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It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs, CIMA, SIM, and ICCP, during the past six years. The Coral Atoll Program is a part of SIM.

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Preliminary Report on Land Animals at Onotoa Atoll, Gilbert Islands

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PRELIMINARY REPORT ON LAND ANIMALS AT
ONOTOA ATOLL, GILBERT ISLANDS

SCIENTIFIC INVESTIGATIONS IN MICRONESIA
Pacific Science Board
National Research Council

Edwin T. Moul
Rutgers University
The State University
of New Jersey
New Brunswick, N. J.
February 1954.

PRELIMINARY REPORT ON LAND ANIMALS AT ONOTOA ATOLL, GILBERT ISLANDS

This represents the first two parts of the preliminary report on the work of the General Naturalist on the Pacific Science Board's 1951 Expedition to Onotoa in the Gilbert Islands. The project was supported by funds granted to the National Academy of Sciences by Contract N7onr-291(04), NR 388-001 with the the Office of Naval Research. The generous cooperation of the U. S. Navy Department, the U. S. Coast Guard, and the Military Air Transport Service is acknowledged.

The author is grateful for the aid and assistance given by Mr. Harold J. Coolidge, Mrs. Lenore Smith and Miss Ernestine Akers. The cooperation and kindness of the British Colonial Government and its local representative, Mr. Richard Turpin and his wife added much to our comfort and success. The advice and assistance of my associates was a constant source of help and encouragement.

Part I. Land Vertebrates of Onotoa Atoll, Gilbert Islands

As general naturalist of the 1951 Pacific Science Board's expedition to Onotoa in the Gilbert Islands it was my duty to collect information about and specimens of all the land animals and plants on the island and to study the ecology of the fresh water and marine algae. In order to treat this material in a systematic manner I have divided my report into four sections. The first of these is the report on the land vertebrates collected and observed on the atoll of Onotoa from June 24 to August 30, 1951.

Due to my hurried preparation, I had very little time to search the literature for known facts about the flora and fauna of the Gilberts. Thus upon my return, I found that some information and specimens that should have been gathered were overlooked. Since very little has been published on the biota of this island group, the information and specimens gathered are of value in extending our knowledge of the distributional patterns of this life in the South Pacific.

In the following accounts of the individual species of vertebrates, I have included all the facts and observations recorded in my field notes. Because of my many other responsibilities, these accounts in many cases are correspondingly brief; most of the information was gathered "on the run."

The birds were identified by the author. Credit for other determinations are given with each group. The native names were supplied by Baru, our cook, and verified in most cases by James Redfern, our interpreter.

The author wishes to thank Dr. David H. Johnson of the United States National Museum staff for traps and other equipment used in collecting the rats; Dr. Joseph P. E. Morrison, also of the Museum staff, for providing the

fire-arms and ammunition for the collection of birds and for his excellent advice and encouragement while making preparations for the trip; and Dr. Waldo Schmitt, who has been extremely helpful on several of my visits to the museum and has assisted in securing the taxonomic information. The cooperation and kindness of the people of Onotoa in securing specimens is appreciated and acknowledged. Last and most important, due recognition should be given to the Office of Naval Research for making the expedition possible and for providing the opportunity to secure valuable basic scientific information on atolls and their ecology. All specimens have been deposited in the U. S. National Museum with provisions made for duplicates to be sent to the Bernice P. Bishop Museum in Honolulu.

MAMMALS

Rattus exulans exulans (Peale), Rat, "te gemoi."

Identification of this native rat was made by Dr. David H. Johnson of the United States National Museum. Four adults, three males and one female, and three young in various stages of growth were collected. The fact that these immature specimens were taken at intervals spanning our stay on the island is evidence that these animals bred from June through August. The specimens taken have been placed in the U. S. National Museum collection as numbers 294547 to 294553.

These rodents are not numerous and we hear no complaints from the natives about them. The number of cats, dogs and pigs around the village certainly keep these animals from becoming pests. I believe also that the construction of the native houses, with floors about two feet from the ground, the extreme cleanliness and order around the house sites, with no accumulation of rubbish, is also a factor in the control of these animals.

The first week of our stay on the island, pits were dug for garbage and latrines. These pits trapped great numbers of hermit crabs and a few rats. Spring traps placed in the kitchen caught several specimens, but on several occasions the activity of some local cat or dog left me only the tail.

At night there was a great amount of rustling noise in the dead leaves of the Scaevola thickets, which at first I attributed to rats, but most of which was later found to be caused by the nocturnal activity of the hermit crabs. Only a few times did I actually see these rodents running from thicket to thicket or scurrying under the rubbish in the thickets. When the camp was dismantled at the end of our stay, there was evidence of several nests under the packing cases in the supply tent. We suffered little damage to our supplies from these rodents. I feel certain from all the evidence I could find that the rat is not abundant enough on Onotoa to be a pest nor is it destructive to food.

Dogs.

The dogs are nondescript, short-haired and medium sized. They are very numerous around the villages and during the heat of the day were found sleeping or resting on loose sand in shady spots along the village street. They rarely paid much attention to the "foreigners." Most of their food seemed to consist of scraps from the family table. Several nights I was awakened by noise from the kitchen and on investigating I found dogs foraging in the garbage can which had not been emptied.

Cats.

These animals were common in the villages. At the village of Aiaki our slumber was disturbed by the horrible crying made by cats congregating in the Maneaba, the community house, where visitors are housed and entertained.

Pigs.

Pigs were not common, but in each village there were a few stockades built of logs to confine one or two. These stockades were usually placed on the opposite side of the road away from the houses and the lagoon shore. An ordinance of the Magistrate made it necessary for pigs to be either confined in pens or tied to stakes to prevent their wandering about. On one of the field trips on the island of Tabuarorae, I saw one large specimen wandering about, rooting in the rubbish, dragging a long rope behind it which it had obviously broken.

We were told that pigs are used for food only on special feast days, when they are roasted in pits lined with pre-heated stones. I am sure the muck in the pig pens is one of the places where the common house fly breeds.

BIRDS

Fifteen species of birds were observed on Onotoa Atoll during our stay there. As one would expect of an oceanic coral island, these species were mainly oceanic birds or migratory shore birds. Only one species of land bird, other than the domestic chicken, was observed and this was a migratory species. The nomenclature is based on Baker (1951)*.

Phaethon rubicauda rothschildi (Mathews), Red Tailed Tropic Bird.

Only one specimen of this bird was seen. It was observed flying low over the camp area on August 10. The trailing red tail feathers and the rosy coloration on breast feathers were quite evident.

Fregata ariel ariel (Gray), Least Man-O-War Bird.

These birds were observed soaring only at rare intervals, and were usually seen at times of high wind velocities and overcast skies. The white patches on the ventral flanks of the males were visible. The fork of the tail was rarely visible, since it was held closed, it formed a straight line with the body. As many as five birds were seen at one time. They are reported to nest in the large Pisonia trees at the extreme south end of the atoll on Tabuarorae Island. During our stay none were observed on this island.

*Baker, R. H., 1951, Avifauna of Micronesia, its origin, evolution and distribution. U. of Kan. Pub. Mus. of Nat. Hist. 3:1-359.

Demigretta sacra sacra (Gmelin), Reef Heron, "te kai."

A fairly common bird seen the whole length of the Atoll. White, blue and variegated individuals were present in the ratio of 3 to 2 to 1. A careful check on peculiarly marked, variegated individuals indicated that these birds are restricted to certain distinct territories along the reef and shore. Most of the birds fed at low tide along the seaward reefs and on the exposed reef flats between the various islands of the atoll. At high tide occasional individuals were observed foraging along the beach. They often capture food by standing motionless in the pools that remain on the dry reef at low tide. They wait for the organisms in these pools to move, then they capture the animal with a rapid jab of the beak. This species was less frequently seen on the lagoon side of the islands. On a number of occasions they were flushed from babai (taro) pits or the area surrounding these pits. They were also seen perched in coconut trees preening their feathers. On Aonteuma, the uninhabited northernmost island of the atoll, a structure resembling a nest was observed in a coconut palm. My attention was attracted to it by the circling and calling of a white specimen of this species. As long as I remained under the tree it continued circling and perching, uttering a loud gutteral call. The nest was placed in a coconut tree on the petioles of several leaves and was built of dead flower stalks of the coconut.

Two specimens were collected, #207, a blue individual, and #254, a white phase. This last bird was feeding along the beach at high tide and had fragments of crustacea in its stomach.

Gallus gallus (Linnaeus), Jungle fowl, "te moa."

I have used this name for the half wild, semi-domestic chicken observed around the villages. The adult males have the typical plumage of the Jungle Fowl, but the hens show a mixture of domestic strains. All are small and lay small eggs. Many of the hens were followed by flocks of chicks in various stages of growth.

The natives apparently do not eat the eggs and inquiry revealed they rarely use the mature birds for food. Both eggs and chickens were offered to us for our use. A whole roasted chicken was served to us on one occasion at a native feast. The feathers are utilized in decorating fans woven from pandanus.

Pluvialis dominica fulva (Gmelin), Pacific Golden Plover; "te kun."

A few birds of this species were observed feeding on the reef at low tide on July 12th. The number of these birds increased during August until small flocks were seen all along the seaward reef and on the lagoon shore. This was the only species of shore bird regularly flushed from sand and grass areas between the scattered coconut trees inside the beach rampart. A male was shot on the seaward reef on August 19 (#275).

Numenius phaeopus variegatus (Scopoli), Whimbrel.

These birds were exceedingly wary and none were collected. A few birds were noticed in late July, but the number increased in August. Individuals were usually seen on the exposed reef flats at the south end of the northern Island. Abenekeneke, a small uninhabited island between the large North and South Islands, was the favorite gathering place for a small flock which was frequently encountered resting under the palms on the seaward side. This species was identified by the black line through the eye and the white back and rump, and barred tail.

Heteroscelus incanus (Gmelin), American Wandering Tattler, "te kiriri."

This was the noisiest of the shore birds and was always present on the reef and lagoon shore, becoming very common in late August. It was characterized by quick movements and frequent teetering of the body, particularly as it alighted. An immature specimen was collected on August 18 on the reef flat at the south end of the North Island (#277).

Arenaria interpres interpres (Linnaeus), Ruddy Turnstone, "te kitiba."

These shore birds were present on the island when we arrived in June. They associated with the Plovers and Tattlers, and flew with them, but fed in separate flocks. In June there were only three or four birds in a group. Late in August the size of the flocks had increased to 8 or 10 birds and every section of the reef seemed to have its own flock. They fed in close formation along the beach, turning over shells, algae, leaves and drift. At low tide they fed on the drying seaward reef. The Tattlers and Plovers were frequently seen on the lagoon shore, but the Turnstones preferred the rocky shore and reef of the seaward side of the atoll, also utilizing the cobble and shingle reef flats between the larger islands. One specimen was taken on the seaward reef, August 18 (#274).

Sterna sumatrana sumatrana Raffles, Black Naped Tern, "te ngutu."

Two colonies of these terns were found on each of the two small islands, Abanekeneke and Nanntabuariki. They seemed to prefer resting on the coarse coral gravel ramparts on the seaward side of these two islands. This species was observed habitually fishing in the shallow water at the northern end of the lagoon. Birds were seen returning to the colonies near the central part of the atoll, carrying fish crosswise in their beaks. When the Long Tailed New Zealand Cuckoo was flushed from shrubbery on Nanntabuariki, a group of these terns attacked and chased the Cuckoo into another thicket, in much the same manner that I have observed terns attacking gulls in eastern Massachusetts. One specimen, #262, was brought in by a native. The bird had a heavy deposit of orange colored fat between the skin and muscle layer.

Sterna fuscata oahuensis Bloxham, Sooty Tern.

The only specimen seen of this species was dead. It was washed up on the seaward beach on August 14, 1951. No living individuals were seen on the atoll.

Thalasseus bergii pelecanoides (King), Crested Tern; "te kabiniwa."

Only two individuals of this species were seen, both on August 19 on the seaward reef. Both birds were resting on large coral boulders facing the reef front. One bird, a male (#276), was collected. The second individual was an immature bird and flew out to sea when disturbed.

Anous stolidus pileatus (Scopoli), Common Noddy Tern; "te nan."

One specimen was collected (#49). This was the commonest bird of the Atoll. Colonies were scattered the whole length of the central area of the large North Island. They were present in large numbers on the two larger southern islands of Aiaki and Tabuarorae. During the middle of the day many birds were observed perched in palm and pandanus, resting and preening, but there always seemed to be some restless individuals moving out to sea and back again. The greatest movement of birds occurred in the early morning and late afternoon, when great numbers constantly moved back and forth between the roosting area and the sea, the reef or the lagoon.

This species and the smaller species of Noddy were frequently seen feeding on an ebbing tide, particularly if the sea beyond the coralline ridge was rough. On these occasions the birds could be observed up and down the shore as far as the eye could see. They hovered low over the reef, darting about, dropping to pick their food from the surface of the water or just below the surface, not diving and submerging like our common Atlantic Tern. Most dives were successful and they came up with small fish in their beaks. They could change the position of the fish in their bills as they flew away. Sometimes they would drop it and catch it in mid air. Other individuals would stand near tide pools and wait for a blennie or other small fish to move into the open water. On July 18 the birds were quite active over the reef in a rain storm. Occasionally they would drop, shaking the water from their wing and tail feathers and then recovering, gain altitude.

The period of our stay on the Atoll covered a long nesting season. The nests were placed in the tops of pandanus trees in the whorl of leaves. Young birds were numerous and advertised their presence by a constant squeaking sound somewhat reminiscent of the young of pigeons. One young bird was seen begging and squeaking about an adult and it was fed after grabbing the bill of the adult. Adults collected fragments of palm and pandanus leaves from the ground in the clear areas between palm groves during the whole period of our stay on the atoll. They appeared very awkward as they walked about looking for satisfactory nesting material. Some dived successfully for fragments of leaves floating in the surf as it washed up on the inner beach.

The raucous call notes of these terns, plus those of the smaller species, were never absent, day or night. The noise seemed greater at night, and moon or no moon they were constantly moving about at all hours,

Anous tenuirostris marcusi (Bryan), White-capped Noddy. Also called "te nan."

There were not as common as the larger species, and were easily recognized by the smaller size, blacker plumage and more rapid wing beat. They were seen more frequently fishing over the lagoon than on the seaward side. Otherwise their habits were very similar to those of the larger species.

The first nests definitely belonging to this species were found on Tabuarorae on July 26 in a grove of Pisonia trees. The nests were small for the size of the birds and straddled the larger horizontal branches of the trees about 30 feet from the ground. At least 20 nests were observed there. Where a nest was occupied the bird's beak was visible over one edge and the tail over the other. The area under the trees had a strong ammonia odor and droppings were visible. These trees are also reputed to be the roosting place for the Man-of-War birds. On August 27, another nesting colony of small Noddies was found, near the center of the North Island, adjacent to the Government Reservation. Here the nests were straddling the petioles of the coconut leaves. There were six to eight nests in a single tree with a maximum of 3 nests on a single petiole. The nests appeared to be much the same as those seen in the Pisonia trees. Birds were on some nests or standing beside them.

Gygis alba, White or Fairy Tern.

This was not a common bird, but occurred widely scattered throughout the atoll, even on the small islets such as Nanntabuariki. We were asked by the Colonial Government to protect this species. The birds moved about in pairs, perched on pandanus or coconut trees, and were most numerous in the central part of the islands. As I approached a pair, they greeted me with loud raucous cries and flew low over my head. No eggs were seen, but a young bird with plumage still tipped with down was brought in by native boys. This is #56 of the collection sent to the U. S. National Museum.

These birds were observed flying in pairs and generally much higher in the air than the other terns.

Eudynamis taitensis (Sparrman), Long-tailed New Zealand Cuckoo.

This bird was seen only on August 22 on the small islet, Nanntabuariki, just north of the large South Island. This islet is covered chiefly with coral gravel. The Scaevola and Guettarda trees are low and scrubby and scattered singly or in small thickets. I flushed this long tailed bird from the base of a Guettarda tree. As it flew away it was attacked by a group of Black Naped Terns who kept diving at it. The Cuckoo paid no attention to the attacking force and flew to the southern tip of the islet and dodged into a thicket. I was successful in finding the bird twice after that. Each time it flew low and swiftly to the opposite end of the island and hid in a thicket. On each flight it was chased by the terns. The bird remained silent. I did not locate the bird on a return trip. This species migrates into this area during the winter of the southern hemisphere.

REPTILES

Lizards and Geckos were common on all the islands of the atoll. Specimens of the species present were collected and have been deposited in the U. S. National Museum in Washington. Dr. Doris Cochran has kindly supplied me with the specific names.

Lepidodactylus lugubris (Dumeril and Bibron), Gecko, "te beru."

This gecko was nocturnal in its habits and was rarely seen during the day. Specimens were found in rotting palm logs in the daytime. They frequently became active in the late afternoon. Once I watched one of these animals on a palm frond, at eye level. The frond was waving gently in the wind and occasionally came close to the frond below it. The Gecko crawled out near the tip of a leaflet and as this leaflet came close to the frond below, the animal jumped to it and then hurried to the mid-rib and out of sight at the base of the leaf.

At dinner time or later in the evening these geckos were seen crawling up the screening on the mess shack, taking advantage of the few insects attracted by the lights. They also crept over the walls of the Residency at night, searching for insects. I assume they were also to be found in the native houses.

On several night collecting trips to Scaevola and Guettarda thickets for insects, I found this Gecko in almost every flower cluster waiting for the night flying insects. On one occasion a Gecko rose on his short legs and stretched out toward a visiting crane-fly, catching it so rapidly that only the subsequent settling back and the "apparent serious business" of swallowing indicated that the prey had been caught. The number of Geckos present at night in a single Scaevola shrub was amazing, considering the apparent scarcity of night-flying insects.

The large Hunstmans spider (Heteropodidae) is one of their natural enemies. A Gecko was caught on the vertical wall of the wash house by one of these spiders and completely covered with silk. When first found the Gecko was still struggling, but became quiet in a very short time. The spider remained with its catch for about a day and a half.

Gehyra oceanica (Lesson), Big tree Gecko

This is the largest lizard on the atoll and one brought in by native boys was about 6 inches long. This specimen was dark brown above and bright yellow on the ventral side except where rough handling had apparently torn off some of the skin.

Only two specimens were secured. I do not know if the animals were rare or overlooked since this species is an inhabitant of trees. Both specimens were brought in by boys.

Emoia cyanurum (Lesson), Skink; "te tikunei."

This was the commonest reptile on the atoll. They were found everywhere, in Scaevola thickets, piles of rubbish, and the litter of the coconut groves. The sparse vegetation of the beach rampart and the smaller islets were favorite places for great numbers of these Skinks. These lizards are very agile and move with a rapid, jerky run. One of the constant sounds heard as you walked over the islands was that made by their scurrying over and through the rubbish to avoid capture or hunting for food. This is a ground inhabiting species but occasionally I saw them dart up the trunk of a coconut or other tree and slip off before they were more than 2 or 3 feet above the soil surface. When alive, their color was bronzy-brown with two longitudinal dorsal stripes, yellow-brown or tan in color. Fifteen specimens were collected.

Part II. Land Invertebrates and Animal Ecology of Onotoa Atoll, Gilbert Islands.

The majority of the Invertebrates collected on Onotoa Atoll belonged to the phylum Arthropoda, principally the class Insecta. Since Onotoa is situated two degrees south of the equator, out of the trade wind belt, rain is not a regular daily occurrence. It is considered a "dry" atoll. The scattered vegetation on the soil surface and areas where the coconut and bread fruit trees are dead, attest to the drought conditions that prevail at intervals.

In contrast to the land Arthropods collected on Arno in the Marshall Islands, where an estimated 500 species were found*, Onotoa at present can boast of no more than approximately 80 species. This number is in agreement with the 96 species reported for Canton Island, another dry island.

In the first part of this paper the invertebrates are reported in their taxonomic groupings. Under the heading of animal ecology, are shown the ecological relationships observed during the short time on the island. Lists of associated species are given at the end grouped under two headings: Habitats and Individual Plants.

PROTOZOA

Protozoans belonging to the genera Paramecium, Frontonia and Difflugia have been recovered in algal material collected in the fresh waters of the babai pits and in the slightly brackish water of pools at the north end of the North Island.

ROTIFERA

In the algal material mentioned above rotifers of two genera were found. One belonging to the order Bdelloidea and the other probably belonging to the genus Monostyla.

NEMATODA

Numbers of Nematode worms were also preserved in algal material taken from babai pits and brackish pools.

MOLLUSCA

The layer of humus and sand under the thickets and under stands of coconut, Pandanus and Messerschmidia trees was sifted for land Gastropods. The large fragments of litter consisting of leaves, old coconut shells and Pandanus seed pods were scraped away and the finer material below was sifted t through a series of nested screens. The material of medium size retained in the screen was bagged and sent to the United States National Museum. The

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*Usinger and LaRivers. Insect Life of Arno. Atoll Research Bulletin 15. April 30, 1953.

following species of snails have been tentatively identified from these soil samples by Dr. Joseph P. E. Morrison:

Opeas gracilis junceus (Gould)

Lamellidea peponum (Gould)

Gastrocopta pedicula (Shuttleworth)

Gastrocopta pedicula nacca (Gould)?

Gastrocopta lyonsiana (Ancey)

One fresh water snail, *Melanoides* cf *naiufouana* Mousson was found in a mass of green algae, *Rhizoclonium hieroglyphicum* Kuetz., collected in a well on the North Island. Dr. Morrison has expressed the belief that this snail was carried with water supplies to Onotoa from some other island. According to his personal communication, this snail closely resembles the large population living on Niaofcu Island.

ARTHROPODA

Crustacea

The coconut crab, a large species adapted to life on land, was brought to us on two occasions. Individuals of this species are rare on the island, probably because the natives utilize them for food. Those brought to us had been captured on the extreme northern end of the atoll.

Hermit crabs, "te makuro", were common and active at night, when their presence was conspicuously evident from the noisy rustling of litter as they moved about in great numbers. These crabs were most frequently found living in turbo shells.

Sow bugs were fairly common throughout the atoll and were collected in rotting logs, under coconut husks, and in the thick humus under old *Messerschmidia* trees. These animals were most abundant on the area of silty loam soil where a caliche-like hardpan is formed.

A large species of Ostracod was fairly common on algae taken from the babai pits.

Chilopoda

One species of centipede was collected from rotten palm logs and under coconut husks in the area of silty loam soil (caliche). Centipedes constituted a part of a community which included sow bugs and Collembola.

Arachnida

Spiders, called "te nareau" by the natives, were the most abundant terrestrial Arachnids on the island. A large black and yellow species of orb weaver was ubiquitous; its webs stretched between branches of low shrubs or across the paths in Scaevola, Guettarda and Pandanus thickets. Most of the webs examined were empty, but the great numbers of spiders present suggested that food was probably abundant. One web had the remains of a dragon fly and a moth in it. A smaller, rarer species of orb weaver was also found.

Large crab spiders (Huntsman spider) provisionally identified as belonging to the family Heteropodidae (Sparassidae) occurred quite commonly. They were frequently seen around Pandanus and retreated noisily into the funnel formed by the leaf bases. A specimen was observed feeding on a small gecko on the thatched wall of the shower room. The gecko was completely covered with silk and the spider spent the better part of two days feeding. The longest legs (second pair) on the largest specimen captured had a length of two and one half inches.

Other species of spiders, including a "jumping spider", were collected by sweeping the sparse vegetation, in packing cases, in the litter under trees and on the leaves of trees.

A species of scorpion, Hormurus, was collected in the Residency building in boxes of food and clothing. These were not considered common, for had they been, certainly more specimens would have been brought in by the natives.

Gorged ticks were found on native dogs and were collected from the region back of the ears and around the head.

Insecta

The abundance and variety of insect life usually evident to an entomologist was lacking on this dry atoll. The house fly, one species of dragon fly, and three species of Lepidoptera (two butterflies and one moth) were common. Other insects were generally uncommon and it was necessary to search for them. The clouds of insects so typical of any grass field in eastern United States were never seen.

Odonata and Lepidoptera were collected with an insect net. Diptera, Hymenoptera and some Lepidoptera could be taken from the blossoms of Scaevola and Guettarda. Sweeping the isolated culms of grass produced Cicadellidae, Lygaeidae and a few other small forms belonging to the orders Homoptera, Hemiptera and Diptera. Similarly small spiders were collected. Beating the foliage of trees and shrubs was not very productive although some Diptera and the long horned grasshopper were taken in this manner. Searching under the litter in the coconut groves produced a few sow bugs, centipedes and Collembola. The cocoons of the large ant Odontomachus haematoda (L.) and some adults were found in the same type of habitat. No animals were obtained by means of the Berlese technique.

Fungus beetles and ants were collected in large decaying fungi on dead coconut trees. Termites were found once in an old Pandanus log on the beach rampart. Nymphs of Odonata were found in the water of the babai pits, retting pools and the brackish pools on the north end of the North Island. Dolichopod flies were caught frequently on the leaves of many plants.

Several species of Coleoptera, including the species of Oedemeridae (blister beetle), were taken near lights at night. These, and a lace-wing fly, crane flies and some Noctuid moths were the principal insects so attracted. The absence of large swarms of insects usually found around lights in the temperate zone also indicated a small insect population on the atoll.

The Arachnids, sow bugs, centipedes and insects which were collected on the expedition have been turned over to Dr. J. L. Gressitt of the Bishop Museum for identification and final distribution. All identifications given in this paper are tentative and many were supplied by Dr. Gressitt.

Collembola

Large rafts or colonies of these insects were discovered by Dr. A. H. Banner at low tide in a hollow of an intertidal rock in the lagoon where the tidal amplitude averages two feet. This rocky outcrop is located 300 feet from shore.

A large species of this Order was collected under dead coconut husks in the area of the caliche. Collembolans, sow bugs and centipedes formed an association under this type of litter on the atoll.

Thysanura

Several specimens of Thysanura were taken in a moist area under the bark of a rotting stump of Messerschmidia.

Orthoptera

Cockroaches, "te babatuannanu", were the most common species of this order. The species Cutilia soror (Brunner) were present in abundance under the rubbish that covered the camp site and were exposed as the site was cleared. Individuals continued to appear in luggage and stores throughout the summer, although the majority of them moved away when the area was disturbed. This species is common from Hawaii to the Ellice Islands (Zimmerman, 1948*). At night a number of specimens were taken on the under surface of young palm fronds at one to two feet above the surface of the soil. Evania appendigaster (L.), a Hymenopteran, is parasitic on the eggs of this cockroach. An Evanid fly was fairly common; identification has not yet been made but the great abundance of both insects may be significant. Two other species of cockroaches were collected. One of these, tentatively identified as Pycnoscelis surinamensis (L.), was winged and collected under litter in a coconut grove. These last mentioned species were not common.

A medium sized green Tettigonid grasshopper tentatively identified as the genus Phisis was brought in frequently by the children. The tibia of the first and second pairs of legs were covered with long spines on both the outer and inner surfaces. Since the children were paid for these specimens with candy, they could not be coaxed to divulge the habitat of the species. Search by the author revealed two specimens, resting, with legs stretched out at full length, on the under surface of leaves of Ficus tinctoria. It cannot be said with

*Zimmerman, E. C. 1948. Insects of Hawaii. V. 2. Univ. of Hawaii Press.

certainty whether this was their specific habitat or just one of many places they occurred. Sweeping the grass Lepturus did not produce any specimens of this species.

A small pale yellow cricket was collected near lights around the camp. Their thin weak songs were heard all about at night. The song consists of a short ascending note and a longer descending one, usually repeated about ten times between intervals.

Isoptera

Decaying logs and branches of trees were examined for termites but were located only once in a Pandanus log at the top of the beach rampart on the sea side of the North Island. Judging from its position, it is possible that this log had floated here from some neighboring atoll.

Neuroptera

A single species belonging to the family Chrysopidae was collected near lights. The general body color is yellow green, and the eyes are a distinct black. Specimens were taken in June, July and August.

Odonata

One of the most thrilling sights particularly on calm mornings was the occurrence of huge swarms of dragon flies hawking low over the grass tops or higher up around the tree tops. At such times the house flies were particularly numerous and annoying. It is assumed that the dragon flies were preying upon them. This same swarming of dragon flies was noticed at Majuro in the Marshall Islands and at Bikati in the northern Gilbert Islands. The common species of dragon fly was distributed generally over the atoll, except on the small island of Nanntabuariki. There are no pools or wells present on this island, but it is possible that dragon flies would reach it in passing back and forth from the larger islands. Large swarms were found around the brackish fish ponds on the north end of the large North Island as well as in the region of the brackish pools on the North Island and the South Island of Aiaki. They were also present in the region where babai pits were located. Nymphs were found in the fresh water of babai pits and in the brackish water pools mentioned above. At least three species were collected. A large green and blue species resembling Anax junius of North America, a medium sized reddish brown species (the most common), and a small species of which the males are bright red. This last was the least common.

A single species of damsel fly was found in the babai pit areas and in the area of the brackish pools. These did not venture far from the water.

Hemiptera

True bugs were rare. A species of Lygaeidae of the genus Nyseus was taken by sweeping the isolated clumps of the grass Lepturus growing in the coconut groves. A single reddish brown Pentatomidae was found on the foliage of Guettarda. In the tide pools left in the beach rock on the seaward side of the islands after the exceptionally high spring tides of August, water striders of the family Gerridae, genus Halobates were collected.

Homoptera

Cicadellidae were captured by sweeping the isolated clumps of the grass Lepturus growing in the coconut groves. A Fulgorid related to the sugar cane leaf hopper was collected in the camp area. Plant lice were present on Sida fallax, but were not common. Other plants seemed to be quite free of aphids. Scale insects were common on many of the older Messerschmidia trees.

Coleoptera

Nine families of beetles were represented in the collections from the atoll, with the possibility of a tenth family after the material is properly identified.

Staphylinidae, which were attracted to lights, were also collected on rotting Pandanus fruit left on the ground.

The most abundant beetle was an Oedemeridae of the genus Sessinia. When this beetle was crushed on the skin it caused a blister. These insects were rather abundant and a pest to the human population. The Islanders gathered "toddy" from the coconut trees by allowing the sap from the cut end of a flower bud to drip into an empty coconut shell or bottle. This dripping sap was attractive to these beetles and they frequently drowned in it. A native drinking "toddy", which contains one of these insects will experience violent pain, accompanied by hemorrhage in the urinary tract. One affected by this ailment was known to treat himself by drinking immense quantities of water. These beetles commonly came to lights.

Cleridae was represented by the "copra bug" of the genus Necrobia. These small metallic green beetles were fairly common and were attracted to lights.

A few specimens of the Elateridae, Conoderus pallipes, were collected. One specimen was taken at Scaevola flowers at night.

Beetles of the family Dermestidae were collected on drying skins of rats and birds. Nitidulidae beetles were present on rotting Pandanus fruit and larvae and adults were collected from chocolate bars stored with provisions.

Large old bracket fungus growths on dead coconut palms provide a home for Erotylidae beetles, in company with ants.

Lady-bird beetles, Coccinellidae were taken on Scaevola Morinda citrifolia and Messerschmidia. A large tan colored beetle taken in the mission house on Tabuarorae Island was tentatively identified as a Cerambycidae.

A small species of weevil was taken twice, once on rotting Pandanus fruit and another time near a light.

Lepidoptera

Three species of butterflies were collected, two Nymphalidae and one Hesperidae. The large Nymphalid, Hypolimnas bolina, was the most common and was found all over the atoll. Its food plant Sida fallax was common in the clearings of the palm groves, along the beach ramparts and on coral gravel areas. All stages in the life cycle were found. The eggs were deposited on the underside of Sida leaves. Black hairy larvae were so common in some cases as to defoliate the plants. Chrysalids kept in cages completed their dormancy in 7 to 10 days. Adults were observed at night with wings folded on the underside of Scaevola, coconut and Pandanus leaves. Children caught these large butterflies and tied a string of coconut leaf fiber around their thorax and played with them in much the manner of an American child playing with a pinwheel.

The smaller brown Nymphalid, probably a Precis villida (Fabr.), was also widespread and very common. Its food plant was probably Messerschmidia as smooth caterpillars typical of the genus, with longitudinal black and white stripes, were abundant on this tree.

A single specimen of Hesperidae was collected on Callophyllum inophyllum. If this tree were the food plant of the species, its rarity could be accounted for by the few trees on the island.

The moth fauna of the atoll is more varied, with a greater number of species, representing at this writing the following families: Arctiidae, Noctuidae, Sphingidae and Pyralididae.

The most common moth was a day flying Arctiidae of the genus Utetheisa. This moth was first seen on Kwadak, an island of the Kwajalein Atoll. It was subsequently found on Majuro Atoll, the island of Bikati on Makin Atoll and the island of Betio at Tarawa, all stopping places made on the trip to Onotoa. In most cases it was captured and observed wherever Messerschmidia or Scaevola grew. The black hairy caterpillars, the apparent larvae, were abundant on Scaevola. The moth was common on the North Island, but rare on the southern islands of the atoll.

At least 5 species of moths of the family Noctuidae were collected. The largest and most common species was tentatively identified as Achaea janata. The under wings are banded with black and white stripes superficially resembling a small Catocala. It occurred in swarms on Pemphis wherever that shrub grew. This moth was also taken near lights. At least four other species typical of the family were collected around lights and await identification.

A day flying, clear winged moth of the family Sphingidae was collected from blossoms of Scaevola and Guettarda. It was never abundant, but usually one or two were seen each day. Sphingid caterpillars were taken on Morinda citrifolia, which is evidently the food plant of this species. A Sphingid pupa case was brought in by a native, but unfortunately was destroyed by ants before it matured. A copulating pair of these moths was captured near a light at the Residency on August 2. These moths were also tied with strings and used as living toys by the native children.

A small green winged moth, with pure white body and legs, of the family Pyralididae, was taken on and around Guettarda on the North Island and Aonteuma. It was among the insects drawn to lights.

Several other small moths, almost micro-lepidoptera were captured. One with wings the color of gun metal was on Sida fallax. The other species came to lights.

Diptera

The first Dipteran seen and the one always present was the ubiquitous house fly. Great swarms were present and were especially annoying on calm days. They infested the open sores on the natives and it was quite evident that cuts and abrasions on our own limbs were soon infected by these flies, making it necessary to keep all sores and cuts covered until they were completely healed. The native population was extremely careful about refuse, but the open pits for garbage, the pens in which hogs were kept, and the habit of defecating on the reef and beaches, afford ample breeding areas for these flies.

Flies tentatively identified as Sarcophagids were observed and caught on bags containing decaying mollusk shells set aside for cleaning. These flies also swarmed in our own garbage pit, in spite of the fact that refuse was covered as quickly as possible with soil. At least two species were collected. A blue bodied fly, a Calliphoridae of the genus Chrysomyia, was taken on the flowers of Messerschmidia.

Dolichopod flies were quite common and were seen frequently on the foliage of Scaevola and on other plants. They were collected on most of the islands of the atoll.

Anthomyiidae were collected on unripe Pandanus fruits. These flies were quite sluggish but difficult to capture around the fruits.

A Syrphid fly was taken around Messerschmidia along the beach rampart of the North Island. The markings are typical of this group.

Mosquitoes were never very abundant. They were noticed on several occasions at night in the Maneabas (Community meeting houses) and were extremely abundant in the village of Aiaki on the South Island. At other times they were found personally annoying only when collecting on the babai pits where they breed. Wigglers were found several times in old coconut shells that had become filled with water. The extreme drought conditions on the atoll for the last year and a half may explain the reason for relative freedom from the pests.

A medium sized black crane fly, probably a Tipulidae was taken by sweeping the grass. It was also the chief pest around the lights at night, many of them, dead or drying, were constantly falling on the table where we worked.

Chironomid larvae were found in abundance on algae collected in the babai pits and brackish pools.

A large flat black fly with a buzzing flight was captured near a light. Later another specimen was taken on litter on the beach rampart and a third on the drying skin of a Great Crested Tern. These were members of the family Hippoboscidiae.

A single specimen of an orange bodied fly of questionable identity was taken near a light.

Hymenoptera

The most conspicuous Hymenopteran on the island was the large jawed black ant identified as Odontomachus haematoda. It was seen on all the islands of the atoll in sandy areas, including the beach rampart. Colonies of a few individuals, protecting a few brown cocoons, were found under old Pandanus and coconut logs.

At least two other species of ants were collected, but these were not common. A minute red species lives in fungus growing on dead coconut trees. A nest of the other species containing eggs, larva, pupa and winged adults was uncovered below the hard surface of the "caliche", near the northern end of the North Island. A procession of this species was also attracted by spilled sugar in the storage tent where a few individuals were collected. Pandanus fruit rotting on the ground attracted ants, as well as other insects.

A large tan colored species of Ichneumon fly was found frequently flying around the Scaevola thickets, but its prey was not located. It is recorded on all the islands of the atoll.

An evaniid wasp, probably Evania appendigaster (L.), was common. It is recorded from all of the islands of the atoll. Reference was previously made in this report to the fact that this insect is probably parasitic on the eggs of the abundant cockroach, Cutilia soror.

A small black vespid wasp identified provisionally as belonging to the Odynerinae is common around the flowers of Scaevola and Guettarda. Two of these insects were taken in the hollow twigs of Scaevola, although no nests were found when other dead hollow twigs were examined. These wasps are common throughout the atoll.

A large bronze green Sphecid wasp, Ampulex sp., was observed making nexts and depositing eggs in the holes of the reed furniture of the Residency and in the holes and crevices left in the native lime stone walls of the Residency and mission houses. Mud was employed in the construction of the cells.

A single species of bee, Megachilidae, was found on the north end of the North Island and on Aonteuma. The work of these leaf cutting bees was first noticed on leaves of Pisonia grandis, while trying to secure specimens of the latter for the herbarium collection. The leaves were so badly cut, that entire ones were not available. Small semicircular portions about 3/4 of an inch in diameter had been cut from the margins of the leaves. Damage of this kind was later seen on Morinda citrifolia. Specimens of the bees were collected around Pisonia, Morinda and Pemphis.

Coconut Groves

The major portion of the land area on the atoll is covered with an overstory of coconut groves and an understory of *Pandanus*, *Scaevola* and *Guettarda*. The ground in the groves is strewn with fallen leaves and other litter, with scattered forbs and grass growing through this litter. These groves were usually silent and devoid of animal life. Noddy Terns were sometimes present in the palms and a few Fairy Terns on *Pandanus*, but both birds seemed to prefer the open areas. Near the villages, flocks of chickens were encountered wandering about in search of food. The ground skink (*Emoia*)was the most conspicuous animal throughout these groves and was frequently heard scuttling away over the litter.

Removal of the litter disclosed a large population of the cockroach *Cutilia soror* and colonies of the large ant *Odontomachus haematoda* . Sifting the fine litter and top layer of soil revealed sow bugs and the minute Gastropod snails belonging to the genera *Opeas*, *Lamellidea* and *Gastrocopta*.

Clearings

Along the center of the two large islands and scattered irregularly at other places sunny clearing occurred containing only scattered palm, *Pandanus* and *Messerschmidia* trees, and a more dense shrub and herbaceous cover. These areas supported a large population of both species of Noddy Terns and the Fairy Tern. In these clearings the calls of the adult birds and the food call of the young were heard day and night. Here also adult Noddies frequently swooped down to earth and waddling awkwardly gathered pieces of shredded coconut leaves for nesting material. The Golden Plover was flushed from these clearings several times. Clouds of dragon flies were usually cruising at tree level, particularly on calm days when the house flies seemed to be most annoying. The two common butterflies, *Hypolimnas* and *Precis* flew above the herbs. *Sida fallax*, frequently the dominant herb in these areas was the host plant for *Hypolimnas* and carried a large population of eggs and larvae.

Skinks were as common in the litter here as in the groves. Ants and cockroaches were present under the litter and the large Huntsman Spider was captured around the clumps of *Pandanus*.

Area of Brackish Pools (Caliche-like hardpan)

On the North Island east of the village of Taneang and on the South Island east of Aiaki village are two rather similar areas, differing from the typical coconut groves. The trees were far apart and *Pemphis* formed the understory around a series of small brackish water ponds. The soil is the consistency of nearly dry putty and Dr. Preston E. Cloud, Jr. has designated it as a "caliche-like hardpan". Dragon flies were abundant and nymphs were numerous in the algae filled pools. The fauna of the brackish pools is dealt with in another portion of this report. A few damsel flies were observed resting on the foliage of *Pemphis* bordering some of the pools. Butterflies, the *Achaea* moth and leaf cutting bees were present in addition to the dragon flies. Orb weaving spiders had constructed webs between shrubs.

Skinks ran through the rubbish piles. During the day geckos were found hiding in rotting logs. Under decaying coconut shells and leaves was found an association of sow bugs, Collembola and centipedes. Colonies of a small species of ant seemed to find the soil of the right consistency for their nests. A large species of land crab was seen to occupy burrows in these areas.

<u>Scaevola Thickets</u>

Throughout the atoll, in neglected coconut groves, in clearings and along the sea side beach rampart there were thickets of <u>Scaevola</u>. Since these shrubs were in continuous bloom during our stay on the island, many species of insects were found visiting the blossoms. The list of insect visitors is given in a following section. Many leaves of the plants were attached by leaf miners. Dolichopod flies were frequently seen walking over the leaf surfaces.

The ground skink was observed climbing clumsily into the flower clusters during the day. The orb webs constructed by two species of spiders were numerous and were suspended in gaps between branches. The population of spiders, geckos and skinks present appeared too great for the quantity of insects observed at any one time. However, food must be sufficient to support the population. On only a few occasions were insect remains observed in the spider webs.

Observations of these flowering thickets at night revealed considerable activity. Geckos were present in almost every flower cluster feeding on crane flies and other night flying insects. Crickets were heard all through these thickets. The two common butterflies, <u>Precis</u> and <u>Hypolimnas</u>, were found sleeping on the underside of the leaves. The large Huntsman spider was also active here at night. The constant rustling of the litter under the shrubs indicated the great nocturnal activity of the numerous hermit crabs. On rare occasions rats were observed running from thicket to thicket.

<u>Shrub Growth on Sand Flats</u>

A shrub cover of scattered <u>Scaevola</u>, <u>Guettarda</u>, <u>Pemphis</u>, <u>Sophora</u>, <u>Terminalia</u> and <u>Suriana maritima</u> was growing on sand flats at points where the islands narrowed and were separated by the shallow inlets. These areas were bright from the reflection of the sunlight on the white sand and very hot on calm days. The southern tip of the North Island, the southern end of Aiaki or South Island and the adjoining point of Tabuarorae were the largest of these areas. Noddy Terns were observed with young in this area on Tabuarorae. Reef Herons were flushed from the openings between shrubs. Dragon flies, <u>Precis</u> butterflies and Sphingid moths were the common insects here. The Noctuid moth <u>Achaea</u> was very common on <u>Pemphis</u>.

<u>Coral Gravel Areas</u>

On extremely exposed shores on the seaward side of the atoll were large areas of coral gravel. The few scattered plants offered little cover, explaining the near absence of animal life on these gravel fields. An occasional skink was seen. The butterfly <u>Hypolimnas</u> was present where the scattered <u>Sida</u> plants grew. At the north end of the North Island where the gravel fields bordered the large enclosed fish pond, swarms of dragon flies filled the air above the <u>Pemphis</u> growing along the shore of the pond. However, the dragon flies did not wander far out over the barren gravel.

The Black Naped Terns and Whimbrels seemed to prefer this gravel area on the seaward side of Abanekeneke as headquarters. On every trip to this island we found and disturbed these birds on the gravel flats.

Pisonia Grove

One small grove of Pisonia trees was growing on the edge of a coral gravel area on Aonteuma. The leaves of these trees had been so badly damaged by the leaf cutting bees, that it was impossible to find perfect specimens of the foliage for a herbarium specimen.

A large grove of tall mature Pisonia trees on Tabuarorae Isle supported a large nesting population of the small species of Noddy Tern. Native tradition named the community house or Maneaba of this southernmost village the "Maneaba of the large trees where the birds roost". The Man-of-War birds were reported using these trees frequently as roosting spots. The accumulation of droppings and the odor under the trees indicated a large concentration of birds.

ANIMALS ASSOCIATED WITH HABITATS

Land Communities

A. Coconut Groves

Noddy terns-two species
Fairy terns
Chickens

Skink (Emoia)

Orb weaving spiders

Sow bugs-under the litter

Cockroaches-under the litter
Ant-Odontomachus haemotoda -soil surface and litter

Gastropod snails-three genera in litter

B. Clearings (Widely scattered trees)

Noddy terns-large population of both species
Fairy terns
Golden Plover-rare

Skink (Emoia)

Orb weaving spider
Huntsman spider

B. Clearings, cont'd.:

Cockroaches-in litter
Dragon flies
House flies
Butterflies (_Hypolimnas_ and _Precis_)
Ants-_Odontomachus haematoda_

C. Area of Brackish Pools (Caliche-like hardpan)

Gecko
Skink (_Emoia_)

Sow bugs-under the litter
Land crabs-burrows

Centipedes-under litter

Collembola-under litter
Dragon flies-common   Nymphs in pools
Damsel flies
Butterflies (_Hypolimnas_ and _Precis_)-common
Achaea moth-on _Pemphis_
Mosquitoes-South Island
Leaf cutting bees-around _Pemphis_
Ants-small species-nest in soil

D. _Scaevola_ Thickets

Rats-rare

Gecko-feeding at night
Skink (_Emoia_)

Hermit crabs-in litter beneath shrubs

Orb weaving spider-two species

Crickets-heard at night
Butterflies-_Hypolimnas_ at flowers
    Precis adult at flowers, larva on foliage
Moths-_Utetheisa_-flowers and foliage
    Sphingid-flowers
    Noctuids-resting on leaves
Click beetles
Lady Bird beetles
Crane flies-flowers at night
Ichneumon fly
Wasp-Odynerinae

E. Shrub Growth on Sand Flats

Noddy terns
Reef herons

E. Shrub Growth on Sand Flats, cont'd.:

Precis butterfly
Sphingid moth
Achaea moth-on _Pemphis_
Dragon flies

F. Coral Gravel Area

Black Naped tern
Whimbrel
Long tailed New Zealand cuckoo-in thickets

Skink (_Emoia_)

Orb weaving spider

Dragon flies
Sphingid moth
Butterflies (_Hypolimnas_ and _Precis_)
House flies
Syrphid flies
Dolichopod flies-on foliage
Leaf cutting bees

G. Litter, Rubbish, Rotting Logs (In groves and under isolated trees)

Rats-rare

Noddy terns-for nesting material

Gecko
Skink (_Emoia_)

Sow bugs
Hermit crabs

Huntsman spider

Centipede-under coconut husk

Collembola-under coconut husk
Thysanura-under bark of dead _Messerschmidia_ tree
Cockroaches-three species
Termites-rare, log on rampart
Beetle larvae-in log on rampart
Ants-two species
Mosquitoes-larva in water filled coconut shells

Gastropods
 Opeas gracilis junceus (Gould)
 Lamellidea peponum (Gould)
 Gastrocopta pedicula (Shuttleworth)
 Gastrocopta pedicula nacca (Gould)?
 Gastrocopta lyonsiana (Ancey)

H. Buildings and Huts

Rats-nest with young

Gecko

Spiders-in packing cases and crannies
Huntsman spider
Scorpion-rare

Cockroach-<u>Cutilia soror</u>
House flies-by day
Mosquitoes-at night
Crane flies-near light
Moths-various species to light
Long horned beetle-identification uncertain
Coconut blister beetles (Oedemeridae)
Wasps-two species

I. Insects Taken at Light

Cricket
Lace winged fly (Chrysopidae)
Large dragon fly-<u>Anax</u> sp.
Blister beetles-Oedemeridae
Long Horned beetle (<u>Ceresium</u>)
Rove beetle-Staphylinidae
Copra bug-Cleridae
Click beetles-Elateridae
Noctuid moths-several species including <u>Achaea</u>
Small moths-almost micro-lepidoptera
Pyralididae moth
Sphingid moth
Crane flies
Mosquitoes
Orange bodied fly-family unknown
Hippoboscidiae

J. Rotting fruit on ground

Beetles-Nitidulidae
Staphylinidae
Cleridae
Tan colored beetle?
Weevil
Ants-small species

ANIMALS ASSOCIATED WITH SPECIFIC PLANTS

A. Coconut palm

Noddy terns-two nesting species
Reef heron-nesting

A. Coconut palm, cont'd.:

Gecko-on foliage

Cockroaches-on underside of leaves of small plants at night
Butterflies-on underside of leaves at night
Flies-on underside of leaves at night
Blister beetles-around toddy
Fungus beetles-in fungus on living and dead trees
Ants-in fungus on dead trees

B. Messerschmidia

Sow bugs-in litter beneath

Moths-Utetheisa-adults and larvae
Noctuids at flowers
Syrphid flies
Calliphorid flies-Chrysomyia at flowers
Scale insects on bark of twigs
Lady bird beetles

C. Pandanus

Noddy terns-young and adults of both species
Fairy terns-young and adults

Gecko

Huntsman spider
Orb weaving spiders

Cockroaches-on underside of leaves at night
Butterflies-on underside of leaves at night
Flies-Anthomyiidae-around green fruit
-other species on underside of leaves at night
Rove beetles-Staphylinidae on rotting fruit
Nitidulidae beetles-rotting fruit
Weevil-rotting fruit

D. Sida fallax

Butterfly-Hypolimnas-eggs, larvae, chrysalids and adults
Small tan colored moth
Pyralididae moth
Plant lice

E. Morinda citrifolia

Sphingid moth-larvae on foliage
Lady bird beetles
Ichneumon flies
Leaf cutting bees-attacking foliage

F. *Guettarda speciosa*

Pentatomid-stink bug
Pyralididae moth
Sphingid moth-at flowers
Odynerinae wasp-at flowers

G. *Pisonia grandis*

Noddy tern-small species nesting
Man-of-war bird-reported roosting

Leaf cutting bees-leaves badly damaged

H. *Pemphis acidula*

Moth-*Achaea janata*-very common
Damsel flies-resting on foliage
Leaf cutting bees

Note: Usinger and LaRivers report *Pemphis* on Arno as seemingly a barren tree as far as insect life is concerned. They report the *Achaea* moth, so common on *Pemphis* at Onotoa, as associated with *Cordia*, a plant not present on this atoll.*

FRESH WATER HABITAT

Surface water on the atoll was found in the babai pits used to grow the native "taro", in brackish ponds scattered at several places on the atoll and in wells. Algae samples were taken from these situations and preserved. During preliminary examination of these samples a number of invertebrates have been observed. While they have not been positively identified, mention should be made of them since they are obviously part of the food chain ending in the Odonata or the Reef herons.

Protozoa

Paramecium sp.
Frontonia sp.
Difflugia sp.

Rotifera

Monostyla sp.
Species of Order: Bdelloidea

Nematodes

Mollusca

Melanoides cf. *niaforiana* Mousson (With algae in well)
(Ident. by J. P. E. Morrison)

Crustacea

Ostracods
Crabs

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*Usinger and LaRivers. Insect Life of Arno. Atoll Research Bulletin No. 15. April 30, 1953.

Insecta

Chironomid larvae
Mosquito larvae
Nymphs of dragon flies-3 species
Nymphs of damsel fly-one species

Aves

Reef heron

MARINE HABITATS

Seaward Reef

When the reef was covered by the tide on stormy days the Noddy Terns could be seen flying back and forth over the reef, capturing food. At other times they fished beyond the algal ridge. The Fairy Terns even on stormy days, generally fed beyond the ridge and only occasionally were noticed over the reef itself.

As the tide ebbed, the shore birds and reef herons advanced out over the exposed reef, investigating tide pools and the drying turf of algae.

The water strider, Halobates was found in the tide pools on the reef after the high tides of August.

Seaward Beach and Beach Rampart

The stretch of beach from the Scaevola thickets along the rampart to the high tide line was bare of vegetation. The shore birds were active along this beach at high tide. The Turnstones were most active just at the water's edge, rapidly flicking over pebbles, bits of rubbish, dried sea weed and bits of shells looking for prey. Each section of the beach and reef had its small flock of shore birds. The number of flocks and the number of individuals in the flocks increased during August.

The Reef Herons seemed to have rather definite territories along the beach and reef. By keeping certain peculiarly mottled individuals under observation the approximate size of their beach and reef territories could be roughly estimated. A beach and reef front territory at the cemetery on the south end of the North Island measuring approximately 1000 yards was occupied by a white heron having a slate gray head and a gray stripe down the middle of its back. Another mottled individual occupied a similar territory north of the camp site. Individual herons trespassing into these territories were attacked and forced out by the original occupant.

The skink (Emoia) was observed in the thickets on the rampart and made short journeys down the slope of the upper beach.

Gray rock crabs (Grapsus grapsus L.) were very common on the outcroppings of rock along the beach. At night the ghost crabs (Ocypode sp.) were common. One was observed feeding on a dead jellyfish, stuffing the jelly into its mouth as fast as it could, oblivious to the light from a flashlight. The beach and rampart was also alive at night with large and small species of hermit crabs. The large species living in old turbo shells seemed to come down to the beach at this time from the thickets along the ramparts.

Since _Scaevola_ was the dominant plant along the rampart, the insects here were those native to the thickets of this shrub as was previously mentioned. Dragon flies frequently swarmed above the beaches. Similar swarms were seen on the islands of Bikati, northern Gilberts, during the trip to Onotoa.

Lagoon

Tattlers, Golden Plovers and Reef Herons were the common birds along the lagoon shore. The small species of Noddy Tern seemed to prefer fishing in the lagoon to the seaward reef and was more frequent here than was the larger species. The Black Naped Terns were also lagoon feeders and were rarely absent from the shallow northern end.

Swarms of dragon flies were frequently seen along the lagoon shore. Collembola were collected from the water in a hollow of the rock outcropping, 300 feet from shore, near the village of Taneang by Dr. A. H. Banner. The tidal fluctuations of this spot were about two feet.

MARINE COMMUNITIES

A. Seaward Reef

Wandering tattler
Ruddy turnstone
Golden plover
Whimbrel
Noddy tern-larger species more frequently
Fairy tern-rarely
Crested tern
Reef heron

Water Strider-_Halobates_

B. Beach and Beach Rampart

Wandering tattler
Ruddy turnstone
Golden plover
Reef heron

Skink (_Emoia_)-rampart and upper beach

Rock crab-_Grapsus grapsus_
Ghost crab-_Ocypode sp._
Hermit crabs-several species

Dragon flies-swarming over beach
Ant-_Odontomachus haematoda_ -upper beach and rampart

C. Lagoon

Wandering tattler-along shore
Golden plover-along shore
Reef heron-along shore and shallows
Black naped tern-over lagoon, fishing
Noddy tern-small species usually, fishing over lagoon

Dragon flies-swarming along shore
Collembola-tide pools in rock

Fiddler crabs-sand flats

ATOLL RESEARCH BULLETIN

No. 29

A Summary of Information on Rose Atoll

by

M.-H. Sachet

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A summary of information on Rose Atoll

by
Marie-Hélène Sachet

Rose Atoll, the easternmost of the Samoa Islands, is one of the smallest atolls known and is of special interest, because it has hardly been influenced by man. Its situation not too far from the settled islands of the group, the fact that it is generally easy to enter the lagoon and land on the islets, and various other circumstances have made it one of the better known uninhabited atolls. The literature concerning it has been brought together by Setchell (1924) and by Bryan (1942). This paper is not intended to replace these contributions but to summarize all available information on land aspects of the atoll. It necessarily repeats much information contained in these earlier compilations but may thus be helpful to those students of atolls to whom these are not easily available. In addition to published accounts, it includes notes based on letters of Mr. E. H. Bryan, Jr. and on conversations with Dr. L. P. Schultz and data obtained from their photographs and unpublished records. Their valuable help is gratefully acknowledged.

Geography

Rose Atoll is located between 14°31' and 14°34' S and between 168°08' and 168°10 W. It is a very small atoll, roughly square in outline and about 1 3/4 miles from north to south and 2 miles from east to west. Just west of the north point, or corner of the square, is the only channel into the lagoon. The channel is 100-150 feet wide and of variously reported depth: 6 fathoms or more (Rantzau in Graeffe, 1873), 30 or 40 feet (Anon., 1953) with records of 6 to 9 feet, or 6 feet or more that are probably erroneous or refer to the part of the channel that is choked with coral: Bryan (1942) reported the channel partly blocked with coral heads on the west side. The lagoon is about 2000 yards across its greatest width, and its depth is variously estimated as 6 to 12 fathoms (Wilkes, 1845), not more than 8 fathoms (Mayor, 1924) or up to 50 feet (Bryan, 1942). The floor of the lagoon is sandy, and generally free of living corals (Couthouy, 1942, p. 138). But some corals do grow in it. Wilkes described one such formation: "like a submerged tree, thirty feet in diameter over its top [it] was found in the center of the lagoon rising to the level of low water and having all around it a depth of six fathoms." This may be part of the two coral patches mentioned by Rantzau (Graeffe, 1873) as occurring in the southwest corner of the lagoon and indicated on his and later maps.

The reef is remarkably uniform in width, about 500 yards everywhere, with a very flat surface, most of which is under water even at low tide, though some areas emerge as smooth platforms about a foot above low tide. There is very little loose material on the reef. It supports only two islets. Sand Islet, to the north, near the entrance to the lagoon, is a bank of sand and broken reef material, devoid of vegetation and about 5 feet above sea level. Although the charts are not entirely reliable, there is some indication that the islet has been

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larger (see discussion of Rantzau's chart, (pp. 4 - 5).
Sand Islet is quite possibly variable in area, especially as no plants are present that are capable of colonizing and fixing its soil. In 1938 its dimensions were estimated as 200 yards in length and 50 yards in width (Bryan, 1942). It lies on the lagoon side and has a wide expanse of reef on its seaward side.

At the eastern corner of the square is Rose Island, which is larger than Sand Islet. Mayor, in 1920, gave the length as 240 yards along a north to northeast direction and the width as 200 yards. Bryan, in 1938, estimated the island 350 yards long and 250 yards wide. Schultz (1943, p. 3) says that in 1939 it seemed to be building up on the northwest and being eroded on the south end. This agrees with some notes by Mayor and Bryan. Rose Islet has a greater elevation than Sand Islet, reaching 11 feet above high tide a little inland of the southeast corner (Mayor, 1924, p. 74). It is higher in the south than at the northern end and, like Sand Islet, it is located on the lagoon half of the reef.

History

Rose Atoll was discovered on October 21, 1819, from the ships l'Uranie and la Physicienne, and was named Rose Island by the commander of the expedition, Louis de Freycinet "for a person extremely dear to me." The ships did not enter the lagoon or come very close to the island. However, Freycinet described the island as observed from the sea, and Duperrey drew a chart that is included in the atlas of the expedition reports. In his volume on navigation and hydrography (1826, p. 85), Freycinet gave information on the weather, on the animals observed off the atoll, on the longitude, and on the latitude estimated at noon. He described his discovery (1826, p. 250) marveling at the fact that the atoll had not been observed and charted earlier. He mentioned only Rose Islet, but he said of it:

> "Its height generally mediocre, is greater in the SW; the land gradually slopes down toward the NE where it merges with the sand of the shore.
>
> "Although very small, this island is well wooded, which gives it a very pleasant look of freshness. Various sea birds seem to be the only inhabitants of this lonely place; we particularly noticed frigate birds, boobies, tropic-birds, noddies, and terns /apparently two small species/. Among the trees, there are no coconut trees nor any other kind of palms.
>
> "The whole island, as we have said, is surrounded by a bank just below water level, grossly triangular, of mixed sand and madrepores; it is bristling with small black rocks, not very much raised above its surface, and all of about the same height. One of the angles of the bank is to the SW, another to the E, and the third to the N: its dimensions are 3 miles /nautical/ from N to S, and a little less from E to W. The sea breaks much all around, and the surge can be felt from one or two cable lengths at sea: we followed its eastern part at a distance of one

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and a half mile[s], without seeing bottom under us.

"When one stands to the N of Rose Island, it shows a semi-circular shape; seen from the E it looks like a 'coin de mire' [is wedge-shaped] with its higher part looking to the south. To the NE, and very close [to the islet?] a little black rock, a regular cone, rises above all the rocky heads just mentioned."

This literal translation shows that Freycinet observed the islet and reef exactly, which makes it all the more difficult to understand some aspects of Duperrey's chart, namely, the two areas that Setchell interpreted as two additional sandy islets. Although Freycinet did not mention any sandy "islet", his drawing of the landfall, presumably made from about east to southeast, showed on either side of the wooded islet some little black rocks and a broad mound. These may be sand banks and correspond to the patches of the chart. Freycinet's description of the islet is detailed enough for us to believe that the trees may have formed two groves, a large one to the southwest and a tiny one to the northeast, which apparently does not exist any more. The northeast grove either joined the other one or was destroyed by a change in the shape of the islet. Freycinet described Rose again later in his historical account of the voyage.

The Russian expedition of the Predpriatie (Enterprise), commanded by O. de Kotzebue, passed a little coral island on April 2, 1824, and named it Kordinkoff (Kotzebue, 1830, p. 256), later to realize that it was the same as Rose. Kotzebue's sketch of the atoll is not much better than Duperrey's, although it shows a closed lagoon.

On September 23, 1838, Dumont d'Urville, on another French expedition, passed Rose Island following the reef at a distance of less than a [nautical] mile and gave a brief description of it (1842, pp. 91-92):

"Rose Island is but a pile of sand about 200 m. in diameter, covered with a grove of verdure very fresh looking and pleasant.

"Passing about 600 m. to the north of the reef edge, we saw in the reef a break about 100 m. wide, leading into the lagoon where the water seems rather deep, and which ought to be able to offer shelter to ships as small as ours."

The French expeditions were scientific in purpose, and their instructions placed much emphasis on obtaining physical, nautical, and meteorological information. The discovery and surveying of new lands was recommended also, but these lands were especially worth investigating if they could bring new people and their customs, new plants, new animals, to the notice of Science. The fact that low islands present danger and difficulty in landing, especially with a sailing vessel, as well as their recognized paucity in scientific novelties, resulted in a general avoidance of atolls by most early expeditions, including the French.

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The U. S. Exploring Expedition was different in scope and aims, and without neglecting scientific discovery, visited many of these atolls, reputedly all alike, for the purpose of charting them. It was much larger than any of the previous expeditions both in ships and in naval and scientific personnel. In spite of its vessels and the unending arguing, prosecuting and fantastic mishandling of the results which followed it, the expedition was generally remarkably successful, and, although some of the information has never been published, it brought back vast amounts of data, charts, scientific collections, and drawings. It was the first "Atoll Program", and after surveying many of the Tuamotus, one of the ships, the Vincennes arrived at Rose Atoll, on October 7, 1839. A part of the day was spent in observations, and Wilkes (1845, p. 64) in the narrative of the voyage gave an account of them, but the best description published, and the only one of an eye-witness, is that of Pickering (1876, pp. 235-236):

> "14. ROSE CORAL-ISLAND. As the Vincennes drew near, the supposed rock proved to be a dense clump of trees upon a small coral-island; 'in S. Lat. 14°18' and W. long. 168°05', and about eighty miles' from the nearest rocky island of the Samoan Group. Rose coral-island, though hardly 'two miles' in diameter, was found to contain a lagoon; having a large outlet deep enough to admit a ship, and 'six fathoms' inside, except at the centre of the lagoon, where a column of coral-rock rises to within 'three feet' of the surface. The tide rising 'about five feet', most of the island is submerged at highwater; but the outline continues distinguishable by the line of surf, with here and there a projecting massive coral-block; at all times, we found much water beating over from the windward, and running in streams into the lagoon, and afterwards in a strong current through the outlet.
>
> ......
>
> "Two banks on the rim were never overflowed by the tide; one of them devoid of vegetable growth; the other, containing the above-mentioned dense grove of trees, found to be three or four acres in extent."

Dana (1849, p. 78, 308) also discussed Rose Atoll, but unfortunately he did not see it, as he was traveling in another of the ships. Couthouy, however, was still on the Vincennes (he was going to abandon the Expedition shortly, in Samoa), and presumably landed on Rose. Parts of his account (1842) seem different from what was reported by Wilkes, Pickering, and Dana, and his account has been termed "somewhat fanciful" (Setchell, 1924): but he did give some information on the entrance and lagoon. He noted (p. 99) that the entrance is to leeward, as is often the case on atolls, and water pours out of it at ebb tide "so as to resemble a mill race."

The next recorded visit was that of Captain Rantzau (Graeffe, 1873, p. 32), who visited the atoll at various times while a German firm was trying to establish a fishing station there. He transmitted some valuable information to Graeffe and drew a sketch of the atoll, on which Sand Islet

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is represented as large and extending far into the lagoon and Rose Islet as covering the whole width of the reef and supporting a house and trees. During these times coconut trees were planted and reported to do well and to bear fruit. The island was settled for a while by an Englishman and a few natives. Later one native alone remained with his family, and then the island was finally restored to its loneliness. Rantzau's sketch, together with excerpts from Graeffe's text, was reproduced in the first volume of the Hydrographische Mittheilungen (later Annalen der Hydrographie...) p. 64, 1873. His outline of the reef may have been based on some earlier chart, but his sketch was apparently used at later dates by the Hydrographic Offices of England and the United States.

In 1899, after much tension and political difficulty, Eastern Samoa became an American territory. The first governor, B. F. Tilley, visited Rose Atoll on July 10, 1900, hoisted the American flag "with appropriate ceremonies," and planted coconuts. In January 1920, Governor W. J. Terhune visited the Manu'a district, and on January 12 landed on Rose Atoll, erected a sign to warn trespassers, and planted a variety of fruit trees, including coconuts. His stop at Rose was reported in the monthly government newspaper O Le Fa'atonu, in the issue for February 1920 (Dumstrey, 1920). In June 1920, he returned there and was accompanied by the marine biologist A. G. Mayor who was working in Samoa. The July issue of O Le Fa'atonu gave a short but informative account of the visit and mentioned the value of the information collected by the distinguished scientist. More coconuts were planted, including two on Sand Islet. The invitation extended by Governor Terhune to A. G. Mayor resulted in valuable observations that are the most important body of information on Rose Atoll and are described in other parts of this paper.

There were yearly governor's visits to the atoll after this and more plantings of coconuts. In 1922, Governor Pollock found that Governor Terhune's coconuts had disappeared, so he planted some more. He also collected soil samples for Lipman.

Wray Harris now conchologist at the B. P. Bishop Museum, made at least two visits to Rose in 1937 and 1938 and collected mollusks and a few plants.

In 1938 the U. S. Coast Guard cutter Taney visited the Equatorial Islands and landed a party of scientists on Rose Atoll on August 4, for an hour. E. H. Bryan wrote accounts of his observations (1939 and 1942, pp. 91-93), and much of our knowledge of Rose Atoll is derived from them. W. Donaggho (1953, p. 68), assistant to G. C. Munro, wrote some notes on the birds observed.

