681*

Cantharus fumosus?
Atiu: 685-686
C. undosus Linnaeus
Rarotonga: 682-684

Rhizochilus madreporarum Sowerby
Mauke: 691*-694*

Nassarius granuliferous Kiener
Rarotonga: 695-698
N. hirtus Kiener
Rarotonga: 702-703
N. papillosus Linnaeus
Rarotonga: 699-701

Latirus nodus Martin
Atiu: 704-705

Peristernia nassatula Lamarck
Aitutaki: 710-712. Atiu: 706-709

Pupa sulcata Gmelin
Aitutaki: 713*-717*

Aplustrum aplustre Linnaeus
Rarotonga: 719*-720*

Bulla adamsi Menke?
Mauke: 723*
B. ampulla Linnaeus
Rarotonga: 724-726
B. punctulata Adams?
Aitutaki: 721*

Bullina scabra Gmelin
Rarotonga: 722*

Haminoea sp.?
Aitutaki: 727*

Eulima sp.
Aitutaki: 728-732

Otopleura mitralis Adams
Mauke: 733-741

Pyramidella sulcata Adams
Aitutaki: 744-746, 747*, 748-750, 751*, 752, 753*
P. terebellum Muller
Rarotonga: 742-743

Melampus luteus Quoy and Gaimard
Atiu: 754-756
Melampus sp.
Aitutaki: 757*-764*

Siphonaria normalis Gould?
Aitutaki: 765*

Pinctada margaritifera Linnaeus
Manihiki or Penrhyn: 766-767
Pinctada sp.
Manihiki: 779

Pinna muricata Linnaeus
Rarotonga: 768-769

Pecten sp.?
Rarotonga: 772*-774*. Suwarrow: 770

Trapesium sp.?
Aitutaki: 771

Codakia punctata Linnaeus
Atiu: 775*

Isognomon sp.?
Aitutaki: 776-778. Rarotonga: 780-781

Mytilidae species
Rarotonga: 782*-787*

Lima hians?
Aitutaki: 788-790

Chama sp.
Aitutaki: 791-792, 834

Corculum sp.
Rarotonga: 793-794

Tridacna maxima Röding
Pukapuka: 795*. ?Rarotonga: 796-797

Semele sp.
Aitutaki: 799-800, 803-808. Rarotonga: 798, ?801*-802*

Tellina (Scutarcopagia) scobinata Linnaeus
Atiu: 809-811

Gari (Asaphis deflorata)
Aitutaki: 812-816

Venus (Periglypta) reticulata Linnaeus
Aitutaki: 817-820

Lambis (Harpago) chiragra Linnaeus
Palmerston: 821. Pukapuka: 822-823
L. truncata Kiener
Rarotonga: 824-827

Spondylus sp.
Penrhyn: 837. Suwarrow: 839*. No location: 840

Spirula spirula Linnaeus
Aitutaki: 838*

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