In 1939 the U. S. S. Bushnell made a survey of islands in the central Pacific, and Dr. L. P. Schultz, of the U. S. National Museum, spent 11 days collecting fish around Rose Atoll and in the lagoon (June 11-21).

On February 14, 1941, Rose Atoll was made a Naval Defense Sea Area by an Executive Order of President F. D. Roosevelt.

This order was rescinded by Executive Order 10,341 signed by President Truman on April 8, 1952. Earlier (July 1, 1951) the Samoan

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Islands had come under the jurisdiction of the Office of Territories in the Department of the Interior. In February 1953 a fishing survey was conducted near Rose Atoll, and some information on the island was published in the Weekly News Bulletin on February 21, 1953. Excerpts from this bulletin were received through the kindness of Mr. Emil Sady, chief of the Pacific Division, Office of Territories. This is the latest information available on Rose, and it brings up to date our knowledge of this little atoll.

Meteorology

There are no meteorological records whatsoever from Rose Atoll. Even the visitors whose accounts are used here gave almost no information on the weather at the time of their stays, except for the weather at sea described by Freycinet. The only source of data that gives an idea of meteorologic conditions in the region is the Weather summary for Naval Air Pilot, H. O. 272 of the U. S. Hydrographic Office, which is used throughout this section, without further acknowledgment. It offers information that can be used in getting an idea of weather and climate at Rose Island and is compiled from ships' observations, mapped and tabulated for 5-degree ocean areas, together with general trends as expressed by isobar or isotherm charts. The island nearest to Rose Atoll from which are available data that cannot be collected by ships' observations (such as temperature variation and total rainfall) is Tutuila. But this is a high island, and its weather station at Pago Pago is dominated by a mountain called the "Rainmaker", because it precipitates moisture from every cloud passing over it. The atoll nearest to Rose with some weather data is Puka-Puka (Danger Island). It is in the same 5-degree square as Rose but in the northeast corner (10°53'S, 165°54' W.) The records available since 1929 are summarized in a note by the New Zealand Meteorological Office (Seelye, 1943) and in the Great Britain Pacific Islands Pilot (v. 3, 1946). Both of these publications also offer some information on weather and climate at Aitutaki, the other weather station nearest to Rose Atoll, although much to the southeast. This is a high island (460 feet) on an atoll-like reef. The observations are made on the west side of the main island (18°52'30"W.) at an altitude of 10 feet. Rather than use data from the high Samoan Islands or Niue, those from Puka-Puka and Aitutaki are occasionally mentioned, because they can at least give an idea of the order of magnitude of conditions on Rose Atoll.

Atmospheric pressure: The 1008-millibar isobar for January passes just north of Rose Atoll and just south of Puka-Puka; the 1012-millibar isobar for July passes near the location of Rose, whereas the 1010-millibar isobar for July passes close to Puka-Puka. (Great Britain Pacific Islands Pilot, v. 2, pp. 18-19). These figures probably express the range of variation at Rose Atoll, except, of course, for depressions accompanying possible hurricanes.

Tropical cyclones and hurricanes: No cyclones and hurricanes are reported from Rose Atoll, but among the Samoa Islands, years may pass without a destructive storm, though two or three cyclones have been known to occur in a single year, with January and March as months of highest frequency. The most famous hurricane in Samoan history is that of March 13 to 23, 1899, which, occurring at a moment of great international tension, kept everyone so busy that political issues became

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secondary and were solved more amicably than they might otherwise have been. The track of this hurricane (Chart 23, H.O. 272) does not pass near Rose Atoll, nor do any other tracks of the few cyclones plotted on this chart. East of Rose Atoll, hurricanes have been known to occur and cause much damage, at Puka-Puka, Nassau, and especially at Suwarov, but they are rare.

Prevailing winds at sea: Rose Island lies in the region where the northeasterly trade winds penetrate the south latitudes: In the 5-degree square just north and west of that of Rose (5° to 10° S., 170° to 175° W.), surrounding the Union group, 29 percent of the annual winds are from the northeast, 32 percent from the east, and only 13 percent from the southeast. At about the 10° S. the southeast trade winds definitely become more frequent; and in 10° to 15° S, 165° to 170° W. (Rose Atoll square) southeast winds are recorded as 25 percent of the annual winds, northeast trades as 17 percent, and east winds, the most frequent, as 34 percent (see table p. 9).

Ocean gales, squalls and thunderstorms: Rose Atoll lies in an area where both gales and squalls are rather common, being reported in 14 percent of the ships' weather observations. Thunderstorms are reported in 4 percent of the ships' observations. All the figures for gales, squalls, and thunderstorms are much less for the 5-degree square of Rose Atoll than for the next one west, where the high Samoan Islands are situated.

Sea temperature: Rose Atoll lies in a region between the two 82° F isotherms for sea temperature (north and south of the Equator) for February (southern summer), and the 80° F isotherm for sea temperature (Southern Hemisphere) for August passes just north of Rose (Great Britain Pacific Islands Pilot, v. 2, pp. 18-19). These figures probably express the range of yearly variation of sea temperature at Rose. At Puka-Puka the variation is reported as from 81° to 83° F (Seeley, 1943).

Air temperature: There are no figures at all for air temperature at Rose Island or the ocean around it. At Puka-Puka the mean for the year is 82.2° F, with very slight variation from month to month (83.1° for May, warmest month; 81.8° F for January, coolest month). The averages of the annual extremes are 93° F and 71° F, and the absolute extremes are 97° F and 70° F. At Aitutaki the Southern Hemisphere seasons are well marked; the warmest months are January and February (81.0° F mean temperature), and the coolest is August (75.4° F). The yearly mean is 78.2° F. At Rose Island the southern seasons are probably slightly felt, whereas Puka-Puka still has Northern Hemisphere seasons. Rose probably has a rather even yearly temperature, of about 81° F, the extremes not reaching much above 90° F or below 70° F.

Clouds and visibility: Table p.8 is made from Charts 13 to 17 of H.O. 272, for the 5-degree square of Rose Atoll. The total of ships' weather observations for this square is 760 for the period 1879-1933.

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Feb.	May	July	Oct.	Dec.	
78	49	74	63	63	Figures express percent of observations recording lower type clouds.*
3.4	5.1	4.4	9.5	5.4	Percent of observations with exceptional visibility.
1.7	1.3	1.5	0.0	1.8	Percent of observations with haze.
0.0	0.0	0.0	0.0	0.0	Percent of observations with fog.

* Lower type clouds are apparently the trade wind cumulus and various rain clouds.

Relative humidity: At Puka-Puka the mean relative humidity for the year is 79 percent, with a variation of 2 percent above and below for the individual months (morning observations); the mean dew point ranges from 74° F in July to 78° F in April, the average being 76.3° F (Seelye). It may be assumed that figures for Rose Atoll would be similar.

Rainfall: The evenness of rainfall is an important factor on atolls, in making the amount of precipitation effective. The rain water percolates immediately through the extremely porous material forming the islands, so that the amount of rain that corresponds to extremely arid conditions on an atoll may mean much moister ones on large islands or continents. On Puka-Puka the rainfall is usually heavy, the average for 1930-1942 being 117.57 inches a year, the totals ranging from 85.46 (in 1938) to 155.13 (in 1931). There is a marked rainy season from November to March. The average number of rainy days (with 0.10 inch or more rain) is 170 days per year. This is rather low. At Aitutaki the yearly average is 77.57 inches in 92 days, and there is a wet season from December to March (Seelye, 1943). Rose Atoll probably has a similar rainfall, although the number of rainy days may be greater.

High seas: It may be of interest to mention that on Puka-Puka in February 1935 a hurricane that affected Rarotonga brought rather high seas (Seelye, 1943). The seas rose on the 8th, and canoes left under trees 200 yards from the usual low-tide mark were nearly washed away. Conditions were worse on the 9th and 10th, but the sea went down rapidly the following day. This phenomenon might have affected Rose Atoll also.

Geology*

The reef of Rose Atoll is almost entirely made up of Lithothamnion rock as are the boulders scattered on it. The surface of the atoll rim, where awash at low tide, is covered by vigorous growths of Porolithon that form connected pink patches or -- west of the lagoon entrance -- ridges 6 inches high and 6 inches to several feet wide. The ridges,

* The geology and soils sections were prepared with much assistance from F. R. Fosberg and utilize unpublished data from his investigations in the northern Marshalls in 1952.

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Ocean area S10 165. Position: Latitude 10° - 15°S, Longitude 165° - 170°W.
Greenwich noon observations. Years covered 1883-1933.

Month	Number of observations surveyed	Wind: Mean velocity (knots)	Wind: Percentages of observations from – N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm	Weather: Percentages of observations recording – Haze	Mist	Fog	Drizzle	Rain	Light squalls	Showers	Thunder-storms	Heavy squalls	Gales (force 8 or over)	Exceptional visibility	Mean cloud amount (0-10)
January	45	11.1	8	27	16	21	6	5	7	5	5	0	0	2	0	15	20	9	2	0	8	4	4.6
February	59	8.9	11	30	19	5	2	11	4	17	1	2	0	0	2	8	8	10	5	0	0	3	4.6
March	57	8.4	14	19	29	19	5	0	5	7	2	2	0	0	0	18	16	7	4	0	2	5	5.5
April	66	5.7	5	19	31	15	7	2	0	6	15	2	0	0	0	5	2	3	3	0	0	3	3.8
May	78	9.7	5	19	44	27	1	1	0	0	3	1	0	0	0	8	12	6	3	0	0	5	4.2
June	76	11.1	5	8	54	25	2	1	1	1	3	1	0	0	0	4	12	10	3	1	3	0	3.6
July	68	11.6	5	8	50	29	6	0	0	1	1	1	1	0	0	9	12	12	1	1	0	4	4.8
August	64	11.1	0	10	40	43	3	2	0	2	0	2	0	2	2	5	11	11	0	0	0	8	5.5
September	66	12.0	3	20	34	41	2	0	0	0	0	0	0	0	0	0	15	11	3	2	2	0	4.7
October	63	8.0	7	13	36	29	2	2	4	4	3	0	0	0	0	2	9	14	3	3	0	9	4.2
November	62	8.0	10	10	35	22	5	7	4	7	0	3	0	0	0	5	11	8	5	0	0	8	4.9
December	56	6.8	21	17	20	21	0	7	0	10	4	2	0	0	0	6	4	5	11	0	0	5	4.8
Mean		9.4	8	17	34	25	3	3	2	5	3	1	*	*	*	7	11	9	4	1	1	5	4.6
Total	760																						

From H.O. 272, p. 62. Compiled by the U.S.Weather Bureau

* Less than 0.5 percent.

which are separated by channels, are occupied by other algae. The slopes of the reef are not different in their algal constituents from the flat top, except for the presence of some stunted Acropora and Pocillopora (corals) "at the extreme edges of the atoll rim fronting the lagoon or the sea." The algal ridge at the edge of the reef is very weakly developed, as also are surge channels (Schultz, conversation 1953). Freycinet mentioned small black rocks, all of about the same height, and the U. S. Exploring Expedition found then to be limestone boulders. Mayor gave them much attention and wrote (1924, p. 75):

> "Hundreds of large blocks of limestone lie scattered over the flat, wave-washed rim of Rose Atoll. These loose boulders are quite uniformly about 5.5 feet high, and only when tilted are they any higher. In addition to these boulders there are a few others which are mushroom-shaped and still remain attached to the floor of the atoll-rim, of which indeed they form an integral part. One of the most remarkable of these mushroom-rocks lies to the eastward of Rose Islet, and is supported upon so slender a pedicel that it would seem as if the next storm must cause it to topple over. In many places over the flat, wave-washed floor of the atoll-rim one finds remnants of pedicels which once supported 'mushrooms'. In addition, some of the boulders have become secondarily cemented to the floor of the flat by the growth of Lithothamnium around their bases. The largest boulder we observed lay loosely upon the reef-flat east of Rose Islet and was somewhat tilted by being jammed against another rock. It was 12 feet 5 inches long, 8 feet wide, and 7 feet 6 inches high, and as its specific gravity was 2.3 it apparently weighs 46 tons."

He concluded that the boulders showed that sea level must have been at one time 6 or 8 feet higher than now and that the scattered detached boulders were mushrooms that had been completely undercut. He reported that the boulders were made up of the same algae and had generally the same chemical composition as the solid reef platform, with the same high percentage of magnesium attributable to Porolithon.

Among these boulders, the Exploring Expedition found some scattered blocks of volcanic stone. They are mentioned by Wilkes, Dana, and Couthouy and also by Pickering, who says (1876, p. 235):

> "For the first time on a coral-island, the mineral kingdom was represented; several blocks of vesicular lava being met with by our party; in all instances resting upon the coral-shelf, not imbedded. Two or three of these blocks were seen by myself, the largest weighing perhaps twenty pounds. From the mineral composition, they had evidently been derived from some volcanic island; and there seemed no means of transportation, unless entangled in driftwood. This actually takes place at the Tarawan coral-islands; where Mr. Hale found a native name for 'basaltic stones in the roots of trees drifted to those shores'."

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Mayor failed to find these rocks among the coral blocks and supposed that the members of the Exploring Expedition had mistaken blackened limestone for basalt. The matter rested until 1939, when Schultz again found them. He only mentions (1940, p. 48) collecting lava but (conversation, 1953) observed many volcanic blocks, a dozen or more up to the size of a man's head, scattered on the reef. His specimens were brought back to the U. S. National Museum and were found to be compact olivine basalt. They are being studied further by Gilbert Corwin, who says the rocks are olivine basalts, such as are typical of Pacific islands. Schultz supposed that they might have been thrown up from the sides of the island with the niggerheads.

For an idea of the geology of the two bits of land on this reef, we must rely almost entirely on Mayor's account.

Sand Islet is "a mere accumulation of fragments of Lithothamnium shells, and broken coral .... only about 5 feet above high tide level." The loose and unstable nature of such debris lying on a flat reef surface makes entirely probable the changes in size and shape of the islet indicated in the different accounts and maps. There is no suggestion anywhere that any of this material is consolidated or cemented to the reef.

Rose Islet, on the other hand, seems to be mainly a mass of such debris that has been consolidated into a "coquina" or reef-conglomerate such as is a common feature of other atolls. Probably the word "coquina" is improperly used here, as the material is not primarily composed of shells. Mayor's description of this follows (1924, p. 74):

> "The tree-covered rocky center of the islet is composed of a coquina consisting chiefly of wave-worn fragments of lithothamnium and also rare and occasional fragments of broken coral, such as _Favites_, _Porites_, _Symphallia_, _Pocillopora_, and still more rarely _Acropora_. Embedded in it are many wave-worn half-valves of _Tridacna_ and gasteropod shells, and spines of _Echini_ such as _Cidaris_ were found, as was also the much corroded ulna and part of the skull of a small cetacean about the size of a blackfish, the latter being embedded in the coquina about 8 feet above high-tide level. A large amount of organic matter, dark brown in color and derived from the decomposed roots of the _Pisonia_ trees, permeates this coquina to a depth of several feet. All of the fossils found embedded in the coquina are forms now living on the reef-flat, which have simply been tossed on shore by the waves."

The height of this conglomerate above the reef surface is rather remarkable for such a small islet. Mayor says, "On the southeast side of Rose Islet the sand-beach is reduced to from 1 to 5 feet in width at low tide, and cliffs of coquina from 5 to 8 feet high front the sea .... A few feet inland this rocky ledge rises to a height of about 11 feet above high-tide level."

Schultz (1943, p.3) says that on this southeast side the island apparently is being eroded away. Here, again, on the southeast shore, is some beach-rock, said by Mayor to be more recent than the "rocky matrix of the islet." Schultz (1943, p. 3) adds, "To the east of the island for a few hundred feet are loose slabs of coral-shell conglomerate rock left on the reef, which may have at one time formed part of the island." These must be slabs of beach-rock as shown by photographs.

On the northwest side the islet is reported by Schultz to be building up by accumulation of coral debris (incorrectly called breccia by Mayor). Here the beach is much wider. On the surface of the conglomerate where it is covered by the Pisonia grove there seems to be little accumulation of loose material (Schultz simply says that the conglomerate is "overlaid by coral-shell gravel"). No boulder ridges, dunes, or "ramparts" have been described.

Soils

The surface of Sand Islet and the bare north part of Rose Islet are apparently of unaltered or scarcely altered limestone debris, largely of algal origin. This debris is similar to what is found on bare or newly formed parts of most atolls, except that the proportion of algal material is unusually high here.

The soil within the Pisonia grove is very different and is the subject of an extensive study by Lipman and Shelley (1924). A good description of the profile does not exist, but from Mayor's casual remarks and Lipman and Shelley's descriptions of the materials they analyzed, a profile can be roughly reconstructed as follows:

Top layer -- (Mayor) "a rich chocolate-colored humus which is of considerable depth near the southern end of the grove."

Intermediate layer -- (Lipman and Shelley) "a loose porous mass, very light in weight," (Mayor) "dark brown in color .... to a depth of several feet."

Bedrock -- (Lipman and Shelley) "a compact, fine-textured, almost pure calcium carbonate which shows no vital structure. It is pure white, fairly soft ..." (but see Mayor's description of the coquina, which is the same material, p. 11).

Lipman and Shelley regard the intermediate layer as being an intermediate product in the decomposition of the bedrock, to form, with the addition of much humus, the surface layer of "fine-textured, mellow, organic soil." They had only a small bit of soil adhering to a partly decomposed rock, this rock, and some of the bedrock to examine and work with. Their interpretation of their analytical results is completely dependent upon this conception of the origin of the profile, and if more recent studies in other atolls (Fosberg, in press; Hatheway, 1953) are reliable, their interpretation is erroneous, the situations seeming more or less comparable. Stone (1951, p. 10) regards Lipman and Shelley's conclusions as entirely vitiated by the presence of basalt fragments on the reef.

Lipman and Shelley's analyses are as follows (p. 208):

	Rose Islet soil	Intermediate product	Lithothamnium rock	Water soluble constituents	Rose Islet soil	Intermediate product
					p.p.m.	p.p.m.
	p.ct.	p.ct.	p.ct.			
H_2O at 100°C	5.12	2.49	0.40	Total soluble salts	26,000	11,600
Loss on ignition	22.84	31.09	46.22	Na_2CO_3	1,837	2,171
Si O_2	.18	.20	.16	Na_2SO_4	4,414	2,435
Al_2O_3	16.72	9.20	.46	NaCl	14,391	1,755
Fe_2O_3	.40	.48	....			
P_2O_5	20.94	14.60	.57			
CaO	29.26	35.78	44.01			
MgO	1.75	3.34	7.46			
SO_3	1.14	.87	.61			
Na_2	1.38	1.39	.35			
K_2O	.23	.23	.15			
TOTAL	99.97	99.66	100.40			

The striking facts about these analyses are the increasingly high percentages of Al, P, S, Na, and K (from bedrock to soil), compared with decreasing percentages of Ca and Mg and very little change in Si, also the greater moisture-holding capacity of the organic soil and the "intermediate product."

Lipman and Shelley's explanation of the high aluminum content and low silica content is ingenious. They explain, "The aluminum silicate in the original rock undergoes decomposition through reaction with ammonia, formed from the decomposition of the soil organic matter or of the bird droppings on the islet. Such a reaction would be followed by the leaching out of the ammonium silicate formed and, while allowing of the accumulation of alumina in the soil, would prevent accumulation of silica there." This would necessitate a reduction of 36 times in the weight of soil decomposed to yield this amount of alumina.

The two authors interpret the increased of sodium, potassium and sulfur as results of the great adsorptive capacity of the soil, differential leaching, and increment from spray.

The astonishingly high phosphate content of the soil and the rather high content of the "intermediate product," they regard as resulting from simple accumulation of the phosphate of the original rock, without even taking into account the bird droppings usually considered the source of such phosphates. The correspondence of the figures with those for aluminum would suggest this conclusion, but then the problem would arise of what had actually become of the phosphorus in the droppings of the large bird population that is found on the island.

The picture, in light of investigations, incomplete as yet, in the Marshalls, supported by a survey of the literature, appears to be actually quite different. Generally, under Pisonia forest, a layer of pure humus, corresponding to Mayor's description and acid in reaction (pH 4.5 to 6), accumulates. Usually these forests are inhabited by large numbers of birds, as on Rose Islet. Their droppings (normally pH 6) are acidified by the humus as they are washed down through the humus layer, and the finely divided calcium phosphate is dissolved. When it reaches the sand and rock beneath, it becomes alkaline and therefore insoluble, precipitating out and cementing the loose calcareous material together. The acid solution tends to dissolve out the calcium carbonate and permits it to be replaced by calcium phosphates. Thus a cemented layer or hardpan is formed immediately beneath the humus layer.

This process is not at all similar to the one suggested by Lipman and Shelley. It would not account for the enormous concentration of aluminum, nor the relatively low loss on ignition. It is clear, from the two authors' description of their soil sample "containing many undecomposed particles of the original lithothamnium rock," and the fact that their sample was material adhering to the surface of the partially decomposed rock, that they did not have a typical sample of the pure humus as described by Mayor. The ignition loss would likely have been much higher if the sample had been representative. The high aluminum content may well have been the result of contamination by decomposed pumice pebbles, common enough on atolls, or even from the basalt. How the silicon was lost if so, is not clear, except that it tends to leach out under tropical conditions.

There is a record of subsequent samples being collected for Lipman by Governor Pollock, but though they were studied for soil micro-organisms, no more chemical analyses were reported. Further studies to ascertain whether this high Al content is a general feature or only a localized one would be desirable.

One other fact revealed by Lipman's investigations is the unusually high concentration of water soluble salts in the soil (see table of analyses, p. 13). The authors mention, "If our analyses are to be considered as even approximately correct, the Pisonia tree is to be regarded as one of the most salt-tolerant plants of which we have record at present." They point out that the toxic effects of the salts may be somewhat mitigated by the high content of organic matter present but consider that the tolerance is still remarkable. This concentration may well be of significance in connection with the extremely small land flora of the atoll and possibly with the lack of success of the coconuts planted there repeatedly.

In a bacteriological study of the soil samples collected by Governor Pollock, Lipman and Taylor (1924) found that the numbers of organisms were enormously higher in the humus-rich soil in the Pisonia forest, much lower in the soil where Boerhavia and Portulaca were growing, and extremely low where there was no vegetation. This is exactly what would have been expected and does not require further comment.

The authors found, also, that both nitrite and nitrate producing bacteria are present in all the soils, and that their nitrifying activity is more or less proportional to the amount of organic matter in the soils. What was probably Azotobacter was found, but it was concluded that such organisms "do not find conditions propitious for their rapid development in competition with other forms which occur there."

Land Flora

The land flora of Rose Atoll was first described by Pickering (1876, p. 236):

> "The whole flora of the island consisted of but two species of plants: one of them, as will be perceived, additional:
>
> Portulaca (No. 1). Normal; multicaul and prostrate, having the habit of P. oleracea, but much larger flowers; petals five, yellow. Growing in a scattered manner on top of the beach, and in all instances outside the grove.
> (Calpidia ovatifolia?); bis (No. 1 Paumotu coral-islands). Constituting the grove; some of the trees being fifty feet high, with the trunk four feet or more in diameter. Additional anomalies of growth were here observed: as two proximate upright branches anastomosing ladder-like at intervals; and several instances of upward-tending branches, as in the trees seen in the distance on Serle and other coral-islands. The timber proved on examination to be brittle and to all appearance worthless."

Pickering's observation of the two plants had been reported earlier by Dana (1849, p. 309). The plants were discussed and identified as Pisonia grandis R. Br. and Portulaca lutea Sol. by Setchell (1924) who was studying Mayor's specimens. Mayor gave the second enumeration of the flora, and found one more plant, Boerhavia tetrandra Forst., growing on the rough limestone surface of the north part of the islet, with Portulaca.

In 1938, Bryan recorded no native plants other than those three, which is a remarkable fact. It would be interesting to know when Boerhavia took hold. It would probably not have been missed by Pickering, who was familiar with it and had found it on several of the Tuamotus. No account mentions plants other than the grove of trees, between the time of the U. S. Exploring Expedition's visit and Mayor's visit.

In the U. S. National Herbarium there are no specimens from Rose Atoll collected by Pickering. He may not have made any collections. There are several sheets of Pisonia grandis from later collections, however:

Bryan 1382, Aug. 4, 1938; Wray Harris 287, April 1938; Schultz 26 and 27, June 11, 1939. There is also a sheet of *Portulaca lutea*, Schultz 25.

In the B. P. Bishop Museum (information kindly supplied by E. H. Bryan, Jr., curator) there are sheets of the three phanerogams: *Pisonia grandis*: Setchell 50 (collected by A. G. Mayor, June 6, 1920); Wray Harris 274 and 287, April 21, 1938; Bryan 1382, Aug. 4, 1938. *Boerhavia tetrandra*: Setchell 51 (collected by A. G. Mayor, June 6, 1920); Wray Harris 303, April 21, 1938, and 304, November 30, 1937; Bryan 1384, Aug. 4, 1938. *Portulaca lutea*: Setchell 52 (collected by A. G. Mayor), June 6, 1920); Wray Harris 301 A, Nov. 30, 1937; Bryan 1383, Aug. 4, 1938.

The latest addition to the flora, due to human interference, is that of the coconut palm. The story of the Rose Atoll coconut palms is quite intriguing; the palms flourished at the time of Rantzau's visits, but had disappeared by 1900. Of those planted by Rantzau, one remained in 1920, sterile, probably as suggested by Dumstrey, because it was choked by the *Pisonia* trees. The nuts planted by Terhune in January 1920 were growing in June, but had all disappeared by 1922, when Pollock planted some new ones. Bryan in 1938 found about 20 palms, 8 large and a dozen small. Schultz (unpublished notes) observed seven large trees and two small ones, besides several recent plantings now 1 to 3 feet high. The tall palms were bearing nuts, and photos show that some of the fallen nuts may have been sprouting. By 1953 the total number was reduced to 12 and these were bearing heavily, and it is hoped that no more were planted, and that Rose Atoll will have a chance to increase its flora by natural means only. Why the palms have failed to survive and multiply, when some did grow into adult trees from planted nuts, is hard to explain. Perhaps the coconut palms were destroyed by a typhoon between 1873 and 1900, whereas the *Pisonia* grove was seemingly unaffected; this is possible since *Pisonia* trees are practically indestructible, new trunks springing up from fallen ones (see below, Vegetation). Most of the plantings of nuts probably failed very early. Another possible explanation has been suggested on page 14; it is possible that the high concentration of water-soluble salts in the soil prevents coconut seedlings from developing. The rainfall of Rose Atoll, if estimated at 77 to 110 inches a year, is not very heavy; and it may be irregular. In any case, the minute islet may not be sufficient in area to permit the formation of a fresh-water lens, and the palms may suffer from physiologic drought. There may be also too great an amount of sea spray for coconut seedlings to do well. In this connection, it may be remarked that the three native plants are very hardy ones, often found alone or with a few other such halophytic species, on the most destitute atolls. Schultz (unpublished notes) also records plantings of bananas, papayas, and a few other plants, and indeed a very small banana plant is discernible on one of his photographs. But it is not known whether these plants have persisted.

There is only one record of a macroscopic land cryptogam, a lichen, which Bryan collected on the trunks of the *Pisonia* trees, and which has not been identified as yet (Bryan 1385, in Bishop Museum). In the study of the soil flora, Lipman and Taylor isolated 19 bacterial colonies of which they gave descriptions (pp. 213-214). Most of them were actinomycetes, one or two could clearly be recognized as other than actinomycetes, and one was a mold. The presence in the soil of nitrifying bacteria and *Azotobacter* has been mentioned in the section on soils.

Vegetation

According to all available reports, Sand Islet is completely destitute of vegetation. Governor Terhune planted two coconuts on it, but they did not grow.

The fresh green grove of trees is the most conspicuous feature of the vegetation of Rose Islet, giving it from afar the appearance of a low rounded hill, for which it has often been mistaken. Freycinet seemed to indicate the presence of two separate groves (see History); Wilkes wrote, "The islet is entirely covered by the clump of trees." Pickering said of Portulaca plants that they grew on the top of the beach, which might indicate that indeed the grove covered most of the island surface. Later, Mayor estimated that the trees occupied one half of the land area, and in 1953 this was reported as only one third. It is difficult to decide whether the grove has decreased or the island grown larger. The latter is possible, especially since its estimated dimensions are reported larger in 1938 than 1920, and it seemed in 1939 to be increasing on the northwest side (see Geography). It is more unlikely that the Pisonia grove should become much smaller, unless parts were removed by a hurricane.

The forest is made up entirely of large trees of Pisonia grandis with no undergrowth at all. Pickering, Mayor, and others emphasize the fact that the other plants do not grow at all under the trees. This is, furthermore, quite normal in luxuriant Pisonia groves on atolls. When Mayor visited Rose, one coconut tree, probably planted by Governor Tilley, grew among the Pisonia. Rantzau's sketch map of the island showed mixed coconuts and other trees, but this may not have been meant to express the exact condition, as the Pisonia would probably shade out the growing coconut seedlings. Pure Pisonia forest occurs on various atolls in the Pacific, for instance on some islets of the northern Marshalls, and especially on Vostok Island, which must be very like Rose. The trees have many twisted stems with creamy white bark and large light-green leaves. Pisonias can attain enormous sizes, and those on Rose Atoll were fifty feet in 1839, 80 in 1920 and estimated at 85 feet in 1953. The largest are on the southern part of the islet, and, in 1920, one had a girth of 25'7" at 3 feet (Mayor, p.73). Pisonia can form sprouts from practically any part of the tree, roots, branches, stubs, and fallen trunks, forming luxuriant tangles of stems and branches. This forest on Rose Islet must be a magnificent sight. Two good photos of it by Mayor accompany Setchell's paper, and Bryan published two of his own that show well the rounded contour of the grove.

Along the northeast edge of this grove are the coconut palms. They have been discussed in the description of the flora.

The whole north part of the islet is free of trees, and the surface of broken reef material supports Boerhavia and Portulaca. One of Mayor's photos (in Setchell, 1924) shows well this tangle of low plants. The Boerhavia plants have a thick woody root crown, with creeping stems up to 3 feet long. The Portulaca form little bushy succulent herbs up to 2 feet high, with erect, much branched stems, fleshy but firm. Besides the north part of the island, these two plants seem to be scattered on the strand along the Pisonia grove, at least on the lagoon side (Mayor, p. 74).

Except for the lichen collected by Bryan, no mention is made on macroscopic cryptogams in any of the available accounts. Possibly other cryptogams occur on Rose, and a search might discover them. The black limestone boulders strewn over the reef doubtless owe their color to microscopic blue-green algae.

Fauna

There have been a few collections of land animals on Rose Atoll, by Mayor, by members of the 1938 and 1939 surveys (see History), and by others. The specimens have been added to museum collections but have not been mentioned in the literature.

Birds are the most conspicuous animals on the atoll. Freycinet (see History) mentioned frigate birds, boobies, noddies, tropic birds, and terns. At sea (p. 85) he also observed curlews on the day of the discovery of the atoll. Wilkes observed at least four kinds:

> "Birds were seen flying over the island, and on landing we found them in great numbers and very tame. The frigate-birds, and boobies (sula), whose nest had before been observed on low bushes, were here found on the tops of trees fifty feet high. The noddies laid their eggs on the parts of the island destitute of vegetation. Tern were in great numbers; their breeding-place was in a thicket on the weather side of the island, or that which was exposed to the wind and sea, and was remarkable from the regularity with which the eggs were placed, about three feet apart, without any nest, and, with but few exceptions, out of many thousands, each egg lay separately. The colour of the eggs is a dirty white, mottled with brown. The noise made by these birds when disturbed was almost deafening; but on making a loud sound, such as the firing of a gun, their cries would cease for a moment or two, producing a singular stillness."

Graeffe only said that a great many birds, especially species of Sterna or sea-swallows, nested in the trees.

Mayor wrote:

> "Several hundred boobies (Sula), most of which had half-grown young, were nesting on the coral breccia of Rose Islet ..., while others had constructed nests of sticks high among the branches of the Pisonia trees. A few boatswain-birds with eggs were also nesting in the trees, and several nearly grown young sooty terns visited the island at night. Frigate-birds were hovering over the island, but none were nesting. Wilkes states that the noddies and sooty terns were nesting on

Rose Islet on October 7, 1839, and these species were still nesting when Governor Terhune visited the island on January 10, 1920."

In 1938 (Donaggho, 1953, p. 68) frigate birds were flying above, brown boobies were nesting, and red-footed boobies were sitting in the trees, as did the fairy terns. Munro (1949, p. 50) said that there were numbers of these lovely white birds, and he hoped that they did not too often get gummed with the sticky fruit of Pisonia. Bryan (1942, p. 92) also reported some wandering tattlers; and reef herons, one blue, one white.

Schultz in 1939 (1940, p. 48) observed that in the Pisonia trees were nesting boobies and frigate birds and "underneath, on the ground sooty terns were nesting." This had been mentioned by Donaggho and seems rather unusual. In his unpublished notes Schultz also recorded yellow-billed /blue-faced/ boobies, nesting on the ground with their white and downy young, and brown boobies. He vividly described the enormous numbers of birds, their incessant clatter, the terrific stench of guano, which falls "like rain all day and night" from the trees. His collections of bird skins are preserved in the U. S. National Museum:

USNM 358134	Sula leucogaster plotus (Forst.)	brown booby
USNM 358138	Demiegretta sacra (Gmel.)	reef heron
USNM 358149	Anous stolidus pileatus (Scop.)	common noddy
USNM 358155	Heteroscelus incanus (Gmel.)	wandering tattler

Summary of other birds recorded:

Sula sula rubripes Gould	red-footed booby
Sula dactylatra personata Gould (Schultz photo)	blue-faced booby
Fregatta minor (Gmel.) (?) (probably this, but could be F. ariel)	frigate bird
Phaeton lepturus (Daudin) (probably this, as Mayor says it nests in trees)	white-tailed tropic bird
Sterna fuscata L.	sooty tern
Gygis alba (Sparrm.)	fairy tern
Numenius tahitiensis (Gmel.) (Freycinet, probably this species)	curlew

The 1953 survey only mentions the presence of birds. It is rather interesting to observe the fact that the same species have visited Rose Atoll for more than 100 years and were found in the same situations.

Wilkes and Graeffe do not mention any land animals other than the birds. Mayor on the other hand found a small brown-gray rat, very tame and very abundant, which is probably the Polynesian rat, Rattus exulans (Peale). Besides, he observed a small brown short-tailed lizard that was identified by Thomas Barbour as Lepidodactylus lugubris (Dum. and Bibron). Bryan also noted rats and lizards, but the 1953 survey does not mention the latter.

The only other vertebrates occasionally visiting the land at Rose Atoll are the turtles. Wilkes saw several small ones, "feeding upon a species of fucus that grows upon the reefs." Girard (1858, pp. 459-461) described Chelonia tenuis giving the locality as Honden /Pukapuka, Tuamotus/, Tahiti, Eimeo and Rosa Island. He quoted the "Notebook" of the Expedition which said that the turtle captured at Rose "had the alimentary canal crowded with sea-weeds (the Caulerpa seen at Raraka)." Girard's name, Chelonia tenuis was recognized as a synonym of Chelonia mydas L. by Boulenger (1889, p. 182). Rantzau (Graeffe, 1873) gave the best account of turtles:

> "On the sand island, in the months of August and September, a great number of sea turtles came to lay their eggs. Most of them were the common sea-turtle (Chelonia mydas L.). More seldom came the caret (Chelonia imbricata L.). When the time came for the young to hatch, the surrounding sea was full of sharks who avidly snapped up the little turtles as fast as they arrived in deeper water."

The 1953 survey reported evidences of the presence of turtles, but gave no details. It is often recognized that turtles visit some uninhabited islands repeatedly, and natives of certain groups protect these "turtle-islands": thus the Marshallese know that turtles come to Jemo and Bikar, and certain islets of the larger atolls, and had very strict rules concerning them (Tobin, 1952, pp. 23-27). It is to be hoped that Rose Atoll will remain a bird and turtle island.

Very few land invertebrates are recorded from Rose Atoll. Mayor observed a sphinx-moth larva of the genus Celerio (Oken) feeding upon the Portulaca. He also observed a few gnats and flies, but supposed that they might have been introduced by the ship. Most of the reports of Governors' visits, in O Le Fa'atonu, point out the absence of flies and mosquitoes. There are no mentions of insects in the published accounts of the 1938 and 1939 visits. However, Bryan (unpublished field notes) collected small moths, crickets, numerous flies on the Pisonia foliage and adjacent Boerhavia, and ants. The ants were especially noticed by Schultz, who said that they were small, red, nonbiting, but quite a plague because of their enormous numbers. He also noted a small beetle and collected various other insects. Neither of these collections has been identified. On the specimen of Portulaca lutea seen in the U. S. National Herbarium, a scale insect was found. Dr. Harold Morrison, of the U. S. Department of Agriculture identified it as a species of Coccus, very close to or possibly identical with Coccus hesperidum L. The specimen was too poor to permit a more positive determination.

Strangely enough, the only group of Rose Atoll land animals on which some systematic work has been published is that of mites. Ewing (1924) found two species in the fur of some rats sent him from the Bishop Museum in 1920. It is supposed that these were the rats that Mayor mentioned presenting to the Museum. The mites identified were: Laelaps echidnidus Berlese on Rattus sp., Laelaps hawaiiensis n. sp. described from Hawaii (on R. hawaiiensis) but recorded also from Rose on Rattus sp.

Of other invertebrates, Bryan simply reports "the usual hermit-crabs." Schultz collected an earthworm, a very interesting fact, but the specimen has not been identified.

The land fauna of Rose Atoll is undoubtedly larger than is indicated by these sketchy records, and it would be interesting to have a complete investigation of it and to correlate it with the flora, the paucity of which certainly must influence the number of animal species, especially small invertebrates, that can take hold on the atoll. Some larger invertebrates, such as Birgus latro, may be absent because of lack of food.

Conclusion

In many ways, Rose is an unusual atoll. Its pink Lithothamnion reef, and the basalt on it, its interesting soils, its enormous trees, and its curiously small flora and fauna are some of its striking features. More is known about Rose Atoll than about most uninhabited islands, but this knowledge is just sufficient to show that a detailed survey of the little atoll may be extremely interesting and may help us to understand certain features and ecological aspects of larger and more disturbed atolls.

A comparison with Vostok Island, which is very like Rose Islet, with a dense Pisonia forest and some Boerhavia, might be of use to explain some of their common characters. Vostok, unlike Rose Atoll, is very difficult to land on, and therefore no attempt at coconut plantings has been made (Fosberg 1937).

Few undisturbed atolls remain in the Pacific, and the pressure of increasing populations makes the utilization of unoccupied atolls likely. To maintain an example of a natural atoll, it may be suggested that Rose Atoll, so remote, so tiny, so devoid of economic possibilities, except for the fish found in the surrounding water, be protected in its present state. Some measures should be taken to prevent the introduction of coconuts and other fruits, and of animals transported by ships, especially large rats, and to instruct fishing parties in the purpose of conservation. The recent colonization of the almost unstudied Phoenix Islands by Gilbertese with resulting destruction of natural conditions makes urgent the preservation of one of the few undisturbed atolls. Phoenix, McKean, and Birnie Islands had previously been officially declared sanctuaries for birds but have been turned over to these colonists for plantations (Maude, 1952, p. 87). Experience in the Marshalls shows that sea birds, in numbers, do not persist in proximity to human settlements. Conceivably, Rose may soon be the only refuge left for breeding of the sea bird and turtle faunas of the Central Pacific.

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ATOLL RESEARCH BULLETIN

No. 30

The Hydrology of the Northern Marshall Islands

by

Ted Arnow

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THE HYDROLOGY OF THE NORTHERN MARSHALL ISLANDS [1/]

By

Ted Arnow [2/]

INTRODUCTION

The field work on which this paper is based was carried out in conjunction with an engineering survey of the northern Marshall Islands [3/] by the 71st Engineering Survey Liaison Detachment, General Headquarters, Far East Command. The hydrologic studies, which were made by the U. S. Geological Survey, were part of a comprehensive investigation of atoll features. The field work was done in December 1951 and January, February, and August, 1952 during which time the following atolls were visited: Utirik, Taka, Likiep, Ailuk, Lae, Kwajalein, Ujelang, Wotho, Ujae, Taongi, and Bikar (fig. 1). An average of 4 working days was spent at each atoll. The author wishes to acknowledge the assistance of the Marshallese guides and well diggers who aided in collecting ground-water data. In particular he wishes to express appreciation to his colleagues F. S. MacNeil and F. R. Fosberg, who collected water samples on Utirik and Likiep, and C. G. Johnson, who collected water samples on Taongi and Bikar. The author did not visit Likiep, Taongi, or Bikar. Groundwater data for Eniwetok Atoll were furnished by Harry Ladd of the Geological Survey. Appreciation is expressed also to Dan A. Davis, district geologist of the Ground Water Branch, Geological Survey, at Honolulu, Hawaii, who reviewed the report and made numerous valuable comments and suggestions.

A comprehensive report of hydrologic conditions in the northern Marshalls, including a discussion of the principles of the occurrence of ground water on small oceanic islands, is to be incorporated in an extensive report which will include all phases of the investigation. The main purpose of this paper, therefore, is to present factual data collected in the Marshall Islands rather than to give a discussion of principles.

CLIMATE

General Statement

The northern Marshall Islands have a tropical marine climate characterized by uniformity of air pressure, temperature, cloudiness, and humidity. Wind conditions are somewhat more variable, depending upon the season, and precipitation shows considerable variation depending upon the season and latitude. The predominant weather condition is one of moderate easterly trade winds and partly cloudy skys. This is usually broken by relatively brief showers or infrequent thunderstorms. Strong winds and long periods of continuous rain are infrequent, and hurricanes (typhoons) are relatively uncommon.

1/ Publication authorized by the Director, U. S. Geological Survey.

2/ Geologist, Ground Water Branch, Water Resources Division, U. S. Geological Survey, Agana, Guam.

3/ In this report the "northern Marshall Islands" are considered as comprising Kwajalein Atoll and all atolls north of Kwajalein.

Statistical Data

Meteorological records are comparatively scarce for the northern Marshall Islands. The only continuous long-term data available that were collected before World War II are from Ujelang for the period 1894 to 1913. Since World War II, data have been collected almost continuously at Eniwetok and Kwajalein. Because of the extremely short period of time spent on each atoll, no significant climatological data were collected during the work reported here.

The meteorological factor that has the most bearing on water supply is precipitation. The presence of the equatorial front, which seasonally may extend as far as 11 degrees north latitude, results in a marked gradation of rainfall from south to north in the northern Marshalls because the southern islands are deeper within the front whereas, to the north, the effect of the front becomes progressively weaker. (See fig. 2.) Comparative rainfall data for Ujelang, Kwajalein, and Eniwetok are shown in table 1.

Other climatic data have been published previously. (See references 1 and 4 at end of paper.)

TIDES

Tidal data were obtained at each of the atolls visited, by contract personnel of the 71st Engineers. The data were obtained by hourly observations at a staff gage placed in the lagoon. Approximately 2½ days of observations were made at each atoll. Because of the short term of observations and particularly because of the method of observation, the tide data are unreliable for the determination of a datum plane and therefore can be used only for general comparisons.

Tide data for seven of the atolls visited are published by the U. S. Coast and Geodetic Survey in its annual "Tide Tables for the Central and Western Pacific Ocean." These data are based on a primary station established at Kwajalein Island, Kwajalein Atoll. At Kwajalein the mean tide range, as measured in the atoll lagoon, is 3.5 feet; the spring range is 5.0 feet. There are some differences between the ranges at Kwajalein and those of some of the other atolls. The greatest difference from the average is at Ujelang where the mean range is 2.8 feet and the spring range is 3.9 feet.

WATER SUPPLY

Rain Water

Rain water is the most important source of fresh water for the Marshellese people. They prefer to use it for all purposes, but during the dry season the available rain water is reserved for drinking purposes and water from wells is used for washing and cooking.

The bulk of the rain water is caught on corrugated iron sheets hung over concrete cisterns or corrugated iron roofs of houses or other buildings. The

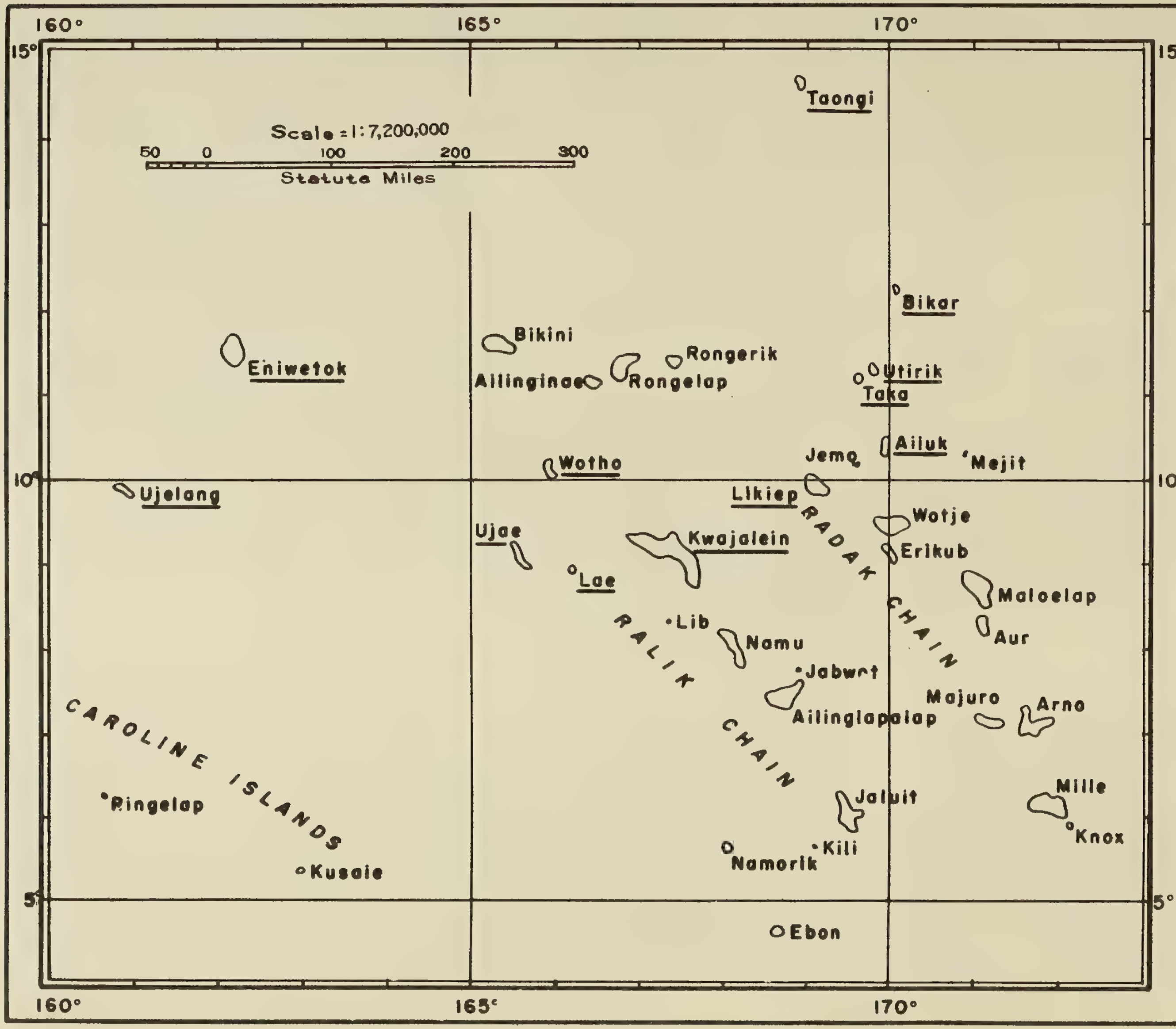

Figure 1. -- Outline map of the Marshall Islands. Islands covered in report are underlined.

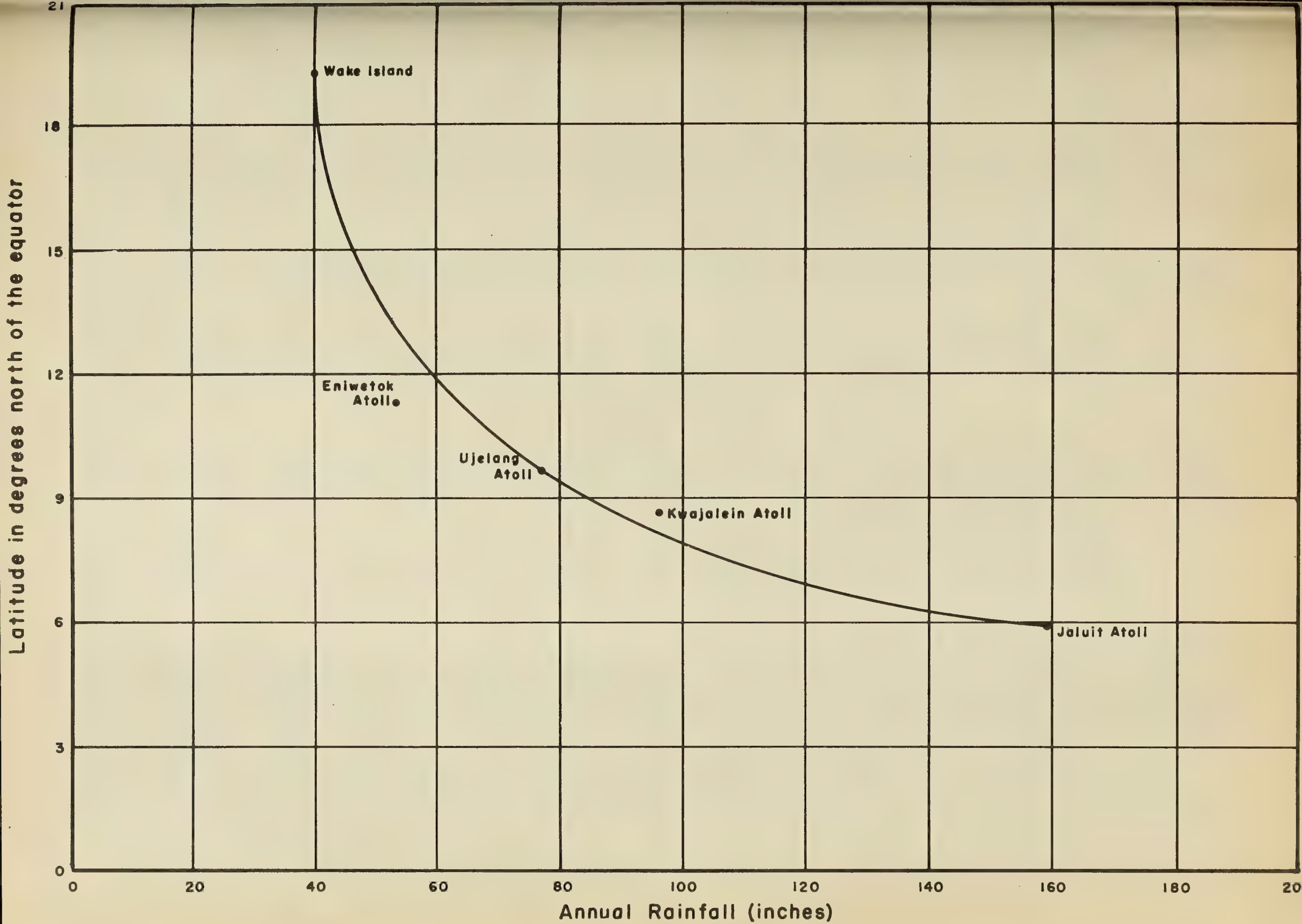

Figure 2.--Variation of rainfall with latitude in the Marshall Islands.

Table 1.--Comparative precipitation data for Eniwetok, Ujelang, and Kwajalein Atolls, Marshall Islands.

Eniwetok Atoll. Length of record: 5 years, 1944-1946, 1949-1953.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Mean monthly	0.80	0.71	2.63	2.54	6.22	2.47	5.54	6.38	6.00	9.18	4.61	2.31	49.39
Minimum monthly	0.12	0.39	0.39	0.22	1.40	1.06	2.34	3.00	2.79	5.19	2.51	0.79	
Maximum monthly	1.57	1.30	6.21	10.71	14.89	7.72	12.89	9.05	12.85	14.15	6.56	3.77	

Kwajalein Atoll. Length of record: 8 years, 1944-1953

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Mean monthly	3.97	2.20	7.39	3.87	8.44	7.39	7.67	9.14	10.78	11.80	11.25	11.76	95.66
Minimum monthly	1.16	0.61	0.59	0.43	4.25	2.26	2.54	4.45	5.04	3.02	4.40	5.10	
Maximum monthly	15.66	5.13	24.33	9.40	15.88	13.02	13.20	16.95	17.38	20.10	16.76	30.33	

Ujelang Atoll. Length of record: 16 years, 1894-1913.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Mean monthly	2.1	1.8	2.6	5.2	6.6	7.1	8.4	8.5	10.3	10.4	9.6	4.8	77.4
Minimum monthly	0.7	0.3	0.4	0.6	0.8	0.8	2.9	3.4	6.1	5.6	3.0	1.9	
Maximum monthly	7.3	6.6	10.6	14.2	14.3	23.2	18.5	14.1	16.3	14.3	24.3	8.5	

water is stored in the cisterns and in oil drums. Where corrugated iron is not available, rain water is obtained by collecting the water that falls on coconut palms, or occasionally, Pandanus trees. The water caught on trees is stored in drums or any other available receptacle, such as paint cans or wash basins.

No determined effort is made by the Marshallese people to insure a year-round supply of rain water. Extensive roof areas are unguttered and some of the cisterns are fed by catchment areas that are not large enough to supply the maximum amount of water that could be handled by the cistern. If maximum use were made of existing facilities there would be much less likelihood of the exhaustion of rain-water supplies that now occurs frequently during the dry season.

No samples of rain water were caught on a surface previously tested to make sure it was free of salt. Samples obtained directly from cisterns ranged in chloride content from 20 parts per million on Lae to 60 parts per million on Wotho. The total hardness of these two samples was 80 and 70 parts per million, respectively. A sample obtained on Lae from an oil drum fed from catchment on a palm tree had a chloride content of 60 parts per million and a total hardness of 40 parts per million.

Ground Water

Physical nature.--The only source of fresh water on any island in the northern Marshalls is the rain that falls directly on that island. Part of the rainfall evaporates or is transpired by plants, and the remainder, because of the high permeability of the island sediments, seeps directly into the ground. There is no significant surface runoff. The fresh water, which is about 40/41 as heavy as salt water, floats on the surface of the salt water roughly in the shape of a dome, the edges of which coincide with the edges of the island. The fresh water displaces a volume of salt water equal to its own weight and depresses the fresh-salt-water interface below sea level under the island. Under ideal conditions in a homogeneous island, because of the 40/41 weight relationship of fresh to salt water, the interface extends about 40 times as far below sea level as the dome stands above sea level. Actually, the shape of the fresh-water body varies, depending upon local geologic conditions, and the 40-to-1 depth ratio is modified by a transition zone of variable thickness in which there is a mixture of fresh and salt water. This double-convex fresh-water body floating on sea water is known as the Ghyben-Herzberg lens. It is the only source of potable ground water in the northern Marshall Islands.

The average height of fresh water above mean sea level in the northern Marshall islands is less than 1 foot. At well 7, on Lae Island, Lae Atoll, which is about 1,035 feet from the lagoon shore, the mean height of water above mean sea level was found to be 1.41 feet. This figure is based on the determination of mean sea level by tide gage. Unfortunately, the tide-gage determinations were such that the accuracy of the calculated heights of levels in the well is highly questionable. Theoretically, therefore, the depth of fresh water below sea level in the islands of the atolls generally is not more than about 40 feet at the deepest point, tapering to zero at the edges of the lenses. Because of the mixing effect in the zone of transition, however, only the upper part of the lens is fresh enough for human consumption.

Fresh water is miscible with salt water, and the Ghyben-Herzberg lens will not form or will be destroyed unless certain prerequisites of permeability, water-level fluctuation, and precipitation are fulfilled. The permeability of the soil and rocks constituting the island must be great enough to allow the fresh water to infiltrate rapidly enough to maintain a positive hydrostatic pressure against the salt water, but must not be so great as to allow free mixing of the fresh and salt water. The islands in the northern Marshalls consist mostly of sand overlying rubble deposits, both of which have a degree of permeability that is conducive to the formation of a Ghyben-Herzberg lens. The windward side of many of the islands, however, is composed of coarse-grained materials ranging in size up to boulders, and because of the high permeability of these materials the lens may not be developed as well on the windward side as it is on the leeward side or in the central part of an island. At Taka Island, Taka Atoll, water from well 6, which is on the windward side of the island, had a chloride content of 6,480 parts per million, whereas water from wells 1 and 7, on the leeward side, had chloride contents of 840 and 2,480 parts per million, respectively. This condition existed in spite of the fact that well 6, at 400 feet, is farther from the windward shore than wells laand 7, at 300 and 55 feet respectively, are from the lagoon shore.

The second prerequisite for a functioning Ghyben-Herzberg lens is that tidal and seasonal fluctuations in the ground-water level be small, thereby reducing the mixing of fresh and salt water. The magnitude of the tidal fluctuations in the ground-water body at a given point in an island is inversely proportional to the distance to the shoreline and directly proportional to the permeability of the soil and rocks constituting the island. A comparison of tidal fluctuations in the ocean and in the ground-water body in four islands indicates that the ocean tides are damped by approximately nine-tenths as they move through the land (see table 2). Presumably in smaller islands there would be considerably less damping of the ocean tides. Inasmuch as each atoll was visited only once it was not possible to obtain any data concerning the magnitude of seasonal or annual fluctuations of the levels of the fresh-water lens.

The third prerequisite for the existence of a Ghyben-Herzberg lens is that the precipitation be sufficient to provide adequate infiltration of water to the ground-water body after losses due to evaporation and transpiration are deducted. It is estimated that less than half and perhaps only about a quarter of the rainfall is available after evapo-transpiration losses are deducted. The infiltration areas are small, owing to the size of the islands, and, in addition as shown in figure 2, the precipitation in the northernmost Marshall Islands is light. The total recharge to the ground-water lens, therefore, is so small in the northernmost islands that a permanent Ghyben-Herzberg lens probably does not exist on any island north of the latitude of Eniwetok Atoll. South of Eniwetok infiltration from rainfall is adequate to maintain a permanent lens if the island is at least 0.1 square mile in area. This area is great enough to provide sufficient catchment area, and adequate width for the damping of tidal fluctuations. During the rainy season smaller islands south of Eniwetok and larger islands north of Eniwetok may receive enough precipitation to build up small fresh-water lenses, but these lenses deteriorate or are destroyed during the dry season because of the lack of sufficient water from precipitation to maintain them against natural discharge and mixing with the ocean water.

Table 2.--Comparison of tidal fluctuations in the ocean and in the ground-water lens of four islands in the northern Marshall Islands.

Island	Well number	Distance to lagoon shore (feet)	Maximum tidal range in well (feet)	Mean tidal range in well (feet)	Maximum tidal range in ocean (feet)	Mean tidal range in ocean (feet)	Ratio of mean tidal range in well to mean tidal range in ocean	Period of observation (days)	Chloride content of well water (ppm)
Ailuk	1	115	0.62	0.32	5.8	4.0	0.08	5	272
Lae	7	1,035	.22	.16	3.5	2.1	.08	3	15
Ujelang	2	140	.23	.20	3.0	1.7	.12	3	100
Wotho	4	330	.26	.22	5.1	4.8	.05	1.5	130

Quality of water.--The extent of development of the Ghyben-Herzberg lens controls the quality of the ground water found in the islands of the northern Marshalls. Where there is a combination of such factors as low rainfall and small island area (conditions inimical to the development of a Ghyben-Herzberg lens) as is found for example on Bogallua Island, Eniwetok Atoll, the ground water is very similar to sea water in composition. On a larger island such as Lae Island, Lae Atoll, however, where the precipitation is considerably greater, the ground water in the central part of the island is comparable, in certain dissolved constituents, to water obtained by rain catchment. Between these extremes may be found ground water having varying chemical characteristics, depending upon the development of the Ghyben-Herzberg lens and the location with respect to the shoreline. (See table 3.)

All the 53 ground-water samples tested in the northern Marshalls had a total hardness of more than 200 parts per million[1/] and 50 exceeded 300 parts per million. The relation of total hardness to distance from the shoreline was not the same in every island. Two examples are shown in figures 3 and 4. At Ailuk Island, Ailuk Atoll, the total hardness varied inversely with distance from the lagoon shore, whereas at Lae Island, Lae Atoll, the total hardness of the samples tested remained approximately uniform and showed no relation to distance from the shoreline.[2/] The increase in total hardness at Ailuk toward the lagoon shore is apparently due to contamination by sea water mixing with the ground water. At Ailuk the calcium hardness of the ground water remained relatively constant, regardless of distance to the shoreline, whereas at Lae the calcium hardness seemed to decrease toward the shore (figs. 3 and 4). The increase in total hardness at Ailuk, where the calcium hardness remained constant, and the decrease in calcium hardness at Lae, where the total hardness remained constant, must be accounted for by an increase in magnesium hardness.

The chloride content of the ground water varies widely, depending upon the amount of contamination by sea water. The chloride content of sea water is approximately 18,000 to 20,000 parts per million, whereas that of rain water theoretically is zero. The rain water, however, dissolves salt crystals floating in the air and deposited on the vegetation and soil. Therefore, a "base" chloride content is always present regardless of whether the ground water has been contaminated by sea water. The lowest chloride determination obtained, 15 parts per million, was at well 7 in Lae Island (see table 3), and this may be considered as the base chloride content in the northern Marshalls until and unless a lower determination is obtained. The highest value obtained was for a well on Bogallua Island, Eniwetok Atoll, where the chloride content of a well sampled was 19,300 parts per million (see table 3). Chloride of about this magnitude, of course, is present in the ground water of most of the small islands in the northern Marshalls on which fresh-water lenses have not formed. In places the ground water on the main islands in Likiep, Lae, Ailuk,

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1/ Water having a hardness of less than 50 or 60 parts per million is generally rated as soft. Where the hardness is 200 or 300 parts per million it is common practice in the United States to soften water for household use.

2/ Ailuk and Lae are used as type examples because the most satisfactory well distribution was obtained on these islands.

Wotho, Eniwetok, and Ujae atolls was found to contain less than 250 parts per million of chloride, and on Utirik, Ujelang, and Kwajalein Atolls to contain less than 500 parts per million of chloride. Such waters are definitely potable and contain considerably less dissolved mineral matter than is present in public water supplies in parts of Guam and in certain other islands in the Pacific.

On some of the larger islands the chloride content of the ground water was found to be controlled by the distance of the point of sampling from the shoreline. On both Ailuk and Lae Islands there was an inverse relationship between chloride content and distance to Lagoon shore (fig. 5). On other islands, notably Wotho Island, Wotho Atoll, and Lado Island, Likiep Atoll, however, no such relationship was observed.

As would be expected in islands composed almost exclusively of limestone or limestone derivatives, the ground water is slightly alkaline (see fig. 6). The average pH of 50 samples tested was 7.4. Of the total, 45 had a pH between 7.0 and 8.0 and 39, between 7.2 and 7.6. Two of the samples had a pH of 6.7, which is slightly on the acid side. Both samples were obtained from pits on Lae Island dug in taro plots where the soil was a mucky peat containing much decaying vegetal matter. Two of the samples had a pH of 8.3. This, however, was due to the influence of sea water. The two samples were obtained from wells on Sibylla Island, Taongi Atoll, where the ground water had salinities corresponding to 65 and 85 percent of that of ocean water, which may be expected to have a pH ranging from 8.1 to 8.3. One sample, with a pH of 8.2, was from a well on Engebi Island, Eniwetok Atoll. The high pH value probably was caused by the concrete lining in the well. This effect of concrete, which evidently still is curing, was noted also in several samples of rain water collected from concrete cisterns. Five such samples showed pH values ranging from 8.0 to 8.5, whereas one sample of rain water that had been stored in a discarded oil drum had a pH of 7.4.

The temperature of the ground water in the northern Marshall Islands averaged 81° Fahrenheit. This is 1 degree less than the mean annual air temperature (based on records for Ujelang Atoll). No relationship between temperature of the ground water and latitude of the atoll was observed.

Use.--Ground water is used by the Marshallese people for all domestic purposes. Although rain water is preferred, ground water is used for washing and cooking during the dry season and for drinking purposes when the rain cisterns are completely empty.

All the ground water is obtained from dug wells. Most of the wells are less than 10 feet deep and penetrate about 1 foot below the water table. Many of the wells are cased with limestone blocks or discarded oil drums, but some of the very shallow ones are not cased at all. None of the wells was reported to antedate the German period of control and it is unlikely that the Marshallese people were aware of the presence of fresh water under their islands before the German period. Even today on Lae Island, where there is an excellent Ghyben-Herzberg lens, some of the Marshallese were skeptical of the widespread existence of fresh water beneath the island. They showed considerable surprise when a well dug through the boulder rampart near the ocean side of the island yielded fresh water.

Table 3.--Chemical analyses of water from selected wells in the northern Marshall Islands
(Analyses by U. S. Geological Survey. Dissolved constituents in parts per million)

Island Well no. Atoll	Ailuk 1 Ailuk	Engebi 1 Eniwetok	Engebi 2 Eniwetok	Engebi 3 Eniwetok	Engebi 4 Eniwetok	Runit 1 Eniwetok	Biijiki 1 Eniwetok	Bogallua 1 Eniwetok	Lae 1 Lae	Lae 7 Lae	Wotho 4 Wotho	Wotho 7 Wotho	Wotho 8 Wotho
Distance from shore (ft.)	115	925	410	710	250	175	65	40	345	1,035	330	210	490
Area of island (sq. mi.)	.19	.38	.38	.38	.38	.13	.08	.03	.21	.21	.09	.09	.09
Specific conductance (micromhos at 25°C)	1,390	1,470	1,630	1,040	8,070	14,800.	14,200	42,500	354	589	786	824	872
Dissolved solids	767	a800	a890	a570	a5,200	a10,200.	a9,800	a31,900	201	406	421	546	473
Hardness (total, as $CaCO_3$)	464	432	324	388	1,000	1,920	1,800	6,400	148	380	370	380	310
Silica	---	14	9.4	8.5	9.9	9.0	8.5	4.1	---	---	---	---	---
Iron	.02	.07	.27	.11	---	---	---	---	.02	.02	.02	.02	.03
Calcium	30	---	---	---	---	---	---	---	41	145	54	40	50
Magnesium	54	---	---	---	---	---	---	---	11	2.7	28	80	24
Sodium	---	31	46	77	1,500	2,850	2,700	10,600	---	---	---	---	---
Potassium	---	8.0	6.0	5.4	48	70	70	200	---	---	---	---	---
Sulfate	81	62	83	40	17	43	36	132	12	9.1	17	54	30
Chloride	272	222	326	88	2,680	5,200	4,860	19,300	44	15	130	156	129
Nitrate	---	50	.3	46	12	10	10	2.0	---	---	---	---	---
Phosphate	---	.2	.0	.0	.0	.1	.1	.2	---	---	---	---	---
pH	8.0	7.4	7.7	7.3	8.2	7.6	---	7.8	7.4	6.7	7.2	7.2	---
Temperature (°F)	78	79	77	79	79	75	77	82	79	80	81	81	82

a Calculated from specific conductance.

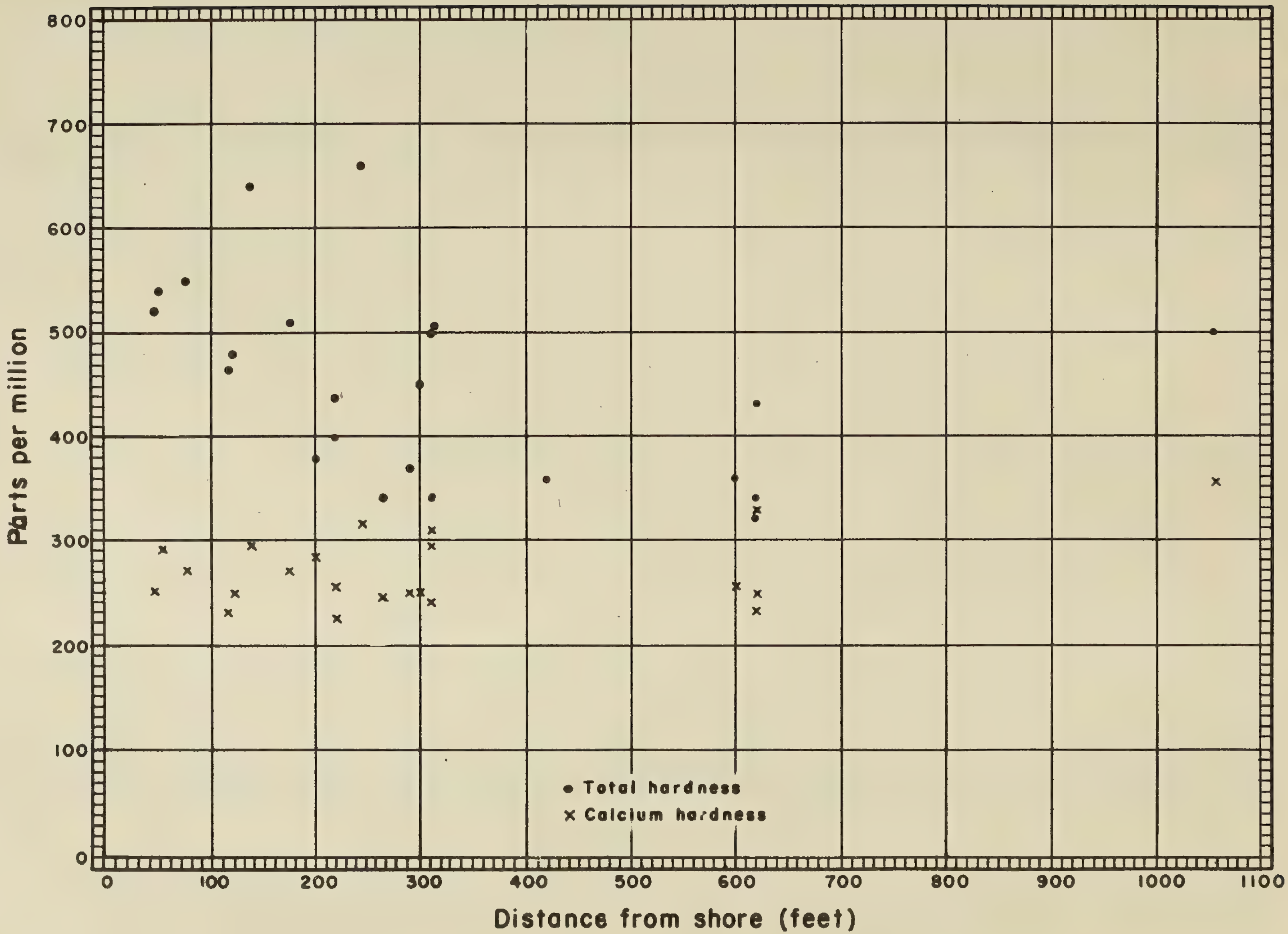

Figure 3.--Relation of total hardness and calcium hardness to distance from shoreline in the ground water of Ailuk Island, Ailuk Atoll, Marshall Islands.

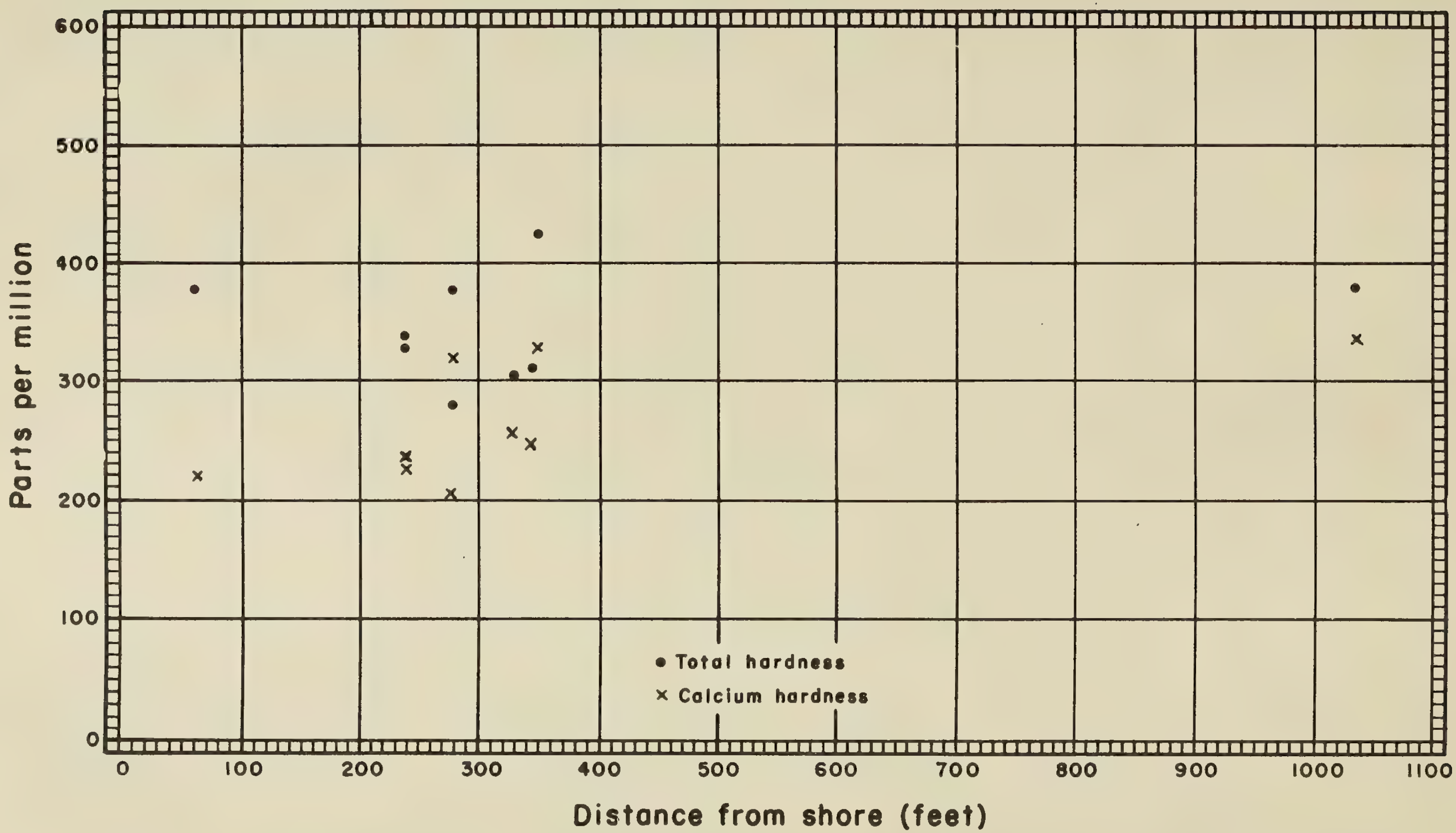

Figure 4.--Relation of total hardness and calcium hardness to distance from shoreline in the ground water of Lae Island, Lae Atoll, Marshall Islands.

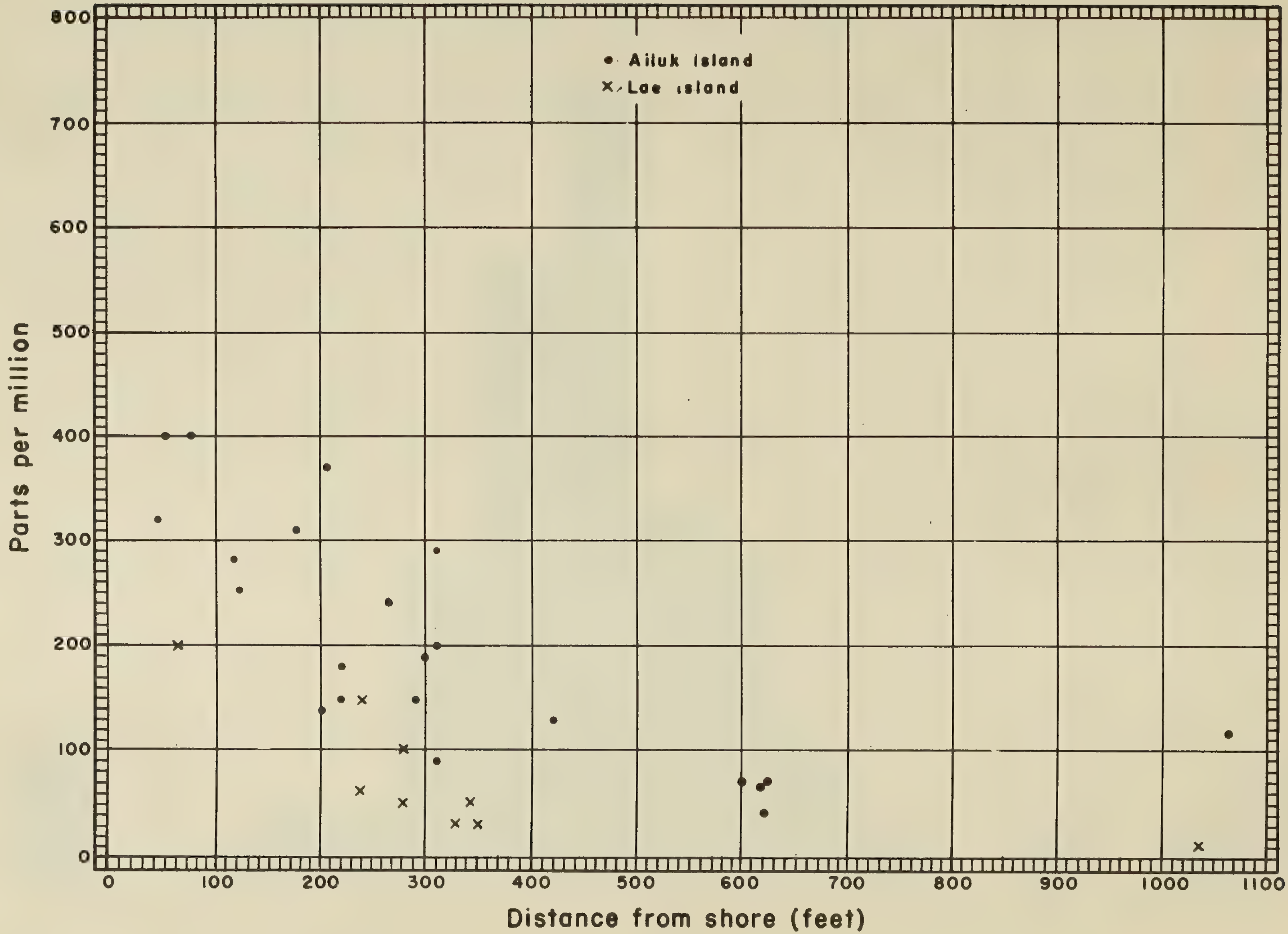

Figure 5.--Relation of chloride content to distance from shoreline in the ground water of Ailuk Island, Ailuk Atoll, and Lae Island, Lae Atoll, Marshal Islands.

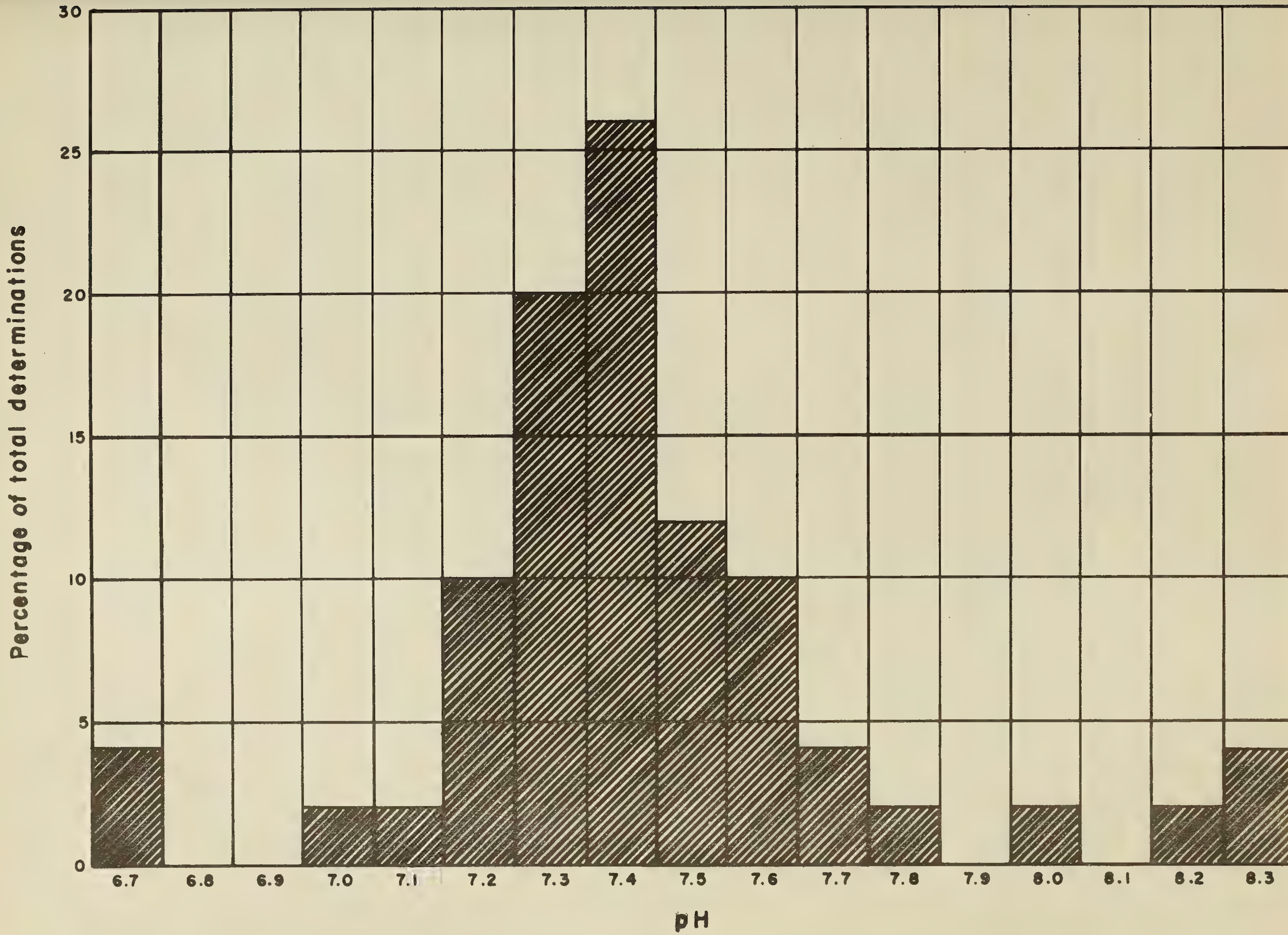

Figure 6.-- Histogram of 50 pH determinations of ground water in the Marshall Islands.

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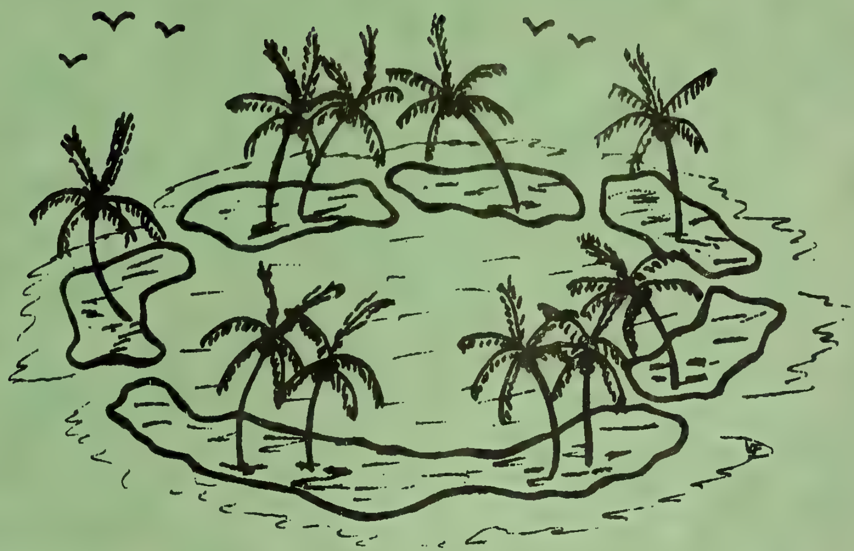
32. Raroian Culture



Issued by

THE PACIFIC SCIENCE BOARD

National Academy of Sciences—National Research Council

Washington, D. C., U.S.A.

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Washington, D. C.

November 30, 1954

ACKNOWLEDGMENT

It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs, CIMA, SIM, and ICCP, during the past six years. The Coral Atoll Program is a part of SIM.

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ATOLL RESEARCH BULLETIN

No. 31

Expedition to Raroia, Tuamotus

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Washington, D. C.

November 30, 1954

Part 1

EXPEDITION TO RAROIA, TUAMOTUS

by Norman D. Newell

Illustrations

EXPEDITION TO RAROIA, TUAMOTUS 1/

by Norman D. Newell

INTRODUCTION

Preface

An intensive ecological reconnaissance of Raroia, 2/ a Polynesian atoll about 450 miles northeast of Tahiti, was successfully completed during July and August, 1952, by a seven man research team representing the biological and geological sciences. This study, the third project in a program of atoll studies organized by the Pacific Science Board of the National Research Council and supported principally by contract N7-onr-291(04), NR 388-001 with the Office of Naval Research, enjoyed the active aid of the French colonial government at Tahiti, without which the study of Raroia could not have been undertaken. Funds equal to about 20 per cent of the total budget were supplied to some of the team members by The American Museum of Natural History, under a grant from the Humble Oil and Refining Company, and by the U. S. National Museum, The University of Hawaii, and Mr. George Vanderbilt.

Although splendid results were obtained, the team was handicapped by failure to receive approximately one-half of the expedition equipment, strike-bound on the eve of departure in a California port. Part of this highly specialized equipment, assembled at considerable cost over many months, was generally irreplaceable and the success of the expedition was, therefore, jeopardized. Essential items withheld from the team in this way included a boat, several rafts, outboard motors, a compound microscope, books for field determinations of corals and plants, an underwater camera, fishing gear, warfarin for studies in rat extermination, fish poison and gasoline. Without replacement of some of the most crucial of these items a comprehensive study of Raroia could not have been undertaken.

The problem of supply was difficult for the expedition because freight sailings from the United States to Tahiti are infrequent and there are none from Hawaii, where the team members were convening early in June. The expedition was reprieved by the circumstance that the Tahiti government had just purchased a small vessel which was being prepared in Honolulu for an early voyage to Papeete. Through the courtesy of H. René Petitbon, Governor of French Oceania, certain replacement items were carried on this vessel to Tahiti. These included fishing gear and poison, warfarin, special fish drums, cans and canning equipment for sea weeds, and one outboard motor. The equipment and supplies were delivered to the team on Raroia in time for use of most items but too late for use of the warfarin in the projected studies on

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1/ Pronounded Rah-ro-ee'-a

2/ Members of expedition, in addition to author, were John V. Byrne, Bengt Danielsson, Maxwell S. Doty, Robert R. Harry, J. P. E. Morrison, and W Jan Newhouse.

rats. The rat poison was returned to Papeete and turned over to the Institut de Recherches Médicales de l'Océanie Francaise for studies in Tahiti.

The selection of Raroia among the numerous atolls of French Oceania was most fortunate. The selection was made because the team anthropologist, Bengt Danielsson, had recently spent 18 months on the atoll studying acculturation of the people. He was thoroughly familiar with the language, the inhabitants, and working conditions. More important, he was assured of the complete support of the people. He was enthusiastically welcomed as an adopted son of a Raroian family and a member of the community. Having come to them, first as a member of the intrepid Kon Tiki crew, later as scholar and student of their ways, the people had acquired respect for Danielsson that amounted almost to veneration.

Because of these special circumstances the people made available to the expedition team their considerable resources including boats, outboard motors, clean cistern water, several houses, a shower bath house, a toilet, refrigerators, and all-wave radio receivers. The transportation facilities were neither adequate nor reliable, but they permitted a successful comprehensive reconnaissance of the atoll.

Cooperation of the French Administration in Tahiti

Besides supplying transportation for part of our equipment from Honolulu to Tahiti, Governor Petitbon provided round trip transportation from Papeete to Raroia on the government schooner Tamara. M. Frederick Ahnne, Administrator of the Tuamotu Archipelago, accompanied the team to Raroia to explain the government's interest in the project to the people of the atoll. The Governor arranged also for the charter of the Air Tahiti Gruman-Condor seaplane for the purpose of an aerial photographic survey of Raroia by the expedition members. The Papeete government contributed a substantial part of the charter cost so that a medical officer could visit Raroia, Hikueru and Anaa for routine examinations of the population. He also persuaded Colonel Chavat, chief of a French mapping mission, to accompany the flight to Raroia in order to assist in obtaining suitable photographs of the atoll.

The staff of the Institut de Recherches Médicales de l'Océanie Francaise, Dr. John Kessel, Dr. Georges Torres, and Mr. and Mrs. Glen Parrish, were helpful and courteous to members of the expedition. Helpful aid and counsel were freely given by many of the citizens of Papeete.

Valerie Zirkle Newell and G. Robert Adlington of The American Museum of Natural History devoted many weeks in the selection, purchase, and packaging of expedition supplies in New York, and Mrs. Newell, who preceded the research team to Tahiti, gave valuable aid there in completion of arrangements with the Government. Without Mrs. Newell's intervention it is doubtful that the difficult but urgent radio communication between Papeete and Raroia would have been finally established. Untiring efforts of the staff of the Pacific Science Board, Mr. Harold J. Coolidge, Mrs. Lenore Smith, and especially Miss Ernestine Akers, on behalf of the expedition were in large measure responsible for the successful conclusion of the field work.

Through the courtesy of Dr. Preston E. Cloud, Jr., a pH meter and a plane table, alidade, and surveying rod of the U. S. Geological Survey were made available on loan for our studies. Dr. John W. Wells identified the corals and Mr. J. Sperrazza, the Foraminifera.

Fortunately for the needs of the expedition, the people of Raroia are moderately prosperous. They live in a single village, Garumaoa[1/] (Ngarumaova), situated on the lagoon near the single ship pass. The numerous facilities of the village of 127 persons were more or less continuously available to the research group. Two radio receivers monitored the Papeete programs almost continuously, so that official messages in the Tahitian language sent to us from Tahiti were promptly received and delivered. This was a valuable service during three difficult weeks before our contact with Papeete, via Hikueru, was established by means of our small hand-generated two-way radio.

The climate of Raroia is ideal and altogether the working conditions were very comfortable.

Field Operations

All direct negotiations with the people were turned over to Danielsson, who was aided by Miss Aurora Natua, a Tahitian scholar. Besides his own scientific investigations of the people, Danielsson was given charge of the medical supplies, the kitchen help, and the paying of wages. General camp policies and project plans were developed by the combined team.

Scientific activities were distributed as follows: Physical ecology of the atoll (geology) and coral distribution, Norman D. Newell, assisted by John V. Byrne; biological factors of ecology, and plant distribution, Maxwell S. Doty, assisted by Jan Newhouse; animal distribution, excepting corals and fishes, J. P. E. Morrison; fish distribution and ecology, Robert R. Harry; ethnology and human ecology, Bengt Danielsson.

The Map

The flight for aerial photographs was taken during the early morning of June 20, 1952, which luckily happened to be the only clear day of a long series of overcast days. Two 35 mm Argus C-3 cameras with K2 filter were used interchangeably for vertical views. One camera at a time was mounted in a blister replacing a side window. Bengt Danielsson and Maxwell Doty operated these two cameras, making exposures at 15 second intervals. The flight was made at an altitude of 3000 meters in order to obtain negatives of convenient scale (1:60,000) and the scale was later confirmed on the ground by plane-table traverse. Surprisingly good results were obtained in two circuits of

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1/ We have adopted standard Polynesian rather than French forms of the native names. The Polynesian <u>g</u> is pronounced and often spelled <u>ng</u>.

the atoll with nearly complete coverage (95 per cent) of the rim. In addition, oblique photographs of the lagoon show hundreds of small patch reefs many of which eventually may be approximately plotted on the map after calculating corrections for oblique perspective. The vertical photographs were printed at 1:20,000 and this scale was employed for compilation of a base map. The negatives have been filed with the Colonial Government in Papeete. The final map is Part 3 of this Bulletin.

Collaboration in Field Work

Integration of heterogeneous field data from diverse disciplines is essential in an ecological reconnaissance such as this study of Raroia. Personal bias in the collecting and evaluation of data is not easily weighed, however, and it is usually difficult for the specialist to accommodate his attention to problems outside the fringe of his personal experience. Efforts were made at Raroia to overcome these natural difficulties. Time was taken by each participant from his special tasks to accompany the other members in the field in order to establish and maintain contacts in overlapping areas of investigation and to learn about more divergent matters. There were several round-table discussions and innumerable conversations involving various combinations of personnel. In general, the smaller groups were more satisfactory for discussions than the assembled team.

Within the framework of the project a number of special studies were undertaken involving two or more collaborating members of the team. Examples are: 1) several transect surveys, 2) land tenure and copra production, 3) classification of native names of, and utilization of plants and animals, 4) native terms for geologic features, and many others.

General Results

Raroia is similar to other Tuamotuan atolls, but conspicuously unlike recently studied atolls of Micronesia (Bikini, Arno, and Onotoa). Since Polynesian atolls generally have been inadequately known, Raroia may well serve as a standard of reference for Polynesia. Great quantities of field data and specimens were obtained. These include photogrammetric data probably superior to those available for other South Pacific atolls. The collections indicate an unexpectedly rich biota comparable to those of Samoa and Bikini. Our results suggest that previous conclusions have been based on inadequate collecting. For example, 286 species of fishes have been known from all of the Tuamotus, but our collections from Raroia include approximately 400 species. Fifteen species of corals have been known previously from the Tuamotus, but our collections from Raroia contain 53 species. This work shows that very many species range much farther to the east in the Pacific than had been believed, and knowledge of the biota of the central South Pacific has been greatly expanded. Data on the people and their history are especially complete. The first results on the expedition to Raroia have been issued as Bulletin 18, Ichthyological Field Data of Raroia Atoll, Atoll Research Bulletin, 190 pp., 1953. Other reports appear in the present and subsequent numbers of the Atoll Research Bulletin.

Some Fundamental Problems of Atolls

Coral atolls, justly celebrated in a voluminous scientific literature running into tens of thousands of pages, have long attracted the fascinated attention of voyagers in tropic seas. The center of interest until recently has lain chiefly in the genesis of reef forms and the nature and origin of the central lagoon which gives atolls their most characteristic expression.

Atolls support more or less balanced marine and usually also terrestrial communities surrounded by relatively sterile waters such as characterize the plankton-poor waters of the tropics and subtropics (Sargent & Austin, 1949). The origin and economy of these relatively simple communities provide many unsolved ecological problems of the greatest fundamental importance.

Consider the difficult and complex initial colonization of a newly formed shoal area or volcanic island surrounded by deep sea. In the great eruption of Krakatau in 1883 the local island life and shaol-water organisms were largely exterminated and the area for a time was rendered uninhabitable for most species (Dammerman, 1948). Within a few weeks reinoculation by airborne and seaborne spores, seeds, larvae, and adults of hardy pioneers was begun. Colonization of Krakatau, carefully studied by Dutch biologists, seems to have followed predictable chance frequence directly related to larval hardiness, length of migratory stage, and various other factors that make up the repertory of dispersal facilities. Some species arrived early, others later, the relative time of introduction being directly related to the frequency with which colonizers of each species could successfully bridge the barrier of deep water. Only the barest outline in this complex series of events is really known. Much must still be inferred.

The colonization of a volcanic mountain like Krakatau on first consideration may appear much more complex than the colonization of a low, relatively sterile atoll. However, avoiding for the moment the involved question of the various origins of atolls, it is generally agreed that many atolls undoubtedly did originate through the gradual sinking of reef-encircled volcanic mountains. The biota of such atolls, in a sense, are in some quarters considered relicts derived from the ancestral high islands, restricted and modified by relatively homogeneous and almost monotonous ecologic conditions. The ecologic simplicity of atolls makes them especially attractive to those who would try to understand the interrelationships and processes among the organisms of a primitive sea-land community. This simplicity, however, is only apparent and misleading. Most of the ecologic problems of atolls are indeed poorly understood.

The ecologic interrelationships between coralline and other kinds of algae on the one hand and the coral animals so characteristic of tropical reefs are not understood. The intimate and almost universal association in reefs of these specialized plants and animals strongly suggests that they may be interdependent. Reef-building (hermatypic) corals invariably contain in their tissues zooxanthellae, unicellular algal symbionts, which aid the corals by utilization of animal waste and by secretion of oxygen. However, many corals may feed exclusively on animal plankton (Yonge, 1940), which in turn must feed on phytoplankton. Sargent & Austin (1949) have determined that the quantity of plankton swept across the reefs of the northern Marshalls by wind-driven currents is grossly inadequate to support the reef animals. They conclude, therefore, that the reefs are self-supporting; that is, the reef algae produce at least as much organic matter as consumed by the reef animals, and that the rate of production of organic matter by an atoll as a whole is several times as high as that of the surrounding ocean. Rather than filtering plankton, the marine community of the atoll, according to these investigators, absorbs inorganic nutrients from the passing equatorial current (Sargent & Austin, 1949, pp. 245-249).

Surface tropical waters in midocean are classically considered deficient in nutrient salts. The situation over deep waters near coral reefs has not been sufficiently investigated, but it seems probable that turbulence extends to considerable depth where coral reefs are bathed in the equatorial currents and this turbulence would certainly bring nutrient rich deeper waters to the surface. Orr (1933, p. 62) found evidence of upwelling along the Great Barrier reef. This might well be most pronounced during rough weather when adequate observations have not been made.

Coral animals, as well as coralline algae, generally are most productive at the outer margins of seaward reefs. This growth vigor on the seaward side, according to Yonge (1940, p. 382) is most probably related to the greater transparency of the water there as compared to the lagoon which allows photosynthesis of zooxanthellae and coralline algae to extend to maximum depths. He considers this factor more important than greater supplies of oxygen and animal plankton at the outer reef edge. This matter requires further study.

It is a matter of considerable interest that a low bank of coral gravel thrown up above high tide level by a storm very quickly supports a characteristic varied assemblage of higher plants without the development of humus and a soil profile. Coconuts germinate and become healthy trees in apparently sterile gravel. It has been demonstrated that several kinds of algae fix nitrogen from the air. Some of these (Myxophyta) grow better on an alkaline substratum than elsewhere. Algae aided by bacteria fix nitrogen better than do the bacteria alone (Chapman, 1941, p. 304). It may be considered as probable that the fertility of newly exposed accumulations of coral gravel and sand is to a large extent a result of the activities of nitrogen-fixing algae and bacteria having a range of osmotic tolerance such as characterizes the flora of the littoral zone. Some of these very likely are normal inhabitants of the sea. Sea birds, which rest on rocks and gravel bars, precede the terrestrial vegetation and enrich the ground with fertilizer gathered over a wide radius of open sea. Investigations into the colonization and productivity of atolls, along these and other lines, promise to yield significant results. Hatheway (Atoll Research Bulletin 16) has emphasized the relationship between atoll vegetation and variations in the bird populations and phosphate concentrations in the soil.

Coral atolls are enormous accumulations of calcium carbonate. Interest in the conditions of origin of limestones has greatly stimulated the investigation by geologists of calcium carbonate in modern seas. In most areas of the sea floor at the present time and during the geologic past calcareous material has been predominantly in the form of skeletal structures of animals and plants, hence, the sedimentationist, the paleontologist and the marine biologist are all directly concerned with the problem of formation of such sediments.

Calcium carbonate is also precipitated directly from sea water to form inorganic muds and sands (Newell, et al., 1951). Although the problem has been under study for many years, final conclusions cannot be reached regarding the relative importance of inorganic precipitation because the solubility of calcium carbonate in sea water is not well understood.

Surveys by many investigators (Trask, 1937), show that the calcium carbonate content of modern marine sediments is greatest at low latitudes. This is related certainly to the higher production of calcareous animals and plants in warm waters, and to the fact that warm marine waters often are supersaturated with calcium carbonate. It is well known that animals with calcareous skeletons, such as corals, mollusks and foraminifera, can extract lime from unsaturated waters, but the exact manner in which this is done is not fully understood. In any case, the secretion of lime by these organisms is enormously greater in warm, shallow seas where the waters are supersaturated with respect to calcium carbonate. In the case of lime-secreting algae, extraction of carbon dioxide during photosynthesis causes concentration of carbonate ions and precipitation of lime. Heating of the water and concentration due to evaporation will also cause precipitation of calcium carbonate from sea water, particularly when the water is agitated.

The coral reefs of the South Pacific are among the chief areas of calcium carbonate deposition of the world. It is no doubt significant that these, like other important areas of lime accumulation in the Atlantic and Indian Oceans, are bathed by warm equatorial currents (Fig. 1) probably supersaturated with respect to calcium carbonate. It is highly probable that deposition of lime sediments in all of these areas would be greatly diminished or even negligible without a "conveyor belt" source of supply.

Regional Setting of the Tuamotu Archipelago

General introduction.-Lying near the center of the Pacific Ocean the Tuamotu Archipelago is exceptionally isolated from both eastern and western continents. The atolls of this group are outposts at the southeastern fringe of the great Indo-Pacific biological realm, separated from the Americas by the most effective water barrier on earth to migrations of shallow marine and terrestrial organisms, the broad and uninterrupted deep waters of the eastern Pacific (Fig. 2). The biota of the Tuamotu is an attenuated Indo-Pacific 1/ assemblage having little in common with that of the Americas (Ekman, 1953, p. 72). It was derived mainly from the west, partly by innumerable island jumps and perhaps via the equatorial counter current (Fig. 1) and other occasional drifts opposed to the prevalent westerly circulation at these low latitudes.

Most of the Polynesian islands are oceanic in the sense that they lie well inside the andesite line (Fig. 2) which is rather generally held by geologists to form the structural margin of the Pacific Ocean.

1/ Locally, as at Clipperton Islands, less than 700 miles from Mexico, Indo-Pacific elements have successfully crossed most of the eastern Pacific without really obtaining a foothold along the Americas (Hertlein and Emerson, 1953).

Many geologists now favor the view that the continents are gradually expanding by successive orogenies at the expense of the ocean basins. Implicit in this view, the island arcs of the western Pacific rather than representing old and collapsed areas are late increments welded to the Austral-Asiatic continent.

Next to the Maldives the Tuamotu Archipelago contains the greatest number of atolls, spread in a broad belt two hundred miles wide and more than a thousand miles long from northwest to southeast. The 78 islands of the Archipelago of which 76 are atolls are arranged in several linear series reminiscent of island arcs (Fig. 3). The distribution and proximity of these atolls to the volcanic Society Islands, which ideally illustrate the successive stages in Darwin's theory of subsidence, encourage the view that the Tuamotu atolls rest on chains of volcanic mountains which have sunk beneath the sea so slowly that the reef growth has been successfully maintained near the surface. This is not the same as Stearns (1946) suggestion that the reefs of low islands were formed in shallow water on the crests of submarine folds.1/

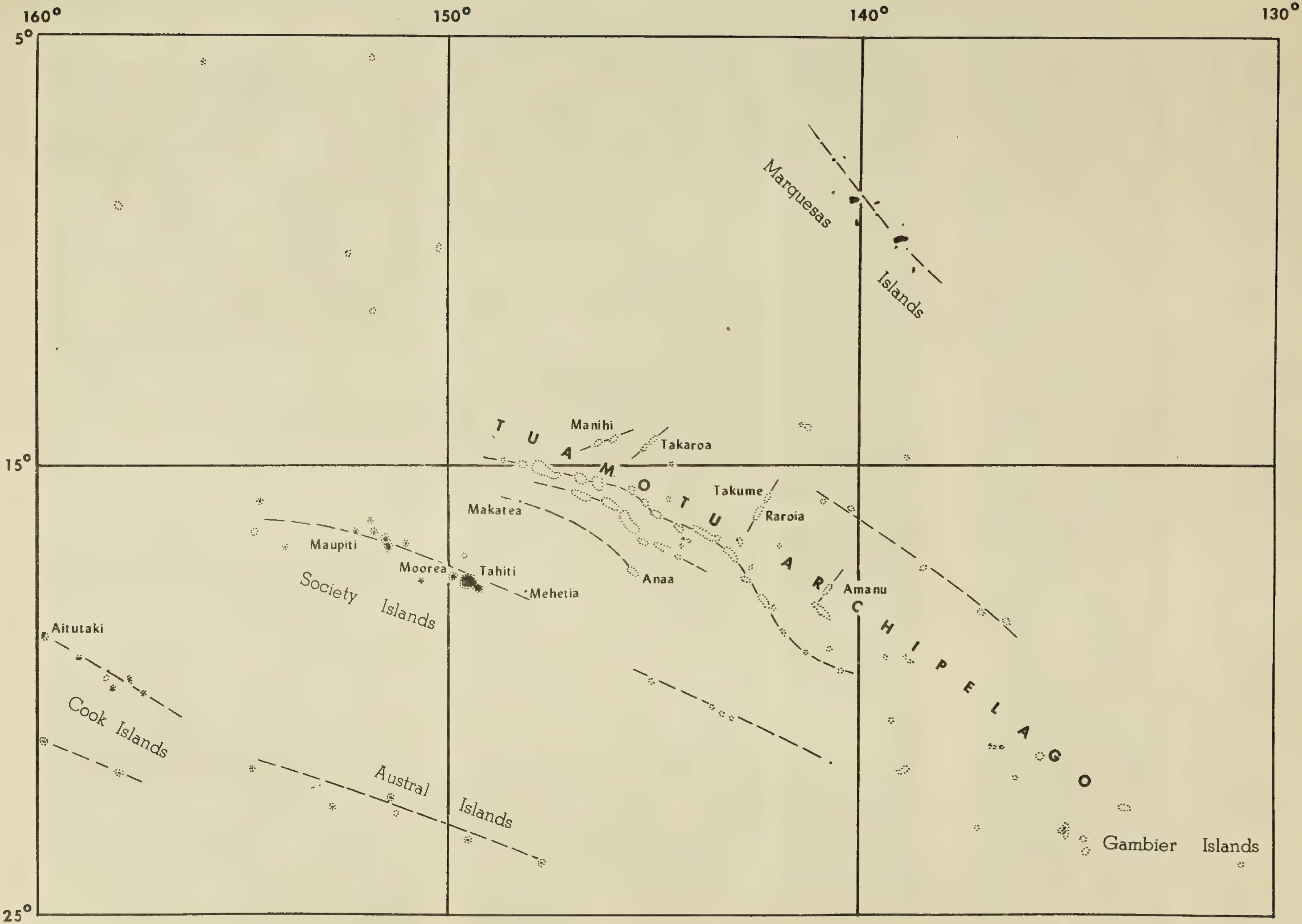
There are rather striking features that characterize most of the Tuamotu atolls and Raroia is in most respects typical of the group. The regional trend of islands in the south central Pacific is from southeast to northwest, but a few of the atolls along the northeast side of the archipelago, including Raroia, are elongate toward the northeast, at right angles to the regional trend. The prevailing currents in this area are also from the northeast. However, since there is no correspondence of form with current directions in most of the atolls, it seems safe to conclude that the northeast trend of Raroia and a few other atolls reflects structural conditions of the basement divergent from the regional trend.

The configuration of the sea floor around the Tuamotu group is very poorly known. A few soundings taken by the Albatross suggest that the northwestern atolls of the archipelago rise from a platform about 800 fathoms beneath the surface. Soundings around the central and eastern atolls indicate smaller plateaus or spurs uniting adjoining islands and show that the eastern atolls are separated by channels of great depths (Agassiz, 1903, p. xxviii).

1/ Kuenen (1947) points out that the postulated folds would all have to rise to about the same critical level of reef growth near the surface, an extremely unlikely coincidence. Following Daly's conclusion (1910) that all pre-Pleistocene reefs were killed and destroyed during low water levels of the Pleistocene Kuenen argues that solution, rather than mechanical destruction, may have reduced many limestone banks and islands to the temporary low water levels. I am inclined to believe, that only the smallest limestone islands were truncated during Pleistocene lows. For example, there are innumerable small limestone cays and islands in the Bahamas, B.W.I., which were terraced during Pleistocene low levels, but the general forms of the islands were not much affected. Terraces cut at this time are rarely more than a half mile wide (e.g. Newell, et al., 1951). Most likely the Pleistocene low levels resulted in some denudation of exposed surfaces, but there is no compelling evidence for extensive marine planation during the short duration of the low levels. Evidently the reef organisms were not eliminated but they were maintained near the level of the fluctuating sea. Of course, this argument does not affect the possibility that some atolls may lie over submerged guyots (see Hamilton, 1953).

1. Map of Pacific Ocean showing relationship of equatorial currents to the Tuamotus and other island groups.

2. Map of Pacific Ocean showing andesite line and Eastern Pacific barrier to animal and plant migrations.



3. Structure lines in part of the South Pacific.

The bottom deposits in the deep parts of the ocean (1700 to 2500 fathoms) separating the groups of Tuamotu atolls are predominantly red clay. In shallower waters pteropod and coral sandy ooze is the principal sediment (Op. cit., p. xvii). Soundings near the atolls show steep slopes characteristic of atolls (Op. cit., p. xxix).

Several observers have recognized elevated reef limestone in some of the atolls at the northwest end of the archipelago. From this evidence Agassiz has concluded that Makatea, which is somewhat dissected, was uplifted almost 230 feet (Agassiz, op. cit., p. 20), Matahiva, 10 to 12 feet (Op. cit., p. 55), Tikahau, several feet (Op. cit., p. 52), Rangiroa, 15 to 16 feet (Op. cit., p. 20), Kaukura, 17 feet (Op. cit., p. 17), and Niau, 20 feet (Op. cit., p. 20). In addition might be cited elevated coral reef limestone examined by us on Anaa, which rises at least 18 feet above low water, near the village, along the northern shore of the atoll.

Evidence of appreciable and uneven recent uplift throughout the northwestern part of the Tuamotus is well established. Agassiz's observations bearing on uplift farther to the southeast must be taken with reservations because he frequently mistook large reef blocks thrown up by storms and welded to the reef flat as erosion remnants of once higher platforms.1/ Dana had earlier correctly interpreted these as erratic reef blocks (Dana, 1890, pp. 179-180).

As pointed out long ago by both Dana (1890) and Agassiz (1903) the Tuamotu atolls are characterized by a narrow rim and by relatively few and narrow ship passes. Of the 76 atolls of the group 47 are without a ship pass, 21 have a single pass, and 10 are each provided with two ship passes (Carte de la Marine, No. 1716). The passes mark gaps in the atoll rim where organic accretions evidently have not kept pace with the general upward growth during subsidence. The majority of the passes occur approximately on the leeward side (Fig. 4). This suggests that the distribution of passes may in some way be controlled by the prevailing winds. Production and deposition of calcium carbonate sediments apparently is greatest on the windward side of Raroia atoll since the deepest part of the lagoon is downwind from the center. Early gaps along the windward rim doubtless were filled before those of the leeward rim. Possibly the flow of waters through the leeward passes, especially concentrated at ebb tide,

1/ In general, Agassiz's work on coral reefs is poorly documented and strongly colored by his crusade for the view expressed by Semper (1863) that subsidence is not involved in the origin of atolls. Many of Agassiz's assertions, such as the prevalence of outcrops of basaltic rocks on barrier reefs in the Society Islands, lack documentation and subsequent confirmation. His general explanation of the origin of the Tuamotus seems fantastic. "In the Tuamotus there is a great development of Tertiary coralliferous limestone, the last remnants of the former elevated land once covering a large area of the atolls as found also in the Gilberts" (Op. cit., p. xvii). "It is to the cutting down of the elevations of the old ledge to the general level, and the subsequent building up of the atolls by the material supplied from the reef flats and from the coral slopes that is due the great uniformity of all these atolls" (Op. cit., p. 13). This casual dating of elevated limestones of Tuamotu atolls was based entirely on supposed lithologic resemblances to certain Tertiary limestones of Fiji (Agassiz, op. cit., p. 18).

inhibits growth of corals and coralline algae, but the particular factors involved are not clearly understood.

Climate.-The Tuamotu Archipelago lies within the belt of southeast trade winds and enjoys a mild and equable climate. Danielsson (1951) reports dominantly easterly winds 1/ at Raroia with a maximum velocity in 1950 of 7 (Beaufort). There were 37 calm days in 1950. The mean diurnal high temperature in 1950 was 30.4° C and the mean low 23.3°C, giving an average of 26.8°C. The rainfall for that year was 1181 millimeters. Out of the entire year 215 days were clear (Danielsson, 1951). According to the inhabitants of Raroia, 1950 was not an exceptional year. However, Danielsson does not record westerly winds such as are supposed to occur during the rainy season (Sailing directions, Pacific Islands, vol. 2, Eastern groups, 1940, Publ. 166, U. S. Hydrographic Office).

Currents.-In accordance with the Coriolis effect the circulation of surface waters in the Tuamotus moved along by the southeast trades is usually toward the southwest at rates ranging from five to 25 miles a day. "In the rainy season, from October to March, when westerly winds, squalls, and rains are frequent, the currents vary most and occasionally set to the eastward at rates from one-half to two knots." (Saling directions, Pacific Islands, vol. 2, Eastern groups, 1940, Publ. 166, U. S. Hydrographic Office).

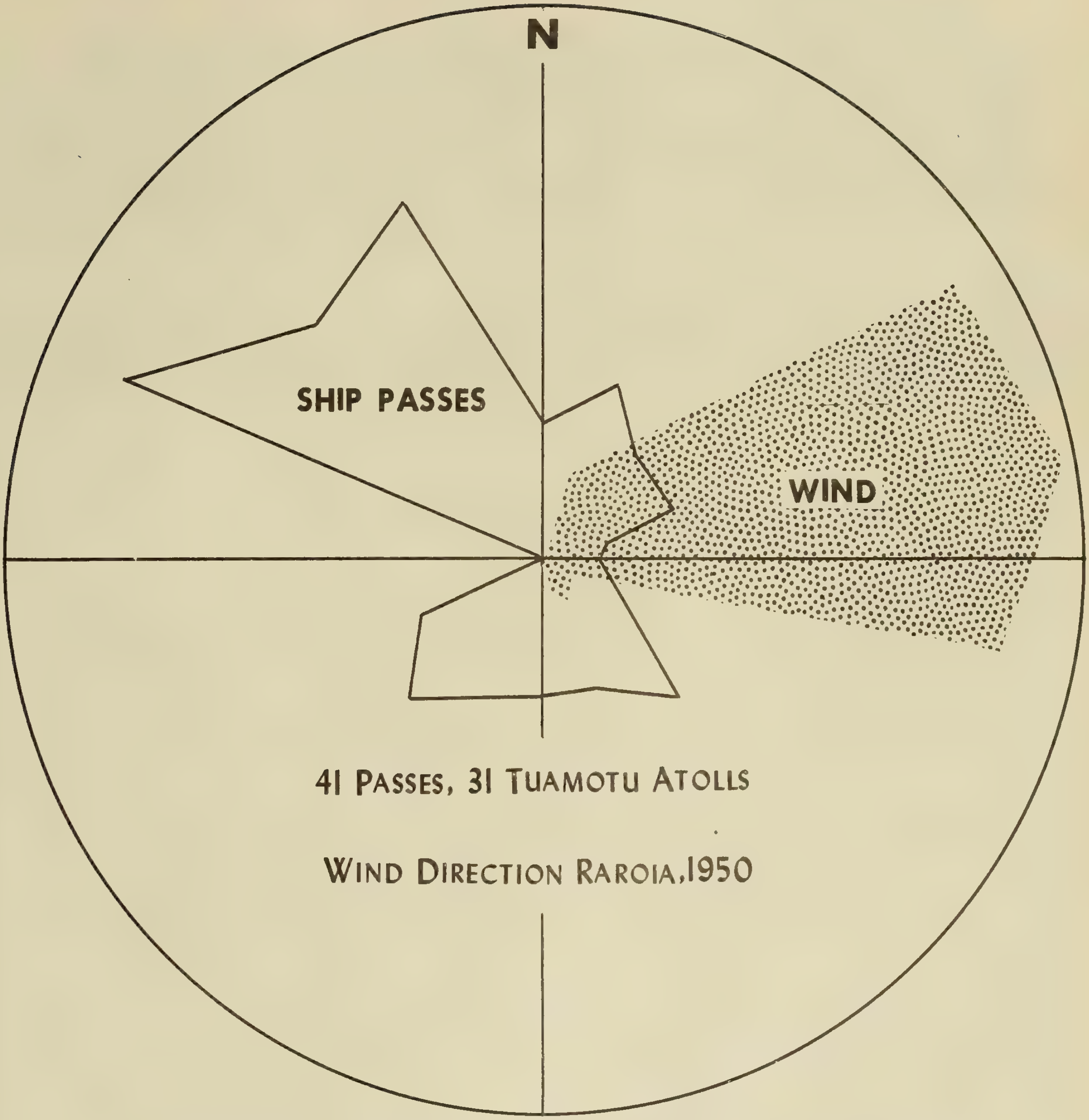
Dispersal of larvae of shallow-water animals toward the east may be largely accomplished at these times.

Southern swell.-Atolls of the Tuamotus are pounded on the south and southwest by a strong swell which produces continuous surf usually heavier than that of the windward side. The south margin of the rim in many of the atolls is relatively broad, low, and free from islets, characteristics which result apparently from the exceptionally vigorous and continuous sheet flow of water across this sector.

"The effect of the prevalent southwesterly gales in high southern latitudes in transmitting the heavy sea, which is felt many hundreds of miles from the latitudes of its origin, occasions a serious obstacle to landing on these low islands by rolling in on the shore in an opposite direction to the trade wind, making it often more dangerous to land on the lee than on the weather side of the islands." (Sailing directions, Pacific Islands, vol. 2, Eastern groups, 1940, Publ. 166, U. S. Hydrographic Office).

Hurricanes and tsunami.-According to native tradition violent storms have played an important part in modification of Tuamotuan atolls and this is abundantly confirmed by the physical characteristics of the islands. According to the Raroians winds of hurricane velocities that occasionally strike Raroia and neighboring Takume generally blow from the northwest, ordinarily the lee side of the atolls. These and many of the Tuamotu atolls have the highest and most extensive land, the coarsest coral rubble, and the largest displaced reef blocks on the lee side.

1/ Wind directions given by Danielsson (personal communication) were uncorrected for magnetic declination. The declination at Raroia for 1950, when his observations were made, was approximately 12° 02' east.



4. Relationship between ship passes and prevailing winds in the Tuamotus.

The actual frequency of tropical cyclones in these waters is unknown, but there are published records of seven severe hurricanes in the Tuamotus between 1878 and 1906. There are also less well substantiated accounts of a hurricane in 1823 and another in the 1850's. The latest hurricane, of minor consequence, touched Raroia in 1926. The wind of this storm is said to have blown from the southeast quarter at Raroia.

During the storm of 1903, still clearly recalled by many inhabitants at Raroia, sea waves were 40 feet high at the outer reef and water was higher than the house tops at the village. Opposing waves are said to have swept over the highest land from both sea and lagoon, meeting within the islands. Topographic forms of the islands, including conspicuous flow-lines in the coarse coral rubble, generally at right angles to the atoll rim strongly suggest that the land has been inundated many times, indeed built up in places, by translation waves that sweep across the atoll rim to the lagoon.

Native traditions refer to tsunami, but apparently these had but little geological significance in the Tuamotus. The latest occurrence was on April 1, 1946, when the water of the lagoon at Raroia rose some two feet above the level of spring highs flooding the village, Garumaoa, to a depth of about one foot.

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Part 2

PHYSICAL CHARACTERISTICS OF RAROIA

by Norman D. Newell

Illustrations

PHYSICAL CHARACTERISTICS OF RAROIA

by Norman D. Newell

General Introduction

According to a survey of Raroia and Takume, made in 1950 by the Service Hydrographique (L. V. Nay), Raroia lies between 15° 55' and 16° 14' south latitude and 142° 18' and 142° 32' west longitude. It is elliptical with the long dimension toward the northeast. In size it is intermediate among the atolls of the Tuamotus with dimensions of 14.4 km by 44 km. The most obvious features of Raroia are a relatively large proportion of land surface to water along the rim and a large number of shallow, narrow channels, many of which are storm spillways, incomplete at the seaward end. The land surface is low, rarely exceeding four meters above normal high water[1], and for the most part the surface is less than one meter high. The normal tidal fluctuation is small, about one-half meter, attaining perhaps one meter at spring tides; hence wind direction and velocity influence the water level far more than do the tidal fluctuations.

Raroia, like many other Tuamotuan atolls (Fig. 5) has a single ship pass on the leeward side of the atoll. The lagoon waters are clear, and relatively deep (55 m) in the center. Neighboring Takume on the other hand, and several other atolls of the Tuamotus lack passes. In every case, these lagoons are shallow, being largely filled with muddy sediments. Evidently sediments accumulate slowly in open lagoons.

Characteristics of Raroia

Location 15° 55' S to 16° 14' S Lat., and 142° 18' W to 142° 32' W Long.

Winter temperature of surface sea water	26° C
Prevailing winds	Easterly
Cyclones (hurricanes)	Westerly
Rainfall (1950)	110 cm
Tides	0.6 m
Area of atoll (including lagoon)	400 km^2
Area of lagoon	340 km^2
Area of atoll rim	60 km^2
Length of atoll	44 km
Breadth of atoll	14 km
Maximum depth of lagoon	55 m
Maximum height of land	6 m
Circumference at outer reef edge	90 km
Average breadth of atoll rim	0.6 km

1/ The outer gravel rampart at the elbow of Oneroa, the westernmost point of Raroia, reaches the extreme elevation of 19 to 20 feet above normal high water. A few other points on the atoll are 12 to 15 feet above normal high water.

Land area (35% of rim)	21 km^2
Vegetated area	6 km^2
Lagoon patch reefs (number)	ca 2000
Ship passes (number)	1
Visibility of 8" secchi disk	
Ocean	34 m
Lagoon	28 m

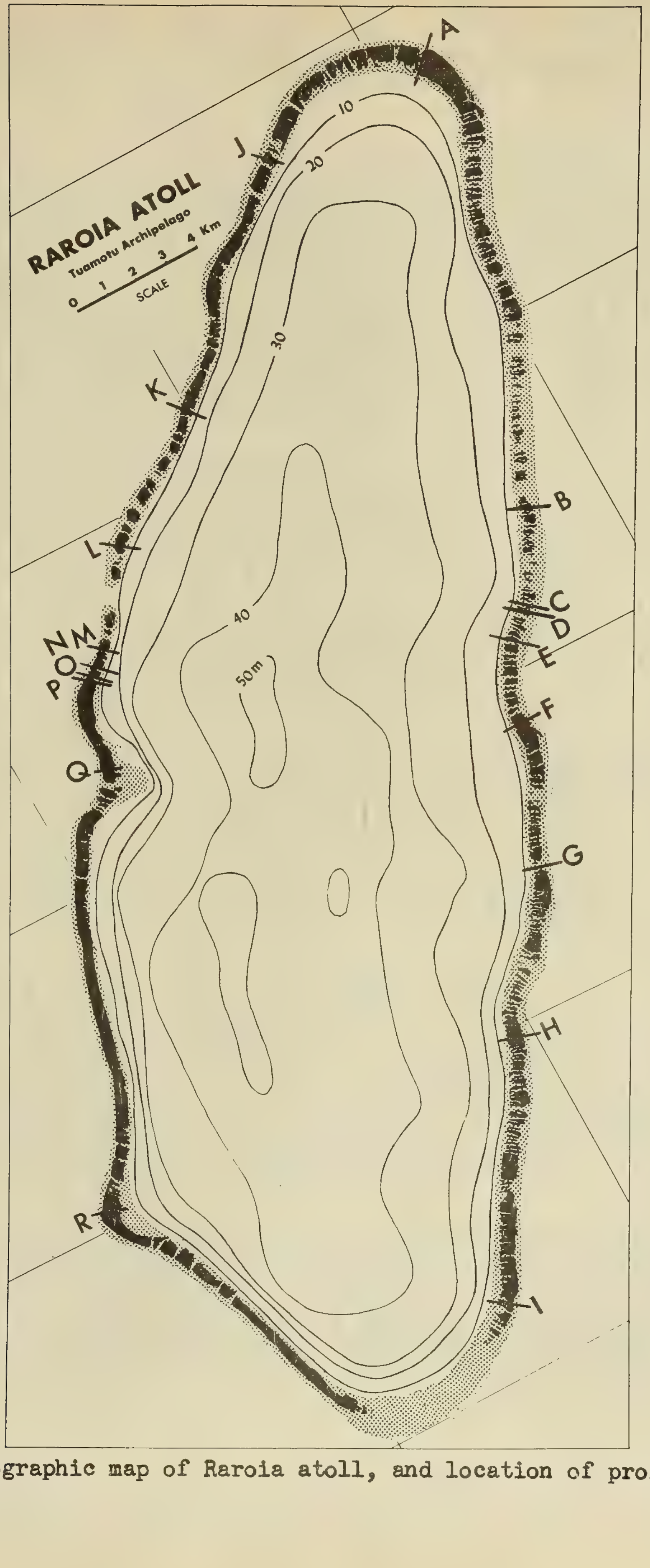
Distribution of underwater terraces, reef, and land forms recognizable on the photographs were mapped for the entire atoll and salient geologic features were recorded by means of aerial and ground photographs and by maps and cross-sections. A number of topographic profiles were constructed across the atoll rim, and in certain critical places levels were surveyed by means of alidade and plane table. Underwater observations and photographs were made with the aid of two Browne masks and a motor-compressor built at The American Museum of Natural History. A bathymetric map of the lagoon was prepared by Byrne from handline soundings. All of these observations reveal a number of facts of interest.

The Atoll Rim

Introduction.-The rim of Raroia atoll is narrowest, averaging 500 to 700 meters wide, along the northwest side where there are relatively few channels and the greatest extent of vegetated island upland. Much of the surface here rises from one and a half meters to three meters above normal high water level. On the other hand, the broadest sector of the rim, 800 to 1250 meters wide, is at the south end of the atoll (see general map, Section 3 of this Bulletin), where the surface is more or less continuously awash. This is the lowest part of the rim. In other sectors intermediate conditions between these extremes are found.

Although it cannot, of course, be supposed that the rates of reef growth are uniform all around the atoll, it is probable that wave truncation of the existing land areas and deposition of the resulting debris in the lagoon would result in a more nearly uniform rim width than is now the case. We may surmise with confidence that the relative narrowness and height of the northwestern rim are a result of full exposure to the most violent storms.

Channels and islets.-There is only one ship pass through the leeward rim and on the neighboring twin atoll, Takume, there is none. The Raroia pass is narrow (700 m) and shallow (five and one-half to eight meters) and choked by vigorous coral growth which may eventually block the pass. At the south end of the atoll facing the strong southern swell characteristic of the region, there is a broad inundated sector of the rim approximately five kilometers long and one and a half kilometers wide which is barely awash at low tide. Elsewhere, there are approximately 260 shallow channels across the rim which are drained or are awash during low water at the seaward ends and covered by two to two and a half meters of water near the lagoon ends. There are roughly 280 islets around the atoll, of which only 60, including most of the larger and higher land areas, are on the leeward (northwest) side of the atoll. Although the larger islets also lie on the leeward side of neighboring Takume, this is



5. Hydrographic map of Raroia atoll, and location of profiles.

unusual among atolls, even in the Tuamotus, because most frequently the land areas are concentrated to the windward where gravel and sand are most vigorously heaped up by waves. The storms of greatest violence regularly strike the west (lee) side of Raroia and Takume and there is much evidence of island building by hurricanes there.

In addition to the shallow channels or spillways between islets, there are some 160 deep, angular clefts or notches (incomplete channels) in the lagoon shore similar to the channels except that they do not extend across the island to the seaward side. These clearly are being lengthened headward as storm waters cross the islets toward the lagoon, and they represent various steps in formation of shallow channels. The method of formation of the channels is itself an interesting problem considered more fully on subsequent pages. It is concluded that the shallow channels are all of very recent origin and were formed chiefly by mechanical (hydraulic) erosion of the uplifted rim, but the ship pass probably has been inherited from a Pleistocene low water level.

Island conglomerate platform.-The smaller islets are formed of a flat platform of coarse limestone conglomerate (pakokota in Tuamotuan) from about one-half to a little less than one meter above normal high water on which, here and there, are small patches of sand and coral debris generally lagoonward of the islet center (Figs. 6, 7). A few of these patches of rubble are vegetated; the rock platform is bare. The larger islands are bordered by the rock platform, but wells dug in the interior (Garumaoa, Oneroa, Tetou) reveal that the central areas are underlain by uncemented sand and gravel to the water table, becoming loosely cemented below the water table.

Joints.-Irregular joints are visible here and there on the conglomerate pavement but they do not show lineation. Joints somewhat opened by solution are occasionally visible on bare areas of the outer reef flat near the shore. These are slightly sinuous and generally are approximately parallel with the reef front. None can be followed more than about 100 meters. Presumably they have been produced by adjustments or slump in the marginal talus of the atoll. There is not any visible displacement along these joints, but the effects of differential movement would probably be quickly effaced by erosion.

Ramparts and beaches.-One or more rampart ridges of gravel on the rock platform defend the seaward sides of nearly all the islands. These are coarsest and highest along exposed promontories. The highest surface on the atoll (approximately six meters) is the crest of a rampart on the leeward side of the atoll (at Oneroa, Fig. 7,R). In more sheltered places the ramparts tend to flatten, becoming sandy beaches. These are all storm features which lie inland upon the rock platform at some distance from the normal high water line. Eolian sediments are completely lacking on Raroia.

Island gravel.-A striking feature of the surface away from the lagoon shore on the lee side of the atoll is a veneer of coarse, algal-blackened coral rubble with very little sand. Reef blocks up to a meter or so in diameter, including corals which live only in fairly deep water outside the atoll (*Acropora conigera*), are scattered over the land on the leeward side of the atoll as far as the lagoon shore. These are storm gravels deposited by sheet flood during hurricanes. The gravel is coarsest on the northwest rim of the atoll, appreciably finer on the southeast side, which generally is the sheltered side during hurricanes. This surface gravel does not contain fine sediment, but the interstices are sandfilled a few centimeters below the surface. Presumably, the water which passes over the islands during storms has capacity to carry sand and humus lagoonward, leaving well-washed coarser rubble on the higher ground near the outer shore and somewhat finer sediments near the lagoon. Some sand is trapped between pebbles, however, and doubtless it is washed downward by the rain. Pits dug on the larger islands show that the upper one to two meters of earth is composed of coarse rubble and entrapped sand which could have been deposited only by violent storms.

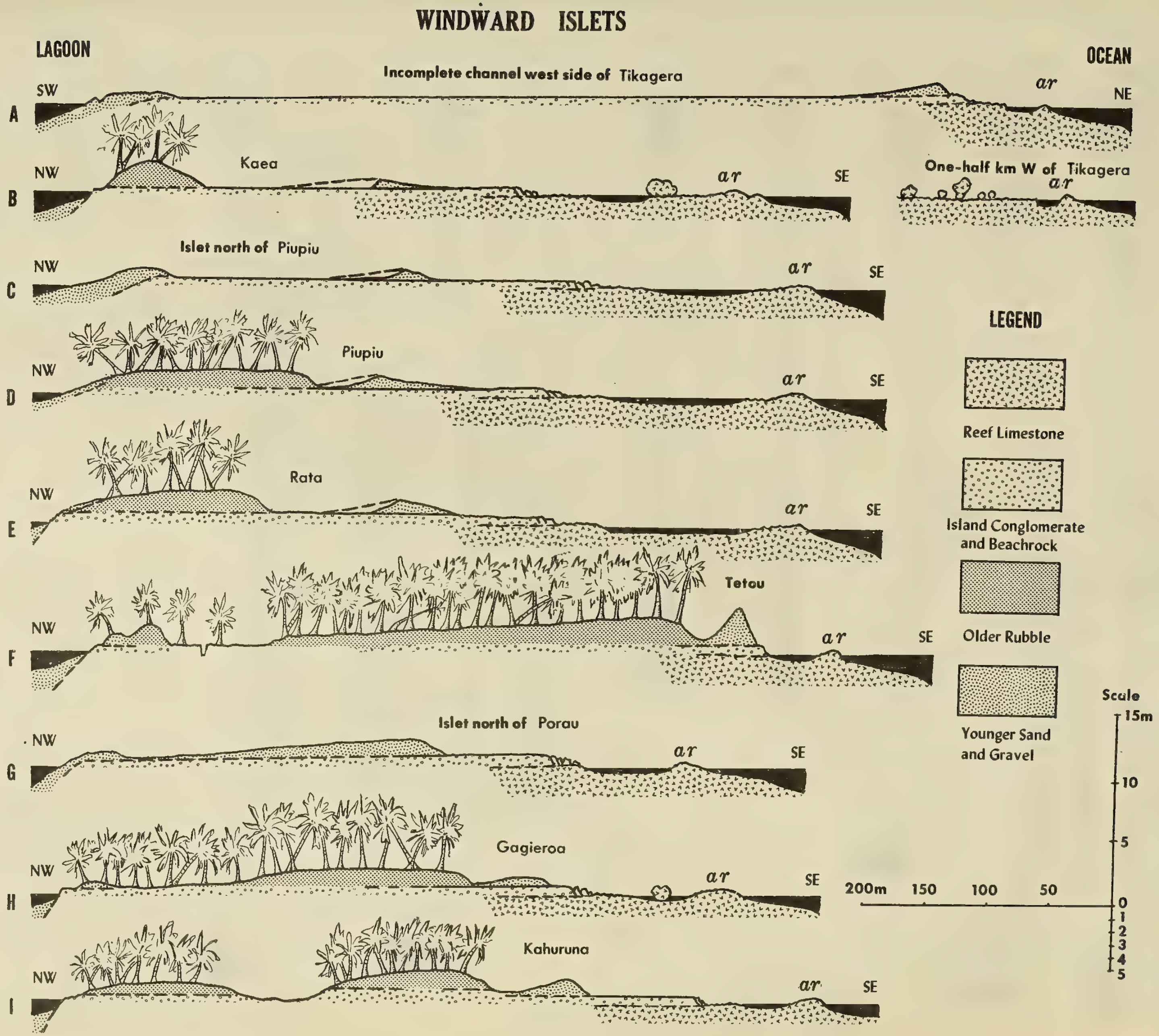
Submerged terraces.-There is evidence of an outer terrace believed to lie at approximately 20 meters similar to those described for Bikini (Tracey, Ladd, and Hoffmeister, 1948) and Andros Island (Newell, Rigby, Whiteman and Bradley, 1951) and there is a shallower terrace which slopes outward at the reef front from about low water level to eight meters. A submerged rock terrace, probably also at about eight meters, lies along the lagoon shore. This is largely covered, however, by sediments and fringing reefs so that the depth to the terrace rim cannot be determined accurately. Usually there is a pronounced break in slope at about five meters or so.

Erosion of the land.-The rocky outer shore all around the atoll is being cut away and the land area is decreasing. Outlying erosion remnants on the reef flat show clearly that the shore has retreated along a broadly curved front as much as 20 or 30 meters since the conglomerate platform was formed and elevated. Most of the products of this erosion together with the coral gravel and foraminiferal sand swept through the channels during storms accumulates in the lagoon, which in spite of heavy sedimentation is moderately deep (55 m) and is floored by fine sand and gravel rather than mud.

The water of the channels on the windward side and at the broad reef flat at the south end of the atoll generally flows lagoonward, even during low water, because of the strong swell. There is reversal of flow in the larger channels on the leeward side of the atoll where the wind generates a feeble seaward current during high water, but this current carries hardly any sediment.

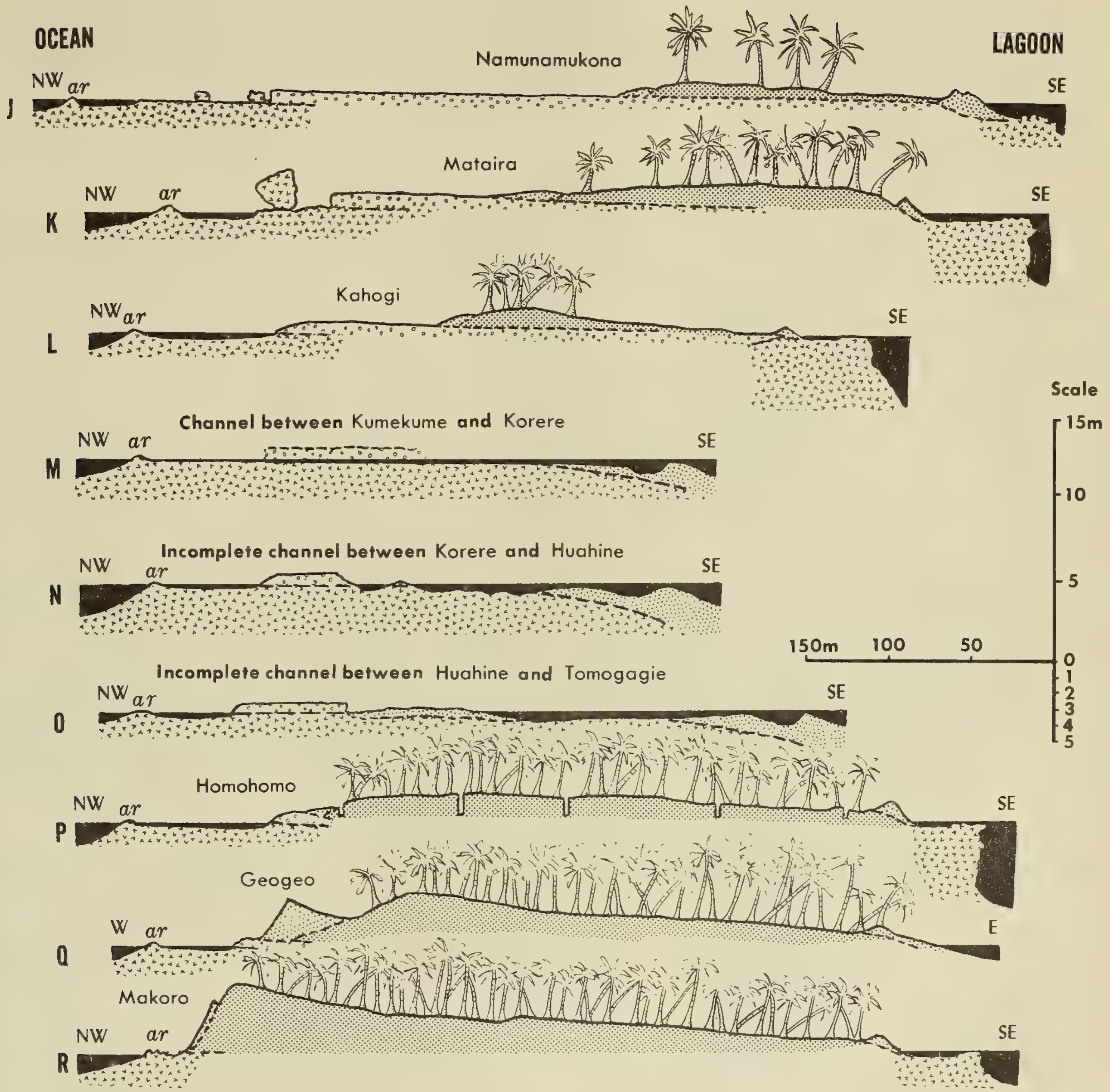
Lagoon shore currents receive and rework the debris from the seaward reef which, together with lagoonal sediments, forms a nearly continuous band of beaches, beach ridges, spits and bars; these are mainly sand along the leeward (southeastern) shore and sand and gravel on the windward (northwestern) shore of the lagoon. Each channel is marked at the lagoon by a small crescentic delta of more or less loose sediments, and there is little or no reef growth at these places.

Accretion of sediments along the lagoon shore tends to mask signs of erosion and retreat of the shore, but almost all the islands have low headlands and outliers of beach rock rising a few centimeters above high water. The edge of the beachrock has been cut back at many places some 15 or 20 meters since it was formed. However, it appears that the lagoon shore may be advancing lagoonward at the northeast and southwest ends of the atoll.



6. Windward islets, profiles.

LEEWARD ISLETS



7. Leeward islets, profiles.

Ground water.-Analyses of nine well waters were made at the Garumaoa village near the close of a dry period (June 29) when the wells were being used to capacity. Therefore, the salinity was probably higher than the average for a year. Salinity was determined by hydrometer measurement. Values for pH were obtained with a Gamma electric meter loaned by the U. S. Geological Survey for the purpose. Total hardness was determined by titration. Because of inadvertent omission of an essential reagent, chlorinity of the water could not be determined. The wells ranged from about 14 to 17 parts per thousand salinity, with pH of 7.6 to 7.8. Total hardness ranged between 240 ± 13 to 360 ± 13 parts per million.

Garumaoa and other well waters

Well #	Temperature C°	Salinity o/oo	Hardness o/ooo	pH
1	26.5	14.4	320 ± 13	7.8
2	25.0	14.6	360 ± 13	7.6
3	25.0	13.9	280 ± 13	7.7
4	26.0	14.2	240 ± 13	7.7
5	26.0	14.2	300 ± 13	7.6
6	25.0	14.1	340 ± 13	7.8
7	27.0	14.2	360 ± 13	7.7
8	25.0	15.4	360 ± 13	7.7
9	26.0	16.6	360 ± 13	7.6
10*	--	4.1	-- -	-

*Well at Tetou, little used, August 23; the others are at Garumaoa, June 29.

Five test pits were dug to the water table in a series across the north end of Garumaoa Islet (Fig. 8). The pits at each end of the series were within 75 meters of the sea. Analyses of water samples from these pits are shown below. Pits four and five were not dug until after the onset of showers which came shortly after the middle of July, breaking a drought of many weeks.

Water analyses from test pits on Garumaoa

Pit #	Temperature C°	Salinity o/oo	Hardness o/ooo	pH
A (5)	26.0	4.1	380 ± 13	7.5
B (2)	26.0	9.0	420 ± 13	7.9
C (4)	25.0	3.5	420 ± 13	8.0
D (3)	27.5	7.6	420 ± 13	8.1
E (1)	24.2	3.7	420 ± 13	7.9
Pond #				
1	24.7	35.5	4000 ± 130	7.9
2	23.5	5.6	400 ± 13	8.3

All of the wells and moat ponds rise and fall with the tides, but the details of effects of tides on the lens of ground water were not studied. In general it appears that the fresh water lens is adequate for plants and animals on the larger islands even during periods of drought. Rain-water cisterns supply nearly all of the drinking water, however, at the village. In all of the wells and pits the sand and gravel were unconsolidated down to the highest level of the fluctuating water table. Below this level the sediments are loosely cemented to form friable calcarenite.

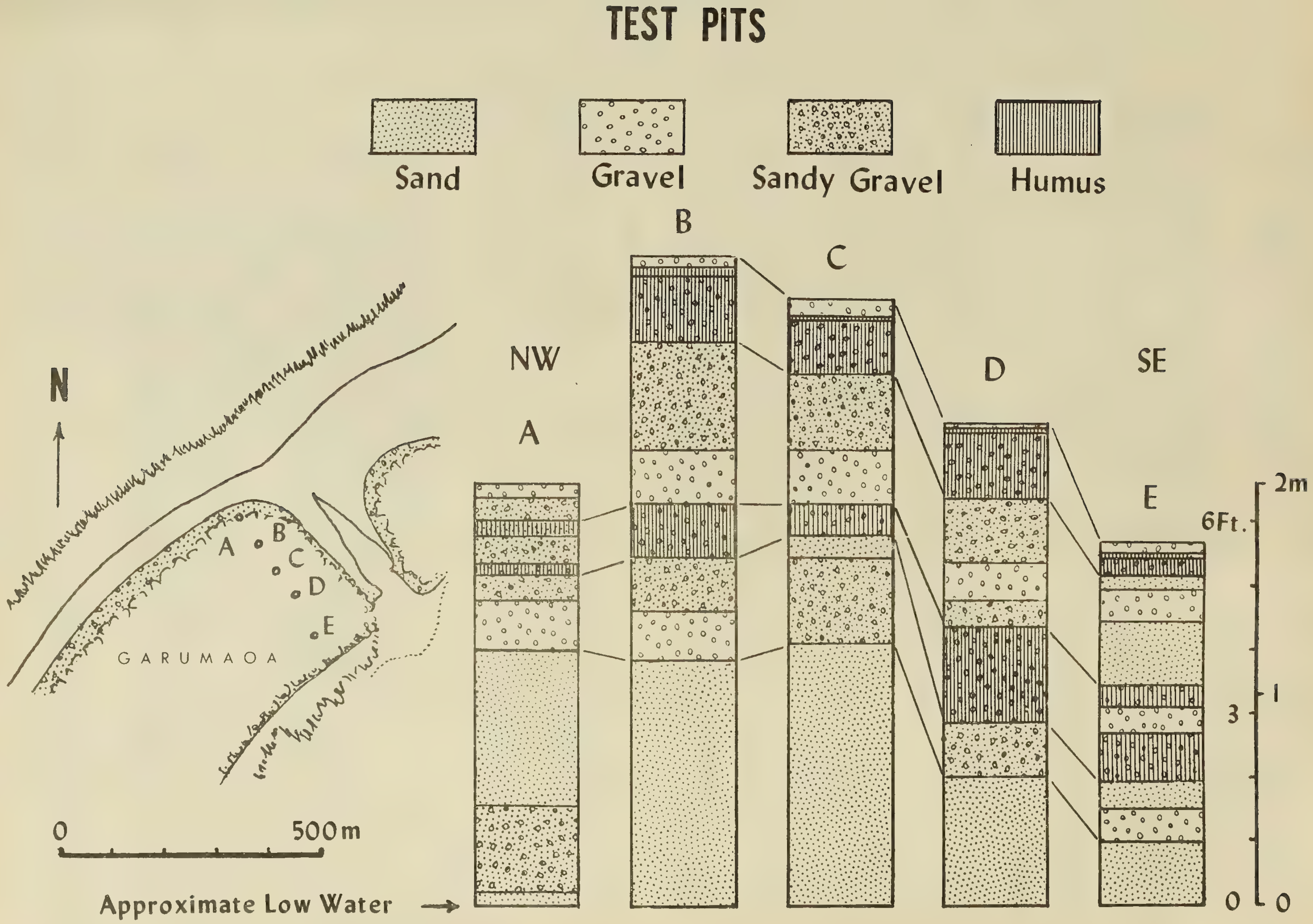
Soils.-The land areas of Raroia are almost destitute of soil over all but the lowest surfaces. Probably leaf mold and humus are periodically stripped away or buried by sheet flood during hurricanes. Sulphurous muck is found in a few swampy areas just inside the lagoon beach ridges. These are natural moats and the waters are quite saline (see preceding table, pond 1). Farther inland are small taro pits all dug before the present century. The muck of these pits is acid. As might be expected, the surface rubble of the islands generally is alkaline. The conglomerate, coral gravel and foraminiferal sand which compose the islands are nearly pure calcium carbonate. Clay minerals and silica occur only as traces and do not form significant accumulations. High alkalinity is assured by the local custom of periodically burning over underbrush and coconut husks, which results in the disintegration and calcining of the surface gravel.

Stratigraphy.-Five test pits two to three meters deep were dug across Homohomo (north end of Garumaoa Islet) in order to study the succession of deposits and to secure samples of ground water (Fig. 8). The outer pits were near the two shores and the oceanward hole was dug within 20 meters of the conglomerate platform. Contrary to expectation the conglomerate, composed of firmly cemented coarse debris of corals, was not encountered in any of the pits, although all were deep enough. Thus apparently it does not form the foundation of this large island as with the small islands. The succession of strata penetrated in these pits is remarkably uniform across the island. There is a lower unit of well sorted medium limesand which extends upward from the high water level some 50 to 240 centimeters. This is overlain by coarse, sandy gravel 150 to 350 centimeters thick containing one or two buried soil zones and a poorly developed humus zone at the top. Wells at Garumaoa, at Oneroa and Tetou also show that the sediments are generally finer below and coarser above. Samples of the sediments exposed on the five test pits were collected for soil analysis and carbon 14 determination. It seems probable that the onset of deposition of the coarse materials may have originated in a marked climatic change, such as development of, or shift in, a hurricane track. The slight drop in sea level discussed earlier probably resulted in increased rates of erosion of reef and island conglomerate.

Logs of five test pits at the north end of Garumaoa Islet (Fig. 8)

Test pit A (5). Northeast corner of Garumaoa Islet, Depth of hole, 79 inches.

Top	Inches
Bed 1. Loose gravel	2
2. Algal crust on pebbles	½
3. Gray-buff sand and gravel	4
4. Gray sand with some humus	3
5. Gravel, subangular pebbles up to 4"	5



8. Correlation of strata in test pits, Garumaoa Islet.

Bed 6.	Sandy gravel with roots	2
7.	Sand, light-buff with scattered pebbles	5
8.	Coarse gravel, washed, angular, a few boulders	9
9.	Sand, medium, well sorted, light-buff	29
10.	Sand, gravelly, grayish	16
11.	Sandstone, like above	3+

Salinity 4.1; original temperature 27°C.

N.B. Roots occur scattered throughout, but predominate at levels indicated above. The section looks as though beds above #6 are result of burial of older profile, perhaps by 1903 hurricane.

Test pit B (2). North end Garumaoa Islet. Depth of hole, 121 inches.

Top		Inches
Bed 1.	Mantle of coarse angular coral fragments, the whole being coated black at surface by blue-green algae	2
2.	Dark-gray sandy gravel with organic material	2
3.	Gray sandy gravel with many roots	12
4.	Gray sandy gravel	20
5.	Open coarse gravel	10
6.	Small cobbles with open interstices several inches across; lowest root zone	10
7.	Poorly sorted sand and gravel	10
8.	Poorly sorted subangular gravel, no sand, unconsolidated	9
9.	Semi-consolidated, coarse sand, light-buff, rather well sorted (beach sand)	46
	Water table	

Salinity 9.0; original temperature 27.5 C; pH 7.92; hardness 420 ± 13 parts per million.

Test pit C (4). North end of Garumaoa Islet. Depth of hole, 113 inches

Top		Inches
Bed 1.	Unsorted coral gravel, washed	3½
2.	Algal film on pebbles, black	½
3.	Gravelly sand, dark-gray, with small roots	6
4.	Sand and gravel, darker, major root zone	4
5.	Sand and gravel, light-gray, buff, some cobbles	14
6.	Angular small cobbles and gravel, grading down into sand, light-gray	10
7.	Brownish dark-gray, sandy, with a few roots, humic soil with a few pebbles	6
8.	Brown, well sorted medium to fine sand	4
9.	Brown gravel, sandy, fragments up to 8 inches	16
10.	Sand, coarse, light-tan, well sorted with a few small pebbles; lightly cemented	49
	Water table	

Salinity 3.5 (diluted by recent rain); original temperature 28°C, pH 8.0.

Test pit D (3). North end of Garumaoa Islet. Depth of hole, 90 inches.

Top		Inches
Bed 1.	Surface veneer gravel	1
2.	Black humus and leaf mold	1
3.	Gravel, gray, sandy, with roots	12
4.	Gravel and cobbles, sandy, light-gray, with a few small roots	12
5.	Gravel, washed, subangular, up to 3 inches with open interstices, fine roots	7
6.	Sand and coarse gravel, light-buff, fine roots	5
7.	Brown sandy humic soil, gravelly, darker at top	18
8.	Gravelly sand, yellowish tan	10
9.	Sand, coarse, light-buff, well sorted with a few small pebbles	24
	Water table	

Fluctuation of water level at least 10 inches.

N.B. The sediments below #7 are tan, those above are light-buff to bone colored.

Test pit E (1). Northeast corner of Garumaoa Islet (see Figure for location). Depth of hole, 68 inches.

Profile

Top		Inches
Bed 1.	Surface coral rubble, partly calcined by burning; no sand visible; fragments small pebbles to boulders	2
2.	Upper half inch black, humic, lower part dark brownish-gray sandy gravel full of small roots, mainly horizontal (2 samples)	$4\frac{1}{2}$
3.	Sand with pebbles, light-gray (sample taken)	$2\frac{1}{2}$
4.	Pebbles and cobbles, subangular, light-gray, no sand	6
5.	Sandy gravel, light-gray	12
6.	Humic soil, dark-gray, sandy gravel, full of living roots, both horizontal or vertical (sample)	4
7.	Gravel, hardly any sand (sample)	5
8.	Sand, brown, pebbly (sample)	9
9.	Buff sand and pebbles (sample)	5
10.	Gravel, washed, no sand	6
11.	Sand, buff, with a few pebbles (sample)	12
	Water table	

Original temperature 27.5°C.

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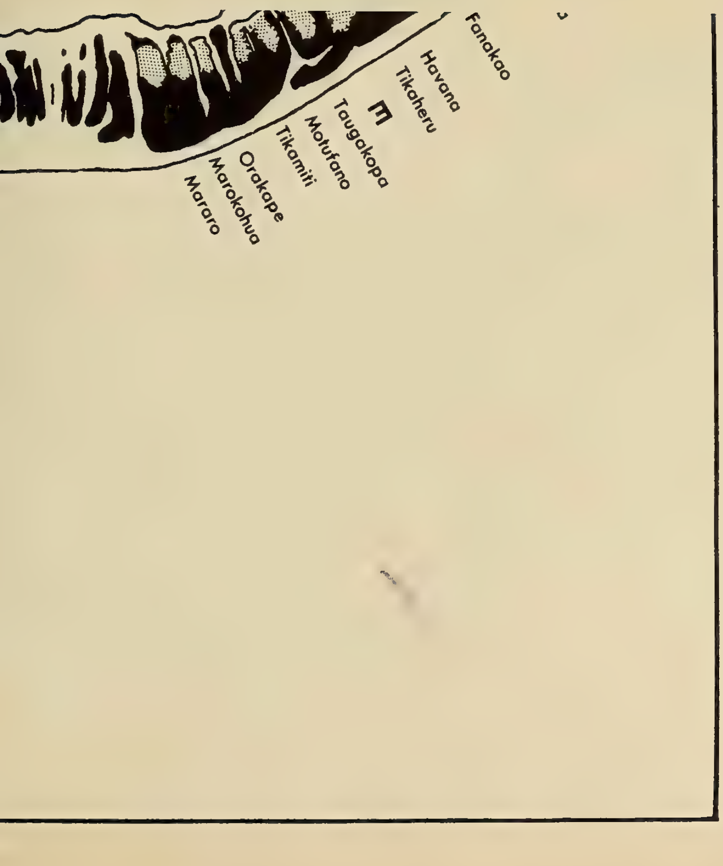
Part 3

GENERAL MAP OF RAROIA

by Norman D. Newell

Abundant patch reefs across the central part of the lagoon have not been mapped. Stippled areas, vegetation cover; black areas, bare land surface (limestone, gravel and sand). Original wind data corrected for magnetic declination.


Fanakao
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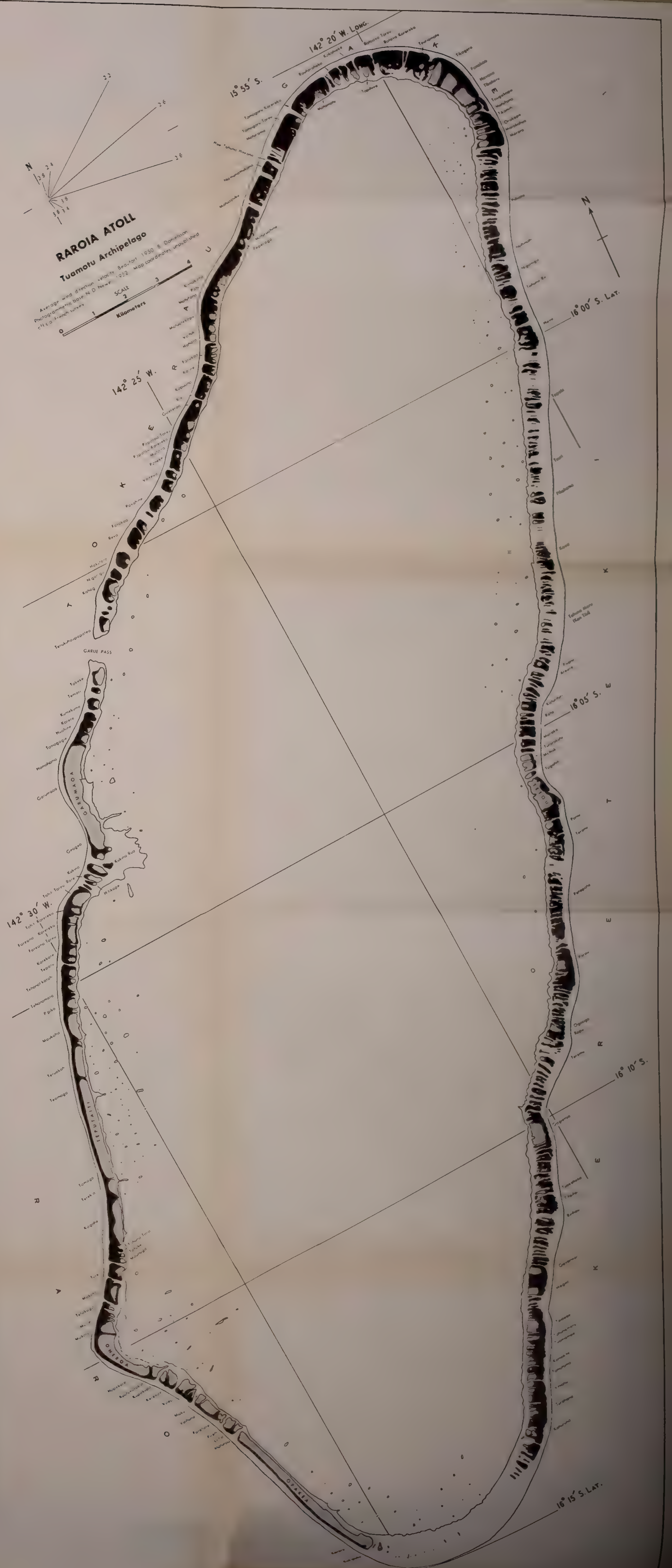
Mararo


RAROIA ATOLL
Tuamotu Archipelago
Average wind direction velocity Beaufort 1950 & Danielsson
Photogrammetric base N D Newell 1952 Map coordinates unpublished
French survey
SCALE
0 1 2 3 4
Kilometers
N
142° 20' W. LONG.
15° 55' S.
142° 25' W.
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GARUE PASS
GARUMAOA
16° 00' S. LAT.
16° 05' S.
16° 10' S.
16° 15' S. LAT.
N

ATOLL RESEARCH BULLETIN

No. 32

Raroian Culture

Part 1. Economy of Raroia Atoll, Tuamotu Archipelago

by Bengt Danielsson

Part 2. Native Topographical Terms in Raroia, Tuamotus

by Bengt Danielsson

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by Bengt Danielsson

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Part 1

ECONOMY OF RAROIA ATOLL, TUAMOTU ARCHIPELAGO

by Bengt Danielsson

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ECONOMY OF RAROIA ATOLL,

TUAMOTU ARCHIPELAGO

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INTRODUCTION

When and how the study was made

In accordance with the general aims of the Pacific Science Board's Coral Atoll Project, this study deals principally with ecological relationships considered from the point of view of the native population, or, in other words, it is a study of the economic life on Raroia atoll in the Tuamotu Group, French Oceania. As it examines the present-day economy seen in its wider context, it could also be called an acculturation and functional study, but the simpler and more commonly acceptable title "Economy of Raroia" has been preferred.

Most of the data on which the study is based were collected by 1950, i. e. two years before the Pacific Science Board's expedition visited Raroia.

Raroia was actually chosen primarily because of this previous knowledge of ours on conditions there.

Our own first visit to Raroia dates back to August, 1947, when we spent a fortnight there together with the other members of the Kon-Tiki expedition. This short stay was enough to make us interested in the acculturation processes in the Tuamotus and to convince us of the advantages of undertaking study of this aspect of the culture in Raroia, where (a) the population was small enough to be studied in its entirety and not just by means of sampling and (b) we could be sure of whole-hearted cooperation with the islanders. Our project was eventually realized when we returned to Raroia in November, 1949. The total time spent on the atoll this time was 18 months (until April, 1951), and the period covered by our study included the whole year of 1950.*

From our rather comprehensive data on acculturation collected during this period, we selected during our third stay in Raroia, June 19 to September 7, 1952, as anthropologist of the Pacific Science Board's team, those data dealing with economic and related activities. The data were carefully checked whenever possible and a certain amount of additional information was obtained. Some rough outlines were prepared even while we were still in the field, but practical duties and the collaboration with other team members on various studies (which will be presented separately), made it impossible to write up our material on the spot, although we had planned to do so in order to achieve maximum accuracy.

The final shape of the study is determined principally by our endeavour to conform as much as possible to the general plan for the Coral Atoll Project, decided upon at the outset. In Spoehr's words (Atoll Research Bulletin No. 17, Handbook for Atoll Research, page 109) the guiding principles are, that observations during field expeditions should:

"(a) Focus on the present rather than the aboriginal past...

(b) ...elucidate processes involved rather than static patterns...

(c) Operate with a set of problems suitable for comparative investigations..."

These principles already guided our work before our participation in the Coral Atoll Project, and were still more rigidly adhered to during the preparation of the present study.

The data which were judged essential to gather for a study of this type were grouped by Mason (Atoll Research Bulletin No. 17, Handbook for Atoll Research, page 111) under the following headings:

1. population inventory
2. economic activities
3. land tenure
4. social and political organization
5. movement of peoples

*For a popular account of our experiences during this stay, see: Danielsson, 1953.

We have followed this general outline - as Mason did himself at Arno and Goodenough did at Onotoa - in order to achieve the goal which we believe is of utmost importance, viz. to provide a common basis for comparisons of atoll cultures. It is also our conviction, that only through this standardization of methods will it be possible, ultimately, to transcend the short-time practical value of the studies and make contributions to the more important theoretical task of discerning and formulating basic social laws.

It must be noted here in passing, that the present study, although planned with these objectives in mind, nevertheless covers two of the three fields of special interest to the South Pacific Commission, viz. Economic and Social Development, and partly follows the program for coral research of immediate practical value, as outlined in Project No. E.6 of the Commission.

Thus, while our selection of data has been determined by the considerations detailed above, the presentation has been guided by their place in the functional context. Both the population inventory and the data on inter- and intra-island movements are for instance grouped together in the same chapter, called Demography. Two specific chapters are devoted to surplus production and subsistence activities, whereas discussions of social implications of the economic organization are interspersed throughout the text. Land tenure is linked with inheritance practices and legal problems, and so on. Wherever necessary for the elucidation of the situation, historical material has been included.

The curious situation in Raroia, where the economy is neither primitive nor modern but somewhere in between, has made it impossible to use the conventional classification of the material under the heads of Production, Distribution, Exchange and Consumption, and in this case also the functional context has, therefore, determined the presentation of the material.

Finally it must be understood that the present study is not in any way definitive, but should rather be regarded simply as a collection of raw data together with some tentative interpretations. We hope eventually to be able to enlarge and improve on the study in the following ways during a future visit to Raroia:

(1) by gathering additional material on the economy (especially the nutrition);

(2) by including material dealing with other aspects of the culture, such as health, religion, political organization, recreational activities and others;

(3) by further analyzing the interactions and interrelationships.

In addition it would certainly be worth-while comparing the situation in Raroia with that in other parts of Polynesia as recorded in the literature, in order to gain a wider perspective and better understanding of universal acculturation processes. Or in Keesing's words: "Polynesia thus forms an ideal laboratory of acculturation processes, with the open spaces of the Pacific giving perhaps the nearest equivalent available in human studies to test tube isolation and control." (Keesing, 1947 p. 39).

Chapter I

HABITAT AND HISTORY

Physical features

The Tuamotu Group, which is a part of French Oceania (Etablissements Francais de l'Oceanie), lies immediately East of Tahiti. It is made up of 78 atolls scattered over the huge area between 135 to 149 degrees West and 14 to 23 degrees South. The distance from Tahiti to the nearest atoll is 130 nautical miles and to the most distant easternmost about 800 nautical miles.

With the exception of the raised phosphate island of Makatea all the atolls are low with a maximum elevation rarely exceeding 20 feet. Three of the atolls are more than 60 km (kilometers) in length, about 30 are less than 10 km in diameter, and the rest are of all sizes in between. Most of the atolls in the Western part of the group have passes deep enough for trading schooners; most of the atolls in the Eastern half of the group lack passes.

The following more detailed description of Raroia is taken from the preliminary report of the geologist of the Pacific Science Board team, Dr. Norman D. Newell:

"The rim of Raroia is extraordinarily narrow and contains much land surface. There are many shallow channels that have cut since the land was formed, but there is only one ship pass....The lagoon is moderately deep and occupied by a large number of patch reefs (between 1,600 and 2,000) arranged in quadrangular patterns."

The general characteristics of the atoll are, according to Dr. Newell, as follows:

Length	44 km
Breadth	14.4 km
Circumference at edge of outer reef	90 km
Area	ca 400 km^2
Lagoon area	ca 340 km^2
Lagoon maximum depth	55 m
Atoll rim area	60 km^2
Land area	21 km^2
Average breadth of rim	0.6 km
Maximum height of land	6 m

Dr. Maxwell Doty has calculated the vegetated area with the help of the aerial photographs and found it to be 921 hectares. Of these, 587 seem to be planted with coconut palms, while the remaining 334 hectares are covered with other vegetation, mostly _Guettarda speciosa_, _Messerschmidia argentea_, _Pemphis acidula_ and Pandanus.

Climate

The climate in the Tuamotu Group is hot and dry, but refreshing easterly trade winds blow all round the year. The temperature varies very little between night and day, and the water is only slightly cooler than the air. There are two clearly distinguishable seasons, one relatively rainy period lasting from November to April and one relatively dry period from May to October. During the rainy season devastating hurricanes occur at long intervals, the last ones sweeping through the group in 1903 and 1906.

It must be recalled here, that these hurricanes accelerated the acculturation process in many atolls, as the taro pits were filled with gravel. Houses, tools and canoes were completely destroyed. When the islanders had to recover and rebuilt after the hurricanes they replaced in most cases the native foods and objects with imported European articles. The cyclones constitute therefore a break in the economy and material culture (and in many atolls in spiritual culture too, through the loss of the old family books containing the historical traditions).

We recorded meteorological data in Raroia for the whole year of 1950. These are published elsewhere (See Danielsson, 1951), therefore only the main characteristics of the climate are given here:

Maximum temperature, annual average	30.4°C(86.7°F)
Minimum temperature, annual average	23.3°C(73.9°F)
Total annual rainfall	1181 mm (46.5 in.)
Total number of days with rain	132
Number of windless days	37

Natural resources and acculturation

Few plants and land animals exist in the group (For detailed information see the publications on botany and zoology by other team members in following numbers of the Atoll Res. Bull.) and only about twenty species of sea birds are found, but the sea teems with fish (See Atoll Res. Bull. No. 18) and the lagoons contain an abundance of clams and crustacea in most atolls. The environment and natural resources are therefore very similar to those found everywhere on atolls in the South Pacific.

Keesing has classified the Polynesian islands in the following way (Keesing, 1953):

Type I: Small islets without adequate resources.

Type II: Small islands, usually atolls, with limited resources and poor sea approaches.

Type III: Small islands with special commercial resources.

Type IV: Larger islands, usually volcanic, which are isolated and have poor sea approaches.

Type V: Larger islands, usually volcanic, which are conveniently situated and have good harbors.

There is a definite correlation between the type of island and the acculturation process, a fact which has been brought out repeatedly by previous studies in Polynesia. That the cultural situation in Raroia is typical for islands of type II will be shown by the present paper.

Pre-European culture

The Tuamotu atolls were settled from Tahiti, the Marquesas and perhaps also from other surrounding islands at varying periods. The Raroian traditions claim that the atoll has been permanently inhabited since 30 generations ago (about 1450 AD). The Tuamotuan culture therefore naturally resembled that of the neighbour groups, but had also several unique features. Many local variations existed within the group and some cultural sub-areas like Napuka, Reao-Pukarua, Fagatau* and Anaa could be distinguished. (See Report, 1932).

The social system was fairly democratic, and there were no classes. Generally each atoll was divided up into a number of districts inhabited by extended families. A paramount chief was sometimes recognized on an atoll, but his power was rather nominal, and the greatest social unit was in reality the family.

Hostilities were common between the atolls and sometimes even between the districts. The most feared warriors were those from Anaa, who at several instances ravaged even distant atolls in the group and killed or carried away their inhabitants.

The economy was a simple food-gathering and planting economy. The staple food plants were the pandanus, the coconut palm and the coarse taro. The pandanus and coconut palms did not require much care, but huge ditches had to be dug for the taro and considerable time was spent on the cultivation of it. Of animal food, fish occupied a very important place on the menu, and clams and crustacea were also regularly collected. Sea birds, eggs and turtles were seasonal sources of food. Of the commonly domesticated Polynesian animals, the pig and fowl were absent, but dogs were frequently kept and eaten.

The material culture was poor, and the only material for tools accessible in the atolls was bone and mother-of-pearl shell. Basalt adzes were therefore often imported from Tahiti. The houses were made of palm or pandanus leaves and rather crude, however good craftmanship was shown in the construction of sea-going ships. These were twin-hulled canoes with platforms and pandanus sails, capable of transporting several dozens of persons. There are known instances of travels exceeding 1,000 nautical miles in length.

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*In accordance with the generally adopted convention "g" is used to indicate the English "ng" sound as in "sing." The vowels are pronounced as in Spanish.

Early discoverers

Quiros discovered seven atolls in the group as early as 1606, but with the exception of Anaa it is extremely difficult to identify them due to the vague positions given in the account of the voyage. The Dutchmen LeMaire and Shouten in 1616 and Roggeveen in 1722 were the next Europeans who passed through the group, and they discovered about a dozen more atolls. During the following hundred years Byron, Wallis, Carteret, Bougainville, Cook, Boenechea, Varela, Edwards, Bligh, Wilson, Turnbull, Kotzebue, Bellingshausen and Beechey gradually found the remaining atolls (See Buck, 1945). The last atoll was discovered as late as 1835.

Raroia was sighted for the first time on July 12, 1820 by the Russian explorer Bellingshausen, who proceeded along the Eastern shore. His observations are summarized in the following brief passage in the narrative of the voyage (Bellingshausen, 1945, Vol. I: 236):

"It (the Eastern shore) is covered with scattered undergrowth and low trees. Surf was breaking heavily on this coral shore. The northern and western sides from which the lagoon was visible were quite covered with trees, and at various points on the north-western shore we could see smoke rising up out of the trees, which showed that the island was inhabited. Mr. Lazarev informed me that he could see people and canoes on the shore."

Bellingshausen called the atoll, Barclay de Tollay, but this name, like all other European names bestowed on the Tuamotuan atolls, is absolete today and not even known by the natives.

History of later culture contacts

All these early explorers passed through the group quickly, and their contact with the natives was limited to the exchange of some small trinkets for coconuts and scurvy grass on the rare occasions when a ship hove to for a couple of hours at an atoll. From 1830 on, however, a new type of ship began to appear in the group, the trading vessel in search of pearls, mother-of-pearl shell and sea slugs. Native divers were engaged and islanders were taught to prepare the sea slugs.

As a result of these contacts new diseases spread and severe epidemics soon ravaged the group. As the natives had no resistance through previous immunity and lacked all notions of modern hygiene, even such comparably harmless diseases as measles and influenza were fatal. Many died and the population decrease was further accelerated through syphilitic sterility. The natives' mode of life was, however, very little affected by these infrequent visits of trading vessels, and during the period up to the 1860's, for instance, an atoll like Raroia was visited maybe only once a year or every second year.

During the second half of the century two new groups of Europeans gradually brought about profound changes. These were the missionaries and the copra traders. The first converts in the group were made already in 1817 in Anaa by protestant native missionaries instructed in Tahiti, but the new religion did not at this time spread widely and the number of protestant converts remained small.

An American missionary from the Church of Jesus Christ of the Latter Day Saints arrived in 1845 in Anaa and immediately won a foothold. Catholic missionaries prospected the Tuamotus for the first time in 1849, and installed themselves also at Anaa two years later.

Some of the inhabitants of Raroia were converted by other natives from Anaa at least as early as 1846, but the majority of the islanders still clung to their old faith when the first European missionary, a Catholic priest, arrived in 1869. Between this date and 1875 he succeeded during his repeated visits in converting practically the whole population, and a solid stone church, which is still standing today, was constructed.

The Protestant Church and the Latter Day Saints also made progress in the group during the same period, and with the increasing number of trading vessels that appeared, with the rise of the copra trade (for more details, see Chapter V), gradually all the natives became converted. The last islanders in the Tuamotus abandoned their old faith in 1888.

Politically the status of the group continued to be very vague even after the establishment of the French protectorate in Tahiti in 1843. Many of the western atolls in the group were regarded as a part of the Tahitian kingdom, and the Queen, Pomare, appointed in several cases both regents and judges, but no real authority was exercised. Most of the eastern atolls, among them Raroia, did not recognize even the formal sovereignty of Queen Pomare.

When Tahiti and other islands were annexed by France in 1880, the Tuamotu group was also incorporated as a new administrative unit, and from then on the atolls have been governed by French administrators aided by local chiefs, first appointed but since the end of the last war elected locally by popular vote. All the natives have been French citizens since 1945.

The situation today

The Tuamotus are today the part of French Oceania which is least affected by European culture, and practically no foreigners, White or Chinese, have settled in the group. This does not, however, mean that much of the old culture is left. On the contrary, the changes have been profound, and lovers of South Sea movies would not feel at home in Raroia. The material culture is almost wholly Western, and the natives use European tools exclusively, dress in European way and frequently have even such luxuries as radios, bikes and refrigerators. Many houses are, however, still made of plaited palm leaves, and the canoes are in general of Polynesian model with outriggers.

Of course not a trace of the old religion is left. The social structure has also changed considerably with the concentration of the people in central villages and the emergence of a new class of leaders, the native traders and catechists or ministers. Economically a whole revolution has occurred with the rise of the copra trade, and today almost everywhere in the Tuamotus the natives have abandoned the old subsistence economy in favor of a surplus production.

Even the language has undergone profound changes, and the Tuamotuan dialect is spoken today only by the old men and women in Raroia. As a result of the frequent contacts with Tahiti, the local dialect will probably in the end be completely replaced by Tahitian.

The main difference between the Tuamotus and Tahiti, (like most other large islands of type V, according to Keesing's classification) is that the Tuamotuan natives have preserved their economic independence and spiritual wholeness to a much greater degree than those in the islands of the latter type. In Raroia, as practically everywhere in the group, all the inhabitants still have enough land to secure a good living and many have a considerable income by any standard. With the words "spiritual wholeness" we simply mean that the atoll communities still are fairly homogeneous with few social, economic, religious or other stratifications. This difference between the acculturation situation in the two types of islands is more important than the similarities, and it is the main justification for affirming that the Tuamotus are the islands in French Oceania still least affected by Western culture.

The cultural situation, like the environment, is in its main characteristics similar throughout the group. There is a slight difference of degree, and as a general rule it can be said the impact of Western culture diminishes as the distance from Papeete increases. Raroia, situated at 142° West and 16° South, occupies therefore not only geographically but also culturally an intermediate position in the group.

Summary of culture contacts

In order to get a more quantitative measure of the acculturation process we shall try, finally, to summarize the type and frequency of the culture contacts. This summary, which of course is only a very rough and tentative evaluation, is presented in the following table:

Table I: Culture contacts

A. In Raroia:

Type of contact	Duration	Frequency	Period
Visits of trading schooners	1 - 2 days	Once a year	1830 - 60
Visits of trading schooners	1 - 2 days	5 - 6 times a year	1860 - 1920
Visits of trading schooners	1 - 2 days	Once a month	1920 -
Visits of missionaries	About a month	Once a year	1870 -
Visits of administrators	1 - 2 days	Twice a year	1900 -

B. Elsewhere:

Type of contact	Duration	Frequency	Period
Average visits by a Raroian to Tahiti	1 - 2 months	Every second or third year	1920 -
Average visits by a Raroian to other atolls during the diving season	1 - 4 months	Every second or third year	1900 -

Chapter II

DEMOGRAPHY

A. The Place of Raroia in the Tuamotus and French Oceania.

Before proceeding to the presentation and analysis of the detailed population data collected by us in Raroia, the place of the atoll in its larger demographic context has to be determined.

From the geographical, botanical and geological point of view Raroia is certainly typical for the Tuamotu group and does not in any marked respect deviate from the general pattern found, with surprisingly few variations, everywhere in the archipelago. Culturally Raroia occupies a central position between the more "conservative" Eastern atolls and the more "progressive" Western atolls, and is thus truly an "average" Tuamotuan atoll. But is the composition of the population also representative for the Tuamotus in general, and how does the Tuamotu group in its turn compare to French Oceania as a whole?

In order to answer these questions, we have compiled some comparative tables based on the latest census report (Teissier, 1953), to some extent supplemented with our own data. All figures in this section refer therefore to the situation at the time of the census, September 17-18, 1951. Our study is otherwise limited to the period January 1st to December 31st, 1950, but as no significant changes took place during the time up to the census, all findings in this section are valid also for the study as a whole.

The figures are broken down according to the following criteria: administrative unit, race, sex, age, marital status, professional situation, and church membership. No further analysis is possible on the basis of the available census data, and are, anyway, unnecessary for our limited purpose.

1. Administrative units.

On September 17-18, 1951, the total population in French Oceania was 62,828, divided among the five administrative units or groups in the following way:

Tahiti and dependencies	35,423
Leeward Islands	12,920
Tuamotu group	6,733
Austral Islands	3,983
Marquesas Islands	3,257
Mangareva	512

Of the 78 atolls in the Tuamotu group, many are grouped together for administrative purposes, which for instance is the case with Raroia and its neighbour atoll, Takume. The total number of these smaller units, usually called "districts" is 35, and the frequency distribution of the population is as follows:

Population	Below 100	101–200	201–300	301–400	401–500	Above 500
No. of distr.	4	19	8	1	1	2

The average population per district is 192, which is very close to the figure for Raroia-Takume, 160, but still more significant is of course the frequency distribution above, in which Raroia-Takume is in the modal class. As it is impossible with available data to compute the average population for each inhabited atoll, we have to content ourselves with these rather crude figures, which, however, clearly show that Raroia-Takume in this respect is typical for the Tuamotus as a whole.

Comparisons between the Tuamotus on the one hand and the whole of French Oceania on the other, are of course meaningless, as the other groups are completely different as to topography and general conditions.

2. Racial composition.

Race	French Oceania		Tuamotu		Raroia	
	Total	Per cent	Total	Per cent	Total	Per cent
Pure Polynesian	40,099	64.3	5,905	87.8	97	87.3
Mixed Polynesian	13,769	21.9	742	11.0	12	11.0
Chinese	6,655	10.6	68	1.0	2	1.7
Caucasian	1,860	2.9	18	0.2	0	0.0
Other	445	0.3	0	0.0	0	0.0
Total	62,828	100.0	6,733	100.0	109	100.0

The attribution of a person to the class of pure or mixed Polynesians is in the official census made simply on the basis of his own declaration, and therefore can not be regarded as reliable. As a rule, however, the intermixture is undoubtedly less in the Tuamotus than in any other group in French Oceania, and the figures therefore certainly have some basis in fact. The percentages are anyway strikingly similar for Raroia and the Tuamotu group.

3. Sex ratio.

Sex	French Oceania		Tuamotu		Raroia	
	Total	Per cent	Total	Per cent	Total	Per cent
Male	32,920	52.3	3,677	54.6	51	47.5
Female	29,908	47.7	3,056	45.4	58	52.5
Total	62,828	100.0	6,733	100.0	109	100.0

The disproportion between the male and female figures is very marked, especially if they are compared with Europe and America, where in almost all countries the difference is insignificant. The most surprising thing is that there is a surplus of males in all the five groups in French Oceania in spite of the varying local conditions. This situation seems also to be fairly stable, or at least has been for the last 50 years for which we have reliable data (Valenziani, 1949, p. 666).

Whatever the explanation may be for this curious preponderance of males, the Tuamotus follow the general pattern. That the figures are slightly more disproportionate in this group than in French Oceania as a whole is certainly due to a greater female migration to Tahiti. The figures for Raroia are strangely enough reversed, and seem to have been so for a long period. The percentages correspond to a sex ratio of 120 males to 100 females for the whole group, and 88 males for 100 females for Raroia.

4. Age classes.

Age	French Oceania		Tuamotu		Raroia	
	Total	Per cent	Total	Per cent	Total	Per cent
Below 20	33,239	52.9	3,249	49.4	49	46.6
Above 20	29,422	46.9	3,317	50.6	60	53.4
Total	62,661	100.00	6,566	100.0	109	100.0

The official census separates the population only into two groups, those above and those below 20 years of age. For Raroia a more complete break-down and also separation according to sex has been undertaken in the section on Population trends (Part B. 2 of this Chapter), but here we follow simply the census.

The reversed figures for the Tuamotus when compared with French Oceania as a whole are certainly - like the similar disproportion between the sexes in the previous table - due to a migration to Tahiti. It seems to be a little more pronounced in Raroia than on the average, but on the whole it can certainly be said that generally speaking Raroia also in this case is typical for the group.

5. Marital status.

Status	French Oceania		Tuamotu		Raroia	
	Total	Per cent	Total	Per cent	Total	Per cent
Unmarried	48,491	77.5	4,772	72.7	76	68.4
Married	14,170	22.5	1,794	27.3	33	31.6
Total	62,661	100.0	6,566	100.0	109	100.0

These figures should be compared with those in the preceeding table showing the age classes, where we find that roughly half of the population is above 20 and consequently of marriage age. (The figure is actually somewhat higher as the natives often are physically mature long before the age of 20.) The discrepancy between the number of marriageable and married persons is easily explained by the fact that the majority of the natives still have a considerable reluctance to adopt foreign patterns of a complicated legal character. Co-habitation without legal marriage is therefore the rule, and these de facto marriages are not shown in the census. The situation is evidently the same in Raroia as in the Tuamotus and French Oceania as a whole.

6. Professional status.

Status	French Oceania		Tuamotu		Raroia	
	Total	Per cent	Total	per cent	Total	per cent
Employer	748	1.1	10	0.1	0	0.0
Employee	3,529	5.6	21	0.2	0	0.0
Independent	58,384	93.3	6,535	99.7	109	100.0
Total	62,661	100.0	6,566	100.0	109	100.0

The few employers, usually French or Chinese, and employees in the total population almost all live in Tahiti, the only island with an embryo of industry. In Raroia as well as everywhere else in the Tuamotu group the natives are practically all independent land owners who prepare the copra themselves, or with the help of friends who work part-time.

7. Church membership.

Denomination	French Oceania		Tuamotu		Raroia	
	Total	Per cent	Total	per cent	Total	per cent
Protestant	34,441	54.8	494	7.6	3	2.8
Catholic	15,096	24.0	3,443	52.4	100	91.7
Kanito*	2,073	3.1	1,346	20.5	4	3.7
Mormon**	1,218	1.9	510	7.7	1	0.9
Other	9,832	15.5	773	11.8	1	0.9
Total	62,661	100.0	6,566	100.0	109	100.0

* The Reorganized Church of LDS (Independence Branch)

** The Church of LDS (Salt Lake City Branch)

The clearly distinguishable geographical patterns are easily explained if we consider the historical sequences. The first missionaries in French Oceania were protestants. They established themselves principally in Tahiti, Moorea and the Austral and Leeward islands, where they soon converted the totality of the natives. Later arriving missionaries representing other churches (Catholic, Mormon and Kanito) concentrated therefore naturally on virgin fields like the Tuamotus and the Marquesas. There they succeeded in establishing themselves firmly before the protestants took up the competition in earnest. It is thus not surprising at all that the religious situation is different in the Tuamotus from that in the rest of French Oceania.

Whether Raroia is typical for the Tuamotu group or not, is another question which it is unfair to answer on basis of the averages alone, as the churches are not evenly distributed throughout the group. A more important criterion than the simple average number of persons belonging to the various churches, is therefore the <u>number</u> of churches represented on <u>each</u> atoll. In the following table the administrative units or districts into which the group is divided have been classified according to this criterion. "Major" is arbitrarily defined to mean a church of which above 50% of the population is member. If two churches exceed 35%, both are regarded as major, churches with less than 10% members have not been included.

Total no. of districts*	Number of atolls with -						
	1 major church	1 major + no. of smaller			2 major	2 major + no. of smaller	
		1	2	3		1	2
35	17	3	3	2	6	3	1

Out of the total number of 25 single major churches, 18 are Catholic, and out of the total number of 10 major churches sharing the dominance, 7 are Catholic. As Raroia-Takume not only belongs to the first class (atolls with only one major church), but also is Catholic, the district can be said to be much more representative than the mere averages in the census indicate.

8. <u>Summary</u>.

The question of the relationship between the Tuamotu group and French Oceania as a whole is already sufficiently illuminated by the data presented above, and we shall therefore limit ourselves here to a brief summary of the place of Raroia in the Tuamotu group. The size of the population of Raroia is close to the average. As to the racial composition, the age classes, the marital and professional status, the population in Raroia is identical or only insignificantly different from that of the whole group. The sex ratio shows a slight surplus of females, whereas generally in the Tuamotus there is a small surplus of men. In the religious field, finally there is a greater homogeneity than on most other atolls, as more than 90% of the population belong to the same church. These two last mentioned facts may have some influence on the social structure and economic pattern, the possibility of which will be discussed in later chapters.

*Atolls or group of atolls.

This influence must, however, at any rate be exceedingly small, and without hesitation it can be said definitely that Raroia in practically all respects is typical for the demographic set-up in the Tuamotuan atolls. As other factors like physical environment, general culture and economy are also shared with the whole group, the findings of the present study can certainly to a large extent be applied to the group as a whole.

B. Population Trends.

In the previous section a comparison of the composition of the populations in French Oceania, the Tuamotus and Raroia at a fixed time (census of 17-18 September, 1951) was made. The comparison was based on some basic characteristics selected by the census officials. Here additional data collected by ourselves in Raroia will be presented, and where possible the changes over longer or shorter periods will be followed, thus showing also the dynamic aspect of the population.

The material is arranged in three groups. The first deals simply with the general population trend in Raroia compared with that in the Tuamotus and other groups in French Oceania since 1863. The second contains data from Raroia on the natural increase during the period 1930-50. In the third group we find detailed information about the composition, migration and mobility of the population in Raroia, during the time of our repeated visits 1950-52. This gradual increase in the wealth of the documentation proportional to the nearness in time is only natural, as during our stays in the atoll we were able to gather much more and detailed information than usually can be included in the official records.

1. The native come-back.

At the end of the last century the Polynesian race seemed doomed. Since the first contact with Western culture the decline had everywhere been rapid, and it was widely thought that the Polynesians ultimately were to become extinct. A marked change has, however, taken place since then - maybe principally due to intermarriage and to a greater immunity against epidemic diseases - and in French Oceania as everywhere elese in Polynesia, the survival of the native population seems now assured.

In order to show this evolutionary trend and the possible local variations in the principal groups of French Oceania, we have prepared Table II, which excludes all other racial groups than the Polynesians, pure and mixed. The reason for lumping the pure and mixed groups together is simply that the exact degree of intermixture is impossible to determine in most groups (see Section A, 2). In Raroia where the islanders, as in many other of the Tuamotu atolls, still preserve their genealogies, an attempt has been made in Part 5 of this section to classify the inhabitants more accurately, but here the census figures, grouping mixed and pure natives together, will be used in order to permit comparisons.

Table II: Population trends in French Oceania, 1863-1951.

Group	YEAR								
	1863	1881	1892	1902	1911	1926	1936	1946	1951
E. F. O.	--	--	--	27,167	28,875	30,043	38,132	48,370	53,868
Tuamotu	6,588	5,500	4,734	4,294	4,711	4,276	4,668	6,142	6,647
Tahiti	7,642	8,500	9,500	9,634	9,128	8,335	13,182	17,456	23,812
Marquesas	12,000	5,776	4,445	3,563	3,116	2,255	2,400	2,968	3,257
Austral	2,000	1,500	1,814	2,106	2,484	3,170	3,341	3,921	3,983

Table III: Differential evolution in some of of the groups in French Oceania

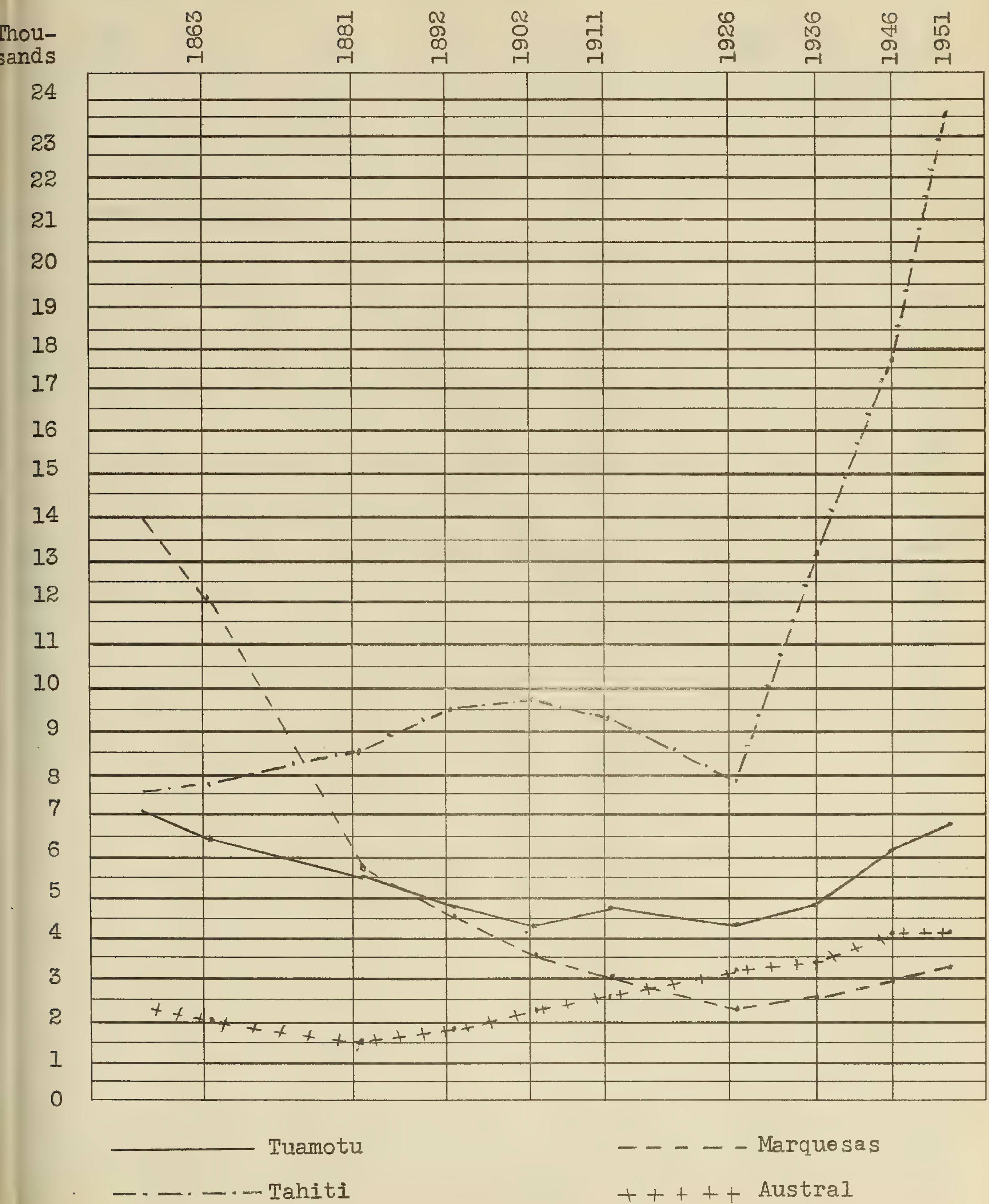
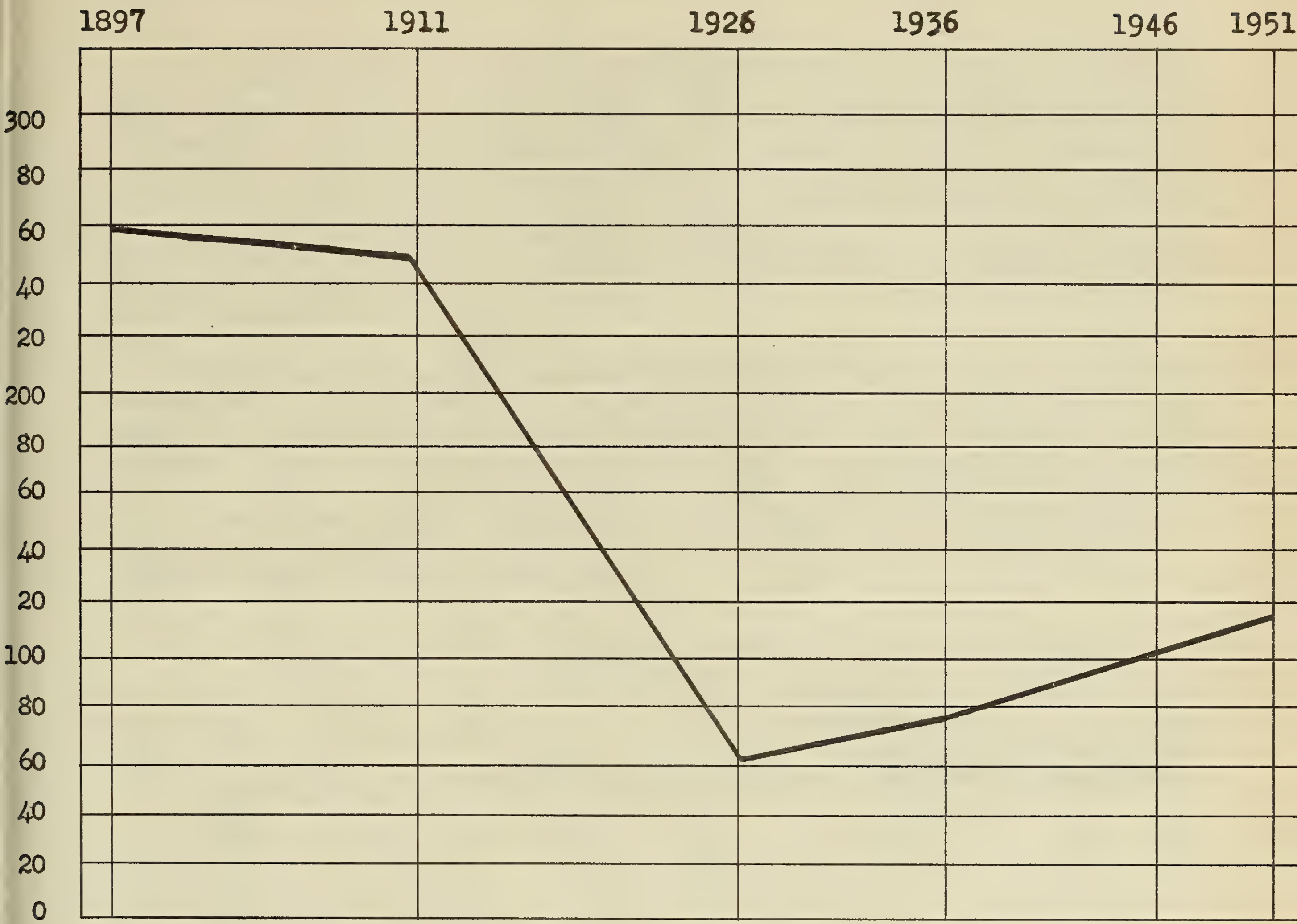


Table IV: Population Changes in Raroia, 1897-1951.



As the figures show, the unexpected native come-back was for French Oceania as a whole very slow until 1926, and thereafter increasingly rapid. (The statistics permit valid comparisons for French Oceania, only from 1902, as previously the Leeward islands were not pacified and no figures are available).

The trend for French Oceania as a whole, is, however, not followed in detail in each of the listed groups, taken separately, and this fact is still better brought out in the graph (Table III). The most striking feature is the varying time at which each group reached the bottom. In Tahiti this occurred in the 1840's (not shown in the graph), in the Austral Islands in the 1880's, in the Tuamotu group around 1900, and in the Marquesas not until the 1920's. The main reason for this differential evolution seems to be the uneven impact of epidemics in the different groups. The Spanish influenza caused, for instance, a downward trend between the 1911 and 1926 census in all the groups, except the Austral Islands!

If we now compare the trend in the Tuamotu group as a whole with that in Raroia, as is done in Table IV, the most significant difference is that the upward trend seems to have started later in Raroia than on the average for the Tuamotus. Whether this is due to prolonged epidemics or migratory movements is hard to say. As to the period prior to 1897 it must be noticed that no accurate census was taken. The estimate in the Annuaire des Etablissements Francais de l'Oceanie for 1863 gives 300 persons for Raroia, which is only slightly higher than the 1897 figure.

Table V: Number of Births and Deaths in Raroia, 1931-1950

Year	Births	Deaths			
		Total	Below 1 yr.	1-20 yrs.	Above 20 yrs.
1931	5	1	0	1	0
1932	5	1	1	0	0
1933	5	2	2	0	0
1934	4	1	0	0	1
1935	5	2	1	0	1
1936	5	1	0	0	1
1937	0	0	0	0	0
1938	5	3	1	0	2
1939	6	1	0	0	1
1940	2	0	0	0	0
1941	8	0	0	0	0
1942	2	2	0	0	2
1943	5	4	2	1	1
1944	2	4	2	0	2
1945	6	3	1	0	2
1946	2	2	1	0	1
1947	2	1	1	0	0
1948	2	1	0	0	1
1949	1	4	3	0	1
1950	5	3	2	0	1
Total	77	36	17	2	17

2. Natural increase, 1930-50.

No detailed population statistics for the individual atolls in the Tuamotu group have ever been published, but in the existing civil register in Raroia we have found complete data as to the number of births and deaths for at least the last 20 years, and they are presented in Table V.

Few comments are needed. The high infant mortality which, expressed per thousand is as high as 220, is of course to a large extent due to an ignorance on the part of the parents of even the most elementary principles of hygiene, but seems also to be a result of the lack of appropriate baby food. As the mothers usually participate in the copra work and take their young children with them to the copra sectors outside the village many of the babies easily catch colds or get pneumonia.

The detailed composition of the permanent population on January 1, 1950, is shown in Table VI. Graphically the composition is pictured below. An interpretation of the facts will be attempted in the following parts of this chapter.

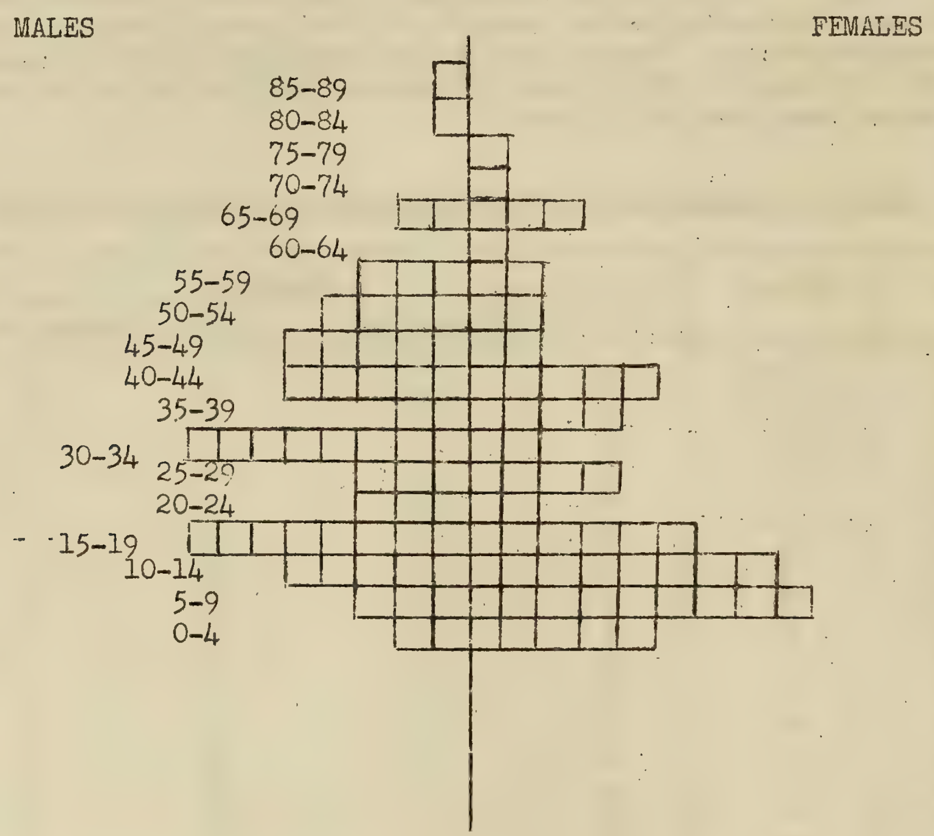


Table VI: Composition of the permanent population as to sex and age, January 1, 1950.

Age	Males	Females	Total
- 4	2	6	8
5- 9	3	10	13
10-14	5	9	14
15-19	8	7	15
20-24	3	2	5
25-29	3	4	7
30-34	8	2	10
35-39	2	4	6
40-44	5	5	10
45-49	5	2	7
50-54	4	2	6
55-59	3	2	5
60-64	0	1	1
65-69	2	3	5
70-74	0	1	1
75-79	0	1	1
80-84	1	0	1
85-89	1	0	1
Total	55	61	116

3. Inter-atoll mobility.

When living in the village on an atoll in the Tuamotus, even for a very short time, one is immediately struck by the continuous changes in the number of persons present. One week the whole population may be there, the next only a handful, a third week only the women or the older people, and so on. As these frequent variations - which of course are not shown in any ordinary population statistics - may be of great significance for understanding the economic and social system, we have also recorded them.

These population movements are of three types:

1. Intra-atoll traveling, i.e. trips to others parts of the home atoll.

2. Inter-atoll traveling, i.e. visits to other atolls.

3. Real emigration or immigration.

The intra-atoll mobility (1) depends in Raroia entirely on the economic activities and will therefore be considered in a later chapter on copra production but the other two types of mobility will be dealt with here.

In order to distinguish between inter-atoll traveling (2) and migratory movements (3), we have recorded not only the actual number of persons in Raroia at the dates of our own censuses, but also all the persons who still could be regarded as permanent residents, i.e. having their home (houses) there. The result is presented in Table VII.

If we compare the permanent population for each year in Table VII with the natural increase during the same period also according to our own records, (See Table V), we get the following series:

Date	Perm.	Actual	Natural Increase
1/1 1950	116	107	-
1/1 1951	118	95	2
1/7 1952	121	101	2
1/7 1953	123	112	4

Some interesting conclusions can immediately be drawn:

1. There is a uninterrupted steady increase of the population, as shown in the column for the permanent residents. This increase would eventually be brought out even if only the number of actual residents were counted (as during the official censuses), but for shorter periods these figures may be deceptive, as seen in the second column.

2. There is very little immigration or emigration, as shown by a comparison between the number of permanent residents and the natural increase.

3. There is a considerable mobility, as shown by the discrepancy between the permanent and the actual population.

The natural increase has been discussed in Part 2 of this section, and the figures here simply show that the general trend noticed for the period 1931-50 continues. The true migratory movement will be dealt with the next part, and some explanations of the figures in the table will therefore suffice here.

During the period 1950-53 there was only one "immigrant", a young man who took up living with a Raroian woman, built a house in the village and seemed intent on staying. This explains the increase of three persons between 1/1 1951 and 1/7 1952, when the natural increase was only two persons. Between 1952 and 1953 the natural increase was four, but two girls went to live with men, elsewhere in French Oceania, and the actual increase is thus only two. If we are to judge from our limited data, some migration to Tahiti is thus going on. The extent of it and the reasons for it will be discussed in the next part.

The general mobility, which is our main concern here, is actually much greater than the figures indicate, as they simply show the balance between the number of departed and returned persons at the given time. If instead we take into consideration not only these figures, but also who was absent at the time of the various censuses, the natives' fondness for traveling is still more evident. The difference in actual population between the 1/1 1950 and 1/1 1951 is 12 persons. The number of persons absent for longer or shorter periods during the year was, however, more than the double, or 29.

Table VII: Composition of the permanent and actual population, 1950-53.

	1/1 1950				1/1/1951				1/7 1952				1/7 1953			
Age	Perm.		Actual		Perm.		Actual		Perm.		Actual		Perm.		Actual	
	M	F	M	F	M	F	M	F	M.	F	M	F	M	F	M	F
0 - 14	10	25	9	25	11	27	10	20	15	28	9	20	17	26	15	25
15 - 29	14	13	13	13	14	13	12	12	14	12	14	12	15	13	12	13
30 - 44	15	11	15	11	15	11	13	11	15	11	16	14	14	12	14	10
45 - 59	12	6	10	5	11	6	9	5	10	6	7	5	9	7	8	7
60 -	4	6	3	3	4	6	2	1	4	6	2	2	4	6	3	5
Total	55	61	50	57	55	63	46	49	58	63	48	53	59	64	52	60

Table VIII: Number of Raroians visiting Papeete in 1950.

Age	Jan.		Febr.		Mar.		Apr.		May		June	
	M	F	M	F	M	F	M	F	M	F	M	F
0 - 14	1	1	0	2	0	2	0	2	1	3	1	0
15 - 29	0	0	1	0	0	0	2	1	1	0	0	0
30 - 44	1	0	1	0	1	0	1	0	1	0	0	1
45 - 59	3	3	2	1	3	3	2	2	1	1	1	1
60 -	0	2	1	0	0	2	0	1	0	1	1	1
	5	6	5	5	4	7	5	6	4	5	3	2
	11		10		11		11		9		5	

Age	July		Aug.		Sept.		Oct.		Nov.		Dec.	
	M	F	M	F	M	F	M	F	M	F	M	F
0 - 14	1	0	1	1	0	1	1	6	1	6	1	6
15 - 29	0	1	1	1	2	2	3	2	2	2	2	2
30 - 44	0	0	0	0	1	1	4	2	4	2	4	2
45 - 59	0	2	1	0	1	1	1	0	1	0	1	0
60 -	1	1	1	3	0	3	1	2	1	2	1	2
	2	4	4	5	4	8	10	12	9	12	9	12
	6		9		12		22		21		21	

Some of our other data are still more eloquent. Between January 1, 1950 and July 1, 1952, for instance, the following changes took place:

Out of the 107 persons on the atoll on January 1, 1950, 22 were elsewhere in French Oceania in July 1952, and 6 were dead.

On the other hand, on July 1, 1952 there were on the atoll 14 persons (Raroians and others) who lived in or visited other islands on January 1, 1950. The number of births was 10.

If we went only by the absolute figures in table, the difference between the figures for 1950 and 1952 is 6 persons. As a matter of fact, the total number of persons, who have been away from Raroia during these two and one-half years is at least 36 (22 ≠ 14)!

Of the 29 Raroians visiting other islands in 1950, 25 had Tahiti as their destination. The main reasons for undertaking a voyage to Tahiti, which may take anywhere from five days to two weeks (see Chapter III), are in probable order of importance:

1. A desire for a change and diversion.

2. Necessity of medical treatment.

3. Legal matters which must be settled.

4. A wish to see relatives.

There seems to be a seasonal pattern for these visits if we are to judge from the data collected during a single year and presented in Table VIII. The increased number of visits towards the end of the year is certainly due to the fact that the months of November and December is an off-season immediately preceeded by copra work in the most productive sector (see Chapter V). The Raroians then have considerable money and no imperative duties. The length of a visit to Tahiti is rarely less than one month, and often it is prolonged for several months or even half a year, but the limited data we have does not permit any far-ranging conclusions.

The visiting between Raroia and Tahiti is pronounced but natural with the paramount importance of Papeete. The Raroians are practically never visited in return by their relatives living in Tahiti, and other Tahitians than those employed on the schooners rarely have reason for visiting an atoll. The few Tahitians living in Raroia in 1950 were either married to Raroians or temporarily employed as workers by wealthy local landowners (see Chapter VII).

Only four of the 29 Raroians who visited other islands in 1950 had an atoll in the Tuamotus as their destination. It must be noted, however, that the frequent visits to Takume, the only atoll which can be reached by existing canoes and boats in Raroia, are not included in this figure. Neither have we recorded the great number of visits from Takume to Raroia.

It is surprising that so little visiting is going on between Raroia and the other atolls in the group (except Takume), in spite of the fact that there is a great deal of intermarriage (see next part). The explanation might simply be that Tahiti is the common meeting-ground for natives from all the atolls, and that it always is difficult to secure a passage both ways within reasonable time between Raroia and other atolls.

4. Migration and intermarriage.

The figures in the previous sections indicated that some real migration occurred, although the period for which we had data was too short to permit any general conclusions as to its extent. The only way to get any additional information and the necessary time perspective seems to be to investigate the geographic origin of the population and to study family stories, both of which methods we have tried. The geographic origin, defined as the home-place or permanent residence of the parents, is shown in the following table:

Table IX: Geographic origin of population, 1/1 1950.

Origin	Male	Female	Total
Raroia	34	43	77
Tuamotu	5	8	13
Tahiti	9	5	14
Moorea	0	1	1
Raiatea	2	0	2
Total	50	57	107

There are thus 16 "foreign" men and 14 "foreign" women in the atoll, all from the Tuamotus and the Society Islands, or from two out of the five groups in French Oceania. That there is no intermarrying with the Marquesas is not too surprising, as the natives of this group speak their own local dialect and have somewhat different customs, but why the Austral Islands and Mangareva are not represented is difficult to explain.

If we now consider the marital status of these "foreigners" we find the following. Out of the total number of 16 "foreign" males, 13 are married to Raroian women, 1 is the widower of a Raroian woman, 1 is an adopted baby, and only 1 is married to a woman who is also a "foreigner". Out of the total number of 14 "foreign" women, 8 are married to Raroian men, 2 are widows of Raroian husbands, 3 are adopted young girls, and only 1 is married to a "foreign" male.

Immigration into Raroia is thus intimately linked with marriage. This intermarrying has probably been constant over the years, which is shown by the fact that of these 24 marriages between a Raroian and a "foreigner" (13 + 1 males and 8 + 2 females), 15 were contracted more than 10 years ago and 9 since then.

A corresponding emigration is going on all the time, too, as a perusal of the family stories and genealogies indicates, but the extent of it is of course impossible to ascertain with the same exactness, and we have not tried to compile any statistics.

The main reason for these frequest inter-atoll alliances is the continued operation of the pre-European incest rules, which forbid marriage between all persons more closely related than third degree cousins. As the population is small, most families are closely related and the common practice of adoption, which has the same force as actual blood ties, still further reduces the number of "unrelated" people, the possibilities for an individual to find a sexual mate and marriage partner in the home island are thus considerably limited. The same conditions are prevalent on all the other atolls in the group, and there is therefore every reason to suppose that in the long run the emigration from Raroia is compensated by an equally extensive immigration to the atoll.

The residence rule is bilocal and neolocal, and the actual choice of dwelling place seems to a large extent to be determined by economical considerations, i.e. the home atoll of the partner who possesses the more land is usually preferred. In all probability both sexes are therefore represented in approximately the same number among the emigrants. This is rendered still more likely by the fact that the number of male and female immigrants is roughly the same for the period covered by Table IX.

5. Race mixture.

An inevitable result of the frequent intermarriages between Raroians and other islanders is of course a progressive race mixture. In section A. 2 of this Chapter the number of mixed Polynesians in Raroia was, according to the census of 17/18 September 1951, only 12, while the remaining 97 natives were listed as pure-blooded, and the number of Chinese was 2.

These figures were based solely on the verbal declaration of each person, and thus of doubtful reliability. We tried therefore to determine the number of mixed persons on a more exact basis, viz. the pedigree of each individual. Contrary to the situation in other parts of French Oceania, the islanders in the Tuamotus (especially in the eastern half) almost all possess genealogies going back at least to the time of the first contact with other racial groups. We have gone over each individual's pedigree in Raroia and marked off all persons of non-Polynesian extraction, and, depending on the nearness to these ancestors, the degree of intermixture has been fixed for every islander present on January 1, 1950.

Persons who did not know their genealogies (mostly Tahitians) and Tahitians found in the pedigrees have arbitrarily been counted as having 1/8 foreign admixture. Persons with less than 1/8 foreign admixture have been counted as pure Polynesians. There may still be some hidden intermixture, but as the islanders seem to keep track of all adulterous children and usually without hesitation indicate the real father, this source of error is negligible.

The result of the classification of the Raroians according to this considerably more rigorous, although of course not completely satisfactory, definition of racial purity is shown in the following table:

Table X: Racial composition of the population on January 1, 1950.

Race	Males	Females	Total
Pure Polynesian	34	39	73
Pure white	0	0	0
Pure Chinese	1	0	1
Mixed Polynesian-White	14	15	29
Mixed Polynesian-Chinese	1	1	2
Mixed White-Chinese	0	2	2
Total	50	57	107

The number of mixed persons is thus altogether 33, or almost three times higher than the figure based on the verbal declarations, which was 12 (see Section A, part 2). That the mixed persons are justified to a large extent in identifying themselves with the group of pure Polynesians is however proved by the fact that the admixture is very slight in most cases, as shown in the following table.

Table XI: Extent to which the mixed persons are Polynesian, Jan. 1, 1950.

Degree Polynesian	Males	Females	Total
7/8	5	5	10
3/4	2	7	9
1/2	5	4	9
1/4	3	2	5

The many varying degrees of intermixture show that the intermarrying between the various racial groups has gone on for a considerable time. A still better way to follow the trend backwards is simply to classify all the mixed persons according to age, which is done here:

Table XII: Age of the mixed persons in Raroia, January 1, 1950.

Sex	Age			Total
	0-14	15-44	45-	
Male	2	10	3	15
Female	9	6	3	18
Total	11	16	6	33

The distribution of mixed bloods over all three age classes in a number roughly proportionate to the total number of persons in each age group (see Section A, part 4), shows definitely that racial mixture first appeared several generations ago, and that it still occurs to a large extent. It is very likely that this process evenutally will lead to the same thorough changes of the islanders' physical characters as those which have taken place in so many other Polynesian groups.

This logically brings up the question of how representative are physical measurements taken today on living Polynesians for determining the racial type of the <u>pre-European</u> population. We have measured the total adult population and shall present the result in a separate study. No attempt will therefore be made to discuss this problem here. It may, however, be worth while mentioning that the cephalix index is considerably lower for the group of individuals classified as pure Polynesians according to our criterion than for the <u>total</u> number of adults in the atoll.

Chapter III

ANNUAL CYCLE OF EVENTS IN 1950

January	1st	Sunday. Whole population in village.
	2 - 10	Repair work on the wharf and preparations for an expected visit by the governor. Rains and calm.
	13	The administrator of the Tuamotu group visits Raroia.
	middle	Some of the islanders begin to prepare copra in the Raro sector on the southwest side of the atoll.
	16	Schooner loads copra.
	21	Schooner loads copra.
	end	Half of the population works in Raro.
February	beginning	Strong wind. Between half and three fourths of the population works in Raro.
	middle	Heavy rains.
	16	Schooner loads copra.
	22	Schooner loads copra.
March	beginning	The work in Raro continues.
	19-21	Schooner loads 18 tons in Raro, the whole population back in village for several days. Many persons drunk.
	end	Work continued in Raro.
April	1st	Whole population back in village for Easter.
	2 - 7	Complete calm.
	6	Two schooners load copra.
	7	Good Friday.
	10-11	Three schooners load copra.
	end	First shoals of Selar crumenophtholmnus appear, and many postpone their departure to Raro.

May	beginning	About a fourth of the population works in a new copra sector, Gake.
	7 - 8	Schooner loads copra.
	15	Schooner loads copra.
	14	Jeanne d'Arc celebration. The whole population in village.
	middle	Numerous shoals of Selar crumenophtholmnus. Heavy rains and winds.
	18	Ascension Day. The whole population still in village.
	end	Most people back in Gake.
June	whole month	Shell diving by a small number of men.
	beginning	A few families continue the work in Gake
	3 - 6	Three schooners load copra.
	7	The missionary arrives. The whole population in village.
	16	Schooner loads copra.
	18	De Gaulle Day celebrated. Restaurants and wheel of fortune. The celebrations continue a week.
	second half	The turtles begin to appear.
	27 - 30	Schooner loads copra in Gake.
	30	Communion for the children. The whole population in village.
July	whole month	Shell diving by a small number of men.
	beginning	Strong wind. The whole population stays in village waiting for better weather and provisions. Turtles frequently caught.
	middle	No food and very little water left. Most people live on fish and coconuts.
	14	French National Day celebrated. Restaurants and wheel of fortune continue a week.
	23 - 24	Schooner arrives with provisions.
August	beginning	Some families return to work in Raro. Many men chase turtles.
	15	Assumption celebrated. The whole population in village.
	18	The missionary leaves.
	end	Calm. Impossible to return to Raro. The men on turtle hunt.

September 1st	Schooner loads copra. Visit by the deputy.
12	The administrator of the Tuamotu group visits Raroia. The whole population in village.
middle	The turtle season over.
rest of the month	Three fourths of the population works in Raro.
October beginning	Three fourths of the population still in Raro.
15 - 19	Two schooners load copra. Everybody plays card. Many drunk.
end	Most islanders work again in Raro.
November whole month	The lands around the village worked. Everybody permanently returned to the village.
8 - 10	Schooner loads copra.
middle	Bird catching and egg collecting begin and last until the end of the year.
11	Armistice Day celebrated. Wheels of fortune and restaurants. The celebration continues two weeks.
end	Strong wind.
December whole month	Everybody in village making copra on the adjacent lands.
middle	Rest period.
20	Christmas celebrations begin and last until the end of the year.

Schooners calling at Raroia in 1950.

The schooner calls are such important events in the annual cycle and play so vital a part in the islanders' lives, that we have decided to present here separately the complete data on the frequency of the schooner communications with Papeete.

There is no boat or schooner in Raroia seaworthy enough to carry people or freight to Papeete, and the few canoes or boats in existence can not even be used for visiting other atolls in the Tuamotu group with the exception of the neighbour atoll of Takume. The Raroians depend therefore for traveling and transport exclusively on the trading schooners belonging to private owners or (in one case) to the Tuamotu Co-operative Society.

The total number of boats calling at Raroia in 1950 was 38. Of these three were administration schooners and one a naval hydrographic ship. The Raroians had thus 34 opportunities to sell copra and to buy merchandise. (Which was more than enough from the commercial point of view as the islanders had copra to sell only to 24 of the schooners.)

All the trading schooners have their base in Papeete and return there after each cruise to unload the copra and take aboard a new stock of merchandise. This does not necessarily mean that the islanders had 34 opportunities to go to Papeete during the year. Practical and economic considerations reduce seriously this number. A trading voyage to the Tuamotus usually lasts from four to six weeks, and in some instance when the schooner visits also the Marquesas or Mangareva, it takes at least two months. Since the passengers pay so much per day for their transportation, the itinerary of the schooner <u>after</u> it leaves Raroia is of considerable importance. Thus it can be seen that all the schooner calls cannot be regarded as of the same value to the islanders, and we have therefore classified them according to the practical opportunities to travel which they offer. (See Table XIII.)

Let us first consider the opportunities to take passage <u>from Raroia to Tahiti</u>. The important factor here is of course the length of the voyage, and we have therefore separated the 34 schooners calling at Raroia into two groups: Those which call at Raroia at the beginning, and those which call at Raroia towards the end of their cruise. (Called respectively "Coming" and "Returning".) If we disregard all the schooners in the first category, as the Raroians do themselves, the number of opportunities to go to Papeete is immediately reduced to 14. (Whether the schooner's call is announced beforehand over the radio is of no importance in this case, as the islanders are ready to leave at any time.)

The number of occasions to travel in the opposite direction, <u>from Papeete to Raroia</u>, must also be reduced. None of the schooners follows a regular schedule or a fixed itinerary, but the atolls where the schooner is to call are announced for each voyage over "Radio Tahiti". Depending on the circumstances and information gathered during the cruise the itinerary, may, however, be changed, some atolls by-passed and additional ones visited. For Raroians who want to take passage from Papeete the only communications on which they can depend are of course the schooners which have announced that they have included Raroia in their itinerary, and the fact that other schooners may call there eventually does not help them the slightest. When the announced schooners coming from Papeete are separated from the unannounced ones, the number of practical opportunities for transportation is reduced from 20 to 12.

For Raroians who wanted to go to Tahiti in 1950 there was at least one schooner a month, except during the months of July and December, and the average number of opportunities per month was 1.2. For Raroians who wanted to return to their home island from Papeete, there were no schooners during the months of March, May, July and August, and the monthly average was only 1.0.

These relatively rare and irregular communications with Papeete are certainly to a large extent the cause of the retarded development of certain aspects of the economic and social life in Raroia. The results of these "lags" will, where possible, be studied in their relation to the culture as a whole in subsequent chapters.

Table XIII: Number of trading schooners calling at Raroia in 1950.

Month	Total	Coming from Papeete		Returning to Papeete	
		Announced	Unannounced	Announced	Unannounced
January	4	1	2	-	1
February	3	1	1	1	-
March	2	-	1	-	1
April	6	2	2	-	2
May	3	-	-	1	2
June	5	3	-	-	2
July	1	-	1	-	-
August	1	-	-	1	-
September	4	2	1	1	-
October	2	1	-	1	-
November	2	1	-	-	1
December	1	1	-	-	-
Total	34	12	8	5	9

Chapter IV

LAND OWNERSHIP

1. Historical background.

The problems of land ownership are serious and extremely complex in Raroia as everywhere else in the Tuamotus, and a special study would be required in order to throw full light on them. We have lacked the time for this, and the following is therefore only a rapid survey of the situation with some general observations.

At the root of all difficulties is undoubtedly the rapid change of the economic system without corresponding necessary adjustments in land usage and ownership. Before the rise of the copra trade, each atoll was divided into districts, which belonged to the extended family units, and even if there was some rivalry over the food resources, certainly no disputes occurred within each district concerning the land itself.

When, however, during the second half of the last century (see Chapter I), the natives began to realize the value and advantage of making plantations of coconut palms, they also gradually became "land-conscious" and wanted to secure the exclusive rights to the profit from the lands they had planted. This created considerable friction, and the situation soon became very confused.

When France finally established undisputed sovereignty over the Tuamotus in 1880, an attempt was immediately made to create order and to introduce legal procedures. Committees of prominent natives were created in all the atolls - in Raroia in 1883 - which were to examine thoroughly the question of land ownership.

The basic principle governing the work of these committees was that legal title to land should be given only to the individual who could prove by reciting his genealogy that he belonged to the extended family, which occupied that land in pre-European times. When there were conflicting claims, the ownership was to be attributed to the person with the closest genealogical affiliation with the founder of the lineage occupying the disputed land. This principle was generally respected by the natives, and the genealogies for each district were officially recorded in public books, which henceforth were to be the basis of all land settlements.

The committees were furthermore charged with the task of making accurate surveys and determining the boundaries of each parcel. (A work for which they were poorly equipped and prepared and therefore could not perform properly.) In each case the documents were sent to the Land Bureau in Tahiti, and once confirmed by publication in the official journal and registered at the bureau they had legal validity.

This arrangement seems at first glance adequate, but a basic injustice was inherent in it. Many epidemics and diseases had already ravaged the group, and a great number of people had died in Raroia as elsewhere in the Tuamotus.

The population decrease was naturally not proportionate in all the different districts into which the atoll was divided. Thus while in one district only some few persons had survived, in an other of approximately the same size, there were perhaps ten times as many survivors. As assigning of land titles was based on genealogical affiliation with the lineage occupying the district, in the former case each individual got a considerable piece of land, whereas in the latter, the allotment for each individual was diminutive.

Leaving the question of equitable distribution aside, the problem seemed nevertheless to be satisfactorily resolved. New difficulties arose soon, however, and they were principally of two kinds:

1. Due to the instability of the marriages, the complexity of the relationships and the uncertain status of the various children (legal, illegal and adopted), the inheritors preferred in many cases to cultivate the land in common in accordance with old native custom. In this way the clear titles established in 1883 were already confused after one or two generations.

2. In other cases the existing land was carefully divided up among all inheritors, which meant that the land parcels continuously increased in number, grew smaller and became more widely scattered. A family which in one generation applied this principle, might in the next adhere to the first, which of course did not make the situation any better.

The only possible remedies would have been: in the first place to settle the inheritance questions after each death, and in the second place to redistribute and concentrate the land holdings through buying and selling. These solutions, which are applied regularly in countries with Western economic and legal systems, have not been tried by the natives. The reasons for this are probably the following:

1. The natives have still not adopted a commercial attitude towards land, but regard it as inalienable, as did their ancestors.

2. Many of the land surveys made by the committees in 1883 were faulty and could never be used as a basis for commercial transactions.

3. Many of the titles established in 1883 were never registered for one reason or another, and others were lost at the Land Bureau in Papeete during the cyclones of 1903 and 1906. Therefore no one knows any longer who is the owner of these lands, and they can not be traded.

4. The natives are completely ignorant and even suspicious of Western legal procedures. Furthermore they have to go to Papeete each time, even for legalizing a will, which makes them still less inclined to have recourse to the law.

The situation has gradually deteriorated, and today the atoll is split up in innumerable parcels of iridculously small size; each owner's land holdings are extremely scattered and very few Raroians have clear titles or any titles at all to the land they use. As a result there are many disputes, much time is lost in traveling between the scattered lands, and long stretches of land are not planted, as nobody knows who the owners are. When we subsequently speak of ownership, de facto occupancy is thereby meant.

2. Present situation.

The total number of land parcels outside the village, where the conditions of course are different, is in Raroia approximately 1,000 for a total vegetated area of 921 hectares. Theoretically the barren parts of the atoll rim have owners, too, but as nobody is interested in these portions and no reliable information concerning ownership could be obtained, they are not included in the total number of land parcels above.

Of the 921 hectares of vegetated area, 334 are covered with other vegetation than coconut palms (see Chapter I), which probably indicates the approximate proportion of disputed lands or lands without known owners. The average size of each parcel is thus less than one hectare, and few seem to surpass or fall below this figure. There are maybe 20 or 30 land holdings bigger than 2 hectares, but on the other side, even many of the 75 islets with a vegetated area smaller than one hectare are divided up between two or more owners.

The greatest land holdings exist on the five big islets with the notable exception of the islet where the village is situated. We have surveyed three of these islets: Tetou on the east side of the atoll, Teputaiti, south of the village, on the west side, and the whole stretch of land north of the village. The figures for these islets are:

Tetou	18 hect.	19 parcels
Teputaiti	63 hect.	52 parcels
North of the village	27 hect.	63 parcels

How much land, measured in hectares, each individual owns unfortunately can not be computed with any exactness, as no detailed map of the atoll exists and titles are lacking for a great number of lands as mentioned above. In order to get at least a rough idea of the distribution of the land, we have chosen to use as a basis for our estimate the amount of copra produced by each adult individual on his own lands during a year. As these figures are complete and reliable, we think that they give a better picture of the situation, than simply a list of the number of land parcels owned by each person.

Table XIV shows the annual production of copra for each adult individual (above 20 years of age) in Raroia.

Table XIV: Land holdings in Raroia as judged from production figures.

Annual production in tons	Number of producing		Total number of persons	Total number of tons
	Males	Females		
0	16	13	29	0
1	2	1	3	3
2	3	2	5	10
3	2	4	6	18
4	2	3	5	20
5	2	2	4	20
6	2	2	4	24
7	3	0	3	21
8	1	2	3	24
9	3	0	3	27
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0
13	1	0	1	13
Total	37	29	66	180

The difference between the total annual production of copra, 187 tons (see Chapter V, 8), and the figure above, 180 tons, is due to the fact that some few individuals who own land in Raroia live elsewhere in French Oceania. But as a person, who migrates to another island, as a rule can not depend on his remaining relatives to send him money from the produce of his lands, the actual number of absent land owners is probably somewhat higher than the statistics indicate.

The group of landless persons is principally made up of "foreigners", i.e. natives from other islands in French Oceania, married to Raroians. The only exceptions are two "foreigners" who were adopted young and given land. A yound Raroian man or woman customarily receives a parcel of land from his or her parents when marrying, and as the Raroians marry young, all men and women above 20, with one exception, also have their own lands.

3. Concrete examples.

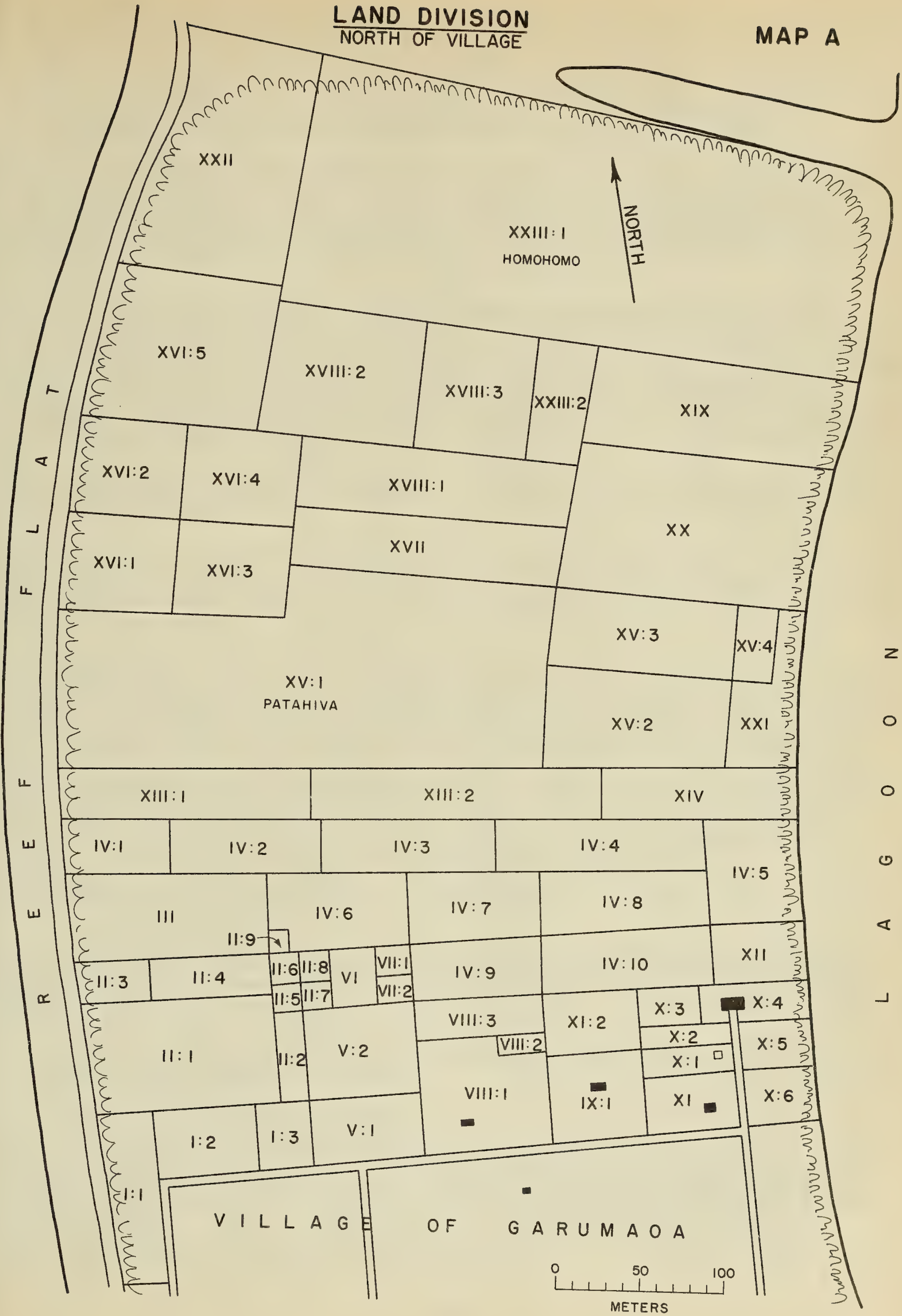
In order to give a concrete example of how confused the land question is in all its aspects, we include finally here more detailed data for one section of the atoll. The section is the northern part of the islet on which the village is situated, and it measures roughly 450 x 600 meters. We surveyed it simply by pacing in company of the members of the village council who indicated the boundaries of the land holdings. The result is shown on the accompanying map (Map A).

The total number of land parcels for this section, measuring 27 hectares, is 63. Many of the parcels have identical names, and altogether there are only 23 names for these 63 parcels. This fact seems to indicate that larger land units have been divided fairly recently. This is also the opinion of the natives, who claim that the splitting into smaller units has occurred since the official survey in 1883.

In order to verify this and to study more in detail the changes which have taken place since 1883, we have searched through the entire register for Raroia at the Land Bureau in Tahiti. That the register is incomplete was immediately shown by the fact that titles for only 19 land parcels in the chosen section were found. These 19 parcels totalled roughly 10 hectares, whereas the section actually measures 27 hectares! For almost two thirds of the land there are thus no titles at all.

Of the 23 land names in use today 8 were found in the register, and the number of parcels with identical names were in 1883 and 1950 respectively:

Land on the map no.	Number of parcels	
	1883	1950
IV	3	10
V	1	2
X	3	6
XV	1	4
XVI	3	5
XIX	2	1
XX	3	1
XXIII	1	2
Total	17	31



LAND DIVISION
NORTH OF VILLAGE
MAP A
NORTH
XXII
XXIII:1
HOMOHOMO
XVI:5
XVIII:2
XVIII:3
XXIII:2
XIX
XVI:2
XVI:4
XVIII:1
XX
XVI:1
XVI:3
XVII
XV:3
XV:4
XV:1
PATAHIVA
XV:2
XXI
XIII:1
XIII:2
XIV
IV:1
IV:2
IV:3
IV:4
IV:5
III
IV:6
IV:7
IV:8
II:9
XII
II:3
II:4
II:6
II:8
VI
VII:1
IV:9
IV:10
II:5
II:7
VII:2
X:3
X:4
VIII:3
XI:2
X:2
X:5
II:1
II:2
V:2
VIII:2
X:1
VIII:1
IX:1
XI
X:6
I:2
I:3
V:1
I:1
VILLAGE OF GARUMAOA
0 50 100
METERS
REEF FLAT
LAGOON

That a considerable fragmentation really has taken place during the last 70 years is thus amply demonstrated for our sample, and everything seems to indicate that this is a general trend in Raroia, and probably also in the Tuamotus as a whole. Subdivision of lands had, however, in all likeness also occurred in post-White time previous to 1883, as the situation already then was at variance with the old Polynesian principle: one land - one name.

Out of the 17 land parcels for which titles were found in the register, 16 had single owners, and one had three brothers as owners in 1883. The situation was thus surprisingly clear at the outset, but during the intervening 70 years it has become so confused that it now is almost impossible to trace the history of many of these parcels with certainty.

We have interrogated all the individuals at present regarded as owners of the 63 parcels into which the section (Map A) is divided. They are at least 150 in number - we gave up at this point of sheer exhaustion - but many of them are of course identical, as the same person frequently claims more than one parcel. It would be useless to repeat the explanations of each individual as to how he establishes his claims, as they are too conflicting and fragmentary, and we shall therefore only give a few examples.

Let us for instance take land no. IV (Map A) and cite the case stories of a couple of parcels:

<u>Parcel 1</u> is owned by a person "A" and his sister who lives in Takume. Their right is, however, violently contested by three second degree cousins. "A" makes the copra, but does not send any money to his sister. He has no title to the land.

<u>Parcel 2</u> is owned by a woman who received it in the following way: Three generations ago there lived in Raroia a couple who possessed a great number of lands. The two daughters "B" and "C" inherited all the lands, but did not divide them up between themselves. "B" died first and left four children, but her sister "C" took control of all the lands. "C" had no children and before she died she distributed the lands among her nieces, the four daughters of "B". The first received 30 parcels (among them the one in question), the second 27, the third 6 and the fourth 5. The reason for this unequal distribution is said to have been that the two first nieces were the favorites of "C". The husband of "C" received nothing. He is still alive but does not seem to have any objection to the arrangement. No title exists.

<u>Parcel 4</u> is owned by a single person. There is a title to the land, or at least a title, which with some benevolence could be interpreted as describing this parcel, but the owner is not able to prove his relationship with the original owner, in whose name the title is issued.

<u>Parcel 5</u> is disputed by half a dozen persons with conflicting versions of the legal and genealogical facts.

And so on and on <u>ad absurdum</u>.

It is of course outside the scope of the present study to try to indicate definite solutions to the problem, but it must be mentioned that a prescription law, granting title to a person after 30 years of uninterupted and uncontested occupancy of land, has been applied elsewhere in French Oceania in troublesome cases. Such a solution requires, however, first a detailed land survey and careful examination of the situation.

SURPLUS PRODUCTION

The main feature of the economic system in Raroia is the extreme dependence of the population on one single source of income, the copra crop, and the startling degree to which the islanders have abandoned the old direct subsistence activities in favour of a surplus economy. It is therefore only logical to begin the description of production in Raroia with the activities directed at the creating of a surplus, and leave the treatment of the other economic activities until a later chapter.

Due to the infertile soil and the limited natural resources there are few products of an atoll like Raroia on which a surplus economy dependent on the world market could be based, and the only ones which have been tried so far are the sea slugs, the mother of pearl shells and the copra. Of these the copra has gradually become of paramount importance. For almost a century beginning in the 1830's there was a regular export of sea slugs, and many natives in Raroia and other atolls regularly dived for and prepared sea slugs for export. Since the last world war the Chinese market has, however, been closed, and the consumption of the local Chinese population in French Oceania (about 7,000) is so limited that nobody finds it worth-while to collect sea slugs any more.

A. Mother-of-Pearl Shell-Diving.

The diving for mother-of-pearl shell began almost simultaneously with sea slug collecting, but whereas the sea slug collectors worked individually and sold their product to the traders, the pearl shell collecting was organized largely by foreign merchants, who hired natives to do the diving. In the beginning the numerous pearls were a more important source of income than the shells themselves, but today pearls are extremely rare, due to the frequent diving, and a negligible source of income.

There is some danger that the supply of shells may become exhausted. Strict measures have been necessary to preserve the beds. Diving is permitted now only at certain atolls during limited periods in well defined sectors. As the shells grow only under specific conditions they are not found everywhere in the group. The actual number of highly productive lagoons (above 100 tons per season) is not more than five. The number of lagoons of secondary importance (among them Raroia) is seven. In Raroia diving is, however, difficult as the lagoon is rather deep, 75-150 feet, and only the most skilled divers can share in this source of incoem.

Sometimes during the open diving seasons a limited number of natives from other atolls come to Raroia in order to participate in the diving, and the last time this happened in 1947 the total amount of shell gathered was 11.7 tons. The Raroians contribute, however, only a small proportion of this amount. The number of Raroians diving during the two months the season lasted in 1950, when no natives from other atolls participated, was only eleven. The total amount of shells collected was 2,742 kgs, or an average of 236 kgs per diver. Since the sums earned in this way are insignificant (in spite of the high 1950 price of 30 francs a kilo) compared to their copra earnings, the men do not take this diving in the home atoll seriously, but combine it with fishing or do it mostly for fun.

Like all other natives in French Oceania, the Raroians may participate in the diving permitted seasonally every year in certain of the other atolls in the Tuamotu group. As a rule few of them find it worth while, in spite of the huge sums a good diver can earn. When the neighbouring atoll of Takume is open for diving, however, almost the whole population migrates there. The reasons for this preference for Takume are very simple. The atoll is so close to Raroia that it can be reached with outrigger canoes, and the lagoon is so shallow that even inexperienced divers and women can participate. Furthermore it is enclosed, which means that there are no dangerous sharks.

No diving occurred at Takume during 1950, when most of the data for the present study were collected, but in July-September 1952, when we revisited the atoll with the other members of the Pacific Science Board's team, diving was going on, and we gathered some additional information.

The tendency to migrate to Takume in whole family groups seemed very pronounced, as seen by the following table showing the number of Raroians living in Takume during the middle of the diving season, on September 8, 1952:

Age	Males	Females	Total
0 - 14	5	14	19
15 - 29	9	8	17
30 - 44	13	9	22
45 - 59	5	3	8
60 -	2	1	3
Total	34	35	69

About two thirds of the total population of Raroia lived at this time thus on Takume, and all except the children below 14 were more or less actively engaged in the diving. Those left behind in Raroia were mainly small children and old people.

The income derived from diving is good by any standard. An adult male can collect between 50 and 100 kilos of shells per day, and a woman or younger man at least half that amount. We have no exact figures for the total income of the Raroians, as we visited Takume only once. The diving was still going on when we left, but we have tried to make a rough estimate based on information volunteered by the divers themselves.

As a rule the divers do not stay the full season of four months on Takume, but relax from time to time and return to Raroia. Between 45 and 60 days of actual diving per individual per season is therefore a fair guess. As

As the price paid for the shells varied between 30 and 45 francs a kilo, a good diver should have earned around 200,000 francs ($3,175) and a woman or young man half that sum during a season.

It must, however, once more be stressed that the diving is a strictly seasonal activity; that the prices fluctuate greatly; and that most of the money earned is immediately spent. In spite of the big occasional income a Raroian may derive from shell diving, it plays nevertheless a subordinate part to copra growing and preparation in the economic life of the islanders.

A special study of the diving is highly needed, not only from the economic point of view but also for clarifying certain social processes, as a great deal of acculturation takes place during visits to atolls during the diving season. The limited time and the concentration of our work on one atoll, has hitherto prevented us from studying this interesting complex. We hope it will be possible to do this sometime in the future.

B. Copra Production.

As the base of the economy and the only regular source of income, copra production, has profoundly influenced all aspects of the natives' lives. We have therefore judged it more appropriate and convenient to treat here in its functional context not only the purely economic activities related to copra growing, but also the interrelation and interdependence among these and other activities or aspects of the culture. We have also found it useful to include a short outline of the historical background.

1. The rise of the copra trade.

Contrary to the present situation, there existed in the Tuamotu group in pre-European times very few coconut palms, and on uninhabited atolls there were no coconut trees at all. This fact is proved not only by the numerous native traditions but also by the observations of the first European visitors to the group.*

This relative rarity of palms, which has surprised many anthropologists, is easily explained if we consider the smallness of the atoll populations and the productivity of the coconut palm. With three or four exceptions there were only some hundred inhabitants on each atoll in pre-European times, and as each palm produces at least 50 nuts a year, 20 to 30 palms amply provided for an individual's needs. Spread out over the whole atoll in accordance with the scattered habitation pattern, the few thousand palm trees required by the inhabitants, were thus easily lost among the other vegetation. This other vegetation consisted principally of pandanus palms, which gave the natives an equally if not still more important crop in the form of highly nutritive nuts.

The first traders who visited the atolls from the 1830's and onward were principally interested in sea slugs, pearls and shells, as already mentioned, but gradually they began also to encourage the natives to plant more palm trees, and many of them even brought sprouting nuts from Tahiti and had barren atolls

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*For a list of these see Introduction.

planted with them. The missionaries proselytising in the group during the second half of the century accelerated further this trend and many times even directed the planting themselves. The result was that at the turn of the century on practically all atolls the pandanus and other vegetation had been replaced extensively with palm trees.

At the beginning the oil was extracted on the spot and exported in barrels, which was a somewhat wasteful and inefficient procedure. The introduction in the 1870's of the simple method of drying the meat of the nut, which then was exported undoubtedly gave the planting and the trade further impetus.

2. Change of settlement patterns.

In pre-European times the population of each atoll was fairly evenly spread out over all the inhabitable land, and each extended family had its own section of the land and lagoon. Ownership was invested in the family as a whole. The use of the products was decided by the head of the family group after more or less democratic deliberation with the other members.

An important change in residence pattern was effected during the second half of the century, when the natives were gradually converted by European missionaries, who for practical reasons persuaded the natives to group themselves together in villages. The scattered habitations had not been an obstacle for the ancient religion, as each family had its own priest, and cult places were easily constructed wherever needed. But with only one missionary priest for each atoll, who could visit it only for limited periods each year, and a single church building, the concentration of the population became a necessity.

The traders, too, preferred to have the natives gathered in one place, and that trading possibilities were deemed important by the natives is shown by the fact that many of the new villages were built near the pass or ship landing place of the atoll.

Another fact which certainly also contributed to accelerate the change in settlement pattern was the population decrease due to the ravages of newly introduced diseases. It was only natural for the surviving members in each section to seek each others' company, especially as with the advent of the new order many old hostilities and suspicions between the local groups had disappeared.

The main reason for the scattered distribution of population all over the atoll, had of course in pre-European times been economic: the food-resources were more easily and thoroughly exploited in this way. A logical consequence of the abandonment of the ancient dwelling sites and concentration into a village, was therefore the development of a new type of economy. Here the contact groups, the missionaries and traders, had handily something new to offer. The surplus copra crop provided the natives with money to buy food on the schooners and thus made them independent of the local supply of food. So interrelated was the type of habitation with the type of economy, that certainly no re-grouping of the population would have been possible, had it not been correlated with a change of the economic life.

3. Sectors and seasons.

For the purpose of making copra, the atoll is divided into several sectors (Map B), which are visited in turn simultaneously by all land owners, according to a previously agreed-upon rotation system. The main reason for this system is the scattered distribution of land holdings which makes it virtually impossible for the owner to watch his parcels from the village where he lives, and to prevent the theft of nuts. The system has an ancient taboo practice at its basis, and the same word, rahui, which formerly was used for trees periodically set aside, is now used for the sectors.

A certain sector is declared open for copra work for a well defined period by the chief after close consultation with the village council (and frequently the whole population). The owners who have land in this sector - and usually all have at least one parcel - sail over from the village and establish themselves somewhere in the sector until the work is done, whereafter they return to the village and await the opening of the next sector.

The number and boundaries of sectors vary somewhat, but at the beginning of 1950 there were three, called Raro, Village and Gake. Raro (I) comprises all the land south of the islet on which the village is situated. The village lands (II) stretch from there to the pass. The rest (III) which thus includes both Tokerau, Gake and Kereteki, forms the remaining sector, which takes the name Gake (see Map B).

The sectors are open for work 2, 3 or 4 months depending on the prospects for the harvest and the land holdings of each person. The round of all sectors is usually made in eight months, and some adjustments have therefore to be made to the annual weather seasons.

In November and December 1949, the islanders worked in Gake. According to their previous agreement, they should therefore have continued to work the sectors in the following order in 1950:

I. Raro — 4 months (January-April)

II. Village — 2 months (May-June)

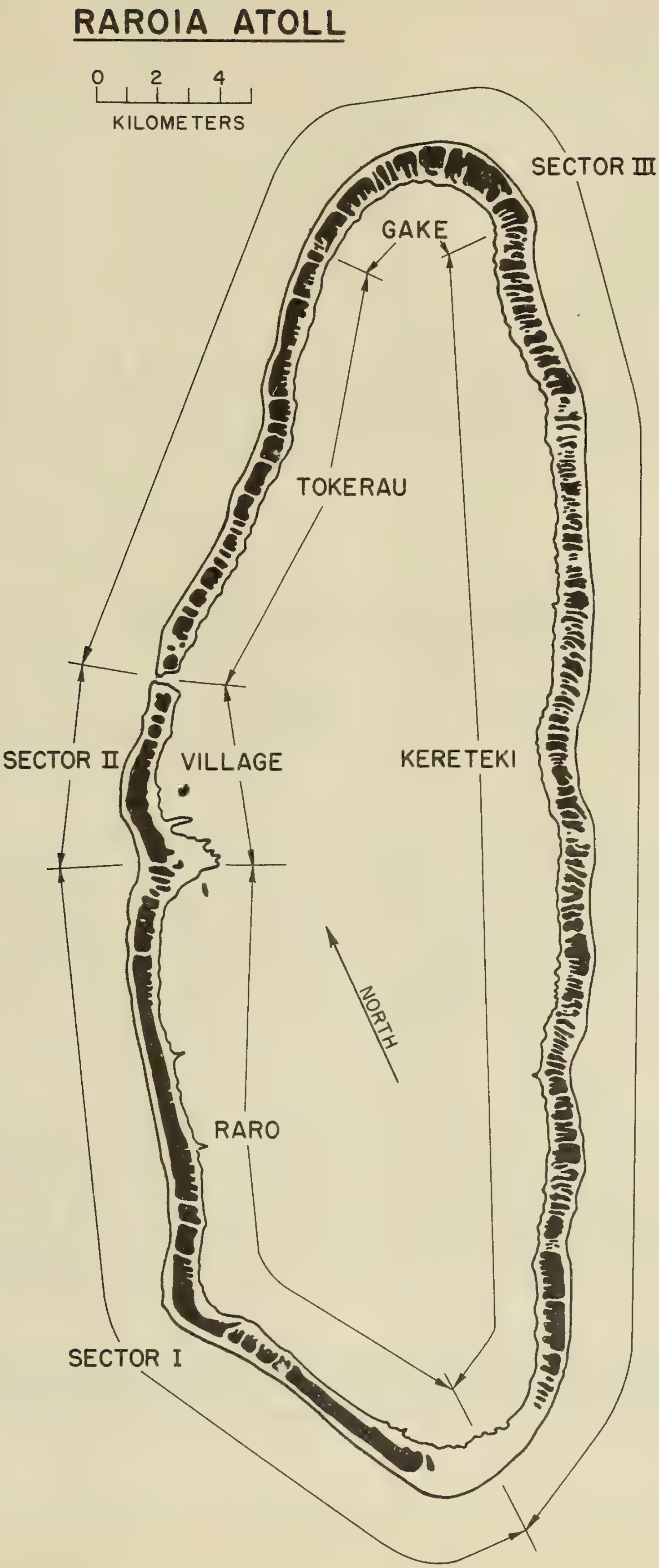
III. Gake — 2 months (July-August)

And beginning the cycle anew:

I. Raro — 4 months (September-December)

According to the schedule the islanders worked the Raro sector during the first 4 months of the year, but already by April it was decided to change the sequence and work the Gake sector before the village lands. The next change in the schedule was made in June, when the Raroians discovered that there was an unusual abundance of nuts in Raro. They decided immediately to return there in July instead of working the Gake sector. The period was eventually extended to the end of October. After the termination of the work in the Raro sector, the population decided suddenly to change the schedule completely. The atoll was now divided into only two sectors, Raro and the rest, and work was to be done 4 months at a time in each sector.

MAP B


RAROIA ATOLL
0 2 4
KILOMETERS
SECTOR III
GAKE
TOKERAU
SECTOR II
VILLAGE
KERETEKI
NORTH
RARO
SECTOR I

Not even these modified schedules were adhered to, and the time was actually divided between the sectors in the following way in 1950:

January	Raro
February	"
March	"
April	"
May	Gake
June	"
July	Raro
August	"
September	"
October	"
November	Village
December	"

That rigid working programs are and cannot be followed is not surprising, as they do not leave room for other activities, religious and civil celebrations, seasonal fishing, bad weather and so on. How closely the copra work actually depends on other activities and events will be shown in the next chapter.

4. Interdependence of activities.

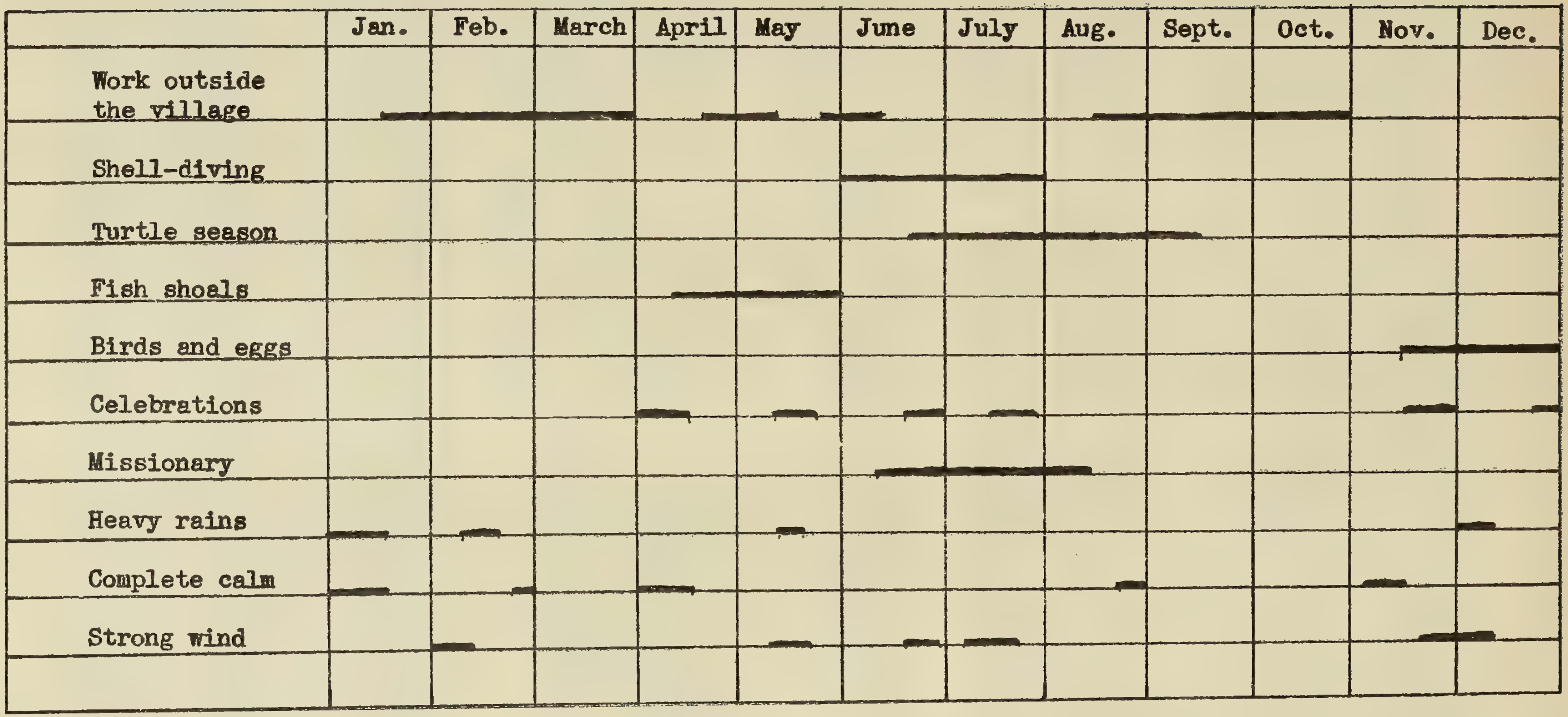
Some important interrelationships are immediately brought out by the plotting of the main activities in the accompanying chart (Table XV). In order to determine the possible influence of the weather, all periods longer than five days of heavy rains, complete calm and strong wind have been indicated. The stress here is on the interdependence of the activities, and for more detailed information on the various events during the year of 1950, Chapter III, The Annual Cycle, must be consulted.

The Raro sector was opened on January 1, but the first workers did not leave the village until the middle of January mainly because of complete calm. As there was only one motor-boat in the atoll and the majority of the natives therefore had to depend on their sailing canoes, calm or stormy weather of course completely prevented all intra-island travelling. From the middle of January to the end of March most of the islanders worked in Raro. The two spells of calm and the strong winds in February resulted principally in fewer visits back to the village, and thus more effective time spent on work.

The first gap in the work schedule occurred in April. It corresponded to the Easter week, which is elaborately celebrated in Raroia, and was prolonged a couple of days by the unique event of three schooners simultaneously loading copra. In May, only a short time after the opening of Gake, the whole population returned again to the village for Jeanne d'Arc Day (May 14th) and Ascension Day (May 18). The stay in the village was prolonged about ten days this time, as the wind was too strong and large shoals of fish appeared along the village shore.

This fish, Selar crumenophtholmnus, is caught with long palm leaf sweeps, both the preparation and handling of which require a great number of men and women. The result is, however, always splendid, and many of the Raroians were

Table XV: Interdependence of activities in 1950



Note: The heavy lines indicate the activities of the main body of the islanders and the approximate duration of these activities. The exact degree of participation in copra work is shown in Chapter V, Table XVI and the relative importance of the other activities is indicated in Chapter VI. See also: Annual cycle of events, Chapter III.

so tempted by this easy way to procure delicious food, that they stayed on in the village from Easter, when the fishes first appeared, until their disappearance at the end of May. This can be seen clearly in the production records. (See part 8 of this Chapter.)

The long work interval from the beginning of June to the middle of August was partly due to the weather. June and July are the winter months with relative cold and strong winds, which frequently prevent canoe voyages. Still more important is that it is also the turtle season. The turtle is an eagerly sought food and each time a turtle is caught the whole population gathers. Two national holidays also fall in these months, the anniversary of General de Gaulle's rallying speeach on June 18, and Bastille Day on July 14. Both celebrations, which include speeches, games, and markets with wheels of fortune, were prolonged about a week.

The work stoppage - which never was complete (see Table XVI in part 6 of this Chapter) - would certainly not have been of such a long duration, if some additional reasons for staying in the village had not existed this year. The first one was the visit by the missionary, who came at the middle of June and remained on the atoll until the middle of August. Although it was certainly a coincidence that the gap in the work schedule exactly corresponded to the time of the missionary's stay, the importance attached to this visit by the islanders must not be underrated.

Diving for mother-of-pearl shell was allowed during June and July, and though the number of men who actually dived was only about a dozen, this meant at least double that number of persons absent from copra work, as the divers' families stayed in the village.

In spite of all these events and activities, the Raroians would probably have begun work in Raro, which sector was opened July 1, much earlier if an unexpected and rather unfortunate circumstance had not prevented them from doing so. Due to the capricious schedules of the schooners (see Chapter III), none appeared in time to replenish the stocks of the store-keepers, and during the first three weeks of July there was a severe food shortage. As the islanders to a great extent depend on flour, canned food, cigarettes, coffee and other imported goods when making copra, they naturally hesitated to go to work before they had been able to buy new supplies.

It is thus evident that it is a combination of factors rather than any single event which influences the working cycle. Probably still other factors than those listed above are influential in determining the decisions of the islanders and could be discovered through deeper probing, but we have to content ourselves here with these main indications and clues.

From the middle of August to the end of October there were no additional activities going on, except turtle catching until mid-September, and the uninterrupted concentration on the copra work is therefore easily explained. During all this time the sector worked was Raro.

During the final months of the year, the whole population resided in the village. A certain amount of copra was prepared on adjacent lands, but much

time was also devoted to bird catching and egg collecting in Tokerau. The weather which was very capricious, as always during this time of the year, usually determined whether the islanders prepared copra or sailed over to the northern islets on food gathering expeditions. The last week of December was of course dominated by the Christmas celebration and no work whatsoever was done.

5. Working conditions and technique.

Raroia is an atoll of considerable size with a length of 44 km and a breadth of 14.4 km. The total area is about 400 km^2 and the circumference of the reef 90 km (Chapter I). With the scattered distribution of land holdings and the concentration of the whole population in one village the islanders have to make repeated long canoe voyages in order to work the copra.

All these trips are made in sailing canoes with outriggers or in small boats, and as the wind as a rule is fairly strong and the surface of the lagoon rather rough for such small craft, the voyages to and from copra sectors are far from comfortable. The travelers are frequently drenched and suffer many times during bad weather from cold. The result is an almost continuous prevalence of coughs and bronchitis, as the Raroians have no rain cloth or warm dresses.

Under most favorable conditions, a canoe voyage from the village to the southern sector (Raro) or the northern (Gake) takes a little more than two hours. Heavy seas or contrary winds can, however, easily prolong the voyage to five or six hours. Only one person had an outboard motor and boat of European type in 1950, but it was little more seaworthy than the outrigger canoes, and could not be used at all when the sea was rough.

It must be noticed, incidentally, that for easy canoe communications, the village is not ideally situated; as it lies on the western side of the atoll, along the lagoon shore, exposed to the eternal easterly trade winds. The nearness to the pass and the good anchorage, seem, however, in the opinion of the islanders, to compensate for this disadvantage.

Only one sector, Raro, can be reached by foot from the village, and even then only with considerable difficulty as there are many intervening channels with waist-deep water. If the easterly trade winds are exceptionally strong for a prolonged period, the men may drag their canoes across the land rim and travel outside the reef along the west coast of the atoll, keeping close to the shore. Only Raro and Tokerau can be visited in this way from the village (see general map of Raroia, Section 3 of Atoll Research Bulletin No. 31).

If possible, most of the Raroians prefer to band together when working in the copra sectors. There is a total of four small villages or hamlets: two in Raro (Teputaiti and Oneroa), one in Kereteki (Tetou) and one in Gake (Tikaheru). The houses are rather primitive and invariably made of plaited palm fronds. No furniture whatsoever is used, and the family members sleep either on the earth floor or on elevated platforms. The food is cooked over open fires. No good fresh water wells exist anywhere, and the most serious inconvenience with life in the copra sector is, according to the islanders themselves, the inability over extended periods to wash in fresh water. Most of the sectors are infested with mosquitoes, and in some places fires are necessary to keep them away. The prevalent attitude towards work in the sectors is that it is trying and uncomfortable, and always everybody expresses great satisfaction upon return to the permanent village.

The preparation of copra follows the general pattern found everywhere in the Tuamotus. The ripe nuts which fall are gathered into heaps in open clearings. They are cleft into halves by a single, well-directed blow of the axe. The halves are piled one upon the other in wall-like rows with the convex outside upwards and the hollow inside downwards. This protects the flesh against rain and provides good air circulation.

In Tahiti and other mountain islands with high humidity, drying boards which can be covered at night are required, but in Raroia where the air is comparatively dry, this is unnecessary. The simple method just described is very well suited to the local conditions with scattered land holdings and great mobility of the population, but of course it takes more time to pile the coconut halves than immediately to take out the flesh and lay it on a drying board.

When the copra meat has dried - in 4 to 8 days, depending on the weather - it is separated from the husk and put into sacks holding about 50 kgs each. The husk, together with uprooted plants and weeds, is burned. The clearing of the land may continue, but as a general rule very little time is spent in the copra sectors above the minimum required for the copra preparation.

The only implements used are a stick with a hook for gathering nuts, an axe for cleaving them and an S-formed knife for separating the meat from the husk. A long bush-knife, similar to the South American machete, is used for clearing the bush. These implements are the same as those originally introduced when the islanders first were taught copra preparation about a hundred years ago. The only technological improvement during this time which we have been able to discover is the method of drying the nut halves. Until the early 1930's the islanders suspended the nut-halves on fiber cords from the trees, as still is done for instance in the Leeward Islands. After having been persuaded by a missionary of the time gain and work economy of the method of piling the nuts in rows, they all changed over to that method.

6. Agricultural methods.

The islanders' attitude towards his plantation is very different from for instance that of an American farmer. As a rule he regards the trees as able to take care of themselves and seems never to think that the yield could be increased with better agricultural methods. This is not really surprising, as it certainly was the prevailing attitude towards the coconut tree as well as the pandanus palm in pre-European times.

The change-over to a modern surplus economy was in this case as in so many others only partial. The islanders were taught to plant trees, and did so out of profit motives, but no pertinent knowledge about new or better plantation methods ever reached them. This can be seen in innumerable instances.

To begin with, the palms are rarely planted with enough space between the trees, and there is today hardly a single plantation in Raroia planned so as to give a maximum yield. A condition which undoubtedly has contributed greatly to over-planting is the small size of the land holdings. In order to make maximum use of his diminutive plots, each owner has planted his trees right up to the border line. The result is of course double lines of palms along nearly all borders!

The necessity of replacing old trees seems hardly to be understood either. Most of the palms are too old and the returns greatly reduced, but due to the work it requires to cut down the palms with hand axes and to the temporary loss that ensues, few owners are inclined to replant their lands.

Instead of controlled replanting, a spontaneous planting occurs all the time; as in many cases nuts which have fallen are left on the ground so long (especially when lost in the brush) that they finally grow into new palm trees. The islanders rarely want to cut down these trees under the false conviction that they mean additional nuts. 300 to 400 trees per hectare is therefore not an unusual average.

Even if the nuts are not allowed to grow into trees, they lose their value for copra making if allowed to remain on the ground too long. Ordinarily a nut begins to sprout after three or four months, after which time the flesh is unsuitable for copra. Therefore the time between the visits to a sector should not be longer than about three months. Actually the sectors are many times unworked for periods greatly exceeding this limit, as in 1950 in the case of the village lands which were revisited first after eight months, and the lands in Gake which were not visited during six months.

Very few lands are cleared, which to some extent certainly can be explained by the fact that the labor force (almost exclusively the land-owners themselves) in Raroia is not sufficient, but also probably due in part to the system of joint ownership. If a land is owned by several persons, none of course is inclined to clear and improve it; as he does not know whether he will inherit it eventually and reap the fruit of his work or not.

No fertilizers are used, and no trees are circled with rat-protecting bands of aluminum. How many nuts are eaten by the rats is of course impossible to compute with exactness. Judging from the number of pierced nuts found on the ground, the natives estimate that the rats eat between one third and one half of the crop.

The annual output is still further reduced by insects of which <u>Aspidiotus destructor</u>* is the worst. This insect first appeared in Raroia after the cyclone of 1906 and has since then gradually spread over the atoll. The insect attaches itself to the leaves and sucks out the sap, which seriously impedes the growth of the nuts and in extreme cases eventually kills the tree. On the seaward side, where the soil is poor, a great number of palm trees are actually unproductive. The natives are not fully aware of the menace, and the only action they have taken so far to exterminate the insects is to burn husk and refuse at the root of the palm tree, which of course is a completely inefficient measure and furthermore is harmful to the tree.

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*This insect was identified during a visit to Raroia in 1953 by Dr. W. V. D. Pieris from the South Pacific Commission. We are also indebted to him for other valuable information concerning agricultural methods.

The general outlook in Raroia is far from bright, in spite of the fact that the present annual production of coconuts is more than enough for the islanders' needs. The greatest impediment to greater agricultural efficiency is simply the ignorance of the islanders. The Raroians have taken over the idea of planting and producing a surplus, but are still unaware of the necessary requirements for such large scale enterprise. As in so many other cases, they have adopted only one element of a cultural complex, and they now suffer from the consequences of this partial lag.

7. Work participation and organization.

As we considered it of the greatest importance and interest to have complete and detailed data on the work participation and organization, we took exceptional pains to record during the whole year of 1950 exactly who participated in the copra preparation, to what extent and for how long. As we lived most of the time in the village, which is the permanent dwelling place of all the islanders and the point of departure in each case, and thus could easily keep track of the movements of every individual, the errors and omissions are at a minimum.

The work participation broken down according to sex and age is shown in Table XVI, and the percentages and averages are given in Table XVII. These tables cover the first ten months of 1950, when the Raroians worked exclusively in sectors outside of the village. For the remaining two months, November and December, the whole population lived in the village and worked the lands adjacent to it alternately with performing all sorts of minor tasks.

The continuous coming and going during these last months of the year made it of course impossible to record the number of persons working the copra each day with the same exactness as during the previous months. Therefore we abstained completely from collecting data during November and December. A fairly accurate estimate of the number of working days during these months can, however, be made on the basis of the amount of copra produced.

If we study Tables XVI and XVII closely, some general patterns are immediately discernable. The total number of persons going away to the sectors outside the village each month does not seem very impressive and rarely amounts to more than approximately half of the population. The figures may give the impression that many islanders never work, and this is of course the case with most of the children and old people, but all those of the most productive ages spend at least some months a year working in the various copra sectors. Due to the unequal distribution of the lands a Raroian may, however, work for a prolonged period in one sector and very little in another one. Hence the rotation of the working personnel every month.

The number of persons who never left the village during the whole year was 17, mostly aged people and children. The relation between family composition and work participation is shown in Table XVIII. This will be discussed further in its context.

The difference between male and female participation is not great; as seen from the figures of the percentages and the average number of working days,

Table XVI: Number of persons per month working outside the village January-October 1950.

JANUARY

AGE	MALES			FEMALES		
	Total	Working		Total	Working	
		Persons	Days		Persons	Days
0 - 14	9	6	55	24	8	94
15 - 29	14	9	127	13	9	94
30 - 44	14	8	113	11	6	95
45 - 59	9	3	18	3	0	0
60 -	4	2	22	4	0	0
Total	50	28	335	55	23	283

FEBRUARY

AGE	MALES			FEMALES		
	Total	Working		Total	Working	
		Persons	Days		Persons	Days
0 - 14	10	6	182	23	11	207
15 - 29	13	12	246	13	10	124
30 - 44	14	10	248	11	6	164
45 - 59	10	4	46	5	2	21
60 -	3	2	39	4	0	0
Total	50	34	761	56	29	516

MARCH

AGE	MALES			FEMALES		
	Total	Working		Total	Working	
		Persons	Days		Persons	Days
0 - 14	10	6	165	23	11	261
15 - 29	14	12	240	13	7	193
30 - 44	14	6	188	11	6	133
45 - 59	9	4	33	3	0	0
60 -	4	2	27	4	0	0
Total	51	30	653	54	24	587

APRIL

AGE	MALES			FEMALES		
	Total	Working		Total	Working	
		Persons	Days		Persons	Days
0 - 14	10	2	8	23	9	62
15 - 29	12	9	88	12	7	55
30 - 44	14	7	63	11	5	51
45 - 59	10	5	21	4	2	12
60 -	4	1	8	5	0	0
Total	50	24	188	55	23	180

MAY

AGE	MALES			FEMALES		
	Total	Working		Total	Working	
		Persons	Days		Persons	Days
0 - 14	9	3	40	22	11	108
15 - 29	13	11	98	13	8	76
30 - 44	14	8	81	11	6	52
45 - 59	11	4	44	5	2	15
60 -	4	0	0	5	0	0
Total	51	26	263	56	27	251

JUNE

AGE	MALES			FEMALES		
	Total	Working		Total	Working	
		Persons	Days		Persons	Days
0 - 14	9	2	18	25	7	30
15 - 29	14	12	88	13	4	35
30 - 44	15	5	40	11	5	45
45 - 59	11	5	33	5	2	18
60 -	3	0	0	5	0	0
Total	52	24	179	59	18	128

JULY

AGE	MALES			FEMALES		
	Total	Working		Total	Working	
		Persons	Days		Persons	Days
0 - 14	9	0	0	25	3	14
15 - 29	14	5	27	12	2	18
30 - 44	15	5	16	11	2	9
45 - 59	12	4	24	4	3	14
60 -	3	0	0	5	0	0
Total	53	14	67	57	10	55

AUGUST

AGE	MALES			FEMALES		
	Total	Working		Total	Working	
		Persons	Days		Persons	Days
0 - 14	9	4	24	24	11	92
15 - 29	13	13	106	12	10	96
30 - 44	15	15	119	11	6	65
45 - 59	11	7	72	6	5	54
60 -	3	1	2	3	1	7
Total	51	40	323	56	33	314

SEPTEMBER

AGE	MALES			FEMALES		
	Total	Working		Total	Working	
		Persons	Days		Persons	Days
0 - 14	10	4	77	24	11	209
15 - 29	12	11	241	11	8	168
30 - 44	14	14	273	10	6	139
45 - 59	11	9	108	5	4	89
60 -	4	1	30	3	1	28
Total	51	39	729	53	30	633

OCTOBER

AGE	MALES			FEMALES		
	Total	Working		Total	Working	
		Persons	Days		Persons	Days
0 - 14	8	3	52	21	3	13
15 - 29	10	7	73	8	4	31
30 - 44	12	11	93	9	5	72
45 - 59	11	5	51	6	3	53
60 -	4	1	2	5	0	0
Total	45	27	291	49	15	169

Table XVII: Number of persons and days spent in work outside the village in 1950.

Month	MALES					FEMALES				
	Total population	Working	Per cent working	Days of work	Ave. no. of work days	Total population	Working	Per cent working	Days of work	Ave. no. of work days
January	50	28	56.0	335	11.9	55	23	41.8	283	12.3
February	50	34	68.0	761	22.4	56	29	51.8	516	17.8
March	51	30	58.8	653	21.8	54	24	44.4	587	24.5
April	50	24	48.0	188	7.8	55	23	41.8	180	7.8
May	51	26	50.9	263	10.1	56	27	48.2	251	9.3
June	52	24	46.2	179	7.5	59	18	30.5	128	7.1
July	53	14	26.4	67	4.8	57	10	17.5	55	5.5
August	51	40	78.4	323	8.1	56	33	58.9	314	9.5
September	51	39	76.5	729	18.7	56	30	53.6	633	21.1
October	45	27	60.0	291	10.8	49	15	30.6	169	11.3
Average	50.4	28.6	56.9	378.9	12.4	55.3	23.2	41.9	311.6	12.6

which are 56.9% and 12.4 days, respectively 41.9% and 12.6 days. The high female participation is not surprising, as most women are land-owners. It must, however, be noted that their husbands usually do the copra preparation while the women take care of clearing and household duties.

As so many women participate, a natural consequence is that many of the children also spend prolonged periods in the working sectors outside the village. The number of children in the working population varies considerably from month to month as seen in Table XVI, but is on the average between 1/4 and 1/5. Older people usually stay behind in the village, and as could be expected, the bulk of the copra workers are the males and females in the most productive ages, 15-44, who account for 61.8% of the total number of working days for the period January-October. (2,568 out of 3,809 days for the males and 1,715 out of 3,116 days for the females.)

The participation or non-participation cannot, however, be explained solely on the basis of such isolated criteria as sex and age. The total family situation of each individual must be taken into consideration. In Table XVIII all persons in Raroia have been grouped according to the composition of the family. Whereas Table XVI shows how many persons participate in work, Table XVIII shows who they are as determined by family status. Those who as a rule participate in the work have been indicated by the letter w (work), and those who as a rule stay behind in the village by the letter v (village).

Only in two families out of the total number of 27 did both husband and wife regularly stay in the village all year. The exceptions are number 21 and 25. The husband in family 21 was sickly and his wife therefore stayed home in order to take care of him. The copra was made by the grown-up children. Family 25 is made up by the storekeeper and his wife, who both attend to the business. The grown-up children here also made the copra.

In the remaining 25 familes, both husband and wife went to work in 21 cases (two widows and one single man are included in this figure), only the husband in three cases and only the wife in one case. The husband staying behind in the village and letting his wife go to work alone is the chief, who considers it necessary always to be accessible in the village.

As a rule it can therefore be said, that all men who can possibly do so participate in work, which undoubtedly shows the importance of the economic motive. The women accompany their husbands in almost all cases, which is somewhat surprising as their participation in the work is negligible. A possible explanation which the islanders themselves frequently give is that the women are jealous and do not want to let their husbands go away alone to a copra sector where young girls are always present.

As the women work too, the participation or non-participation of the children depends on the existence of old relatives living in the village. Eleven of the 27 parents have small children below school-age. Seven of these parents take the children with them and the remaining four leave them in the village with an old relative. Four of the seven parents who take their children with them have old relatives in the village.

Table XVIII: Family composition and wor

Table XVIII: Family composition and work participation.

Family composition	Participation by family member					
	Husband	Wife	Small child	School child	Grown-up child	Old relative
Single:						
Family 1	W	–	–	–	–	–
Husband, wife:						
Family 2	W	W	–	–	–	–
" 3	W	W	–	–	–	–
" 4	W	W	–	–	–	–
" 5	W	W	–	–	–	–
" 6	W	W	–	–	–	–
Husband, wife, small child:						
Family 7	W	W	W	–	–	–
Husband, wife, small child, old relative:						
Family 8	W	W	W	–	–	V
Husband, wife, small child, school age, old relative:						
Family 9	W	W	W	V	–	V
" 10	W	–	V	V	–	V
" 11	W	V	V	V	–	W
Husband, wife, small child, school age, grown-up child:						
Family 12	W	–	W	W	W	–
Husband, wife, small child, school age, grown-up child, old relative:						
Family 13	V	W	V	V	W	V
" 14	W	W	W	V	W	V

Family composition	Hus-band	Wife	Small child	School child	Grown-up child	Old relative
Husband, wife, small child, grown-up child						
Family 15	W	V	V	–	V	–
" 16	W	W	W	–	W	–
" 17	W	W	W	–	W	–
Husband, wife, school age child:						
Family 18	W	W	–	W	–	–
" 19	W	W	–	W	–	–
Husband, wife, school age child, old relative:						
Family 20	W	V	–	V	–	V
Husband, wife, school age child, grown-up child:						
Family 21	V	V	–	V	W	–
" 22	W	W	–	W	W	–
" 23	W	W	–	W	W	–
" 24	W	W	–	W	W	–
Husband, wife, grown-up child:						
Family 25	V	V	–	–	W	–
" 26	W	W	–	–	W	–
Husband, wife, grown-up child, old relative:						
Family 27	W	W	–	V	–	V

Out of the 15 parents with children of school-age (6-14 years), nine leave their children in the village. Seven of these nine parents have an old relative in the village who takes care of the children, whereas in the remaining two cases one or both parents stay in the village. The remaining six parents usually take their children of school age with them to the copra sectors. Significantly none of these parents has an old relative in the village.

The grown-up children work regularly in nine cases out of ten.

The dependence on older relatives for the care of the young children is thus amply proved by the figures. In the case of the children below school-age there is no problem, as they can travel with the parents, if no old relatives exist. The children of school-age create, however, a conflict when there is no old relative living in the village. All parents affirm that they want their children to go to school and seem to have a firm belief in the advantages of acquiring a European education. Yet, in spite of this, each time when this desire conflicts with the work, the latter is given precedence, as seen in the six cases enumerated.

A simple solution would of course be to leave the wife behind in the village with the children. Another would be to better co-ordinate the annual working cycle with the school terms. As the women seem to have a strong inclination - due to jealousy or whatever it may be - to accompany their husbands to the work outside the village, the second solution would certainly be the most acceptable. No attempt has yet been made, however, to achieve such a co-ordination, which shows once more how erratic the islanders' efforts are to adjust themselves to new situations and how unsatisfactory the integration of the various cultural elements is.

8. Weekly variations.

The predominance of economical considerations in the case of the conflict between work and school duty of the children was evident (see previous section). It may therefore be of interest to examine also the relationship between economic and religious activities.

From the very beginning of our stay we noticed a marked tendency among the islanders to return every Sunday to the permanent village, where the only church on the atoll is situated. That this is a regular habit is confirmed by our data for the whole year, but in order to avoid unnecessary repetitions, we have limited our analysis here to a sample month, September.

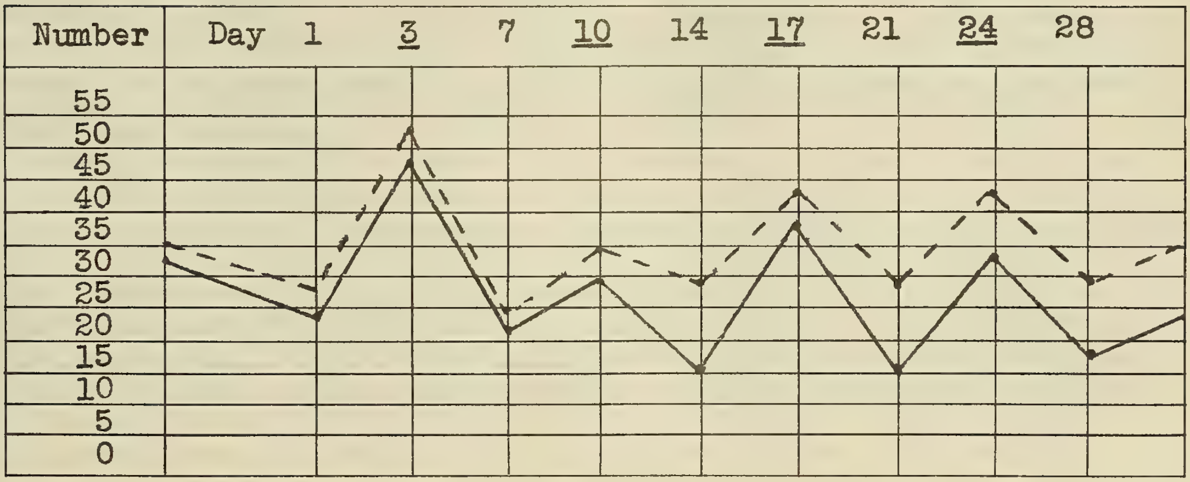
In Table XIX are shown the number of persons in the village on Sundays (September 3, 10, 17 and 24) and Thursdays (September 7, 14, 21 and 28). In addition, two other tables have been prepared, one showing the variations according to sex and another according to age classes. This differential treatment of the data brings out some unsuspected facts.

The extent to which the islanders return to the village on Sundays - even if it requires a long canoe trip and the loss of at least one working day - is surprisingly great, as shown by the differences between the village population on weekdays and Sundays, which are respectively: + 44, - 50, + 17, - 19, + 35, - 36, + 30, - 26! The high figures are, however, less surprising if we take into consideration that Sunday in any event is sacred, and that no islander works this day, even if he is alone on an isolated islet far from the village.

Table XIXa: Number of persons in village on weekdays and Sundays in September 1950.

Sex	Age	Total	Number of persons in village on								
			1	3	7	10	14	17	21	24	28
MALES	0 - 14	10	6	9	7	6	5	7	4	6	4
	15 - 29	12	2	12	3	8	3	11	2	10	3
	30 - 44	14	4	13	4	8	2	11	3	10	3
	45 - 59	11	8	11	6	5	3	6	4	5	6
	60 -	4	3	2	2	2	2	2	2	2	2
	Total	51	23	47	22	29	15	37	15	33	18
FEMALES	0 - 14	24	15	22	13	15	14	18	13	14	14
	15 - 29	11	3	11	2	7	5	9	4	11	3
	30 - 44	10	4	10	4	6	5	8	6	7	5
	45 - 59	5	4	4	3	4	3	5	3	5	5
	60 -	3	3	2	2	2	2	2	2	3	2
	Total	53	29	49	24	34	29	42	28	40	29
Males & females		104	52	96	46	63	44	79	43	73	47

Table XIXb: The same data presented in graphical form.



_ _ _ _ _ _ _ women

________ men

That there are no significant differences between the sexes can clearly be seen in Table XIXb (the graph).

On the basis of the data presented hitherto, it seems natural to conclude that the islanders return solely for the purpose of attending the church service. If we, however, take the age factor into consideration, as done in the following table, we shall find that there evidently is an additional motive present.

Table XX: Average number of persons in village weekdays and Sundays during September 1950.

Sex	Age	Total	Weekdays	Per cent	Sundays	Per cent
M	0 - 14	10	5.2	52.0	7.0	70.0
A	15 - 29	12	2.6	21.6	10.2	85.0
L	30 - 44	14	3.2	22.8	10.5	75.0
E	45 - 59	11	5.4	49.0	6.7	60.9
S	60 -	4	2.2	55.0	2.0	50.0
F	0 - 14	24	13.8	57.5	17.2	71.6
E M	15 - 29	11	3.4	30.9	9.7	88.1
A	30 - 44	10	4.8	48.0	7.7	77.0
L E	45 - 59	5	3.6	72.0	4.5	90.0
S	60 -	3	2.2	73.3	2.2	73.3

This table gives the average number of males and females present in the village on Thursdays and Sundays, arranged according to age. The percentage shown is the per cent of persons present on Thursdays and Sundays as compared to the total number of individuals in each age class. The significant factor is thus the increase of the percentages on Sundays.

One is immediately struck by the fact that this increase is considerably less for the youngest and oldest age groups than for individuals of the "most" active ages. In age group 0 - 14 the increase is only from 52.0% to 70.0% for the males and from 57.5% to 71.6% for the females. For the age groups above 45 it is still less, and in one case, males above 60, even replaced by a decrease. On the other hand, for the age groups 15 - 29 and 30 - 44 there is a big jump from the percentage figures for weekdays to these for Sundays, doubling or tripling them.

If the motive to return to the village were exclusively religious, it should be expected to operate with equal force for all age groups, but this is clearly not the case. The only possible explanation is therefore, that the social and recrea ional motives are as important as the religious one. These motives are of course more dominant in the ages 15 - 44, and most men and women of these ages return evidently to the village seeking diversion, whereas the older people stay behind with the children in the working sector.

During the great church holidays, religious considerations are, however, paramount, as all the workers irrespective of age return to the village.

This tendency to return regularly on Sundays to the village, reduces of course greatly the time actually spent on copra work, as the sectors are situated at a great distance and bad weather frequently prolongs the canoe trips. The influence of this habit on the annual output of copra must not be overlooked.

9. Actual and potential production.

According to the chief, the total copra production in 1948 was 221 tons and in 1949 as much as 253 tons. How reliable these figures are is difficult to say, but for 1950 we kept record of all copra produced, and the total amount was 187 tons. If the figures for the preceeding years are correct, the average output per year should be around 200 tons.

For producing about 200 tons of copra a year on the soil found at Raroia, 200 hectares should suffice. The total area planted with coconut palms is according to our estimate, based on a study of the aerial map, 587 hectares (see Chapter I). Almost three times as much copra could therefore be produced on the atoll, if our figures are correct. The great discrepancy between the actual and potential output must be due to such factors as dense planting, old trees, abundant underbrush, ravages by rats, insect pests, lack of fertilizers, picking of drinking nuts, and so on. Some of these aspects have been discussed in previous chapters, but the problem as a whole must of course be left to a specialist.

The tonnages of copra produced each month of 1950 were as follows: January - 7.5, February - 30, March - 24, April - 11, May - 12.5, June - 10, July - 2, August - 14, September - 40, October - 14, November - 8, December - 14. The variations are of course due to the amount of time the islanders devoted to other activities and will be clearly understood only by a comparison with the facts presented in part 4 of this chapter dealing with the interdependence of activities.

Divided between the various sectors (see map accompanying part 3) the copra production for 1950 was as follows:

I	Raro (January-April, July-October)	142.5 tons
II	Village (November-December)	22.0 tons
III	Rest of the atoll (May-June)	22.5 tons

Of the total output in 1950, 76.2% of the copra came from Raro, 11.8% from lands around the village and 12.0% from the rest of the atoll. The relative size of the planted area in the three sectors is approximately, in the same order, as 7 to 2 to 3, or expressed in percentages:

Raro	58 1/3%
Village	16 2/3%
Rest	25 %

This comparison between the relative percentages of the output and of planted area shows some marked differences. For the village lands the output is only slightly below what could be expected judging from the size of the planted area, and the figures are almost identical if we do not count the village itself, where few palm trees are planted. A disproportion between the production and the area in the two other sectors exists, however, undoubtedly, and the figures confirm only our subjective impressions during the year.

The discrepancy of the figures, seems to indicate that the third sector (comprising all the land on the eastern, northern and northwestern side of the atoll) is not worked to full capacity. This neglect is easily explained by the fact that it is more lonely and time-consuming to make copra on the numerous small islets in this sector than on the contiguous lands in the two remaining sectors.

A comparison between the size of the planted area in each sector and the time during which the sectors were open is also illuminating. The sectors were open respectively 8, 2 and 2 months, which expressed in percentages and compared to the proportional size of each sector give us the following table:

Sector	Area	Time
Raro	58 1/3%	66 2/3%
Village	16 2/3%	16 2/3%
Rest	25 %	16 2/3%

The length of time during which each sector is open is thus not completely proportional to the size of it. These periods do, however, correspond to the total time actually spent in each sector, which is determined by various other activities and considerations (see part 4).

10. Working efficiency.

In this chapter we shall finally try to ascertain the working efficiency, or the average time needed for producing one ton of copra, in order to see whether the relatively low annual output can be explained in these terms. The figures presented here are based on the complete records of work participation in part 6 of this chapter (Table XVI).

Before we can proceed to a computation of the average working time and output, some adjustments have to be made. In the first place it should be noted that the time spent in sectors outside the village is counted from the departure to the return. As distances are great and some preparation necessary each time, usually no work is done on travel days. Another factor which frequently reduces the time spent in effective work is bad weather or calms. These often prevent the islanders from fulfilling their work schedules. Finally, as a rule each worker spends some days fishing or gathering other foods. All this reduces considerably the time actually devoted to copra production, and if we estimate the effective working time as 2/3 of the total time, our figure is certainly not too high.

Table XXI: Number of working days of the productive males compared to amount of copra produced in 1950.*

Month	Working days 15-44	Working days 45-59	Tons of copra
January	240	18	7.5
February	494	46	30.0
March	428	33	24.0
April	151	21	11.0
May	179	44	12.5
June	128	33	10.0
July	43	24	2.0
August	225	72	14.0
September	514	108	40.0
October	166	51	14.0
Total	2,568	450	165.0

The contributions of the different age-classes varies. The children below 14 years of age may help a great deal at the camp with food-preparation and also often go fishing, but their contribution to copra production must otherwise be disregarded. The same is true for the few individuals above 60, who occasionally accompany the working parties. As to the age-group 45-59, its output is doubtless much less than that of the younger men, and we have therefore estimated their efficiency as 50% of the latter group.

The females accompany their husbands as a rule, but their contribution to the copra work is very slight, and even the women who are land owners themselves, usually let their husbands or a male helper do the collecting and cutting. This does not mean, however, that the women are without occupation. They tend the children, take care of the household duties, clear lands and assist their husbands in minor ways. This limited role of the women is of course impossible to confirm statistically. The population was always spread out and we lived in the main village most of the time, but repeated visits to the different sectors all round the year, led us to believe it to be the general pattern. In the following estimate of the working tempo, we have therefore preferred to disregard completely the female participation.

The total number of working days for the males during January-October (according to Table XVI) was 2,568 for age class 15-44, and 588 for the age class above 44. If we first reduce these figures by 1/3 for lost time, and then discount 50% for the latter class for lost efficiency, we get the follow-

*The figures are for the first ten months of the year during which the sectors outside of the village were worked. For the remaining two months, when the lands around the village were worked, only the amount of copra produced was recorded. These figures were 8 tons in November and 14 in December.

ing figures:

15-44 years old	2,568	working days
Less 1/3	856	" "
	1,712	" "
45-59 years old	450	" "
Less 1/3	150	" "
	300	" "
Less 1/2	150	" "
	150	" "

1,712 plus 150 = 1,862 effective working days, during which 165 tons of copra were produced, making an average of 11.3 days per ton, which seems reasonable. In Tahiti a good worker prepares one ton a week, but working conditions are very different there, as no time-consuming piling of the nuts is necessary, the undergrowth is kept at a minimum, the plantations are much bigger and the existence of covered platforms makes the work more independent of the weather.

If only men between 15-44 are counted, the average output per individual for 1950 is 7.79 tons. There is thus a wide gap between each individual's actual and potential output, a gap which must be accounted for by the various factors discussed in previous sections.

SUBSISTENCE ACTIVITIES

With the year-round work on the plantations and the good earnings from copra and mother-of-pearl shell sales, the islanders neither have time nor find it necessary to carry on any extensive planting or food-gathering, as they did in pre-European times. The taro fields were abandoned after the cyclone in 1903 and nobody has planted any since then. Some lime and papaya trees have been introduced, but no efforts are spent on their cultivation, and the number of trees is insignificant. The pandanus palm grows wild all over the island, but is not used for food any more.

Few domesticated animals are kept, and these consist almost exclusively of hens, pigs and dogs, which as in ancient times are still eaten. Fishing is practiced to a considerable extent, especially during the working periods away from the village, but shell fish, of which there never has been any abundance in Raroia, are rarely gathered. Turtles are caught and sea birds and eggs collected but these are strictly seasonal activities and more practiced as a sport than as regular food-gathering activities.

Instead of these traditional foods the islanders buy now imported provisions like canned beef, flour, rice and biscuits, which make up a diet much inferior to the ancient one. The main aim is, however, achieved from the islanders' point of view: no working time is lost on prolonged food-gathering and tedious preparations and all efforts can be concentrated on the production of a surplus, the income from which permits the acquisition of all sorts of luxury articles.

1. Plant cultivation.

The poor soil is a serious obstacle to the growing of varied and abundant crops, and the number of plants found on the atoll is actually very limited. The situation is hardly improved by the fact that practically no efforts are devoted to the care of the plants, and the word "cultivation" is therefore definitely an euphemism!

Of food plants which existed on the atoll in pre-European times the coconut palm is still the most important, but strangely enough no distinction is made between palm trees intended for production of copra and food trees, in spite of the fact that certain varieties are much sought after because of the special qualities of the nuts. What has been said about the coconut palm in the previous chapter on copra production applies therefore equally well here.

One of the islanders tries to grow bananas in a ditch filled with refuse but this must be regarded chiefly as a luxury hobby, as the yield is not more than five or six bunches a year. There are 73 breadfruit trees altogether, but only 23 bear any fruit. The total number of fruits on these trees each season does not exceed 300, and therefore their role in the diet is insignificant.

The only introduced plant cultivated to any extent is the papaya, of which there are 87 trees of which one third are fruit-bearing. Most of these have been planted by the Chinese storekeeper, who gives away the fruits as goodwill service. In spite of the fact that the papayas, like the breadfruit, are highly appreciated by the islanders, very few of them have planted any, and only half of the 27 families have trees of their own. Vegetables are not grown as the soil is unsuitable.

This lack of interest in plant growing is probably a result of the islanders' ignorance of modern agricultural methods and of the relative nutritive value of the various kinds of food. Nobody suspects for instance that the fruits contain vitamins which are not found in the imported food, and these additional food resources are therefore over-looked. That the islanders do not take better care of the few existing food-trees is certainly also due to the lack of adequate knowledge of how to increase the yield.

2. Animal husbandry.

The number of pigs, hens, ducks and dogs per family is as follows:

Family*	Pigs	Hens	Ducks	Dogs
1	-	-	-	2
2	1	5	-	2
3	-	-	-	1
4	-	-	2	1
5	-	-	-	-
6	-	-	1	1
7	-	3	-	3
8	1	4	-	2
9	2	-	3	1
10	1	-	-	2
11	-	3	3	2
12	-	-	-	1
13	2	6	2	2
14	2	2	-	-
15	-	7	2	2
16	-	-	4	2
17	-	6	-	1
18	-	12	4	4
19	-	-	-	-
20	1	-	-	-
21	1	10	7	3
22	-	3	2	4
23	-	-	-	2
24	-	-	-	1
25	-	9	7	2
26	-	-	-	1
27	1	6	4	2
Total	12	76	41	44

*For composition, see Table XVIII in part 6, Chapter V.

The total number of domesticated animals is not impressive, and the islanders often say that they should like to keep more, if they only were able to feed them. But this is difficult for the Raroians for two reasons: there is little food for animals besides nut kernels, which are too valuable, and the nomadic character of the islanders' existence does not go very well with animal husbandry.

This applies especially to pigs, which explains their comparatively small number. Significantly enough, pigs are also kept only by families who always leave a member, usually an old relative who takes care of the school children, behind in the village during the working periods in the sectors. But even some of these families hesitate to have a pig due to the fact that it has to be fed with coconuts.

Contrary to the pigs, which because of the feeding, are always kept in enclosures of palm logs, the hens and ducks roam about in complete freedom, as they are supposed to be able to take care of themselves. A greater number of families can therefore keep hens and ducks without interference with the work. The number is nevertheless very limited, which certainly is due to the fact that the hens and ducks under these conditions are of little value. The eggs are never found, or they are eaten by rats, and the hens and ducks so meager that they hardly are palatable.

The dogs alone of all the domesticated animals can accompany the islanders on their trips to other parts of the atoll, which certainly is the main reason for their continued popularity. The dogs seem primarily appreciated for their food value and only in a very secondary way for their companionship. As no dogs are regularly fed, only young dogs are tender enough to be eaten. Many dogs are, however, saved for reproductive reasons, and most of the 44 dogs found at the time of our survey were of a fairly advanced age, many of them actually too old, which is not so surprising as the Raroians never kill a dog except when they intend to eat him. There is a tax imposed in order to keep down the number of dogs, but as it is extremely small it does not have the desired effect.

3. Fishing.*

There is an abundance of fish of all kinds in Raroia both in the lagoon, the pass and the surrounding sea, as well as on the outer reef flats. Some species are seasonal, appearing in most cases from October to December, but throughout the year there is always more than enough fish for the islanders' needs.

Species

The ichthyologist of the 1952 coral atoll research team caught about 400 different species in only two months time (Harry, 1953, page 44). Of these around 150 are food fishes of a size big enough to be worth while catching for the islanders. The most common food fishes are: parrot fishes, goat fishes, trigger fishes, wrasses, jacks and tunas.

*A more detailed and technical paper will be published elsewhere.

Some ocean species like dolphin, swordfish and flying fish, which were frequently taken in ancient times, are not fished for any more because the present-day inferior canoes do not permit extended sea voyages. Most of the edible species in the lagoon, the pass and on the outer reef are, however, still caught; though dependence on fishing has greatly decreased since the rise of the copra trade and the introduction of foreign foods.

Fishing methods

Except for the inevitable replacement of old material like mother-of-pearl shell and bone by iron, the fishing methods have generally preserved their Polynesian character. As a matter of fact no other elements of the old culture, either spiritual or material, have survived so well. As the present study deals primarily with present conditions no effort has been made here to reconstruct the fishing methods, which have been lost, but only those still in use will be described.

The general term for fishing is tautai, but as for so many other highly specialized activities the natives have also in this case numerous specific names. We have indicated the terms, where necessary, in the descriptions under four main categories: hook and line fishing, spear fishing, net fishing and miscellaneous methods.

a. Hook and line fishing.

This is a very popular method used exclusively or principally for catching the following kinds of fish: tunas, snappers, jacks, trigger fish, sea bass, and wrasses. Here, as in the rest of Polynesia, the islanders practically never use floats and rarely rods. A special sinker is usually deemed unnecessary, and when fishing at great depths the hook is simply lowered with the help of a coral stone tied to the line with a slip knot. As soon as the hook reaches the desired depth, the stone is released by giving the line a sharp jerk.

The hooks in pre-European time were made of shell or bone and were of the circular, barbless, Polynesian type, which is ideally suited for the marine environment as it does not get entangled in branching corals. Unfortunately in the Tuamotus they are now everywhere replaced by European iron hooks of the ordinary J-shape, which are far inferior. The excellent commercially made iron hooks of Polynesian model used in Hawaii and previously unknown in French Oceania were introduced in Raroia by us in 1952.

The general word for hook and line fishing is kanehu, but specific names exist for every variety of it. A very common method in ancient times, called topepu, was to swim slowly about in the lagoon or open sea, supported by a log while holding the line in one hand. In most cases, today the islanders fish from an anchored canoe. Trolling with mother-of-pearl shell hooks, tavere, is practiced for catching tuna. Rods are used to a limited extent for fishing from the edge of the outer reef, a method called tiutiu.

b. Spear fishing.

This method is used almost as much as hook and line fishing but mostly for other species of fish, such as parrot fish, goat fish, porcupine fish, butterfly fish, surgeon and unicorn fish. The spears are usually made of mikimiki (Pemphis acidula) wood fitted with an iron point. This point is usually made by the islanders themselves out of scrap-iron over a primitive forge. The spears have either a single barbless tip or four barbed prongs. The single, barbless spears are of two sizes, one 4-5 feet and the other around 10 feet long, whereas the four pronged spears are all 10-12 feet long.

Of the barbless spears, the short ones are used for poking under stones in shallow water, the long ones for under water fishing during which the fisherman dives down and transfixes his quarry. The barbed, four pronged spears are thrown from a standing position on the shore or the edge of the reef. The spear is held by the right hand at the extreme end with the index finger on the butt and supported at the middle by the left hand. The spear is cast with an overhand throw and the precision is amasingly good.

The word patia is used both for the spear and the method in general. The names for the varieties are: pakeke, poking out the fish from holes with the short, barbless spear and transfixing them; tupoa, underwater spearing with the help of tridacna shells which attract the fish; and fautau, throwing the four pronged spear.

c. Net-fishing.

Net-fishing is very little practiced, even less so than in pre-European times, in spite of the fact that ready-made nets and lines can now be bought in Papeete or aboard the schooners. The reasons for this decline are probably the improvement of other types of fishing gear like hooks and spears by the introduction of iron, and the cumbersome character of a net. A man can always take a spear and a couple of hooks with him during his trips to the copra plantation, and invariably does so, whereas a net is heavy and usually cannot be handled by one man alone. Another fact, which certainly limited the use of nets even in pre-European times, is of course simply the unfavorable environment. Nets are easily entangled in sharp and branching corals and sharks destroy both fish in nets and net alike.

The only nets in common use today are small seines attached between poles and handled by two men who encircle the fish with the net. The net is called kope, and used principally in shallow water along the lagoon shore or in the channels between the islets. Fishes caught in this way are goat fish, parrot fish and mullet.

d. Miscellaneous methods.

The only other methods worth mentioning are:

Fakakopa. The fish, usually parrot fish, are chased when they appear in the shallow water on the outer reef until beached or enclosed in an embayment. They are then speared or taken by hand.

Rena. This is the garland fishing with palm leaves called hukilau in Hawaii. The garland may be up to 200 yards long and is made of palm leaves cut in halves length wise, twisted and joined together. The garland is handled by a great number of people and this is actually the only community fishing undertaken today. Seasonal fishes like Selar crumenophtholmnus and small parrot fish are caught in this way.

Rama. Night fishing on the outer reef flat. The fish is blinded by light, usually from a Coleman kerosene lantern, and stunned by a blow over the back with a long bush knife. Fish caught are principally squirrel fish and certain wrasses.

Relative importance of fishing activities.

Since pre-European days, when probably every adult spent several hours a day fishing or gathering shells and clams, the time devoted to these activities has gradually decreased with the emergence of a money-economy.

In order to get some measure of the relative importance of fishing to the present-day economy we recorded the number of persons going out on fishing trips during a sample week, December 4-10, 1950, when the whole population was in the village. Another similar sample taken in a more summary way in June the same year under identical conditions, gave approximately the same results, and it seems reasonable therefore to regard the following sample week as fairly typical for the fishing activities of the islanders during their stays in the village. Two and three hours are spent fishing each time on the average.

Table XXII: Number of persons fishing, Dec. 4-10, 1950.

Age	Total in village		Mon.		Tue.		Wed.		Thu.		Fri.		Sat.	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F
0-14	9	21	4	0	6	2	5	0	6	1	3	2	9	6
15-59	35	27	9	4	7	3	11	3	6	0	10	3	21	7
60-	3	2	1	0	0	1	0	0	0	1	0	0	1	1
Total	47	50	14	4	13	6	16	3	12	2	13	5	31	14

The number of persons fishing each day is strikingly low, especially if we discount the boys below 14, who many times roam about or play instead of making serious efforts. The increase of the number of fishermen on Saturday is in accordance with the Raroians' general working cycle. No work whatever is done on Sundays, which is a real holiday with absolute rest and copious meals. The preceeding day is therefore devoted to food gathering and preparations of all kinds.

Another thing clearly shown in the table is the insignificant participation of the females. The explanation for this is simple. In ancient times there was a sharp division of labor according to sex in this case as in so many others, and the males did the actual fishing with hook and line, spear or net, while the females only gathered shells, clams, crustacea and similar sea foods. The islanders still cling to this labor division, but the supply is not the same as in old times due to the new habitation pattern.

There is still plenty of fish around the village, but the supply of other sea foods is exhausted and insignificant compared to the great number of persons living on this limited part of the atoll. With the scattered dwellings in pre-European days, each family had long stretches of reef at its disposal, but this is no longer the case. Therefore the women cannot continue their traditional activities, and as they consider it unthinkable to take over the males' activities, there is not much use for them to go out collecting.

If this is true, the women should devote more time to the collecting of sea food, when they are away from the village working in the various copra sectors. We have not been able to gather any quantitative data on this, but if we are to judge from our own subjective impressions during repeated visits and stays in the copra sectors, this seems actually to be the case. Even the men seem to fish more frequently when they work in the copra sectors, and we have gained the definite impression that almost all of them spend an hour or so a day fishing. This is only logical as the supply is more abundant in the less-frequented waters far away from the village, and as the amount of other food which can be brought in the canoes always is limited.

4. Turtle catching.

The season lasts from June to September during which months a small number of turtles appear in the sea immediately west of Raroia fairly close to the shore. At the beginning of the season both male and female turtle are caught when they breed in the water. At the end of the season, however, most of the turtles caught are females overtaken when they crawl up on the sand beaches to lay their eggs.

The islanders show a great appreciation for turtles as food. This is understandable as turtles constitute the only first class fresh meat obtainable in the atoll. In ancient times the turtle was an animal eaten only after appropriate religious ceremonies. The meat was reserved for men. In Raroia the women are now allowed their share of the turtle meat, but it was only about 20 years ago that this old taboo was broken.

The tastefulness and rareness of such a delicacy as turtle meat explains why the whole population is on the lookout during the season and why everybody abandons all other occupations when a turtle is sighted. Only one method is generally used today for catching turtles. The hunter, equipped with a long rope, to the end of which a huge iron hook is attached, paddles together with assistants to the spot where a turtle has been seen. He dives into the sea when the turtle appears and tries to place a hook in its throat, the only vulnerable spot of the animal. If he succeeds, his companions in the canoe who have held fast to the other end of the rope all the time, slowly haul up the turtle. It is overturned and towed ashore.

The turtles usually weigh about 200 pounds. One is enough for a real meal for the whole population. The turtle is cut up, cooked in an earth oven (the only occasion when it is still in use), and the meat divided up among all the persons present. In 1950 the total number of turtles caught was 17, and the average number per season seems to have been between 15 and 20 both the preceeding and following years.

The successful turtle hunts are matched by an approximately equal number of unsuccessful ones, which means that between 30 and 40 days a year are devoted to this activity. About a dozen men are engaged in the hunt and food preparation each time. The number of lookouts and assistants is of course much higher. The turtle catching therefore limits to a certain extent the time which can be devoted to other occupations during these months.

5. Egg collecting and bird catching.

These are also strictly seasonal activities taking place during the last months of the year, October - December. Two species of noddies, the brown, goio (*Anous stolidus*) and the white-capped, kikiriri, (*Anous minutus*), nest during these months in amazingly great numbers on the northern part (Tokerau and Gake) of the atoll. As the noddies lay their eggs in nests on the ground or in the branches and hollows of bushes and low trees, they can be collected without any difficulty. The birds caught are young noddies which simply are taken by hand.

Small groups of young people sail during this season once or twice a week over to the northern part of the atoll and spend a day at a time there. Each person brings back at least four or five dozen eggs and half a dozen young birds from such a trip. The eggs are all eaten irrespective of the stage of development of the embryo. Some of the birds may be kept in captivity and fed for some time before being killed, but most of them are eaten immediately.

There are altogether 20 species of birds, either resident or migratory* in the atoll and many are highly prized as food, but the islanders rarely capture them. Most of these birds were commonly trapped in various ingenious ways in pre-European times.

*See list by Danielsson-Natua published in a subsequent section of this Atoll Research Bulletin No. 32.

LABOR DIVISION AND SPECIALIZATION

1. Division according to sex.

The division of labor according to sex, prevalent in pre-European days, is still adhered to, and new activities are divided in a similar manner within this general framework. In the following table we have included not only the activities within the framework of the surplus and subsistence economy dealt with in preceeding chapters, but also most of the other common occupations of the islanders.

Division of work

Work of men	Work of women	Joint work
Copra cutting Clearing of lands Separating the copra from the husk	Piling the nuts	
Fishing with line and hook, spear and net Turtle catching	Gathering shells and crustaceae	Torch fishing Egg collecting and bird catching
Canoe building House building	Plaiting of palm leaves	
Cooking in earth oven	Other cooking and household duties	Water carrying
		Training and care of children
Political offices Religious offices		

2. Co-operation.

Work, which in pre-European times was characterized by a high degree of co-operation, has now become almost wholly individual as a result of the introduction of a competitive money economy and the breakdown of the old social system with hierarchial authority. When, for instance, today a man wants to build a house or needs help for other big enterprises, he has to pay the workers, and the wages are almost as high as in Tahiti, i.e. 100 francs a man per day.

The only instances of extensive co-operation among the islanders during our various stays in Raroia were the garland fishing, the turtle catching, the launching of a boat and repair work on the quay.

The garland fishing requires the co-operation of at least half the population if it is to give good results, and usually all persons present in the village participate in the catch when a fish shoal appears. The fishes caught are divided evenly among all the participants irrespective of age, sex or role during the fishing.

To catch a turtle requires a considerably smaller number of persons, but as a rule at least three or four work together. The whole population helps, however, to prepare the meal and partakes of it. Those who have not participated in the catch pay the captors for their share of meat. The price of a turtle varies between 1,000 and 2,000 francs, according to size. This is the price demanded aboard the schooners when living turtles brought from Puka-puka or other atolls are sold.

The boat-launching we witnessed was undertaken by practically the whole population, who pushed and pulled a newly constructed cutter from the work shed down to the beach 300 yards away. The old work-songs, which otherwise are never heard, were sung, probably to a large extent because the islanders knew that we were interested in ancient customs. The owner of the boat distributed after the launching two cases of corned beef (48 cans) and one sack of flour (50 kg) to the population, and the day ended with a community feast.

The repair work on the quay lasted about a week. It was not a voluntary co-operation like the previous one but actually an imposed chore, organized by the chief on orders from his superiors.

3. Specialization.

The emergence and degree of specialization in Raroia depends evidently on the transformation from the old to the new type of economy. Before we can discuss this aspect a clarification of the meaning of the word "specialization" is necessary.*

In pre-European times there existed in Raroia as elsewhere in Polynesia specialists in the sense that certain individuals were more skilled in the generally known crafts and therefore in addition to their everyday activities also performed work for other members of the community. But if we instead define a specialist as a person who, irrespective of skill, has only one bread-earning occupation and works full time, there were no specialists in ancient times in Raroia.

During the last one hundred years specialists in this latter sense have, however, gradually emerged on the atoll, and we can without exaggeration say that today all the Raroians are specialists, but specialists of only two kinds: copra-growers and traders. The proportion is uneven, with 64 adult (above age of 20) copra growers as compared to two traders, but what is significant is that the persons of both categories all can be regarded as full time professionals.

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*For other meanings than the one adopted here see Herskovits, 1953.

An incipient but rapidly growing tendency to a more varied specialization is, however, noticeable and seems intimately connected with the more and more uneven land distribution. As has been shown in Chapter IV certain individuals have for various reasons very little land, and it is especially these landless persons who have tried to find other ways of earning money.

The most common type of such additional part-time work is the transportation of copra sacks from the distant sectors to the central village, where most of the schooners have to load the copra because of the lack of good anchorages in most of the other parts of the lagoon. There are frequent occasions for those who want to take on such work, as many of the Raroians lack adequate canoes and the wealthy land owners usually find it an unnecessary loss of time to do the transporting themselves. The payment is fixed at 25 francs per 50 kg sack, and most of the islanders who engage in this business have canoes which can take 8 sacks each trip. Some of these canoe owners also transport the workers and their families.

Six men regularly undertake transporting of this kind and they all belong to the group of small landholders. Their employers are all among the richest land owners (see further part 1, Chapter VIII).

Another means of eking out the income, resorted to in three cases is to make a sort of coarse doughnuts which are sold at 5 francs apiece. The demand for them is great and the supply never enough as the production limit is usually about 40 doughnuts a day. As a rule a married couple acts as bakers, and they may carry on for as long a time as the whole population is gathered in the village. As this was the case only during the months of July and November-December in 1950, baking could not form a very important extra source of income. The three couples establishing themselves as bakers during these periods, all belong to the class of small landholders, too.

Some men belonging to this class set out at rare intervals to specialize in manufacturing under-water eye-glasses or repair-work of various kinds; but strangely enough nobody has yet seen fit to try out the most natural expedient, often resorted to in Tahiti, of specializing in fishing. It happens that some of the young men go fishing when they are in special need of money, and the fish they bring back are always eagerly bought at good prices by the other islanders. The reason nobody tries in earnest to become a professional fisherman, at least during the months when the whole population is in the village, seems to be the persistence of an old pre-European attitude that fishes are to be distributed as gifts among relatives and important people. Significantly it is never the landless or land-poor individuals who occasionally practice commercial fishing but young men or boys driven by occasional need.

The relation between land-holdings and part time work will be analyzed more closely in the next chapter dealing with the annual income per family.

Chapter VIII

INCOME AND EXPENDITURES

A description of the economic life of the Raroian would not be complete without some information about the differential income and the use made of the money. In spite of the great difficulties in obtaining exact information of this kind for persons who rarely or never keep any books, we have nevertheless tried to gather enough data to be able to discern at least some basic patterns.

The data which we have been able to collect are of the following kinds:

1. The approximate total income during 1950 for each family, with sources of income indicated.

2. Expenditures for a sample group comprising about one third of the total population.

3. The property holdings for each family.

For data on total income we have relied on existing records of sales of copra and mother-of-pearl shells and our own observations supplemented with interrogation of all the family heads. The expenditures for the sample group are taken from the books of one of the storekeepers, and also in this case we have checked with the islanders themselves as much as possible. The list of property holdings, finally, is based on our own systematic survey. The least reliable figures are thus those for the expenditures, but the errors are probably kept at a minimum and the sampling is representative, as will be shown subsequently.

1. Total income.

The income for each family is shown in Table XXIII. From the total sum of 1,923,060 francs, 104,800 shown under the heading "Other activities" must be deducted, as it comes out of the money earned on copra and mother-of-pearl shell diving. The actual income was therefore 1,818,260 francs for the whole population in 1950, or 16,589 francs per capita. With an exchange rate of 64 Pacific francs* to 1 U.S. dollar, this corresponds to 28,410 U.S. dollars for the year and 260 U.S. dollars per capita.

The main source of income is of course the copra. The price varied during the year between 8.35 francs and 11.35 francs a kilo, but in order to simplify our calculations we have used the average price of 10 francs a kilo as a base. The total amount earned on copra (from own and others land) corresponds thus to 169.7 tons. The difference between this figure and the actual output of 187 tons is easily explained by the fact that some of the income from lands in Raroia goes to absent owners.

The income from copra is divided into two categories: that coming from copra grown on own lands and that from preparation of copra for others. The

*All prices in the present study are in Pacific francs. The rate of exchange is 5.50 metropolitan francs to 1 Pacific franc.

Table XXIII: Total income per family during 1950.

Family*	Copra from own lands	Pearl-shell diving	Making copra for others	Transport	Other activities	Total
6	-	-	20,000	4,100	-	24,100
8*	-	-	20,000	8,600	-	28,600
5	-	-	22,000	7,100	6,000	35,100
4*	20,000	-	10,000	-	7,000	37,000
9*	40,000	12,390	-	-	-	52,390
12	50,000	3,360	-	-	-	53,360
11	20,000	-	20,000	8,300	6,000	54,300
3	40,000	9,330	5,000	-	-	54,330
20	20,000	9,540	20,000	-	4,800	54,340
22	40,000	6,120	10,000	-	-	56,120
24	60,000	-	-	-	-	60,000
26	60,000	-	-	-	-	60,000
2	30,000	5,370	20,000	6,200	-	61,570
15*	35,000	-	15,000	700	13,000	63,700
13*	70,000	-	-	-	-	70,000
7	70,000	-	-	-	-	70,000
1*	65,000	7,590	-	-	-	72,590
10	60,000	14,460	-	-	-	74.460
14	75,000	2,490	-	-	-	77,490
21	90,000	-	-	-	-	90,000
27	90,000	-	-	-	-	90,000
18	90,000	1,560	-	-	-	91,560
19*	100,000	-	-	-	-	100,000
17	110,000	-	-	-	8,000	118,000
25	60,000	-	-	-	60,000	120,000
23*	120,000	4,050	-	-	-	124,050
16	130,000	-	-	-	-	130,000
Total	1,545,000	76.260	162,000	35,000	104,800	1,923,060

*For composition of each family, see Table XVIII, Chapter V, part 7.

persons employed in making copra are namely as a rule not full time wage laborers but simply small land holders who occasionally work for the richer islanders, usually one of their distant relatives. The income from the sale of copra thus produced is always equally divided between the worker and the land owner.

If we are to judge solely from the table, there are three families completely without land, but actually No. 5, a couple of "foreigners" working for the part-native storekeeper, is really landless. Families No. 6 and 5 both form households with other related families and always make the copra on certain lands. As they technically are not regarded by their older relatives, from whom they will eventually inherit, as the owners of the land, they are not here classified thus.

As the families in Table XXIII are arranged according to the gradual increase of their income, the relation between the income from own lands and that from other activities is clearly brought out. Evidently only the families with an annual income of 35,000 francs or less find it necessary to earn money in other ways. The apparent exceptions to this: the income of the heads of family No. 17 (8,000 francs) and No. 25 (60,000 francs) are respectively the annual salary of the chief and the supposed annual income of the part-native trader.

The estimate of the trader's annual income is based on the fixed legal percentage of 10% on an annual turnover of 600,000 francs. As he also acts as a money lender, his actual income is probably much higher. The other trader, a Chinese, was not willing to give any details of his activities, and he is therefore not included in the table.

The means of finding additional sources of income - beside the already discussed copra preparation for wealthy land owners - are limited, and actually only two have been tried out to any extent. These are: transport of copra sacks from other parts of the atoll, inaccessible to the schooners, to the central village, and: setting up a bakery (see also Chapter 7, part 3). The only exceptions are the head of the family No. 20, who earned most of his money classified as coming from "Other activities", as a wage worker, and family No. 11, who earned additional money on the sale of ice cubes from a refrigerator.

Whereas all these activities are limited to the families with small land holdings, the diving for mother-of-pearl shell is undertaken by members of families in all income classes. The reason for the even distribution of this income is simply that diving in Raroia, where the lagoon is very deep, requires special skill, which of course is not limited to the lower classes. Considering the small returns (2,742 kgs, worth 76,260 francs), the diving in Raroia must be regarded more as a sport than a professional activity. The situation is of course different during the diving seasons in other atolls, as mentioned in Chapter V, part A.

2. Expenditures of sample families.

None of the islanders keep any record of their expenses, and the only way to get this information was, as we soon realized, to consult the storekeepers' books. At least we could in this way find out what the islanders' expenses were for such things as they regarded as essential themselves - food (canned food, flour and rice), household items (soap, kerosene and gasoline), clothing, cigarettes and some other few miscellaneous items - as the islanders always buy these in the local stores.

Even if we had wanted to, it would have been impossible to gather data of this kind for the whole population as one of the two storekeepers, the Chinese, was not co-operative and besides his books were kept in Chinese. The other, part-native, storekeeper on the contrary gave us without any hesitation permission to copy the accounts, and we used this opportunity to select representative sample families.

Our sample thus obtained comprises 8 families, who regularly made their purchases at the part-native trader's store, and the accounts included cover two whole months, June, when most of the islanders lived in the village, and August, when they almost all worked in a copra sector. As these families only on rare occasions bought anything from the Chinese storekeeper - who, by the way, carries exactly the same goods as the part-native trader - we can be fairly sure the figures represent the total purchases for these families during the selected months.

The 8 families in our sampling came from the following income classes:

Income class	I Below 35,000	II 36-60,000	III 61-90,000	IV Above 90,000
Total number	3	9	9	6
Number in sample	1	2	3	2

They can thus be said to reflect possible variations in spending habits between the economic classes, if any such variations exist. The composition of these 8 families in respect to relationship, sex and age is as follows:

Family no. 8:	Hu 31, Wi 41, HuMo 65, AdDa 7, AdDa 5
Family no. 4:	Hu 32, Wi 26, AdDa 5
Family no. 9:	Hu 32, Wi 21, WiGrPaSi 58, So 7, Da 1
Family no. 15:	Hu 40, Wi 41, Da 17
Family no. 13:	Hu 42, Wi 37, HuFa 81, So 19, So 18, So 15, Da 10, Da 8
Family no. 1:	Single male 45
Family no. 19:	Hu 46, Wi 35, So 11, So 9
Family no. 23:	Hu 57, Wi 49, So 24, SoWi 16, GrCh 1

Compared to the total population our sampling shows the following characteristics:

Age	MALES			FEMALES		
	Total*	Sample	Per cent	Total*	Sample	Per cent
0 - 14	9	3	30.0	24.5	7	28.5
15 - 29	13.5	4	29.6	12.5	4	32.0
30 - 44	15	5	30.0	11	4	36.3
45 - 59	11	3	27.2	5.5	2	36.3
60 -	3	1	33.3	4	1	25.0
Total	51.5	16	-	57.5	18	-

*As totals the average number of persons present in Raroia during June and August is used. See Chapter II, part 3, Table VII.

The variations in percentages are thus very small among the age groups. In its totality the percentage is for the males 31.6 (16 out of 51.5), for the females 31.1 (18 out of 57.5), and for the whole sample group 31.1 (34 out of 109 persons). The sampling can therefore be regarded as representative of the total population in Raroia.

The figures for the sample group are presented in Table XXIV, and in addition a comparison between income and essential expenses for the same families is made in Table XXV.

If we take these figures as a basis for an estimate of the way the Raroians spend their money, we arrive at the following figures:

The sample group spends 54,255 francs on essential items during two months, which corresponds to an annual expenditure of 325,530 francs. If the expenses were the same proportionally throughout the year for the whole population (109 persons on an average), it should have spent in 1950 1,043,610 francs on essential items, broken down in the following way:

Food	417,476 frs
Cloth	235,898 "
Cigarettes	225,074 "
Miscellaneous	119,159 "
Household	46,892 "
Total	1,044,499 "

As the total income for the whole population was 1,818,260 francs (see part 1), 773,761 francs are unaccounted for. This is, however, not so strange as it seems, as the islanders buy a great amount of articles like planks, cement, corrugated iron and prestige articles of all sorts aboard the schooners or during their visits to Papeete. Our figures are therefore in all likelihood correct, and expressed in percentages the income is spent thus:

Food	23%
Clothing	13%
Cigarettes	12%
Miscellaneous	6%
Household	3%
Surplus	43%
Total	100%

The slight variation among the families as to the expenses for essential items is a little surprising (especially if we remember the different composition of each family), but shows that practically all the islanders have the same idea about what constitutes the minimum necessities for a good living. It is important to note at the same time that all families, even those in the lowest income category, evidently are able to attain this standard. The difference between the families with a small money surplus and those with a big surplus is clearly seen in the amount of money spent on prestige property as will be shown in the next section.

Table XXIV: Expenditures for the sample families during the months of June and August 1950.

Family	Month	Food	Household	Clothing	Cigarettes	Misc.	Total
8	June	682	947	40	549	–	2,218
	Aug.	1,633	46	–	317	491	2,487
4	June	1,350	24	180	105	–	1,659
	Aug.	965	170	200	1,030	389	2,754
9	June	705	130	2,367	917	1,177	5,296
	Aug.	574	–	–	484	543	1,601
15	June	1,276	125	505	330	47	2,287
	Aug.	2,361	55	475	603	315	3,809
13	June	1,199	–	400	970	177	2,746
	Aug.	2,497	66	438	1,441	418	4,910
1	June	403	85	557	331	467	1,843
	Aug.	303	105	–	471	147	1,026
19	June	2,097	181	559	644	508	3,989
	Aug.	1,229	199	60	1,077	120	2,685
23	June	1,482	105	4,755	818	1,053	8,213
	Aug.	2,901	200	1,678	1,614	343	6,736
Total		21,657	2,438	12,264	11,701	6,195	54,255

Table XXV: Income, expenses and surplus.

Family	Income class	Annual income	Expenses 2 months	Estimated annual expenses	Estimated annual surplus
8	I	28,600	4,705	28,230	370
4	II	37,000	4,413	26,478	10,522
9	II	52,390	6,897	41,382	11,008
15	III	63,700	6,092	36,552	27,148
13	III	70,000	7,656	45,936	24,064
1	III	72,590	2,869	17,214	55,376
19	IV	100,000	6,674	40,044	59,956
23	IV	124,050	14,949	89,694	34,356

Table XXVI. : Property holdings of each family in 1950.

Family* no.	Useful property								Prestige property					
	plank-house	canoe	outboard motor	stove	lamp	sewing machine	refrigerator	radio	bed	chair	table	bureau	wall clock	bicycle
6	1	–	–	–	1	–	–	–	–	–	–	–	1	1
8	–	1	–	–	1	–	–	–	–	–	–	–	–	1
5	–	–	–	1	1	–	–	–	–	–	–	–	–	–
4	–	1	–	–	1	–	–	–	1	1	–	–	–	–
9	–	1	–	1	1	–	–	–	1	–	–	–	–	1
12	1	1	–	–	2	–	–	–	–	–	–	–	–	–
11	1	1	–	2	2	1	1	–	2	4	1	–	1	1
3	1	1	–	–	1	–	–	–	1	–	–	–	–	–
20	–	–	–	–	2	–	–	–	1	–	–	–	–	–
22	1	1	–	1	1	–	–	–	1	1	1	1	1	1
24	1	1	–	1	2	–	–	–	–	–	–	–	–	–
26	1	–	–	–	1	–	–	–	1	–	–	–	–	–
2	–	1	–	1	2	1	–	–	2	2	1	–	–	1
15	1	1	–	1	2	1	–	–	2	4	2	1	1	1
13	1	1	–	–	2	–	–	–	2	–	1	–	1	1
7	1	1	–	2	2	1	–	–	2	6	2	1	1	–
1	1	1	–	2	2	–	–	–	1	3	1	–	–	1
10	1	1	–	2	3	–	–	–	2	2	1	–	1	1
14	2	2	–	2	3	1	–	–	3	6	3	1	1	2
21	2	1	–	3	2	1	–	–	4	8	5	2	2	–
27	1	1	–	2	3	1	–	–	3	7	2	2	1	1
18	1	1	–	2	3	1	–	–	3	7	3	2	2	–
19	–	1	–	2	3	–	–	–	1	–	–	1	–	1
17	1	1	–	3	3	1	–	–	2	6	3	2	1	1
25	2	2	1	4	3	1	1	1	4	14	5	2	3	2
23	1	1	–	2	2	1	–	–	3	2	4	1	1	1
16	1	1	–	2	3	1	–	–	2	6	2	1	1	2

3. Property holdings of each family.

Completely lacking any accurate figures on how the islanders' considerable surplus of money is spent, we have chosen the best possible substitute, namely to make a survey of the property holdings of each family (Table XXVI) which gives us a fairly good idea what the Raroians buy in addition to the articles regarded as essential. We have divided the property holdings into two categories: useful and prestige property. The classifications are evident, except perhaps in the case of the inclusion of bed, chair, table, bureau and bike under the heading "Prestige property." As, however, the furniture is not used - all Raroians still prefer, according to ancient custom, to sleep on pandanus mats on the floor - and there are no roads outside the village for bikes, we think it is correct to designate also these items as primarily intended for the enhancement of the family prestige.

Chapter IX

FOOD CONSUMPTION

A complete investigation of the islanders' food habits and average consumption had necessitated - in order to give reliable results - prolonged and repeated observations of several sample groups during both the work and the rest periods. Unfortunately we did not find time for such a study. The only way to give an indication of what the islanders eat is to use once more the family accounts presented in the preceeding chapter on income and expenses, and try to extract additional information on this aspect. Even if we do not get complete data on the total food consumption in this way, we at least get an idea of the consumption of imported foods.

Among the data on essential items which we found in the storekeeper's account books, those dealing with the purchase of food were complete. As the imported food comes in standard cans or the quantity sold is indicated in each customer's account, we have without difficulty been able to determine the amount of imported food consumed by our sample population during two months.

The monthly and daily consumption per person, based on these figures, together with the corresponding averages for the daily consumption in French Oceania as a whole for 1947 (Jacquier, 1949, p. 601), are presented below. As our sampling is representative (see Chapter VIII, part 2) and comprises one third of the total population, there is all reason to trust the figures.

Table XXVII: Consumption of imported food in grams for sample population.

Food item	Raroia 1950			French Oceania 1947
	Sample population 2 months	Per month per person	Daily per person	Daily per person
Flour	840,000	12,353	411	273
Sugar	157,500	2,316	77	95
Corned beef	79,000	1,162	38	48
Rice	63,000	926	31	65
Coffee	45,000	661	22	-
Biscuit	21,000	308	10	-
Peanut oil	17,600	282	9	9
Canned milk	15,880	233	7	17
Canned fruit	14,175	208	7	-
Canned fish	11,350	167	5	10
Starch	8,000	117	4	-
Canned butter	5,902	87	3	8

Some other imported foods like canned vegetables, tomato sauce, pork and beans, onions and jam can also be bought in the stores, but the islanders consume such negligible quantities of these few items that we have not found it worth while including them in the table. As the only additional food available in the atoll and eaten regularly in such quantities that it can be regarded as constituting a part of the staple diet is fish and coconuts, the islanders' menu is evidently very poorly balanced. We limit, however, ourselves to the data presented above and leave the analysis of them to the specialists.*

In order to get a well-rounded and correct picture of the nutrition problem in its entirety in Raroia, continued field research is necessary, and a complete study of the nutrition and health problems is actually placed very high on the list of additional research we should like to undertake, if we find the opportunity to return once more to Raroia.

*Our knowledge of the nutrition problems will be considerably increased when the results of Miss S. Malcolm's studies in the Tuamotus are available. Miss Malcolm, who is the nutrition specialist of the South Pacific Commission, visited the group in 1953.

Chapter X

CONCLUSIONS

In spite of our fairly intimate knowledge of Raroia, we do not yet feel qualified to interpret correctly all the raw data presented in the present paper. The conclusions in this chapter must therefore not be regarded as definitive in any way, and all we have done here is simply to summarize and comment briefly on the general trends which we think we have discerned.

At the outset, in pre-European times, the islanders subsisted on a simple food-gathering and planting economy, and as far as we know, they had achieved a cultural equilibrium. About one hundred years ago the Raroians came for the first time in more intimate contact with Western culture, and since then the acculturation process has continued with increased intensity.

Due to the isolation and poverty of the atoll, it did, however, not attract foreigners to the same extent as Tahiti, Hawaii, Samoa and other mountainous islands, and the agents of change in Raroia were not representative for our Western society as a whole, but consisted of <u>selected groups</u>, principally traders, missionaries and administrators.

Characteristic for the acculturation process under study is that the changes have been <u>peaceful</u> and that a <u>minimum of pressure</u> has been exercised on the islanders. Raroia is thus a good example of a receiving group, which has been offered a <u>limited</u> number of cultural traits with the freedom to select <u>voluntarily</u> those it wished to take over.

Herskovits has proposed four reasons for a receiving group to adopt foreign traits, and they all seem to have been operative in Raroia. These determinants of change are (Herskovits, 1938, p. 134):

1. Economic advantages
2. Social prestige
3. Congruity of culture-patterns
4. Necessity to adopt traits functionally related with other ones selected for one of the previous reasons.

Of these determinants, number 1 seems to have been the most powerful, as indicated by the radical change from a direct subsistence economy to a preponderantly surplus production. Motive number 4 has certainly also been operative to a large extent and good examples are here the changes in settlement patterns and land ownership correlated with the transformation of the economy.

The prestige factor, number 2, is far from negligible in Raroia, as is clearly shown for instance by the list of the property holdings of each family (Table XXVI). Motive number 3, changes caused by the congruity of culture-patterns between the donor and the receiving group, has certainly played a very small role, and the only field we can think of where it can have had some significance is that of religion.

Let us now turn to the <u>results</u> of the acculturation process. Due to the different ways in which the determinants discussed above have been combined and the relative resistance offered to changes in each case, the impact on the native culture has been very <u>uneven</u>. Some parts of the culture have been more thoroughly changed than others, and the probable order of them, <u>from most to least</u> transformed, is according to our rough estimate the following:

1.	Health	The isolation of the atoll in ancient times protected the population against most of the contagious diseases which now occur. Instead of the frequently attested good health in pre-European times, tooth decay and stomach troubles, due to malnutrition are now common.
2.	Material culture	European materials and techniques are used almost exclusively, and the only exception is the still frequent use of plaited palm leaves for house construction.
3.	Religion	All islanders are practicing Christians, but the widespread belief in magic and the formal-ritual conception of religion are ancient survivals.
4.	Economy	European money economy and simple surplus production dominates now, but everybody still devotes some time to fishing, turtle catching, egg collecting and other subsistence activities. It must also be noted that the islanders' surplus economy differs considerably from that usually found in most Western societies as it is a <u>stationary</u> economy.
5.	Political organization	Old hereditary chiefs and priests have been replaced by a popularly elected chief and a village council. As the system was fairly democratic already in ancient times, the changes are not so great as they may seem formally.
6.	Language	The older generations still speak an almost pure local dialect, but the younger generations use Tahitian to a very large extent.
7.	Social organization	As in pre-European times the basic unit is the extended family, even if the size of the family has decreased and the authority of the head is not the same. The old incest rules are applied, adoption is still practiced to a considerable extent, and the kinship-terminology is unchanged. A trend away from collectivism toward individualism is, however, discernable.
8.	General knowledge	Most of the islanders are able to write and read Tahitian, but they do not know French. As there are practically no books in the native vernacular and few of the Raroians have any formal education, they do not know much about the modern world in which they are living. Their general outlook is therefore not very different from that of their ancestors.

It is thus evident that the islanders still are in the middle of an acculturation process, and as could be expected, the integration of the various culture traits is very poor. Characteristic for the present situation is that many lags still exist, that the adjustments often are haphazard, and that a new equilibrium has not yet been achieved. The Raroians are lost and bewildered, many times simply because they are between two cultures. They have abandoned too much of their own culture too rapidly, before acquiring new techniques, habits and values.

The islanders have escaped many of the problems other native groups in the Pacific have had to cope with, like over-population, wars, religious competition and material poverty, but there are still reasons for serious apprehension. Some of the difficulties are due to factors outside the islanders' control, like the infiltration of ruthless Chinese traders and the lack of useful books in the native vernacular, but most of the problems have, of course, their root in the above mentioned poor integration of the various culture traits.

These latter problems, which can be traced back to unsatisfactory adjustments to the new situation created by the introduction of foreign economic, religious and political systems, have been discussed in their context in this paper, and we shall only list them briefly here. These principal immediate problems are:

1. Land questions. Much land is uncultivated because of uncertain or disputed titles. Much time is lost in travelling because the land parcels are so small and scattered. Conflicts arise due to poor co-ordination of the activities.

2. Health and nutrition. The islanders do not know how to treat even the most common diseases, and have of course no idea about modern hygiene. The diet is poorly balanced with too much imported and canned food.

3. Social disintegration. The old leaders, who were religiously sanctioned and therefore obeyed, have disappeared, and their places have been taken by traders and office-seekers, who lack authority. No cooperative enterprises are therefore possible any more.

4. One-sidedness of the economy. The islanders are at present fairly wealthy, but all their income derives from mother-of-pearl shell diving or copra preparation, of which only the latter is a regular activity. As there are practically no other sources of income in the atoll, a sudden price fall or disappearance of the copra and shell trade will mean a complete collapse of the present economic system.

In the first three cases, the type of solution - more detailed suggestions are of course outside the scope of the present paper - which seems most logical is simply a continued and better guided Europeanization of the islanders, aiming at the disappearance of partial lags and the achievement of a new equilibrium. Such a solution seems, however, not possible in the fourth case, the one-sidedness of the economy, and the only alternative points instead backwards, to a return to the old subsistence economy.

This solution was actually tried during the depression in the early 1930's, when all trade virtually ceased. It worked out fairly well, and if we are to trust the islanders themselves their health was even improved. The question is, however, whether such a return to the old subsistence economy is still possible, especially as a permanent solution?

The main hindrance is of course that the persons who were the carriers of the old culture and the leaders during the native revival in the early 1930's are now almost all dead, and that the present Raroians have no knowledge of ancient techniques. If such a solution were to be tried once more in the case of the complete collapse of the copra trade, it would therefore certainly be necessary, no matter how ridiculous it may sound, to call in a team of ethnologists and teach the poor islanders survival technique on an atoll, i.e. courses of the same type as those given American airmen at the Bernice P. Bishop Museum during the last war in the Pacific!

Whether two such conflicting principles, as a more complete Europeanization in some cases and a return to the pre-European patterns in other cases, could co-exist is of course an ultimate question which cannot be solved except by practical experiments.

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Part 2

NATIVE TOPOGRAPHICAL TERMS IN RAROIA, TUAMOTUS

by Bengt Danielsson

As the ancestors of the present day natives in the Tuamotu group came from the surrounding mountainous islands, Tahiti, Marquesas and Mangareva, they evidently had to create new terms for most features of the atolls in which they settled. The fact that the Tuamotuans today have a very detailed and exact terminology, which covers almost every topographical feature, can therefore be taken as a proof that 1) they have lived in atolls for long periods, and 2) there was a very intimate relationship between the land and the people.

In Raroia, where all the terms in this paper were collected in 1952, the first conclusion is definitely confirmed by the traditions, which place the discovery and settlement of the atoll at thirty generations from 1950. As to the ecological relationship, it will be treated principally in my forthcoming paper on the economic organization in Raroia, but a short description of the topographical terminology seems warranted here in order to contrast the natives' concepts with those of the modern geologist.

A quick glance at the subsequent lists will show that the native terminology is extremely comprehensive and well suited. In some cases it seems even that the native has a term lacking in the modern scientist's vocabulary which profitably could be borrowed. Let us for instance take the Tuamotuan and pan-Polynesian word <u>motu</u>, which means a part of the reef with vegetation, surrounded by water <u>or</u> dry arid beach rock. The English word islet is frequently used for translating <u>motu</u>, but it does not carry <u>all</u> the important connotations of the latter, i.e., that it may be separated by dry arid beach rock as well as by water, and that it always has some vegetation. Other Tuamotuan terms, which do not have any English counterparts, are: Tahuna, hoa, kapuku and tai, and these are defined in the lists.

This detailed and exact terminology reflects a very close adaptation and utilization of the natural resources, as it was created during the never-ceasing food-quest, which naturally demanded a thorough knowledge of every part of the land, the reef and the lagoon. Another example of how the terminology certainly has grown out of an immediate need, is the classification of the different types of coral patches in the lagoon. There are thousands of coral patches of all sizes and shapes, and the existence of precise and accurate terms for them of course greatly facilitates navigation.

An equally utilitarian attitude is shown in the use of place names. None of the five major islets in Raroia has, for instance, a name, which applies to the whole of it, but different parts and features of them, which are of importance to the natives, are all named. (For convenience, the name of the most known or prominent place has been extended to the whole islet on the map of Raroia in Atoll Research Bulletin No. 31.) Many names for various parts of the lagoon and the reef exist too, which from a Western point of view at first glance seem illogical and unnecessary, but which on closer examination are found to correspond admirably to certain native needs.

The following lists are by no means complete, and are deliberately limited to the terms most frequently in use. It could easily be supplemented through inquiries of older men, who still remember archaic words no longer known to the younger generations. This disappearance of many terms is in itself very illuminating and constitutes a sort of measure of the changes which already have taken place. The former close dependence on the natural resources has to a large extent ceased to exist with the rise of the copra trade and the introduction of a money economy; and in the same way as the names of ancient cult-places now have been completely forgotten due to the natives' conversion to a new faith, certainly most of the topographical terms will also eventually be lost during the continued acculturation process.

The native terms are listed below under the following headings: Parts of the atoll, Directions, Land and reef features, Features of the sea and the lagoon, Coral patches, and Miscellaneous terms.

Parts of the atoll.

Four different parts of the atoll, Raroia, are distinguished and named. The northeastern part is called gake, the southeastern kereteki, the southwestern raro and the northern tokerau. (See map in Atoll Research Bulletin No. 31.) These are not specific names, but general terms, which curiously enough represent two completely different principles of orientation. The words tokerau and raro are compass and wind directions, the former meaning "northeast" and the latter "below the wind." The words gake and kereteki on the other hand indicate the relative position of these parts of the atoll in relation to the principal human settlement. When one stands at the main village facing the lagoon, kereteki is the part of the atoll farthest away to the right, whereas gake is the part farthest away to the left.

This double frame of reference is used all over the Tuamotus, and the underlying principle is still better recognized on other atolls of different shapes and patterns of settlement than Raroia, where due to the general NNE-SSW direction of the atoll, gake and tokerau to some extent overlap. The only explanation for this curious terminology seems to be that it originally was created in an island where it perfectly fitted the geography and human ecology, and then later carried as a part of the general culture to new islands and there for one reason or another preserved.

The compass directions, of which a great number are distinguished by the natives, are as a rule not used for indicating the parts of the atoll, but for determining the wind direction.

Directions and relative positions.

A typically Polynesian way of indicating the relation between two islands or points is with reference to the prevailing trade wind, which most of the year is blowing in the same principal direction, from the east. The island or place situated farthest towards the east and therefore windward, is said to be ruga, above, the other raro, or below. When the natives for instance say that Takume is situated "above" Raroia, this does not mean, as a non-Polynesian observer may suppose, that Takume is the northernmost atoll, but instead that it is situated slightly closer to the trade wind than Raroia. The name Raroia, or Raro-ia, itself means simply "(the land which) is below (Takume)."

Common terms expressing directions are i uta, towards land, i tua, i tai, towards the sea, and i hopaki, towards the lagoon. A person travelling in a canoe is of course always moving i uta, towards land, either he is coming from the ocean or the lagoon side. A person walking from the lagoon beach towards the outer reef is also moving i uta, until he reaches the center of the islet, and then i tua or i tai - the first term being used if he actually continues out into the sea swimming or by canoe, the second term if he stops before he reaches the edge of the reef. A person walking across the islet in the opposite direction is moving i uta the first half of the distance, and then i hopaki, towards the lagoon. The same terms are also used for indicating the relative position of lands and natural objects.

Land and reef features. (See Figures I and II)

Fenua	atoll, islet or land
Motu	part of the reef with vegetation, surrounded by water or arid dry rock. Literal meaning: "broken off."
Pahere	small part of a motu, united with the main part only through a narrow strip of land
Tahuna	sand dune without vegetation. Literal meaning: "hidden."
Piriatau	indurated sand forming the foundation of a motu
Pakokota	the uncovered beach-rock or island conglomerate
Papa	extremely flat coral platform on the lagoon side
Akau	outer reef flat, covered by water at high tide
Hiti akau	edge of the outer reef flat
Tahora	reef on the lagoon side close to the shore
Papae	edge of the reef on the lagoon side
Koutu	land promontory
Kikiha	wide stretch of the reef between two motu, covered by water at high tide
Ava	pass, deep and wide channel in the reef circle
Hoa	shallow channel beginning on the lagoon side, separating completely or partially two motu
Tairua	closed hoa

Poehoga	inner part of a closed hoa
Kaoa	reef spur on the lagoon side
Tauta	reef spur on the sea side
Koehae	surge channel on the outer reef
Repa	open gap in the outer reef flat where the sea reaches the shore
Puta	opening in the lagoon reef
Mapuna	blow holes on the outer reef
Patuarea	spur on the sea side slightly higher than the surrounding reef
Paepae	upper part of the lagoon beach
Paraha	the part of the sandy lagoon beach intermittently wet by the swash

Features of the sea and the lagoon.

Roto, Tairoto	lagoon
Tai	the sea from the beach to the edge of the reef
Tua	the sea beyond the edge of the reef
Moana	deep, blue water, either in ocean or lagoom
Au	current
Reva	depth
Rokaroka	abyssmal depth
Kare	wave
Garu	breaker
Miti	salt water

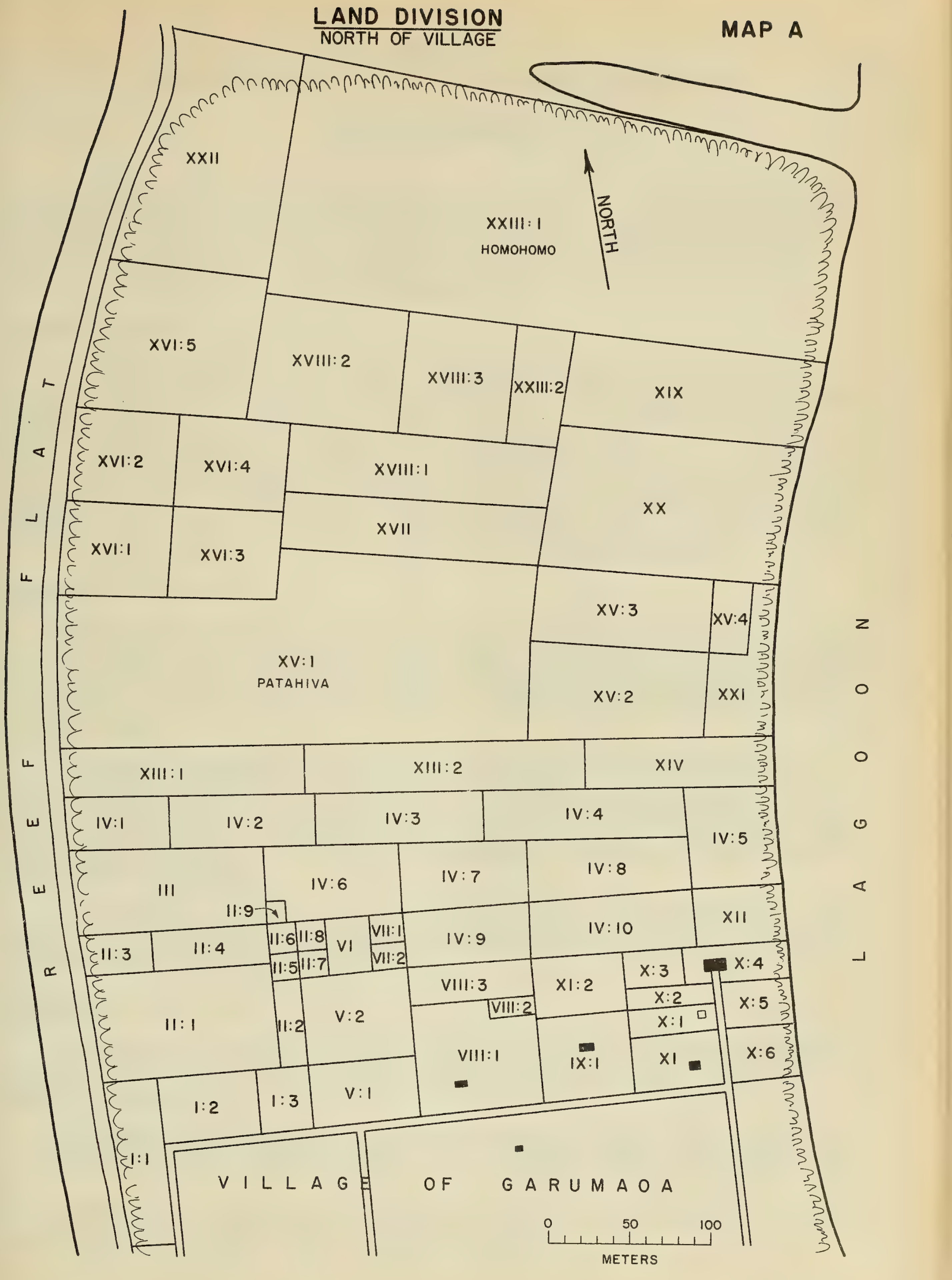
Coral patches. (See Figure III)

Purari	isolated patch
Vata	group of patches

Tohitikia	patch rising up from the bottom in the form of a cylinder or slightly marked cone
Patahora	mushroom-formed patch
Magarua	U-shaped when seen from above
Karena	patch which reaches the surface, big size
Puteu, teu	patch which reaches the surface, but of smaller size
Tirare	patch not reaching the surface, but still visible
Marahi	still visible, but lower than tirare
Kapuku	patches on the bottom, not visible from the surface

Miscellaneous terms.

Ahu	sand bank on the bottom
Puratea	same, but of smaller size
Patetea	same, but of still smaller size
Konao	coral stone
Gaere	sand


LAND DIVISION
NORTH OF VILLAGE
MAP A
NORTH
XXII
XXIII:1
HOMOHOMO
XVI:5
XVIII:2
XVIII:3
XXIII:2
XIX
XVI:2
XVI:4
XVIII:1
XX
XVII
XVI:1
XVI:3
XV:3
XV:4
XV:1
PATAHIVA
XV:2
XXI
XIII:1
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XIV
IV:1
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VIII:3
XI:2
X:2
X:5
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II:2
V:2
VIII:2
X:1
VIII:1
IX:1
XI
X:6
I:2
I:3
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I:1
REEF FLAT
LAGOON
VILLAGE OF GARUMAOA
0
50
100
METERS

Part 3

NATIVE TERMINOLOGY OF THE COCONUT PALM IN RAROIA ATOLL[1]

by Bengt Danielsson

The importance of the coconut palm to the natives is reflected by the detailed terminology. Every part of the tree is given a specific name, and the different stages of development of the nut are distinguished with an almost scientific accuracy. At least a dozen varieties are known to the islanders and used according to their special properties.

Stages of growth.

The usual word for the palm tree is hakari, but niu, the older word of pan-Polynesian distribution, is also known. Only a full-grown tree is called hakari, however, and before it reaches this stage three distinct names are used. Nana is a very young plant with sprouts not yet split into leaflets. The roots are short and the mesocarp or husk is still attached to the sprout. At the next stage, tikovai, the leaves are fully developed, 6-10 feet high, and emerge like a fan from the ground. Gradually the trunk is formed, and from the moment it can properly be called a tree, it is termed hoka. At the age of six or seven years finally, the tree reaches maturity and is a hakari.

The parts of the tree.

The terms for the different parts of the full-grown tree are very numerous. To begin with the roots, these are called aka, which simply is the generic name for root. The lower, thicker part of the trunk is called turei, and the rest of it tumu. The upper part of the stem, the vegetative bud, which is edible, is named muko.

A young undeveloped leaf still folded against the midrib has a special name, mote, in contrast to the fully developed leaf for which two words are used, rauniu or gaofe. The first word is the pan-Polynesian term and the second the local term. Both are curiously enough also used for the smaller leaflets attached to the central midrib, the katakata. The term for the midrib of the leaflet is koitika.

The parts of the fully developed flower and their names are shown in Figure 1. A flower bud is called kumoa, but there is no word for the fully developed flower cluster as a whole.

The nut.

All features of the nut, even the smallest and most insignificant from a Western point of view, are recognized and named by the natives. They are shown in Figure 2.

As everywhere in Polynesia several well defined stages in the growth of the nut are distinguished and in Raroia their number is five. No common term

1/ The terminology varies considerably in many cases from atoll to atoll. We have limited ourselves to that in use in Raroia.

for "nut" exists. This is a typical example of the strictly utilitarian attitude of the islanders. Each type of nut has its own properties, useful in different ways and accordingly each has a special name. A "nut in general", on the other hand, combining in an abstract the way the qualities of several types of nuts, is of no use whatsoever, and no such term has therefore been created.

The names and principal characteristics of the nut at the different stages are as follows:

Stage of growth	Characteristics
Puriri	Recently formed nut, no cavity inside.
Rehi	Almost full size but still green nut. Cavity filled with bitter water. No or very little flesh formed.
Viavia	Full size but still green nut. Thin slimy flesh. Water slightly sweet.
Komoto	Full size nut with spots of darker color. Flesh thick and firm. Water effervescent and bitter.
Gora	Maximum size, brown nut. Flesh of maximum thickness. Water sour.

Varieties.

The natives distinguish at least a dozen varieties of coconut palms, but it is doubtful whether the distinctions are all justified from the point of view of a scientific botanist. The distinctions are based on the following classificatory principles: color of nuts, arrangement of nuts, and special properties of nuts.

Varieties based on the color of the nuts:

mamagu	dark green nuts
motea	pale green nuts
fateka	light yellow-green nuts
koheko heheko	reddish-brown nuts
kurakura	reddish nuts
heru	nuts of which the upper part is scarlet-colored

RAROIAN NAMES OF COCONUT PARTS

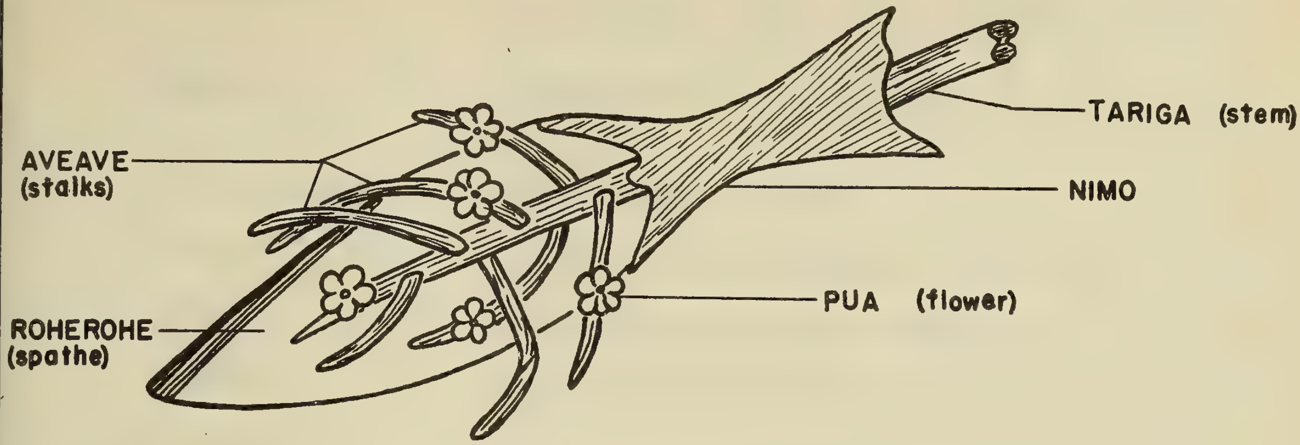
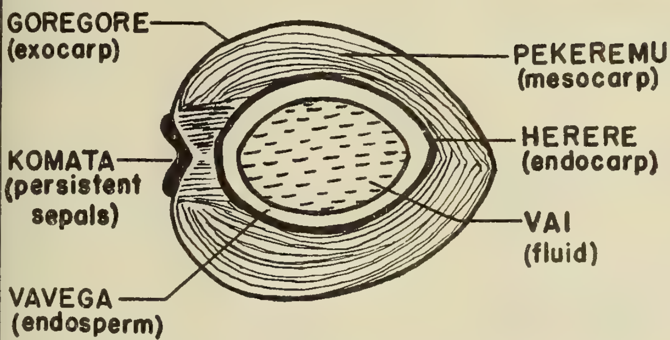
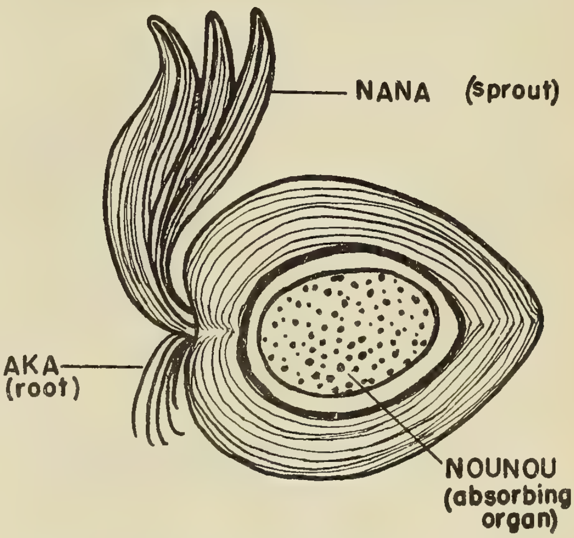


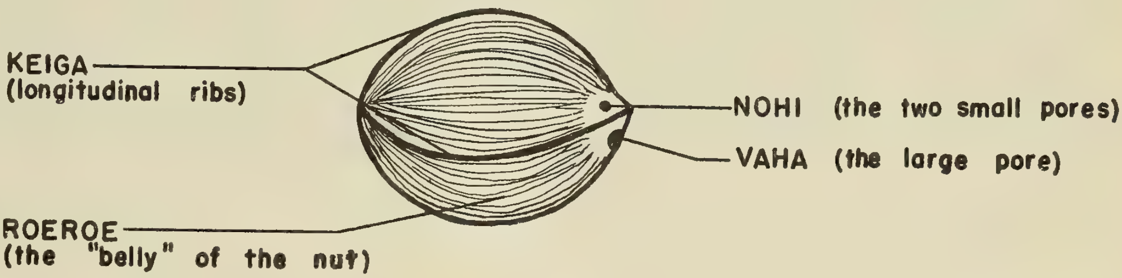
FIGURE 1. FLOWER STEM AND SPATHE



(a) CROSS SECTION OF MATURE NUT



(b) CROSS SECTION OF SPROUTING NUT



(c) HUSKED NUT

FIGURE 2. NUT

Varieties based on the arrangement of nuts:

takaveatika	the nuts lack stalks and are attached directly to the stem
makire	abundant, small nuts in thick grape-like clusters

Varieties based on special properties of nuts:

kaipoa	nut with edible, sweet husk or mesocarp
pururoa	nuts with thick husk and small nuts
karava	oval nuts with long husk fibers

Miscellaneous.

The following miscellaneous terms were recorded:

nounou	absorbing organ (haustorium) in a gora or full-grown nut
koka	oily nounou
puha	gora with dry detached meat
kivako vavako	gora without water or nounou
kovari	prematurely fallen nut
kererau	cluster of nuts
popoga	flesh attacked by insects, or deteriorated in other ways

Final note.

The terms given in this short paper are those still commonly used in the atoll. Some of the older informants could give a certain number of additional terms, which now have become obsolete due to the introduction of factory-made products replacing articles formerly made of the various parts of the palm. As we are mainly interested in the present situation, however, and our lists at any rate contain the native words for all the main features of the palm tree, we have not included these additional and more doubtful terms.

Part 4

BIRD NAMES IN RAROIA ATOLL

by Bengt Danielsson and Aurore Natua

Type	Scientific Name	English Name	Raroian Name
Res.	Anous minutus minutus	white-capped noddy	Kikiriri
Res.	Anous stolidus pileatus	brown noddy	Goio
Res.	Conopoderas atypha atypha	reed warbler	Kokikokiko, kotiotio, Makomako, Komakomako
Res.	Demigretta sacra sacra	reef heron	Kotuku
Res.	Fregata sp.	man-o-war bird	Kotaha
	ariel	white breast	Puhoho
	"	two white spots on the sides	Makino
	minor	white head and breast	Rutu
	"	red throat	Varovaro
Res.	Gygis alba candida	fairy or white tern	Kirarahu, Kitaketake
Res.	Heteroscelus incanus	wandering tattler	Kuriri
Res.	Procelsterna cerulea teretirostris	blue ternlet	Gaga
Res.	Sterna fuscata oahuensis	sooty tern	Kaveka
Res.	Thalasseus bergii cristatus	crested tern	Tara
Res.	Sterna lunata	spectacled tern	Oreore
Res.	Sula leucogastra plotus	brown booby	Kariga
Res.	Sula sula rubripes	redfooted booby	Kariga hopetea

Type	Scientific Name	English Name	Raroian name
Migr.	Urodynamis taitensis	long-tailed cuckoo	Kurevareva, karevareva
Migr.	Numenius tahitiensis	bristle thighed curlew	Kivi, keufea
Migr.	Phaethon lepturus dorotheae	white-tailed tropic bird	Tavake hopetea
Migr.	Phaethon rubricaudra	red-tailed tropic bird	Tavake hopekura
Migr.	Pluvialis dominica fulva	Pacific golden plover	Torea
Migr.	Puffinis nativitatus	brown shear-water	Rako
Migr.	Puffinis Pacificus	black shear-water	Pugapuga
Former Res. now ext.	Aechmorhynchus parvirostris	Polynesian sandpiper	Titi
Former Res. now ext.	Porzana tabuensis	little rail	Moho
Former Res. now ext.	Ptilinopus coralensis	fruit dove	Koko

Part 5

CHECK LIST OF THE NATIVE NAMES OF FISHES FOR RAROIA ATOLL

by Bengt Danielsson

The following list in the first column apparently includes all the names for fishes that the Raroians know. The terms preceded by an asterisk were checked by the authors against specimens collected on the 1952 Coral Atoll Project at Raroia Atoll, Tuamotu Archipelago, and identified in the field. The second column includes these tentative field identifications which will have to be confirmed by additional study. The third column includes the general common name for the fish group involved. For further information on the fishes collected at Raroia see Atoll Research Bulletin No. 18.

The Raroia names are almost always the same as those used throughout the Tuamotus, but there is a strong tendency for Tahitian terms to supplant the original fish vocabulary in the western Tuamotuan islands. Of the 176 native names, 37 could not be confirmed by fishes collected on the Coral Atoll Project.

Alphabetical list according to Raroia name:

Raroian name	Scientific name	General English name
* AHORE	Kuhlia sandwichensis	ahole
* AKEGA	Acanthurus triostegus	surgeon fish
AUHOPO	Euthynnus pelamis	bonito
* AVAI	Acanthurus nigricans	surgeon fish
FAFARUA	Ray	ray
* FAKETA	Epinephelus tauvina	sea bass
* FANEA	Hemirhamphus pacificus	half beak
* GAREA	Epinephelus merra	sea bass
* GAVERE	Scarus pulchellus	parrot fish
GUHURI	Carangidae	jack or crevalla
HAKURA	Xiphias gladius	swordfish
* HAMI	Ctenochaetus strigosus	surgeon fish
* HAPUTU	Cephalopholis argus	sea bass
* HAUEKE	Scarus sp. two	parrot fish

Raroian name	Scientific name	General English name
HAUREPE	Istiophorus	sail fish
HEIMIKI	Lutjanidae	snapper
HEREPOTI	Acanthuridae	surgeon fish
* HIMIKI	Lethrinidae	snapper
* HOKAHOKA	Variola louti	sea bass
HOKE		
* HOMOHOMO	Scarus sp. seven	parrot fish
* HOPIRO	Mugil vaigiensis	mullet
* HOPUPU	Melichthys buniva	trigger fish
* HOROTAHORA	Balistapus aculeatus	trigger fish
* HUE	Tetrodon meleagris, Canthigaster cinctus, C. solandri, C. bennettii.	puffer fish
* HUTIHUTI	Lutjanus kasmira	snapper
* KAGU	Belone platyura	needle gar
KAKAHI	Germo macropterus	tuna
* KAKARIURI	Echeneis naucrates	remora
* KAKAVERE TUPOUPOU	Aulostomus chinensis	trumpet fish
* KANAE	Mugil crenilabis	mullet
KAPUHA	Mullidae	goat fish
* KARAEA	Synodus variegatus, Parapercis tetracanthus	lizard fish
* KARAUA	Naso tuberosus	unicorn fish
* KARAVA	Balistes undulatus, Cantherines pardalis	trigger fish
* KAVATA	Mugil engeli	mullet
* KAVETI	Parupeneus trifasciatus	goat fish

Raroian name	Scientific name	General English name
* KEKE	Chaetodon facula	butterfly fish
* KIKITO	Acanthurus guttatus	surgeon fish
* KIOA	Holocentrus opercularis	squirrel fish
* KIOKIO	Albula vulpes	bonefish
* KITO	Epinephelus maculatus	sea bass
* KOFARUFARU	Epinephelus maculatus	sea bass
* KOKIRI	Balistidae in general	trigger fish
KOKOPU		
* KOKOROHUE	Blenniidae (in toto)	blenny
* KOKOTIKA	Ephinephelus socialis	sea bass
KOMENE	Selar crumenophtholmnus	jack or crevalla
KOMURI	Carangidae	jack or crevalla
* KONIHO	Scarus sp. one	parrot fish
KOPA	Holocentridae	squirrel fish
* KOPAHOPAHO	Pseudoscarus troschelli, Scarus microrhinos	parrot fish
* KOPARIPARI	Tetrodon meleagris	puffer fish
* KOPERU	Decapterus sanctae-helenae	jack or crevalla
* KOPUMERI	Scarus forsteri, Scarus sp. one.	parrot fish
* KORAI	Megaprotopon, Chaetodon in general	butterfly fish
* KORAIMU	Chaetodon lunula	butterfly fish
* KOTIMU	Abudefduf sexfasciatus, A. septemfasciatus, A. sordidus	demoiselle fish
KOUKA	Croyphaena	dolphin
* KOUMA	Mullidae	goatfish

Raroian name	Scientific name	General English name
* KOVIKOVI	Chaetodon ephippium	butterfly fish
* KUKINA	Scarus sp. two	parrot fish
* KUO	Mulloidichthys auriflamma	goat fish
* KUREVAREVA	Balistidae	trigger fish
* KURIPO	Naso sp.	unicorn fish
* KUTARO	Balistes fuscus	trigger fish
KUTEUTEU	Carangidae	jack or crevalla
* KUTU	Scarus sp. eight	parrot fish
MAERE	Variola louti	sea bass
* MAGUMAGU	Lutjanidae	snapper
* MAHEKO	Balistidae	trigger fish
MAHIMAHI	Coryphaena	dolphin
* MAKERE	Scarus sp. nine	parrot fish
* MAKIAMO	Mullidae	goat fish
* MAMO	Pomacentridae	demoiselle fish
MANA	(?) Gempylidae	? oil fish
* MARAIA	Cheilinus undulatus	wrasse
MARAPE	Scaridae	parrot fish
* MARARI	Thalassoma umbrostigma Novaculichthys taeniourus	wrasse
* MARAVA	Siganus sp.	
MAREA	Acanthuridae	surgeon fish
MAROTO	Cypselurus sp.	flying fish
* MEKO	Lethrinus rostratus	snapper
* MEROMERO	Epinephelus bohar	sea bass
* MOAGA	Parupeneus bifasciatus	goat fish

Raroian name	Scientific name	General English name
* MOI	Polydactylus sexfilis	threadfin
* MORORI	Tetrodon meleagris	puffer fish
* MU	Monotaxis grandoculis	mu
MUMU	Acanthuridae	surgeon fish
* NAENAE	Caranx armatus	jack or crevalla
NAKO	Mullidae	goat fish
NANUE	Acanthuridae	surgeon fish
* NIFA	Albula vulpes	bonefish
* NOGA	Scarus forsteri, Scarus sp. three	parrot fish
* ONO	Sphyraena snodgrassi	barracuda
* OROHEA	Acanthurus elongatus	surgeon fish
* PAGO	Balistes sp. one	trigger fish
* PAKERERO	Zebrasoma veliferum	sailfin surgeon fish
* PAKEVA	Caranx ferdu	jack or crevalla
* PAKOU	Thalassoma, Stethojulis phekadopleura	wrasse
* PAKURAKURA	Acanthurus achilles	surgeon fish
* PANAPANA	Zanclus cornutus	moorish idol
* PAPARARI	Scarus, Gomphosus	parrot fish, wrasse
* PAPURAGO	Myripristis murdjan	squirrel fish
* PARAI	Lutjanus marginatus, L. monostigma	snapper
* PARATUKI	Cirrhitus pinnulatus, Cirrhitidae	hawk fish
* PARUKU	Caranx melampygus	jack or crevalla
* PATI	Albula vulpes	bone fish

Raroian name	Scientific name	General English name
* PATIKI	Bothus pantherinus	flat fish
* PEPE	Caranx adscensionis	jack or crevalla
* PETI	Myripristis murdjan	squirrel fish
* PETIMU	Myripristis adustus	squirrel fish
* PIHERERE	Spratelloides sp. one	herring
* PIRIREHI	Bothus pantherinus	flat fish
* PITIKA	Scaridae	parrot fish
* POPOGA	Balistes vidua	trigger fish
* POTAKA	Ray	
* PUAGARI	Scarus sp. ten	parrot fish
* PUAKI	Lutjanus marginatus	snapper
* PUGAPUGA	Synancea verrucosa	stone fish
* " veve	Scorpaenopsis gibbosus	stone fish
* RAI	Scomberoides sancti-petri	leatherback
* REREIOGA	Caranx speciosus	jack or crevalla
ROEROE	Elagatis bipinnulatus	rainbow runner
* ROI	Cephalopholis argus	sea bass
* ROROA	Acanthocybium solandri	wahoo
* RUHI	Caranx adscensionis	jack or crevalla
* RUKERUKE	Holotrachys spinifer	squirrel fish
* RUPO	Caranx melampygus	jack or crevalla
* TAEA	Lutjanus sp. one	snapper
* TAGAU	Epinephelus bohar	sea bass
* TAHAKARI	Apharius furcatus, Kyphosus sp. one	snapper
* TAKIRE	Parupeneus barberinus	goat fish

Raroian name	Scientific name	General English name
* TAMURE	Lethrinus mahsena	snapper
TAPATAI	Alectis ciliaris	thread fish
* TAPERETA	Ray	ray
* TAPIRO	Cheilinus undulatus	wrasse
TAREFA	Aprion virescens	snapper
* TAREI	Naso lituratus	unicorn fish
* TATAHAUTA	Caranx melampygus	jack or crevalla
* TATARAIHAU	Scorpaenodes sp. one, Pterois volitans	scorpion or turkey fish
* TATATATA	Epinephelus bohar	sea bass
* TATIHI	Naso eoume	unicorn fish
* TATIKA	Cheilinus undulatus	wrasse
TAUTE	Scaridae	parrot fish
* TEGATEGA	Scarus microrhinos	parrot fish
* TEMU	Holocentrus caudimaculatus	squirrel fish
* TERO	Lutjanus marginatus	snapper
* TIGITIGIA	Holocentrus sammara, H. laevis	squirrel fish
* TIKAMU	Chaetodon lunula	butterfly fish
* TIKEKE	Holocentrus binotatus	squirrel fish
* TIKEI	Holocentrus microstomus	squirrel fish
* TIKEIKEI	Holocentrus diadema	squirrel fish
TIPA		
TIPUKUPUKU	Echeneididae	remora
* TITEKETEKE	Scaridae	parrot fish
* TITIRIRI	Epinephelus maculatus	sea bass
* TOHARE	Lutjanus kasmira	snapper

Raroian name	Scientific name	General English name
TOHEVERI	*Euthynnus pelamis*	bonito
* TOKATI	*Scarus formosus*	parrot fish
* TONAE	*Pseudoscarus troschelli* *Scarus microrhinos*	parrot fish
* TONU	*Paracanthistius maculatus*	sea bass
* TOPIROPIRO	*Epibulus insidiator*	wrasse
* TOTARA	*Diodon hystrix*	porcupine fish
* TOTOKE	*Scarus sp. six*	parrot fish
TOTOVIRI	Belonidae	needle gar
* TUATAU	*Sphyraena helleri*	barracuda
* TUGOUGOU	*Epinephelus sp. one*	sea bass
* TUTUKE	*Ostracion sebae,* *O. lentiginosum*	box fish box
* UME	*Naso annulatus*	unicorn fish
* UOA	*Myxus leuciscus*	mullet
URAVENA	(?) *Ruvettus pretiosus*	? oil fish
URUA	Carangidae	jack or crevalla
* URUAKAU	*Diodon hystrix*	porcupine fish
VAU	*Germo*	tuna
* VETE	*Mulloidichthys samoensis*	goat fish
* VEVE	*Epinephelus hexagonatus*	sea bass

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ATOLL RESEARCH BULLETIN

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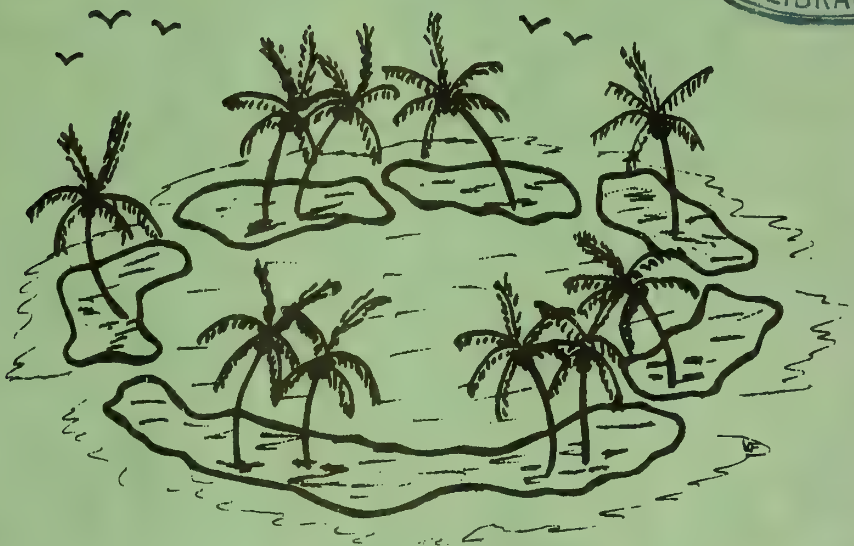
34. Animal Ecology of Raroia Atoll, Tuamotus
35. Interrelationship of the Organisms on Raroia Aside From Man
36. Reefs and Sedimentary Processes of Raroia



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ACKNOWLEDGMENT

It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs, CIMA, SIM, and ICCP, during the past six years. The Coral Atoll Program is a part of SIM.

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2101 Constitution Avenue, N. W.
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ATOLL RESEARCH BULLETIN

No. 33

Floristics and Plant Ecology of Raroia Atoll, Tuamotus

Part 1. Floristic and Ecological Notes on Raroia

by Maxwell S. Doty

Part 2. Ecological and Floristic Notes on the Myxophyta of Raroia

by Jan Newhouse

Part 3. Ecological and Floristic Notes on the Bryophyta of Raroia

by Harvey A. Miller and Maxwell S. Doty

Part 4. Ecological and Floristic Notes on the Pteridophyta of Raroia

by Kenneth Wilson

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Part 1

FLORISTIC AND ECOLOGICAL NOTES ON RAROIA[1/]

by Maxwell S. Doty

It can be readily understood that nine months is not the period for a complete floristic study. The time available has been spent in initiating such a study and in assembling information on what seem to be the most important and predominant forms. It would seem that it would be wise to continue this course and bring the study to a close in the form of a complete report on the fauna and flora and on the environmental features. To contribute toward a presentation of our floristic information in a form useful to atoll workers in general, certain "keys for identification" are presented with this report.

The various groups have been turned over to interested individuals who have provided taxonomic information or have taken over a major portion of the job of assembling the sectional report. The floristic information is treated in the following sections: A. Myxophyta (by Jan Newhouse); B. Mycophyta (determinations by Wm. Bridge Cooke); C. Lichens (determinations by A. W. C. T. Herre); D. Algae (determinations by Maxwell S. Doty); E. Bryophyta (determinations by H. A. Miller); F. Pteridophyta (by Kenneth Wilson); and G. Spermatophyta (determinations by Harold St. John).

It has been impossible to present a floristic account of the fungi and algae. This is because the taxonomy of these very diverse groups is itself sorely incomplete for the Pacific.

The localities listed may be located on Figure 1, a diagrammatic map of Raroia.

Ecological information and inferences, especially of a synecological nature are in general to appear in later Atoll Research Bulletins.

As a guide to these sections for the more embryonic botanists among atoll workers and readers, the following key is appended:

A. Growing in sea water, or not green; ideally the reproductory bodies are microscopic spores.

B. Thalli (plant bodies) colored by tints or shades of red, green or brown, or calcareous in texture; if black then soft when wet with water:

C. Black, orange, blue-green or brown material, no structures visible to the unaided eye other than unbranched filaments; often but a gray or blue-green stain on rocks or wood....<u>Myxophyta</u> (see Section A).

1/ This paper and the following ones in this number of the Atoll Research Bulletin cover field work carried out in 1952 as part of the Coral Atoll Program of the National Research Council's Pacific Science Board. These studies were aided by a contract between the Office of Naval Research, Department of the Navy and the National Academy of Sciences (NR 388-001), and with the assistance of a grant from the Research Committee of the University of Hawaii.

C. Not as above in color, or if so then with structures such as joints, leaves or branched filaments apparent........ Algae (see Section D).

B. Thalli creamy or white or black; never calcareous, if black then carbonaceous...................................... Mycophyta (see Sections B & C).

A. Growing on the land with green (rarely yellow) parts and ideally plants having leaves or having reproductory bodies visible to the unaided eye:

D. Plants producing spores, no flowers or seeds produced; leaves either minute scales or forming the only erect parts of the plant:

E. Plants dichotomously branched or leaves over 10 cm. in length .... Pteridophyta (see Section F).

E. Plants not dichotomously branched, leaves less than 1 cm. in length .... Bryophyta (see Section E).

D. Plants producing seeds from flowers; leaves not all scale like or other parts of plant conspicuous above the ground level Spermatophyta (see Section G).

Section A - Floristic and Ecological Notes on the Myxophyta

At Raroia it was clear that some of the most abundant kinds of living organisms were the blue-green algae. For this reason special care was taken to obtain complete collections of these forms with extensive notations as to their modes of occurrence. Upon returning to Honolulu, the blue-green algae were taken up as having a first priority along with the calcareous algae. The Office of Naval Research, under whose contract with the National Academy of Sciences the field work was carried out, arranged for military transportation to enable Jan Newhouse to spend two months at the Chicago Natural History Museum working out the taxonomy of the Raroia (and Arno) Atoll forms. Mr. Newhouse has taken over the job of preparing the report on the blue-green algae, and this appears as Part 2 of this Bulletin.

Many of the terricolous blue-green algae collected were intimately associated with fungus hyphae in such a way that they might be considered lichens. However, since it is the blue-green algal component that is identifiable, these incipient lichens have been treated as blue-green algae. Physiologically these conspicuous and widely spread associations are potentially of great interest but are quite unknown beyond the realm of speculation.

Section B - Floristic and Ecological Notes on the Mycophyta

About seventy-five fungi were collected on Raroia. These have been sent out for identification.

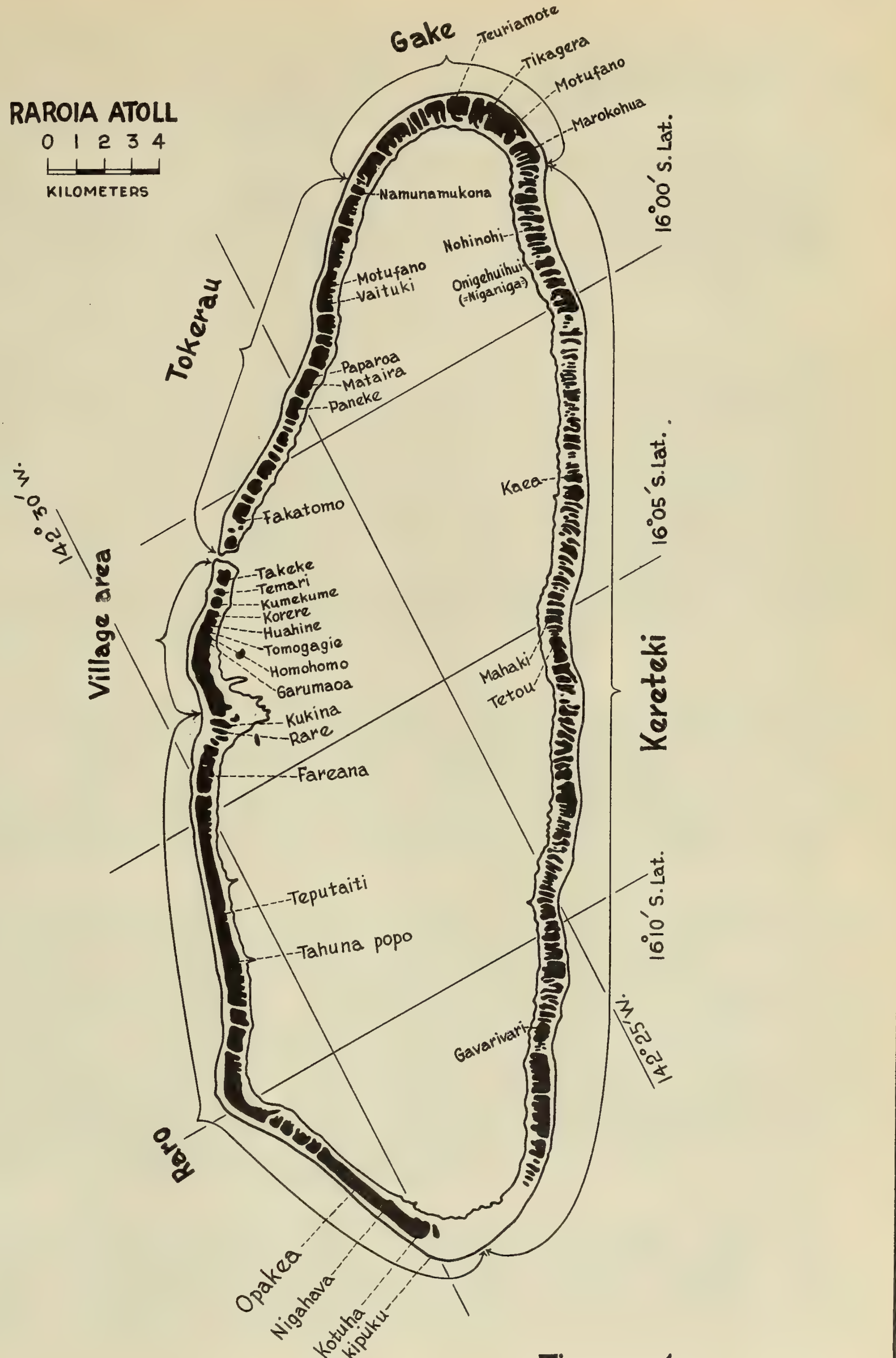
RAROIA ATOLL
0 1 2 3 4
KILOMETERS
Gake
Teuriamote
Tikagera
Motufano
Marokohua
Namunamukona
Nohinohi
Onigehuihui
(=Niganiga=)
Motufano
Vaituki
Tokerau
Paparoa
Mataira
Paneke
16°00' S. Lat.
16°05' S. Lat.
142° 30' W.
Kaea
Fakatomo
Takeke
Temari
Kumekume
Korere
Huahine
Tomogagie
Homohomo
Garumaoa
Kukina
Rare
Village area
Mahaki
Tetou
Kereteki
Fareana
Teputaiti
Tahuna popo
16°10' S. Lat.
142°25' W.
Gavarivari
Raro
Opakea
Nigahava
Papa Kotuha
Kakipuku

Figure 1

No fungi were seen that were considered to be noteworthy parasites. Most conspicuous of the parasitic fungi were a leaf spot on breadfruit and a sooty mold on *Guettarda*. One bracket fungus was called TARIGAKIORE. This is notable for almost no lower forms of life had individual names.

Since fungus hyphae are abundant and neither humus nor fermentative decay seems much in evidence it may very well be that decay of vegetable debris is predominantly of the oxidative fungus kind. An observed abundance of fungus hyphae among the terrestrial algae leads to the conclusion that they may play an important synecological humifying role in the more barren atoll soils.

Section C - Floristic and Ecological Notes on the Lichens

Throughout most of the atoll, lichens were present only as minute crustose forms on dead wood. Little or no lichen growth, depending upon definition, was to be found on the plants, soil or rocks anywhere. The coconut tree trunks bore certain crustose species characteristically. Where trees were most dense near the shore a few parmelioid nearly crustose foliose forms appeared; otherwise, truly foliose and fruticose forms were absent. In the most undisturbed regions of the atoll, for example in the old *Guettarda* areas that had not been planted to coconuts in the Opakea and Oneroa regions, the greatest development of lichens and the most species were to be found. The feeling in the field was that not only the basic few species of less favorable habitats were better developed here, but in addition there were several species not present elsewhere on the atoll.

The Scytonemaceous and coccoid algae which form a more or less sparse coating over the higher parts of the atoll are usually mixed with fungus filaments. Undoubtedly there is a physiological relationship between them. While this relationship is undoubtedly of autecological importance and may very well be of importance synecologically about the only information available is that is exists. For this reason and that the algae members are the taxonomically more recognizable and predominant, such associations are herein included as algae.

To the general collector the lichens of Raroia are not very attractive, and certainly not conspicuous. Dr. A. W. C. T. Herre has very kindly identified the lichens from the Raroia expedition, and provided the information that the Tuamotu Archipelago, as well as the neighboring area of the Pacific, is very poorly known lichenologically. Dr. Herre spent a little time on Takaroa several years back and from that experience and his study of the Raroia collections feels the lichen flora to be representative of a region having considerably less than 25 to 30 inches of annual rainfall. Certain of the results of his study on the present collections have been published elsewhere (The Bryologist 56: 278-282, 1953), including the four species felt to be previously undescribed. Unfortunately many of the lichen growths observed were poorly developed and thus when collected could not be precisely identified.

In the following list the numbers are those assigned in the field by the collectors. The abbreviations immediately following the numbers, USNM and BISH, refer to the herbaria where these particular collections can be expected to be found, the United States National Museum and the B . P. Bishop Museum respectively. Additional specimens were separated and are in the herbarium of Dr. A. W. C . T. Herre.

Anaptychia speciosa (Wulf.) Mass.

On bark of various trees at Opaneke (11402-USNM) and Mataira (11409-BISH on Cocos trunk) in Tokerau, VII-29-1952, and on Messerschmidia or Guettarda on the Homohomo transect (11197-USNM), VII-16-1952. The somewhat cerebriform lobing of the thallose whitish-grey thallus and the capitate sorediose bodies on the surface serve to distinguish this species from the others collected.

Anthracothecium orchraceoflavum (Nyl.) Muell. Arg.

On rather bare wood of Cocos trunk in central part of the island at Tetou (11889-BISH), Kereteki, VIII-21-1952; Oneroa (11601-USNM), Raro, VIII-7-1952; on similar substratum but along the lagoon shore at Homohomo (11254-BISH, -USNM), VII-21-1952; and on Messerschmidia bark on the transect at Homohomo (11203-BISH), VII-16-1952.

Buellia punctata (Hoffm.) Mass.

On dead wood of Messerschmidia at Takeke (11165-USNM), VII-9-1952.

Buellia tuamotensis Herre

TYPE: on Guettarda speciosa bark at Mataira (11414-USNM), Tokerau, VII-29-1952. "PARATYPE": on wood and bark of Cocos nucifera at Oneroa (11600-BISH), Raro, VIII-6-1952.

Caloplaca magnussoni Herre

On bark of Messerschmidia at Takeke (11163-BISH, ISOTYPE), VII-9-1952.

Candelariella vitellina (Ehr.) Muell. Arg.

On rotten wood of Guettarda at Opaneke (11395-USNM), Tokerau, VII-28-1952.

Coccocarpia cronia (Tuck.) Wainio

On coconut bark on trees in central region of Tetou (11885-BISH), Kereteki, VIII-21-1952 and on same substratum overgrowing moss, Calymperes tuamotuense, at Kukina (11171-BISH), Raro, and again on coconut along lagoon shore just north of Garumaoa (11248-USNM & 11249-USNM), VII-21-1952.

Coccocarpia pellita (Ach.) Muell. Arg.

On bark of Guettarda at Oneroa (11595-BISH, 11596-BISH & 11660-USNM), Raro, VIII-7 & 8-1952.

Lecanora raroia Herre

TYPE: on rotten wood of what appears to be Guettarda speciosa at Oneroa (11591-USNM), Raro, VIII-7-1952.
Co-type: on rotten bark at Opaneke (11403-BISH; 11404-BISH), Raro, VII-29-1952.

Lecidia sp. (Section: Biatora, with spores 4.7 to 6 by 9.5 to 11 microns.) Growing on _Suriana_ on the Homohomo transect (11195-USNM), VII-16-1952.

Lepraria sp.

Various Leprarious stages are represented in the often very poorly developed materials from the atoll. Only some of them are mentioned here. On _Messerschmidia_ (11391-BISH), _Cocos_ (11411-USNM), and on a decorticated bleached _Guettarda_ stump (11415-USNM), all at Mataira, Tokerau, VII-29-1952. On _Messerschmidia_ on the Homohomo transect (11198-BISH & 11201-USNM), VII-16-1952.

Microphiale lutea (Dicks.) A. Zahlbr.

On dead _Messerschmidia_ wood at Takeke (11166-USNM & 11167-BISH), VII-9-1952.

Microthelia dotyi Herre

TYPE: apparently on long dead margin of leaf base of _Cocos nucifera_ on transect across island just north of village of Oneroa (11605-USNM/HOLOTYPE/, -BISH/ISOTYPE/) Raro, VIII-7-1952.

Pannaria mariana (E. Fries) Muell. Arg.

On _Guettarda_ bark, Oneroa (11655-USNM), Raro, VII-21-1952.
On _Pandanus_, and by far the best developed specimens seen, Oneroa, (11650-BISH), Raro, VIII-8-1952.
On _Cocos_ at Kukina (11171B-BISH), northern Raro, VII-10-1952.
On _Cocos_ along lagoon shore north of Garumaoa (11247-USNM), VII-21-1952.

Physcia cocoes (Sw.) Nyl.

On _Guettarda_ bark, Mataira (11412-BISH,-USNM), Tokerau, VII-29-1952.

Physcia integrata Nyl.

On rotten wood of _Messerschmidia_ mixed in with the fruiting bodies of some fungus, Mataira (11384-USNM), Tokerau, VII-28-1952.
On coconut trunks in central region of Tetou (11886-BISH), Kereteki, VIII-21-1952.

Physcia integrata var. _serediosa_ Vainio

On _Cocos_ at Oneroa (11500-USNM), Raro, VIII-7-1952.
On _Cocos_ along lagoon shore north of Garumaoa (11251-BISH), VII-21-1952.

Physcia integrata var. _ulcerata_ A. Zahlbr.

From the atoll of Takume (near Raroia), on _Guettarda speciosa_ at Kukina Rahi. (12019-BISH,-USNM) Kereteki, IX-6-1952.

Physcia serediosa (Vainio) Lynge

This seems to be the most common of the lichens to mature to a specifically recognizable stage. Many more lichens, judging from superficial differences

of color and morphology, develop only partially and remain sterile; as evidence of this are the many Leprarious stages to be seen.
On base of dead Cocos stump, Opaneke (11383-BISH), Tokerau, VII-29-1952.
On Cocos (11410-USNM), and Pemphis (11416-BISH & 11417-USNM), at Mataira, Tokerau, VII-29-1952.
On transect at Tetou (11872-BISH & 11873-USNM), Kereteki, VII-21-1952.
On Guettarda at Oneroa (11579-BISH), Raro, VIII-7-1952.
On Cocos along lagoon shore north of Garumaoa (11250-USNM & 11252-USNM), VII-21-1952.

Rinodina sp.

On Cocos along lagoon shore north of Garumaoa (11253), VII-21-1952.

Section D - Floristic and Ecological Notes on the Algae

A satisfactory floristic list of the algae cannot be made at this time. The group is a large one and identification beyond the generic level is technically complex and even more often just plain uncertain. This is a reflection of the status of algal taxonomy for the Central Pacific. Almost nothing has been published referring to the marine algae of Eastern Polynesia, beyond two papers on the Society Islands and a few on Easter Island.

Flying over the atolls in the Tuamotus one sees them as more or less complete rings of rock just barely submerged beneath the sea's surface. Close inspection can be expected to reveal here as elsewhere an increase in the number of fish, zooplankton population and oxygen production as an atoll is approached and a position inside the lagoon attained. The sea edges of the atolls are of solid stone. This edge was seen to be essentially a pink mass, as is much of the water-covered, flat, upper surface. The lagoon edge of the atoll rings may be sandy shores or coelenterate coral dominated reefs. On the atoll rings there are more or less extensive islands (blacked out areas in Figure 1) which protrude above high tide line. There is a distinct black area clearly visible in most aerial photographs wherever the above-tide shores are of solid material. The outermost edge of this black area on the sea shores can be taken as high tide line in interpreting aerial photographs. Where not covered with vegetation the surface of the islands, whether sandy, gravel or solid rock, is grey.

Each of the observations related above is apparently rather directly dependent upon algal populations. The hypothetical roles of these algal populations are of two major kinds, physiological and mechanical. The physiological roles are effected by the action or the utilization of metabolic products. The mechanical roles are structural, due to the physical nature of the products accumulating through the physiological activities.

Our major objective in going on the Tuamotu Expedition was to make observations that would enable better elucidation of the prospective roles of algae in atoll structure and biology. The algal section of this report is correspondingly an enumeration of the hypotheses developed from the observations of all the Atoll Research Teams insofar as phycological observations were made. It is hoped that this enumeration will lead to testing by future observations and experiment and that the theories resulting will thereby come to replace these current hypotheses.

Taking Darwin's hypothesis as a description of the way an atoll forms, we are able to open the first scene on the hypothetical roles played by the algae. The first stage-setting is the sudden appearance of an igneous mountain surrounded by the sea. The shores of this mountain could be expected soon to become coated with attached algal material. In Hawaii it is just these sessile algae that are the first organisms to become apparent on new lava flows. The plankton from an open sea situation would not support the fauna found where it is the animals that dominate the reef, and thus one is inclined to think that the benthic algae must have been the primary organisms of abundance on any new mountain appearing in the ocean. In and on this algal material there would develop and feed the host of animals to be found in the intertidal area.

The essential limiting salts for algal growth would become concentrated from the passing sea currents and from the rain water flowing down the mountain. Through this accumulation of materials, passed on to the animals that eat the algae, the materials required for life would continually accumulate. This would be manifest in an increasingly dense population.

Sargent & Austin (Trans. Amer. Geophys. Union 30: 245-249, 1949) have already studied this problem and concluded that the open ocean water is sufficiently rich neither in available food material nor in nutrient salts to account for the reef populations. The concentration of these materials about an atoll as fish, zooplankton and oxygen in the water has been noted above. Plankton forms would not cause an accumulation of materials. They would float away with the ocean currents. This points again to the role of the benthic sea algae as accumulators of material from the passing sea.

Perhaps largely due to the feeding of fish on fleshy algae, especially below the low level of the tides, the benthic algal population which actually forms is predominantly calcareous. These calcareous algae are important in the ocean in that they deposit calcium salts and carry on photosynthesis, making an excess of food materials. The story of the reef that develops through the accumulation of calcareous material by the coral organisms, algal and animal, has been told often. But an aspect that has not been emphasized is this continuous cumulative action. Dead fragments are for the most part passed over the reef edge onto the islands or into the lagoon. Continued sea reef margin growth is probably largely by accumulation of new material from the sea. Thus though the role of typhoons is argued it seems very likely that otherwise atolls continuously increase in mass through the addition of newly accumulated material at their sea margins by the activity of algae.

The algae cover most of the surface of the atoll with a grey, brown or pink coating and wherever this surface is marine, marine organisms live on the algae. The case of parrot fish feeding on coralline reef formers has already been noted above. Sea urchins at the surface and the countless numbers of boring echinoderms, worms, and other organisms are by their homemaking and feeding habits induced to destroy the algae of the reef and reef flat. The sea is essentially saturated with carbonate ions and while the other materials become absorbed as foods or go into solution the carbonates tend to remain as mineral accumulations. This accumulation of carbonates may be in part swept over the reef into the lagoon sediments sand or gravel fragments. Actually what seems to happen is not so much the solution and production of sediment in situ from the solid algal (and other coral) material but that the structure of the reef locally becomes weakened. Fragments then break off and are carried in over the reef flat and deposited on the islands or as sediment washed on into the lagoon. Undoubtedly many of these fragments fall onto the slope beyond the sea edge of the reef and contribute to the extension of the twenty-meter bench. The most important aspect here is that this breaking away leaves a favorable site for the growth of new coralline organisms and thus induces further accumulation of material from the sea.

From our observations it appeared that erosion of the solid reef surface can go on rapidly. History indicates upward growth takes place rapidly: passes that used to be open to the sailing canoes (e. g. that near Kukina) are no longer open. After studying the history, effects of hurricanes and making various observations on the reef surface one gathers the impression that the atoll surface is in equilibrium with the environment and held to a large extent at the vertical level at which it is found by the activities of, largely, the genus Porolithon.

Another hypothesis of the biological origin of atolls thus comes to mind and should be tested. Observations at Johnston Island as well as at Raroia and elsewhere lead us to suspect that an atoll could form without the sea mount upon which it forms ever breaking the surface. In swimming over the reef edge in the ocean one sees that active Porolithon activity begins at a rather definite level. It seems possible that as the elevation of sea mounts in reference to the sea surface changes with time the sea mount tops could become trapped at the surface by atoll formation. Should the sea mount elevation remain very stable the atoll might gradually mature , i. e. the lagoon become filled in and the reefs broaden. Canton in the Phoenix group and Christmas Island in the Line Islands might be atolls of this type. If the sea mount sinks the lagoons would be deeper and the reefs narrower. Raroia and most of the Tuamotu Archipelago atolls are of this type. If the sea mount base rises faster than erosion takes place a raised reef appears. One corner of Anaa (the northernmost) is such a place, or a raised atoll or island such as Henderson, or more classically Makatea, both in the Tuamotus, may result. Finally if the sea mount may sink so far so fast that reef development does not keep up, the sea mount top then, essentially, escapes from the surface. Examples of this are unknown to the writer unless the southeastern "half" of Johnston Island is an example.

With the energy accumulated by photosynthesis inorganic materials are combined and passed on to other organisms as organic foods. As an example consider Porolithon onkodes, the reef-covering calcareous alga. For a crustose coralline alga it is peculiar in its ability to thrive in brilliant light and withstand brief exposure to the air. This species is eaten by parrot fish. The parrot fish defecate not only calcareous material but nutrient salts and thus enrich the water beyond the reef. Planktonic algae reincorporate this material into algal cells. Plankton feeders can consume the algae material, forage fish and then fish such as the wahoo (Acanthocybium sp.) and yellowfin tuna (Thunus ablunga) and finally the sharks may receive this material. Thus may be outlined the hypothetical explanation of the increase in populations as an atoll island is approached.

This great increase of fish provides food for the island peoples and, potentially, an income source for them. For example production of whole or ground dried fish might very well be developed as a new source of income to atoll peoples. Production of such a product would be feasible on a family basis and require little material beyond what is already available in any copra producing area.

The legal aspects of oceanic waters have an interesting relationship here near an atoll. If one is concerned with the fish population, it would appear that its size would be due to land bound causes. The land owner could cite this in reference to a claim of ownership of the near shore fish. It is to be noted in this connection that the Polynesian peoples did claim the waters that extended away from the shore of their particular piece of land.

With variations in reef exposure and local topography other species of Porolithon, other than P. onkodes, may become locally abundant. They rarely become dominant at Raroia. Rarely a Goniolithon appears in numbers but in the situations seen in the Tuamotus only on the reef flat well inshore. Lithothamnion is a very unusual alga on the reefs in the Tuamotus and it is not likely to be common on any reef edge in the habitats where Porolithon is ordinarily found. The two generic taxa are very distinct, belonging to separate sub-families of the Corallinaceae. Certainly "Lithothamnion ridge" should not be used for the ridge of algal material which often appears near the seaward edge of sea reef flats.

Blue-green algae (or perhaps we should better say blue-green bacteria) grow on and in all surfaces near high tide line. In North Carolina the blue-green algae so solidly bind the surface at sand beaches that airplanes use these places as practice landing strips. On a coral reef and particularly above high tide line undoubtedly such binding stabilizes the sand bars and binds new sand grains that chance to come to rest. It is through such activities that such a sand bar could be expected to increase in size and become an island.

With increase in size an island on an atoll may come to hold in its interior a body of fresh water. Sea water penetrates the island. This body of fresh water floats up and down with the tides on top of the sea water and the fresh water in such a situation gradually become mixed with the salt water. Both the freshness and lateral extent of the fresh water is regulated by such factors (Doak Cox, Atoll Research Bulletin No. 8) as rainfall, island size, tide range and the permeability of the islands, especially near their shores. It has been postulated that the algae play a part in the transformation of the sand at the shore into the beach rock and other atoll rock types. They play a role as well in the destruction of these rock types.

Particularly in this case the algae have a major role in the establishment of the island as a land mass sufficiently permanent that the climax atoll biota may become established.

They are critical agents in the chain of events leading to the removal of another factor limiting to the terrestrial biota, that of available nitrogen and phosphate. The accumulation of these from the passing sea current has been discussed above. However, for the sake of argument, with the appearance of algally induced islands two more possibilities arise. Birds may use the islands as roosts. This effectively initiates a collection on the islands of nutrient salts from the fishing and roosting activities of the birds. Hatheway (Atoll Research Bulletin No. 16) and Fosberg (reported at the Eighth Pacific Science Congress) have discussed this in some detail in reference to the native vegetation. This seems to be a particularly important factor in the case of phosphate. It is to be noted that the fish phosphate got into the fish as phosphate hypothetically accumulated near the atoll by the sessile algae.

The story of available nitrogen is somewhat different. In part it duplicates the phosphate story. Perhaps in a native climax vegetation with a well developed humus beneath, the birds or bacteria might provide a replacement of available nitrogen lost to the sea. Where there is little or no humus, as in the hurricane swept Tuamotus, the upper ten centimeters of sand and gravel have a dense layer of blue-green algae that may very well substitute for humus. In the coconut plantations and Guettarda groves the soil is largely non-humified sand or gravel, with sand filling a few decimeters below the surface. Yet there is a root zone well developed.

There is no growth of legumes on these atolls that could account for nitrogen-fixation by species of Rhizobium. The soil is exceptionally aerobic and of carbonate buffered pH's. There are but few bacteria known (e. g. Azotobacter and the Itersonia described recently by Derx) that fix nitrogen under these conditions. Bortells, Gerloff, as well as Fogg and others, have investigated the nitrogen-fixing properties of blue-green algae. It is found that many related to those dominating the atoll soils do fix significant amounts of nitrogen. This problem is under investigation at present and preliminary cultural experiments lead us to believe that apparently the soil forms of blue-green algae from atolls are significant nitrogen-fixers themselves.

Much attention has been paid to the black zone at high tide line where algae in cooperation with exfoliation must be principal causes of destruction of the rocks of the islands. Gastropods of the genera Littorina, Melaraphe, Tectarius and their herbivorous cohorts feed on blue-green algae. By their rasping of the algae they remove rock material. The surfaces above high tide on which the algae are growing were found to be softer than those freshly exposed or where no algae are growing.

To a certain extent the algae grow into these high tide carbonate rocks. Their pigments diffuse into the rocks and become adsorbed. It is most likely that it is the chemical results of these processes that are the causes of the observed softening.

It has been postulated that the softening noticed beneath the black algal coating is an evidence of solution and again of deposition. It seems more likely that it is an evidence of solution aided by the pH variations (especially at night) and the considerable amounts of heat accumulated and thus higher solubilities (but not of carbonate) under the black layer of algal material.

The only reefs seen by the present author to be predominantly coelenterate reefs are those in the lagoons. Such developments are reduced toward the windward side of atolls such as Raroia and in the more closed atolls such as Takume. The algae very definitely play a part both in the development and in the death of these animals. Firstly they play a role as the food, directly as phytoplankton or zooxanthellae or indirectly as food for the zooplankton which in turn may form the food of the coelenterate corals. They may be at least equally important as removers of waste metabolic products from the coelenterates in which they live. What is said here is true also of the sea reef corals and hermatypic corals at greater depths.

The edges of lagoon reefs are of coelenterate corals at Raroia, elsewhere in the Tuamotus and elsewhere in comparable situations, e. g. at Johnston Island and on the island of Oahu (in Kaneohe Bay) in Hawaii. Often species of Pocillopora or Porites form the uppermost surface near the edge as a series of flattened branches condensed behind the reef edge almost into a pavement.

The upward limit of growth for the coelenterate corals on these reef edges seems to be regulated by their tolerance to air exposure. Some algae seem to tolerate air exposure better than the coelenterate corals and grow on the uppermost, often inactive, coelenterate tips just a decimeter or less from the reef edge. This must interfere with the feeding of nearby polyps especially inshore of the algal patches away from the reef edge. Certainly the shading would interfere with photosynthesis by zooxanthellae in the coelenterates.

Between the closely arranged coelenterate branches circulation must be reduced as the reef extends. In such places algae such as Rhipilia geppii grow. They come to fill the spaces between the branches as do such algae as Zonaria variegata. This latter may extend over the top of the coelenterates a few decimeters in from the edge of the reef so extensively as to mask the coelenterate coral completely. The coelenterate corals become weak structurally and break off; so that in from the edge of the reef there is a lower area, a pool area. In this lower area and on the higher parts of shoreward areas of shore-bound reefs, crustose coralline algae again come to predominate in some localities where the gravel or reef fragments are large.

In any intertidal region, or above on a lagoon shore, the blue-green algae play the same roles as they do on the sea shores already described, but more often on gravel rather than conglomerate material.

The lagoon bottoms of some atolls are reported to be essentially meadows of the green alga Halimeda. At Raroia, in the Tuamotus, no dredge haul indicated living Halimeda on the bottom. However, there the sides of the reef patches in the lagoon are often clothed with this genus and Caulerpa. The latter, as Caulerpa bikinensis, is a favorite food of the turtles.

Halimeda is apparently one of the minor contributors to the sediments that in turn contribute to filling the lagoon. The calcium salts Halimeda deposits are accumulated from the lagoon waters: the other materials filling lagoons come chiefly from outside the lagoon or from alga-smothered dead coelenterate corals within the lagoon.

So far as the above outline is concerned, the most important algal forms are the Corallinaceae, the blue-greens, the phytoplankton, and the Codiaceae; perhaps in that order. At present there is nothing known of the phytoplankton. It may be that some work in this field was done by the Scripps CAPRICORN Expedition in the Tuamotus, but no results of such work have been seen by the author. The Raroia team received none of the equipment sent out which would have made such investigations possible. The blue-green algae have received special attention by Jan Newhouse and the results have been incorporated into Part 2 of this Bulletin.

The Polynesians of Hawaii used many marine algae (LIMU KAI) as food. There are about 150 Polynesian names for them. In Tahiti in 1952, RIMU KARA (for Turbinaria) was the only specifically named marine alga (RIMU TAI) found. In the Tuamotu Archipelago, in 1952, RIMU was applied widely to algae, mosses, tunicates, fungi, sponges and the like, with only one specific reference and that not a RIMU. This name was the KOPARA discussed under Anacystis dimidiata in the section on Myxophyta. Beyond this the Tuamotuans paid no attention to the algae. They used none of them for medicine or food.

Section E - Floristic and Ecological Notes on the Bryophyta

The information on the mosses and liverworts obtained at Raroia appears in Part 3 of this Bulletin.

Section F - Floristic and Ecological Notes on the Pteridophyta

The information on the ferns obtained at Raroia appears in Part 4 of this Bulletin.

Section G - Floristic and Ecological Notes on the Spermatophyta

There are perhaps thirty flowering plants growing on Raroia that could be considered native plants. A whole host of plants has been brought recently from Tahiti or sent as gifts of seeds from overseas. There is then the class of plants which were brought to the atoll by aboriginal peoples. It is the plants of the last group that are of direct importance to the Raroians. We include in this list accepted food plants such as the banana, papaya, breadfruit and citrus, though of relatively recent introduction. We exclude ornamentals such as the gardenia and hibiscus and such curiosities as sugar cane though probably of similar period of introduction.

Plants of importance to the Raroians become fewer and fewer in normal times. Currently with copra prices high, about the only plant of regular use is the coconut. It is a source of food, drink, shelter and utensils. It is the source of the income with which they buy all that which they might otherwise improvise from other plants or wrest from nature. In times of little demand for copra they fall back to varying degrees upon the natural resources or upon the plants (e.g. Tacca) and animals (e.g. dogs, chickens and pigs) of aboriginal range.

The major plants of aboriginal introduction are or were most likely: Cocos nucifera (Coconut), Morinda citrifolia, Tacca leontopetaloides, Colocasia esculenta (Taro is now extinct), Pandanus tectorius var. laevis (Weaving pandanus), Calophyllum inophyllum.

Like anything else once established, and the plant is largely responsible for this too, no care is given a plant. About the most one can say is that the

Raroians have brought in certain plants. Tacca is no longer cultivated and occurs in village areas scattered about, with no attention being given it. It, however, can live and reproduce with no care and thus is still around and is used upon occasion as a starch source during local hard times.

Taro was once a big item in the food budget as is evidenced by the large taro pits near the villages. For example, Gake, Takume, has about one-fourth of a square mile of closely placed pits about 5 meters deep, 30 meters wide and 100 meters long. However, in 1952 no living taro could be found at Raroia or at Takume. After the advent of the "copra-tin can" economy the taro pits were abandoned. At Takume the eventual development of hordes of mosquitoes in these abandoned pits led to the abandonment of the whole village there and the development of a new village at the southern end of the atoll.

There are but few trees of Hibiscus tiliaceus on the atoll now and little of the Cyperus species that must in former times have been producers of the raw materials for fine mats. Pipturus incanus appeared in the lists of Raroian plants prepared previous to 1952 by Bengt Danielsson, where it was listed as having the local name ROGA. However, no Pipturus was found on either Raroia or Takume.

Recent arrivals are the duck among animals and the papaya and breadfruit among the plants. Some of these are food plants, but many such as the oleander, hibiscus and jasmine are mere ornamentals. Some are curiosities such as sugar cane and cotton. Some of the flowers are used as bodily adornment and the gardenia is a source of scent for coconut oil for the hair. The nuts of Calophyllum were formerly grated and the powder used as a scent for tapa cloth, but now the tree has little value other than as a source of nice little balls for juggling. A very few of the older plants have taken on new uses. One example is the use of coconut shells for charcoal, a use related to the flat iron and cotton cloth. With changing customs new plant uses have arisen, e.g. now property lines within the village are expressed by hedges that are often of the very same panax that is common in almost all subtropical regions of the world.

The other ethnic uses of the plants are for the most part detailed elsewhere and thus have not been expanded in this section of the report.

To obtain the native names for the plants found, the fresh and pressed plants were shown to various of the local people. Bengt Danielsson provided a list of plant names gathered during his earlier work at Raroia. Some of these plants no longer exist at Raroia. An even more extensive list of names has been published by Kenneth P. Emory (Tuamotuan Plant Names, Jrnl. of the Polynesian Society, 56(3): 266-277, 1947). None of the names used by the Polynesians at Raroia has the least resemblance to any of those used by the Micronesians at Arno or as reported by St. John & Mason (Vernacular names of the plants of Bikini, Marshall Islands Pacific Plant Studies 12, Pacific Science 7: 165-168, 1953) from Bikini. Following is Danielsson's list inserted here for ready reference:

Sicentific names	Raroian names
Achyranthes velutina	Putarau
Boerhavia diffusa	Runa
Bracket Fungus	Tarigakiore

Calophyllum inophyllum	Ati
Cassytha filiformis	Kainoka
Cocos nucifera	Hakari
Colocasia esculenta	Fakea (Extinct)
Cordia subcordata	Tou
Eragrostis amabilis	Nanamu
Euphorbia hirta	Tahetahe
Fleurya ruderalis	Vaianu, Ogaoga
Guettarda speciosa	Kahaia
Hedyotis romanzoffiensis	Koporoporo
Heliotropium anomalum	Parahirahi
Ipomoea tuba	Pohue
Lepidium bidentatum	Nau, Horahora
Lepturus repens	Mauku (grass in general)
Messerschmidia argentea	Geogeo
Microsorium scolependria	Kikipa (when a sprout = Oro)
Morinda citrifolia	Hora
Mosses (in general)	Rimu
Nesogenes euphrasioides	Toroariki
Pandanus sp.	Fara, Tima
Pemphis acidula	Mikimiki
Phyllanthus niruri	Moemoe
Pisonia grandis	Gatae
Pipturus argenteus	Roga (perhaps extinct since 1906)
Polypodium phymatodes	see Microsorium
Portulaca johnii	Pokea
Psilotum nudum	Tumutumuhenua
Scaevola frutescens	Gapata
Sesbania speciosa	Kohai
Solanum viride	Putamagomago
Suriana maritima	u'u, kuku, kokuru
Timonius polygamus	Paketa, Ketoketo
Triumfetta procumbens	Vavai
Ximenia americana	Rama

As an aid to our field work F. R. Fosberg provided a very workable key to aid in the identification of the plants we might possibly expect to find. This key has been modified in various ways, for example, to include additional species found established outside the village areas. Since it proved so valuable this modification of Fosberg's key is included here:

A KEY TO COMMONLY EXPECTED TUAMOTUAN VASCULAR PLANTS

(* indicates those found on Raroia. ** indicates ferns listed in the previous section.)

1. Plants leafless or young leaves unrolling from apex as elongation begins.

  2. Leafless plants

    3. Dichotomously branching, broom-like in appearance--Psilotum nudum**

    3. Irregularly or pinnately branching, not broom-like in appearance

4. Twining, elongate plants, yellow or yellow-green, parasitic--Cassytha filiformis*

4. Rosettes of pale green flattened roots, with tiny erect flowering stem in center--Taeniophyllum sp.

2. Leafy, fern-like plants

5. Fronds entire, plant rosette-like--Asplenium nidus**

5. Fronds pinnately divided

6. Bases of pinnae wide, confluent; sori round, without indusiam--Microsorium scolopendria**

6. Bases of pinnae narrow; sori with indusia

7. Sori linear, pinnae not disarticulating from rachis when old--Asplenium obtusatum

7. Sori reniform, pinnae disarticulating

7a. Bases of leaflets merely rounded--Nephrolepis biserrata**

7a. Bases of leaflets auriculate or cordate--Nephrolepis shirsutula

1. Plants with leaves and young leaves not unrolling at tip as elongation begins

8. Plants with thin grasslike leaves

9. Flowers large, showy, 2.5 cm. wide, or more--Zephyranthes rosea

9. Flowers reduced, without perianth, enclosed in or subtended by scale-like bracts (grasses and sedges)

10. Stem solid; inflorescence subtended by an involucre of leaf-like bracts (sedges)

11. Scale-like bracts arranged spirally--Fimbristylis cymosa

11. Scale-like bracts arranged in two ranks (Cyperus)

12. Spikelets in a tight globose head--Cyperus kyllingia*

12. Spikelets loosely arranged

13. Plants large and stiff, gray-green, slightly rough when rubbed by fingernail--Cyperus javanicus*

13. Plants small, weak, green, smooth

14. Style-branches two; achenes usually biconvex, elongate--Cyperus polystachyus

14. Style-branches three; achenes trigonous

15. Spikelets dark brown, linear, plants tuberiferous--Cyperus rotundus

10. Stem hollow; inflorescence not subtended by leaf-like bracts (grasses)

16. Inflorescence of two to several digitately arranged spikes

17. Spikes two

18. Spikelets relatively few on a spike; leaves stiff--Paspalum vaginatum

18. Spikelets many on a spike; leaves thin, not stiff--Paspalum conjugatum

17. Spikes more than two

19. Rachis of spike strongly excurrent--Dactyloctenium aegyptium

19. Rachis not excurrent

20. Plants tall; spikes stiffly erect--Digitaria stenotaphrodes*

20. Plants unusually low; spikes strongly spreading

21. Spikes 2-3 mm. wide--Eleusina indica*

21. Spikes about 1 mm. wide; plants mat-forming--Cynodon dactylon*

16. Inflorescence not digitate

22. Inflorescence a cluster of burrs--Cenchrus echinatus*

22. Inflorescence not of burrs

23. Inflorescence a cylindrical, brittle spike, disarticulating when old--Lepturus repens*

23. Inflorescence not cylindrical

24. Spikelets in a diffuse panicle; plant tufted--Eragrostis amabilis*

24. Spikelets one or two on an erect leafy stem; plant creeping--Thuarea involuta

8. Leaves thick or not grasslike

25. Leaf veins parallel or pinnately parallel

26. Large herbs

27. Leaves sword-shaped; flowers umbellate--_Crinum asiaticum_ (or _pedunculatum_)*

27. Leaves, oblong, obtuse; flowers in a spike-like panicle--_Musa sapientum_*

26. Trees

28. Leaves compound--_Cocos nucifera_*

28. Leaves simple

29. Leaves linear, spirally arranged

30. Leaves regularly beset with strong spines on margins and dorsal midrib surface; producing flowers and fruits--_Pandanus tectorius_*

30. Leaves with margins and midrib weakly and irregularly spiney; sterile--_Pandanus tectorius_ var. _laevis_*

29. Leaves oblong, opposite--_Calophyllum inophyllum_*

25. Leaf-veins forming a network, or obscure, or plants leafless

31. Leaves compound (over 1 cm. long)

32. Trees

33. Leaves once pinnate--_Sesbania speciosa_*

33. Leaves twice pinnate--_Leucaena glauca_

32. Herbs or vines

34. Leaves alternate

35. Plants vine-like; leaflets three

36. Flowers yellow; pods cylindric--_Vigna marina_*

36. Flowers pink; pods heavy, flattened--_Canavalia_ sp.

35. Plants not vine-like; leaflets different

37. Leaves erect from the ground and over 30 cm. long; flowers in heads--Tacca leontopetaloides*

37. Leaves from stems branching above ground, smaller; flowers not in heads--Solanum lycopersicon (Lycopersicon esculentum)

34. Leaves opposite

38. Plant prostrate; leaflets a number of pairs; flowers large, solitary--Tribulus cistoides

38. Plant erect; leaflets usually three; flowers in heads--Bidens pilosa

31. Leaves simple; very small

39. Leaves less than 0.25 cm. long; plants prostrate on ground--Pilea microphylla*

39. Leaves over 0.5 cm. long

40. Leaves opposite

41. Stipules present

42. Herbs or subshrubs with milky juice; ovary superior

43. Plants prostrate

44. Purplish green; leaves not crowded, oval--Euphorbia thymifolia

44. Grayish green; leaves crowded, oblong-ovate--Euphorbia prostrata*

43. Plants upright, arching at tip

45. Plant somewhat woody; inflorescence terminal--Euphorbia atoto*

45. Plant herbaceous (rarely somewhat woody in E. hypericifolia)

46. Plant hairy--Euphorbia hirta*

46. Plant smooth--Euphorbia hypericifolia

42. Shrubs or subshrubs; ovary inferior

47. Corolla several cm. long; fruit subglobose, fleshy, with a large stone--<u>Guettarda speciosa</u>*

47. Corolla 1 cm. or less long; fruit not with a single large stone

48. Ovaries of several flowers fused together; fruit large, potato-like in appearance--<u>Morinda citrifolia</u>*

48. Ovaries free; fruits less than 2 cm. thick

49. Flowers and fruits many, in flat-topped clusters--<u>Tarenna sambucina</u>

49. Flowers few, not in flat-topped clusters

50. Leaves ovate, apex short acuminate and margins crenate to serrate--<u>Pipturus argenteus</u>

50. Leaves ovate to obovate elliptic, apex blunt and margins entire

51. Flowers silky outside; seeds large, arranged radially in fruit--<u>Timonius polygamus</u>*

51. Flowers not silky; seeds many, small--<u>Hedyotis romanzoffiensis</u>*

41. Stipules absent

52. Trees or shrubs

53. Juice milky; ovary and fruit double--<u>Ochrosia oppositifolia</u>

53. Juice not milky; ovary and fruit not double

54. Bases of petioles clasping stem; leaves leathery, parallel-veined; fruit spherical, flowers with separate petals, many stamens--<u>Calophyllum inophyllum</u>*

54. Not as above

55. Flowers and fruits in flat-topped clusters; fruit spherical--<u>Premna tahitensis</u>

55. Flower and fruit clusters hemispherical; fruit club-shaped, spiny, very sticky--<u>Pisonia grandis</u>*

52. Herbs

56. Prostrate; flowers solitary, axillary

57. Leaves very thick, linear; perianth in one series--<u>Sesuvium portulacastrum</u>

57. Leaves not very thick, ovate to elliptic; perianth in two series--<u>Nesogenes euphrasioides</u>*

56. Erect or prostrate; flowers in clusters

58. Flowers in spikes

59. Plants fleshy; flowers reduced to a scale with an anther and an ovary--Peperomia subglabra

59. Plants not fleshy; flowers otherwise

60. Perianth not scale-like; fruit sunken in rachis

61. Axis of flowering spike 3/16 in. or more in diameter; fruits buried in deep furrows--Stachytarpheta indica

61. Axis of flowering spike about 1/8 in. in diameter; fruits but slightly embedded in shallow furrows--Stachytarpheta jamaicensis

60. Perianth parts scale-like; fruits reflexed

62. Plants densely pubescent--Achyranthes canescens*

62. Plants sparingly pubescent, green--Achyranthes aspera

58. Flowers in heads or umbels (in some cases heads in terminal compound racemes)

63. Flowers sessile in leaf axils

64. Stems round--Synedrella nodiflora*

64. Stems squarish--Ocimum basilicum*

63. Flowers in pedunculate clusters

65. Flowers over 5 mm. across, bright orange and red; fruit a follicle several cm. long--Asclepias curassavica

65. Flowers 2-3 mm. across, pink or whitish; fruit club-shaped, sticky, up to 5 mm. long

66. Leaves elliptic-oval to oblong, margins regular, firm, inflorescence open--Boerhavia tetrandra

66. Leaves ovate, margins undulate, thin, inflorescence tending to be capitate--Boerhavia diffusa*

40. Leaves alternate or spirally arranged

67. Plants acaulescent or with a thick stem bearing a rosette of large leaves

68. Leaves palmately lobed; flowers in panicles or solitary--_Carica papaya_*

68. Leaves sagittate; flowers on a spike enclosed in a spathe

69. Leaves dull green, peltate--_Colocasia esculenta_

69. Leaves bright green, not peltate

70. Basal lobes of leaves sharply pointed--_Cyrtosperma chamissonis_

70. Basal lobes of leaves rounded or obtuse--_Alocasia macrorrhiza_

67. Not as above

71. Plants woody, at least at base

72. Flowers very irregular, not radially symmetrical, over 1 cm. long, and never in dense heads

73. Flowers 1-2 cm. across, split down one side, appearing as though torn in half--_Scaevola frutescens_*

73. Flowers much larger, with many stamens, not appearing as though torn in half--_Capparis sandwichiana_

72. Flowers regular, or very small, in some cases in dense heads

74. Flowers minute, in small heads strung several on a pendant rachis--_Pipturus argenteus_

74. Flowers larger, not as above

75. Inflorescence a dense axillary cluster--_Waltheria indica_*

75. Inflorescence not as above

76. Leaves cordate, palmately nerved

77. Leaves smooth and green above and below--_Thespesia populnea_

77. Leaves densely felty, velvety or white at least beneath

78. Leaves dark green above--_Hibiscus tiliaceus_* (incl. var. _abortivus_* and var. _sterilis_*)

78. Leaves velvety on both sides--_Abutilon indicum_

76. Leaves neither palmately veined nor cordate

79. Leaves large, over 3 cm. long

80. Leaves thin or leathery, green, entire or not; flowers otherwise

81. Leaves ovate or elliptic, entire; flowers in loose cymes

82. Leaves elliptical; flowers with 4 petals--Ximenia americana*

82. Leaves ovate to cordate; flowers with 5 or more petals

83. Leaf surface with scattered scales--Cordia subcordata*

83. Leaf surface not scaly--Solanum viride*

81. Leaves obovate; flowers not in cymes

84. Young growth glabrous; flowers several cm. long; fruit square--Barringtonia asiatica*

84. Young growth minutely tomentose; flowers small, less than 1 cm. across; fruit not square

85. Young growth pale, ocher-colored; fruit 1-2 cm. long--Terminalia samoensis

85. Young growth brown; fruit over 3 cm. long--Terminalia catappa*

79. Leaves small, less than 3 cm. long

86. Dwarfed, depressed shrubs; leaves densely hairy; flowers in dense, terminal clusters--Heliotropium anomalum*

86. Erect shrubs; flowers not clustered

87. Flowers white, calyx tube prominent, striate; fruit not of separate carpels--Pemphis acidula*

87. Flowers yellow, calyx tube not well-developed; fruit of separate carpels--Suriana maritima*

71. Plants herbaceous

88. Leaves bilobed at apex--Ipomoea pes-caprae

88. Leaves not bilobed at apex

89. Plant a twining vine; leaves cordate

90. Leaves well over 5 cm. across; flowers opening only at apex--Ipomoea tuba*

90. Leaves less than 4 cm. across; flowers opening completely--Ipomoea littoralis*

89. Plant not a twining vine, though sometimes creeping and mat-forming

91. Leaves palmately veined; flowers yellow; fruit burr-like--Triumfetta procumbens*

91. Leaves not palmate; fruit not burr-like

92. Flowers and fruits in erect racems--Lepidium bidentatum*

92. Flowers and fruits not racemose

93. Flowers in purplish heads, small

94. Heads in loose clusters, involucral bracts imbricate--Vernonia cinerea*

94. Heads solitary or few, involucral bracts in one series--Emilia sonchifolia

93. Flowers not in heads

95. Leaves very small; flowers and fruits in leaf axils; leafy branchlets resembling compound leaves--Phyllanthuus niruri*

95. Leaves larger, not as above

96. Leaves petiolate, acute, serrate--Fleurya ruderalis*

96. Leaves sessile, obovate, rounded at apex, fleshy, entire

97. Stems grayish below, 1 cm. or more thick; flower 1.5-2 cm. across; seeds stellately regulose--Portulaca lutea

97. Stems green or brownish below, usually not over 5 mm. thick; flowers 4-7 mm. across

98. Seeds shining smooth--Portulaca johnii*

98. Seeds tuberculate--Portulaca oleracea

For the purposes of this floristic treatment it has been felt desirable to distinguish between the native and aboriginal plants established outside the village sites and the village plants. To be sure, this is an arbitrary distinction in many cases. Almost all of the native and aboriginally introduced plants are found variously about the atoll outside the village. The recently introduced plants and ubiquitous weeds, e.g. Euphorbia hirta, Phyllanthus niruri, and Vernonia cinerea, are restricted largely to the villages where they may be abundant. Thus, two lists, arranged alphabetically for simplicity, follow as: (1) native and aboriginally introduced plants; and (2) exotics and village plants.

The localities given in the following lists may be located on the atoll through reference to Figure 1. Prof. Harold St. John, of the University of Hawaii, has gone over all the flowering plant materials and his determinations have been used in all cases. /Differences in nomenclature between these lists, the key, and the Danielsson list appear because of differences of opinion on nomenclature between the authors of each./

NATIVE AND ABORIGINAL PLANTS

Achyranthes velutina H. & A. f. velutina

Raroia: Marokohua 11478; Opakea, 11790-BISH, USNM
Takume: Gake, 12301-BISH, USNM
Occasionally found established outside the village areas.
PUTARAU is given as the native name by Danielsson.

Artocarpus incisus (Thunb.) L. f.

Raroia: Garumaoa, 11728-BISH, USNM
Only in the main village at Garumaoa, and not established very long though several trees of large size were present.
Raroian breadfruit trees do not have the great amount of sticky sap that is common in other regions. The tar spot common to this plant in the collections from Arno Atoll is present here, too. No deleterious effects were attributed to it. The local name was URU.

Boerhavia diffusa (L.) var. diffusa

Raroia: Opakea, 11786b-BISH, USNM; Garumaoa, 11911-BISH, USNM; Homohomo, 11007b-USNM; 11007-BISH, USNM; Garumaoa, 11111-USNM; Orare, 11172-USNM.
Takume: Gake, 12309-BISH, USNM.
Common in various forms in more open Cocos and Guettarda areas. A specific search was made for variations that might represent other species. The population was extremely variable but in closely intergrading series.
This plant is a component of the local fish poison cure.
Danielsson gives RUNA as the Raroian name.

Calophyllum inophyllum L.

Raroia: Garumaoa, 11717-USNM.
Takume: Gake, 12326-BISH, USNM.
There are several trees but only in the village.

While there were extractives of the nuts used in treating some of the symptoms of leprosy in olden times and the dried nuts were grated and sprinkled on tapa cloth as an odorant, there is little use for the tree now. The wood is very hard and durable. The principal usage at present in Raroia seems to be as a source of nice little balls for juggling.

The native name in Danielsson's list is ATI.

Carica papaya L.

Common in the village of Garumaoa. Seedlings are abundant. The variety seems to be a poor one and could not compete with those grown in Hawaii.

Cassytha filiformis L.

Raroia: Teputaiti, 11243-BISH, USNM; Opakea, 11780-BISH, USNM: Gavarivari, 11908-BISH, USNM.
Takume: Gake, 12305-BISH, USNM.

Growing (11243) over Heliotropium, Suriana and dead Cocos leaves. This was not often on Scaevola, said by Taylor (1950: 181) to be its principal host where he found it in the northern Marshalls. It did occur on Scaevola at Opakea (11780), however. Flowering in July.

Danielsson's list gives KAINOKA as the Raroian name.

Cenchrus echinatus L.

Raroia: Garumaoa, 11047-USNM, 11041-BISH.

Isolated plants in the yards about the center of the village and in the coconut groves. The Raroian variety is a soft grass, except for the burrs, and it is quite erect in growth.

Cocos nucifera L.

No collections made.

Known Raroian distribution: In general, planted on all suitable areas for the economy of this atoll is dependent upon copra production.

Raroia is largely a coconut plantation, but there are areas seemingly suitable to its cultivation where it has never been planted insofar as the local history can tell us.

The local name for the whole plant is HAKARI. The pan-polynesian niu is not used for the whole plant anymore.

KAIPOA is the name given to a variety of nut with an edible husk. This variety is not distinguishable other than by experience with the husk. The nuts when planted are said to give rise to both the KAIPOA and the ordinary varieties, thus suggesting either a recessive factor and cross pollination or a hybrid nature and self pollination. Danielsson says this variety is known in Tahiti but not in the Marquesas.

One tree was seen the rachis (11812-BISH) of which was simple. The local name for this was apparently TAKAVEATIKI, though it has not been possible to check this term. While many small nuts begin development along the simple rachis, usually only two or three mature. The trunk of the tree seemed to be a bit stouter and darker in color than the nearby trees of similar height.

The local uses are detailed elsewhere, but beyond the major economic uses Cocos is a source of coconut cream, drinking water (KOMO VIAVIA), thatch and oil, all of which are still made on Raroia for local consumption.

Rats like coconut meat, especially when roasted, and this would possibly be a major ingredient for an economic rat poison for use on such low atolls.

Natives believe the round fruits give better trees than the longer more slender fruits. Seed for a new grove is sometimes selected, but unfortunately little is done beyond this in the way of crop improvement.

Also Cocos shells are charcoaled and used in charcoal irons. This charcoal gets very hot and if used alone in the irons, burns the irons out more quickly than if the two kinds are mixed. Gasoline drums partially buried and partially filled with IRIIRI (gravel) and with a fairly tight cover are used for making the fuel.

Cordia subcordata Lamarck

Raroia: Opakea, 11777-BISH, USNM; Tomogagie, 11151-BISH, USNM
Takume: Gake, 12299c-BISH, USNM, 12001-BISH.

Tree found (11151) on north end of Tomogagie was toward the inner part of the Guettarda zone. The leaves were rather yellowish as though suffering from drought (they were somewhat limp) or in some stage of defoliation. The tree was about 20 ft. high with many sprouts. The center of the island beginning about 20 ft. away was rather barren and had, perhaps, been wiped off by a hurricane. Almost a rare tree on Raroia. Flowering on Takume in September.

In Danielsson's list, the native name is given as TOU.

Crinum asiaticum L.

No collections made.
In the village spider lilies were present: a larger white-flowered one, the scape of which exceeded the leaf height, and a smaller pink-striped white-flowered variety, the scape of which was shorter than the leaves. These were common, but no collections were made.

Cynodon dactylon (L.) Pers.

Raroia: Garumaoa, 11733-USNM.

Forming an irregular ground voer in a few village areas.

Cyperus kyllingia Endl.

Raroia: Garumaoa, 11739-USNM.

A common village plant.

Cyperus javanicus Houtt.

Raroia: Garumaoa, 11810-BISH, USNM.
Takume: Gake, 12294-BISH, USNM.
South of the village of Garumaoa in brackish abandoned taro pit, and again at Gake, Takume.

Digitaria stenotaphrodes (Nees) Stapf.

Raroia: N. of Garumaoa, 11110-BISH, USNM: Kaea, 11896b-USNM.
Takume: Gake, 12296a-BISH, USNM.

Eragrostis amabilis (L.) Wight & Arn.

Raroia: Kaea, 11897a-USNM; Oneroa, 11550-USNM; Opakea, 11775-BISH, USNM; Garumaoa, 11258-USNM.
Takume: Gake, 12319-BISH, USNM.
This formed a small meadow at Oneroa and was the only such incipient more or less natural grassy area seen. In Garumaoa it was most conspicuous where with a moss ground cover it occurred abundantly with the most luxurious population of Pilea microphylla found. Common elsewhere.
In Danielsson's list NANAMU is given as the native name.

Euphorbia atoto Forst. f.

Raroia: Opakea, 11787-BISH, USNM; Garumaoa, 11009-USNM: Homohomo, 11046-BISH.
Takume: Gake, 12317-BISH, USNM.
Flowers all white at Raroia. Forming cover under Guettarda and often as tall as a meter. Forming in places a low sparse but consistently present stand in less well-kept Cocos plantings. Occasionally extending into Messerschmidia areas. Common in shade everywhere.
Danielsson gives TAHETAHE as the native name for what he lists as E. hirta. According to a tentative manuscript delimitation of the atoll species by Fosberg, that species is herbaceous and has the inflorescences appearing in the upper axils. Only very rarely in the material at hand is an inflorescence seen to arise from what might be called an upper axil and the stems below are quite woody. The local people uniformly named our collections of E. atoto, TAHETAHE.

Euphorbia hirta L.

Raroia: Garumaoa, 11049-BISH, USNM.
Takume: Gake, 12320-BISH, USNM.
A very abundant village weed in more trodden places.

Euphorbia prostrata Ait.

Raroia: Garumaoa, 11050-BISH, USNM.
Common prostrate cover in sandy village areas.

Fleurya ruderalis (Forst f.) Gaud.

Raroia: Nohinohi, 11480; Opakea, 11781-USNM; Homohomo, 11005-BISH, USNM, Onigehuihui, (KERETEKI) 11892-BISH, USNM: Gavarivari, 11912-BISH, USNM.

Takume: Gake, 12316-BISH, USNM.

VAIANU (11005) and OGAOGA are given by Danielsson as the names applied to this plant by the local people. No use of this second name was experienced in reference to our collections.

A component of the local fish poisoning cure. Formerly used for fish lines and prized as the lines would float.

Guettarda speciosa L.

Raroia: Homohomo, 11036-BISH, USNM; Opakea, 11778-BISH, USNM.

Takume: Gake, 12313-BISH, USNM; Ohomo, 12030-BISH, USNM.

This tree seems to mark the area in which Cocos culture might be successful. It is common throughout the atoll. One is led to postulate it as an indicator of the outer edge of the fresh water lens and tending to dominate the fresh water lens area because of its shade tolerance.

While Catala reports this to be the most important mulch source in the Gilberts, Messerschmidia is the favorite on Raroia. Guettarda is the tree most frequently used as a structural material at Raroia.

Hedyotis romanzoffiensis (C. & S.) Fosb.

Raroia: Homohomo, 11008-BISH, USNM; Kukina, 11226-BISH, USNM; Garumaoa, 11453-USNM; Oneroa, 11547-BISH, USNM; 11548-BISH, USNM; Kakipuku, 11768-BISH, USNM; Nohinohi, 11481.

Takume: Gake, 12300-BISH, USNM.

This plant was strikingly variable. Along the shady lagoon shores of Oneroa it was a tall, relatively unbranched herb. On the sea shores, at the edge of or outside the coconut area, this species formed viney masses several feet in diameter and perhaps two feet high. It was usually found only at the ends of the vegetated areas of islands on otherwise barren channel shores, and there as a low somewhat woody shrubby plant a foot high. Here it was more conspicuous opposite the seaward end of the vegetation than it was toward the lagoon.

The local name is KOBORABORA. A preparation of this was said to be used against earache.

Heliotropium anomalum H. & A.

Raroia: Homohomo, 11001-BISH, USNM; Rare, 11169-USNM; Opakea, 11773-BISH, USNM.

Takume: Gake, 12303-BISH, USNM.

A prostrate vine-like shrub among scattered Scaevola and Messerschmidia plants in the sand. Often conspicuous at the edges of vegetated areas on the sea side of islets.

Danielsson gives the Raroian name as PARAHIRAHI, the pronunciation of which was most difficult.

Hibiscus tiliaceus L.

Takume: 12029-BISH, USNM.

Three trees were seen in the Garumaoa village area, about 30 ft. tall. None were seen outside the village. These three were large and had apparently grown up after having been cut down and trimmed repeatedly. This tree is of no value, apparently, to the current Raroians. A tree (12029) from a village at Takume was adjudged by St. John to be of the variety abortivus.

Hibiscus tiliaceus L. var. sterilis F. Br.

Raroia: Tetou, 11833-BISH, USNM; 11834a-USNM.

Common in gravel at outer edge of Guettarda and inner Pemphis along sea shore, but only here at Tetou. This is a very distinctive bush or small tree with smooth gray bark. The blades of the cordate leaves were bent down to a sharply vertical position. In many cases they were almost parallel with their erect petioles. The leaf veins were red to pink as was the dentate margin. The large (3.8 cm. long) stipules were red at their tips and along their margins.

This material supported a scale insect in conspicuous numbers.

A rather careful search revealed no trace of flowers or fruits on the shrubs or ground beneath.

This island was formerly the main island of a major tribe on the atoll. It is only occupied temporarily now and no one was found who knew anything about this species.

Ipomoea gracilis R. Br. [the I. littoralis of the key]

Raroia: Garumaoa, 11740-USNM.

Fruits found but no flowers (reputed to be white) on this common village plant.

Ipomoea tuba (Schlect.) Don

Raroia: Opakea, 11788-BISH, USNM; Tetou, 11834-USNM; Homohomo, 11044-BISH, USNM, 11246-BISH, USNM.
Takume: Gake, 12003-USNM; Gake, 12306-BISH, USNM.

Running over gravel at sea edge of other vegetation, and over that vegetation, e. g. Hibiscus tiliaceus var. sterilis (11833 & 11834a), Pemphis, Suriana, Messerschmidia. The leaves on terricolous runners were often strongly trilobed.

Called POHUE in Danielsson's list.

Lepidium bidentatum Montin.

Raroia: Nohinohi, 11421-USNM; Kawa, 11898-BISH, USNM; Garumaoa, 11452-USNM, 11432.
Takume: Gake, 12302-BISH, USNM.

This is a component of the local fish poisoning cure.

NAU and HORAHORA are given by Danielsson as the names used for this plant locally, and were applied to our collections by the Raroians.

Lepturus repens (Forster) R. Brown

Raroia: Tetou, 11866-USNM; Tikagera, 11428-USNM; Opakea, 11774-BISH, USNM; Oneroa, 11551-USNM; Fareana, 11244-USNM.
Takume: Take, 12327-USNM, 12293-BISH, USNM.

Present as a pioneer with Heliotropium. Present in an amazing series of variations. Common on all nonthoroughly vegetated islets.

The Raroians use the word MAUKU for all grasses in general. They are not considered worthy of distinction as they are considered to be of no use. A somewhat similar situation prevails in reference to the shell bearing gastropods which are all called PUPU and are all rather valueless, with a very few exceptions.

Messerschmidia argentea (L. f.) I. M. Johnston

Raroia: Homohomo, 11035-BISH, USNM; Opakea, 11783-BISH, USNM.
Takume: Gake, 12310-BISH, USNM, 12311-BISH, USNM.

This is one of the plants for which the natives have a use. It is reputed to be the best mulch for taro pit development. The related observation that there are usually but few leaves of Messerschmidia on the ground where it is dominant supports this belief on the part of the local people. It is to be noted here that under Suriana and Pemphis, which grow with Messerschmidia, there is usually a goodly accumulation of their leaves but not of Messerschmidia.

The species seems to be very shade intolerant. Skeletons of quite tall trees (30') were found in dense Guettarda areas.

GEOGEO is the name used for this plant on Raroia.

Morinda citrifolia L.

Raroia: Homohomo, 11045-BISH, USNM; Oneroa, 11549-BISH, USNM; Opakea, 11785-BISH, USNM.
Takume: Gake, 12307-BISH, USNM.

At Homohomo this plant forms a rough line of young and older bushy trees inside the Messerschmidia and probably in the outer edge of what was a Guettarda area. One bush was found on the seaward side of the Garumaoa transect in the middle of a Pemphis-Suriana thicket. Thought to be uncommon at first but later found throughout the better vegetated leeward part of the atoll.

There was little insect work noted on the vegetation at Raroia. This Morinda, however, in places did have on the under surfaces of its leaves many white fly females. These insects (Aleyrodidae) look very much like scale insects.

In Tahiti used as a fish poison component and in the Tuamotus used for stomach aches. The fruit is acid and smells of lactic acid.

Called HORA by the Raroians, according to Danielsson, and brought originally as a medicinal and food plant.

Musa sapientum L.

No collections made.

Grown with little success in mulch filled pits in the village at Garumaoa. Fruits were seen on one such patch only.

Nesogenes euphrasioides DC.

Raroia: Kawa, 11897-BISH, USNM: Motufano, 11419-USNM, 11420-BISH, Gavarivari, 11909-BISH, USNM.

Takume: Gake, 12297-USNM.

This little plant was found only on the less populated windward part of the atoll. It extended from under the innermost Pemphis on the sea side of the islet back beyond the edge of where Guettarda predominated.

Danielsson lists as the Raroian name, TOROARIKI.

Ocimum basilicum L.

Raroia: Garumaoa, 11722-USNM.

Only seen as a weed in the village, Garumaoa.

Pandanus distinctus Martelli [the P. tectorius of the key]

Raroia: Namunamukona, 11478; Onigehuihui, 11895, 11894; Gavarivari, 11907; Opakea, 11776; Oneroa, 11653; Temari, 11168.
Takume: Gake, 12292.

This plant has a very fibrous fruit the taste of which has been likened to a mixture of alum and raw parsnips. They are not very good and the Raroians have no use for them.

There were rumors of good "eating Pandanus", but the location of the plants was mercurial; it was always "over there."

We found the name in Danielsson's list of local names to be FARA. Rogo, one of our principal advisors, volunteered the name TIMA, which was said to be the name for Pandanus in the Western Tuamotus. Later he called it TIMA FARA and finally settled on FARA.

Pandanus tectorius var. laevis (Kunth.) Warb.

Raroia: Garumaoa, 11462.

This variety is distinct from the material called here P. distinctus at Raroia for the margins of the leaves are practically devoid of teeth but for the outer one-fourth of the length. There is a cloaking of the stems with old leaves which in nature may hang on the whole length of the stem. This variety was not seen in fruit. It is reputed to have been brought from Tahiti.

There were several clumps of this variety on the atoll. Those near the village were trampled down both incidentally and with the intention of keeping the plant low.

The local name appeared to be PAIORE but this may have been our misunderstanding of the Tahitian PA'E'ORE.

Pemphis acidula Forster

Raroia: Homohomo, 11033a-BISH, USNM, 11033b-BISH; Homohomo, 11002-BISH, USNM; Papakotuha, 11772-BISH, USNM.
Takume: Gake, 12304-USNM.

Forming on Garumaoa, with Suriana maritima, the bush zone bordering the sandy storm beach. While the Suriana is for the most part dominant along the leeward shore, Pemphis is the more prominent along the channels between the islands. See under Suriana for further notes on this species. Common on all atolls visited.

A number of local residents agreed on MIKIMIKI as the name for collection no. 11002, and this is the name determined by Danielsson.

Phyllanthus niruri L.

Raroia: Garumaoa, 11460-USNM, 11507-BISH.
Takume: Gake, 12315-BISH, USNM.

This is one of the most commonly found weeds of the village along with two species of *Euphorbia*.

MOEMOE is the native name given in Danielsson's list. It is one of the local remedies for earaches. The plant was pounded into mush and the juice added to oil; this preparation was then put into the ear (on cotton).

Pilea microphylla (L.) Liebm

Raroia: Garumaoa, 11037-USNM, 11260-BISH.

Very small where it occurs in the less humidified sandy "roads" in the village. Much more luxuriant where occurring in mossy areas of undisturbed humus with *Eragrostis amabilis*. Common at least about the village of Garumaoa but usually overlooked.

None of the people questioned had a name for this plant or, indeed, had even noticed this insignificant plant before.

Pisonia grandis R. Brown

Raroia: Paparoa, 11821-BISH, USNM: Opakea, 11782-BISH, USNM.
Takume: Gake, 12298a-BISH, USNM.

Found with flowers in July. This species is almost rare, the above and Kahogi (Tokerau) being almost all, or all, the places where this species is now alive. On Takume it was confined to the ridges between the large taro pits at the northern (GAKE) end of the atoll. Seeds were found on *Pisonia* on this atoll.

We received the impressions that (1) reproduction is at least mostly vegetative and (2) that the atolls observed were almost too low for its well being. We were unable to find seeds at Raroia with which to test the theory that this species will only germinate in guano.

These records nicely fill a small gap in the known distribution (The distribution of "Pisonia grandis" (Nyctaginaceae) Pacific plant studies No. 10, Webbia 8: 225-228, 1951) of this plant as recently summarized by St. John. It may be noted here that another addition to St. John's distribution map is the record from Arno Atoll (Anderson, Donald. The plants of the Marshall Islands. Atoll Research Bulletin No. 7, 1951).

GATAI was the name used in Raroia and Takume for this plant.

Portulaca johnii Poeln.

Raroia: Opakea, 11789-BISH, USNM; Homohomo, 11006-BISH, USNM; Onigehuihui, 11891-USNM.
Takume: Gake, 12002-USNM, 12308-BISH, USNM, 12325-BISH, USNM.

This species was found growing best under *Cocos* in the humidified soil to be seen near the leeward shore of the central part of Garumaoa, south of the village. Its distribution was quite general, however, and it was even found growing on top of a large reef boulder, which was about 16 ft. high by 20 feet in each horizontal direction.

Search revealed nothing that resembles *P. lutea* or any of the other species closely related to this one entity.

POKEA is the native name listed by Danielsson and uniformly agreed upon by the local people questioned. This species is used as a food during times of economic distress.

Scaevola frutescens (Mill.) Krause

Raroia: Homohomo, 11211-BISH, USNM; Opakea, 11771-BISH, USNM.
Takume: Gake, 12314-BISH, USNM.

Common in range of vegetation form and flower color variations. Woody stems up to 4 cm. in diameter were collected.

A native who guided us to the makatea patch at the northwestern cape of Anaa told us that this plant, NAUPAKA, was used in the treatment of coral and other cuts. He indicated that the stems are pounded and that the pulp, so made, is smeared in the cut. Bengt Danielsson tells us that the people of Raroia use NAUPAKA in a similar manner.

Sesbania speciosa F. Brown

Raroia: Tetou, 11835; Oneroa, 11559, Garumaoa.

At Oneroa and Tetou there were many young plants or seedlings under the mature plants. This appears to be a well established species developing into a tree 16 ft. tall.

KOHAI is the name applied to this plant by the Raroians according to Danielsson's list. It appears in the village of Garumaoa as an ornamental.

Solanum viride R. Br.

Raroia: Opakea, 11793-BISH, USNM: Garumaoa, 11742-USNM.

At Opakea this formed a bush nine feet tall under Cocos. In the village of Garumaoa it appeared as a weed.

PUTAMAGOMAGO is given as the local name applied in Takume.

Stachytarpheta cayennsis (L. C. Rich.) Vahl. [the S. jamaicensis of the key]

Raroia: Garumaoa, 11721, 11743.
Takume: Gake, 12322.

Suriana maritima L.

Raroia: Opakea, 11784-USNM; Homohomo, 11034-BISH, USNM.
Takume: Gake, 12324-BISH, USNM.

This plant seems to be the one most successful on practically bare beach rock. However, in sandy places where there are many small seedlings the area may be held by the root systems of Messerschmidia. It does not extend inland far from the shore line. Often a clump of beach bushes is made up of a peripheral ring of Suriana surrounding a more central and larger Pemphis. The reverse situation was not found, and there are few sizeable clumps of Suriana alone. Thus one is led to think of Suriana as being intolerant of shade and suspect that its root systems are limited sharply by some soil water content level and inhibited by plants other than Pemphis. The plant occurs inland only to where there is an abundance of Messerschmidia, Scaevola or Euphorbia.

For this plant there is a series of names used which represents well one course of evolution of words in Polynesia in reference to the dropping out of consonants and syllables. According to the Raroians with whom the matter was discussed, largely by manual means, and according to Danielsson, the names most used are KOKURU, KUKU AND U'U, with U'U being by far the most popular. Local custom includes putting this plant in the water in which a mother and her newborn infant are washed. While this is a durable and hard wood its small size limits its use.

Synedrella nodiflora (L.) Gaertn.

Raroia: Garumaoa, 11736-USNM.

Tacca leontopetaloides (L.) Ktze.

Raroia: Garumaoa, 11464-BISH, USNM, 11463-USNM; Opakea, 11794-USNM.

Common throughout village areas on several islands, but far more abundant around Garumaoa. Flowers were much more in evidence during August than they had been upon our arrival about the first of July. This supports the seasonal development suspected by Taylor at Bikini.

It is used as a famine food and as a source of starch for beverages. It is given no attention by the Raroians otherwise. The local name is PIA.

Terminalia catappa L.

No collections made.

There were two young large-leaved spreading-branched trees in Huri's yard and one at another place in the village.

This plant has been discussed by Petard (Journal de la Societe des Oceanistes 77: 260-263. 1951) as an aboriginal tree in the Tuamotus and elsewhere, furnishing an oily, edible nut, medicine and wood for cabinet work. The Raroians consider it one of their RAKAU TAHITI (i.e., "one of those useless plants from Tahiti").

Timonius polygamus (Forst. f.) Robins

Raroia: Takeke, 11150-BISH, USNM; Garumaoa, 11448-BISH, 11450-BISH, 11449-BISH, 11451-BISH, USNM; Opakea, 11770-BISH, USNM; Tomogagie, 11149-BISH, USNM; Paparoa, 11820-BISH; Onigehuihui, 11893-BISH, Nohinohi, 11482.

Takume: Gake, 12011-BISH, USNM, 12295-USNM, 12312-BISH, USNM.

Abundantly in flower and fruit. Flowers white, fruits blackish. Usually on highest part of island just outside the Pandanus area. The species was extremely variable and there was a host of distinct characters distributed seemingly at random among the many bushes found.

Danielsson's list gives two names for this plant, PAKETA and KETOKETO. A lady in the village gave the latter name to the leaves of 11149, as did Vaea our own helper. Vaea would also apply this latter name to some parts of Hedyotis romanzoffiensis as well; if leafy branchlets of both were presented he called them both KETOKETO, though distinguishing the whole plants.

Triumfetta procumbens Forster

Raroia: Garumaoa, 11048-USNM; Patahiva, 11000-BISH, USNM.

Forming ground cover commonly under *Cocos*.

In our material from Patahiva (11000) the blossoming material had very little in the way of trilobed leaves. Coarser, perhaps older, and at the time non-blossoming plants, had trilobed leaves. On the blossoming plants often it was observed that the oldest leaves, i.e., those nearest the main stem of the blossoming short lateral branches, were trilobed and yellowish.

VAVAI appeared to be the native name.

Vernonia cinerea Less.

Raroia: Garumaoa, 11709-BISH, USNM, 11042-BISH, USNM.
Takume: Gake, 12296-USNM.

Scattered about old ashes of trash fire under *Cocos* in the village, and common elsewhere as well.

Vigna marina (Burm.) Merr.

Takume: Ohomo, 12031-BISH, USNM.

Growing among *Euphorbia atoto* on lagoon side of Ohomo; with flowers and fruits in September. Not seen on Raroia.

Waltheria americana L.

Raroia: Garumaoa, 11811-BISH, USNM, 11710-BISH, USNM, 12090-BISH.

Under *Cocos* just south of Garumaoa and a common village weed. There appeared to be something odd about the blooming of this species. Though flowers and fruits were common, at least through August, it took repeated observations over many days to catch open flowers, which if remembered correctly were open at midday. They were not open at night or early morning.

Ximenia americana L.

Raroia: Opakea, 11779-BISH, USNM.

At Opakea this plant was up to 15 feet high and only slightly vinaceous. On Raroia there appeared to be only about 6 somewhat separated growths of this plant extending along the center of the island vegetation in areas where *Cocos* had not been planted between Opakea and Nigahava. The fruits were seen in a circle of ashes where Vaea told us there had been a bush at Vaituki north of the pass in Tokerau.

While reputed to be used as a spice in the Society Islands (Andrews) it was only occasionally eaten as a nut at Raroia.

RAMA is the Raroian name given in Danielsson's list and used by the Raroians for our collections. RAMA in the Marquesas and 'AMA in Tahiti are reputedly "rambling creepers."

EXOTICS AND VILLAGE PLANTS

The Raroians have in general but few names and little use or concern for these plants in this category. One, however, the famous Gardenia tahitensis, is a beautiful single gardenia. The white blossoms are about an inch and a half in diameter and opening on the bushes late in the day seem almost like stars on the rounded bushes, colorless in the evening's grayness. This is their TIARE TAHITI (flower of Tahiti).

To Raroians all exotic plants in general are RAKAU TAHITI (Tahitian plant), which they usually say in such a way with a disinterested shrug of the shoulders that one would be inclined to translate as "another of those useless plants from Tahiti." A bud worn over the ear will open as evening draws nigh. Such a wearing usually is taken as an announcement that the wearer wishes it known, or believed, that he or she has something opening up in the way of a romantic affair with the arrival of the coming evening.

Successful horticultural practice is generally so lacking as to disincline one to ever refer to it as primitive. People pull up a growing plant and stick it in the ground in a new place, usually not even watering it once. If it seems to show signs of surviving that makes it desirable for some other place and the plant is moved again. Thus many of the plants listed here below must be dead now. Indeed their identification was impossible in many cases for, though recognizable as distinct from other village plants, were but mere sprigs too small to yield a specimen and far from being in condition to produce a flower. The coffee plant reported and the guava were hardly more than rooted twigs with less than half a dozen leaves. The Barringtonia was three seedlings, and one disappeared before the team left. It was only through the invaluable assistance of our field assistant Aurora Natua and through her great familiarity with local native and exotic plants that we were able to obtain this rather complete list of village plants.

Again while field determinations were attempted, Prof. Harold St. John went over all the specimens brought back and we have used the names which he could provide.

In addition to the names in the list A below we found the plants in list B for which no satisfactory name has been found as yet and includes three plants for which no name at all was obtained.

List A

Allamanda ?oenotheraefolia Pohl.: a yellow flowered bush with four leaves at each node; thus probably this species. Used as an ornamental.

Amaranthus viridis L. (11732-USNM).

Annona sp.: sugar apple. Growing in one place in the village.

Arachis hypogaea L.: there were several clusters of peanut plants about the village with rather large yellow flowers. These were considered more of a curiosity than anything else, but seemed to grow very well and might possibly be a potential crop, or at least a supplementary food plant, for the region.

Ascelpias curassavica L. (11505-USNM): many plants at village edge behind the Catholic church.

Asparagus plumosus Baker (11719-USNM): strictly ornamental.

Barringtonia asiatica (L.) Kurz.: four seedlings planted about the Huri Estall yard and only about 40 cm. tall.

Beloperone guttata Brandegee: at least there was a "shrimp plant" in one of the yards.

Bougainvillea spectabilis Willd.: a common ornamental growing very well without care in several of the yards of the village.

Brassica pekinenisis (Lour.) Rupr.: locally called "petsi", which is probably the same as pe-tsai the common name used in the Hawaiian Islands today. This Chinese cabbage might very well be a valuable green vegetable as it is palatable either raw or cooked, at least to the American taste, and it grew prolifically in rather fresh beach sand with little or no care.

Breynia disticha var. disticha f. nivosa (W. G. Sm.) Croizat (11822-USNM): introduced long ago into Tahiti for hedges. This produced bushes about 3 feet high in the village of Garumaoa on Raroia.

Caladium sp.: plant in only one yard; no flowers.

Canna ?indica L.: one canna-like plant in the village.

Catharanthus roseus (L.) Don: growing luxuriantly and planted in many places. This common "vinca" is one of the major ornamentals in this sandy village, as it requires almost no attention other than perhaps removal of the stems which, while woody, tend to become vine like and get out of hand. Most of the plants are white flowered with few colored flowered plants being seen.

Citrus ?medica L.: many varieties of the local limes were found. Two were conspicuous differing among other things, in that one had large leaves and fruits, while the other had smaller leaves and smaller fruits. The French name, citron, was applied loosely to all such plants.

Citrus paradisi Macf.: one small grapefruit bush about 3 feet high was to be found.

Citrus sp.: small bush with leaves having alate petioles that were often half the size of the leaf blade. While this may have been a young grapefruit plant the leaves were different from that enumerated above.

Cleome viscosa L. (11735):

?Clerodendron sp.: a vine-like bleeding heart bearing flowers with both white and pink colors.

Coccoloba uvifera (L.) Jacquin: it was a surprise to find this plant nowhere except planted in the village. There were a number of plants of this species up to about 4 meters tall.

Codiaeum variegatum (L.) Bl.: various varieties of croton were scattered about the village. The narrow green leafed forms with yellow mottling and the broader leafed forms with red and green leaves being the most common.

Colubrina asiatica (L.) Brogn.: (12321-BISH, USNM): Gake, Takume only.

Cordyline terminalis (L.) Kunth.: Several ornamental varieties were seen about village. They are planted as ornamentals and do not have the uses or history this species has elsewhere. It is believed that none of them was the variety _ki_ of Hawaii.

Crinum sp.: a red-striped spider lily is very common in the village.

Crinum sp.: white spider lily, having vegetative parts about three times the size of those of the red-striped variety above.

Cyperus rotundus L. (11726-USNM): common ground cover in some of the more "grassy" yards.

Dahlia spp.: several varieties.

Delonix regia (Boher) Raf.: one "royal poinciana", a tree about 20 feet high and not in leaf during our visit. In mid-August it appeared that the buds were about to burst. This tree was in the yard of the old native chief who only called it a "RAKAU TAHITI" (Tahitian plant).

Euphorbia sp.: not unlike _Hylocereus_ in appearance. Aurora Natua told us that this plant has small pink flowers.

Ficus sp.: several small plants of edible figs were in the village.

Gardenia tahitensis DC.: one of the major ornamentals about the village. The bushes seem to grow without care and produce an abundance of flowers. One of the few ornamentals for which a Polynesian name (TIARE TAHITI) is in common use locally. (11723-BISH, USNM)

Gardenia sp.: a species or variety having smaller flowers than _G. tahitensis_.

Gossypium ?brasiliense Macf.: several bushes, in form almost like small trees up to 10 feet tall, were found in the village. These were planted as ornamentals for their large yellow flowers and probably as curiosities. The fiber seemed to be very strong and long.

Hibiscus spp.: there were several red flowered species cultivated in the village. One was a double flowered form. There were two single flowered species, one of which looked rather like the common garden variety of Hawaii, and the other of which was peculiar in that the flowers never more than just began to open. (See bell hibiscus in List B.) Both were caney species.

Hippeastrum equestre (Ait.) Herb.: a short-stemmed red lily bearing one or two flowers. Leaves like _Clevea_ but about 2.5 cm. by 20 to 30 cm. long.

Hippobroma longiflora (L.) G. Don (12137-BISH, USNM): an herb having white Nicotiana-like flowers, found in two places in the village. Flowering in June, July and August.

Inocarpus edulis Forst.: one such Tahitian chestnut was located about one ft. high.

Ipomoea batatas Lam.: sweet potatoes grow in ornamental quantities in several places.

Ixora sp.: a village ornamental ranging from a small viney bush to small tree form and size.

Jasminum spp.: there were bushes of at least two species or varieties growing in the village. Both were sweet-smelling kinds with relatively simple flowers.

Lathyrus odoratus L.: sweet pea.

Mangifera indica L.: several trees have been planted in yards but as yet there are few over 0.6 meters high.

Melia azedarach L. (11741-USNM): village plant.

Nothopanax guilfoylei (Cogn. & March) Merr.: forming many hedges about the village. Often only some limbs bearing the distally fimbriate leaves and again apparently these limbs have been rooted and spread out so that a whole hedge is a clone of plants bearing leaves of the fimbriate form.

Nerium oleander L.: the oleander is a major and conspicuous ornamental in the village. It seems particularly well adapted to life in the village as it grows well without care.

Opuntia ?megacantha Salm-Dyck: a fig d'Barbarie was present as about 2 dozen plants scattered through the village. They were usually less than a meter tall, but the tallest plant was a little less than 2 meters high. The flattened stems of this species are favored sites for carving names.

Oxalis sp.: one clump of a yellow flowered species was found around the cultivated base of a small tree in a yard.

Plumeria acuminata Ait.: occurring as many small trees in the village. Nearly all, if not all, are the more or less yellow flowered form.

Pseuderanthemum atropurpureum (Hort.) Bailey (11825-USNM): village plant.

Psidium sp.: seen as one small sprig growing well but only about 1 ft. high. Had characteristic opposite leaves (about 6) and odor.

Rhoea ?discolor Hance: many plants scattered about the village especially inland. In flower during our stay.

Rosa sp.: as several small bushes growing about the village. They seemed to be one of the small-leaved climbers. No blossoms were seen.

Saccharum officinarum L.: present as three small clumps of up to half a dozen canes each, but these only about 1 meter high. It is a slender black-stemmed variety planted seemingly as a curiosity.

Sapotilla sp.: a small tree bearing round fruits.

Sesbania grandiflora (L.) Pers. var. coccinea Pers. (11906b-USNM): one small bush of this species was found in the village. Aurora Natua has brought in seeds of this plant from La Pagerie, Martinique in recent years and has grown this plant successfully in Tahiti. It is a lovely ornamental flowering from seed the first year. The flowers in August were large and showy with the keels being over two inches long. It is now common in Tahiti.

(Solanum lycopersicon: has reputedly been grown in the village areas. We did not see it.)

Sporobolus poiretii (R. & S.) Hitch. (11737-USNM): a rather common grass in the village.

Syzigium jambolana Lamarck: a small tree in several yards cultivated or "permitted to grow" for its astringent purple fruit. Petard (1951) discusses the uses of this plant in French Oceania for fuel, charcoal, jelly and beverages.

Tagetes spp.: various varieties of marigold were found about the village. Most of them grew well.

Tamarindus indica L.: one small bush-like tree.

Vitex trifolia L. var. trifolia (11730-USNM, 11724-BISH): Two small tree-like shrubs.

List B

Bell hibiscus (in Neal, abutilon pistum Walp.): red single flowers that never open.

Brisbane lily:

Cerise de l'hopital: (11734). Bears berries; not sweet smelling; sticky stems.

Coffee: One small rooted cutting about 0.5 meters high was found in a yard in the village. This may have been Acalypha, the so-called "false coffee."

Folier du jeune fille: with lilac-like flowers.

Hedge plant: with violet flowers, introduced into Tahiti by Harrison Smith.

?PITI: (11741)

Herb: "a kind of Gaugau".

Herb: large pink, sometimes red, plant with partially green leaves, i.e. red and green.

KAVA: a few small trees up to 20 ft. tall. Fruiting in August and fruits globose, green, about 3 cm. in diameter and having a thin flesh over a large seed. The flesh tastes mild, not unlike a cross between chestnuts and cabbage. Certainly not Piper methysticum.

Legume: large bush with big trilobed leaves and yellow flowers on terminal spikes. The leaves are bruised and used as a plaster over boils. Called PIPI, which is merely "Beans." A Vitex sp.?

Legume: source of cassis perfume. A weed in the Marquesas. Looks like Leucaenxa glauca, the koa haole of the Hawaiian Islands.

Lily: crocus-like with pinkish (or rarely white or yellow) flowers and almost grasslike spreading leaves. Is used commonly as a border. None was blooming and no one was found who knew a name for it.

Melons: several cucurbits were being rather unsuccessfully grown in pits filled with mulch.

Mountain beauty: pink flowered.

Quenettes: (11731). Found just west or southwest of Rogo's house. Small disagreeable fruit attractive to children.

Plant: introduced by Mmme. Rost from Martinique.

Plant: unidentified. This and the following two entries are included merely as a better record of the extent of the flora.

Plant: unidentified.

Plant: unidentified.

Part 2

ECOLOGICAL AND FLORISTIC NOTES ON THE MYXOPHYTA OF RAROIA

by Jan Newhouse

The blue-green algal collections obtained during the summer of 1952 at Raroia (and Arno Atoll) have been the subject of an intensive study designed to reveal more of their roles on a coral atoll. The present report is essentially a summary of the field observations and the taxonomic study of these organisms. This material is reported in two sections; Section A is a floristic resume listing the species alphabetically with their distributions and a summary of the field notes accompanying the collections. Section B is a resume of the ecology and prospective roles of the major species. This latter phase of the work is extended by cultural experiment, laboratory studies and a review of the pertinent literature.

The localities listed may be located on the diagrammatic map appearing as Figure 1 in Part 1 of this Atoll Research Bulletin No. 33.

Section A

Anabaena torulosa B. & F.

Kereteki: Tetou (11831)

Appearing with Spirulina tenerrima and Hydrocoleum coccineum as a reddish brown scum on beach rock and in the intertidal zone of the lagoon beach.

Anacystis dimidiata (Kuetzing) Dr. & Daily

Tokerau: Vaituki (11372)

Gake: Teuriamote (11433)
Teuriamote Iti (11429)

This species was associated with other blue-green algae forming prostrate mats in brackish pools. There is the following interesting note concerning this rather velvety or gel-like growth form in which A. dimidiata was present. The food material that remains in a pot after cooking and has to be scraped out in cleaning the pot is called PARA by the natives of Raroia. They compound this term as KOPARA for this blue-green algal material that has the same appearance and consistency as the food residue.

On the lagoon side of the islands at the northern end of the atoll, several small pools in the beach rock with exceptionally thick growths of KOPARA were found. One such pool was investigated and is diagrammed in Figure 2. The KOPARA formed a coating around the rim and extended as a surface covering over the shallow parts of the pool. The uppermost orange pink, cartilaginous layer

(A in Fig. 2) was entirely algal in nature and shaded to a deep green algal layer (B in Fig. 2) intermixed with sand. Together these two layers were 4 mm. thick. Beneath these layers and covering the bottom of the 40 cm. deep pool was a beef red sandy sediment (C in Fig. 2). The major elements in this KOPARA were Schizothrix lacustris and Anacystis dimidiata. A number of fish, juvenile Chanos chanos Forskal, inhabited the water (D in Fig. 2) filling the remainder of the pool.

At this same northern end of the atoll there was an incomplete channel shut off from the lagoon by a sand bar. The pond thus formed was brackish (by taste test judged to be 16-20 parts per thousand sea salt). Visual observation and the odor indicated its use as a repository for refuse and excrement. The bottom of this pond was covered by about 15 cm. of very soft sediment over gravel and on this sediment were irregular soft brownish-purple patches made up of A. dimidiata and Phormidium papyraceum. Around the rim at the water level were large areas of KOPARA as found in the afore mentioned pool.

A. dimidiata was also a constituent of soft mats on the bottoms of rain basins in the seaward beach rock. Here it was associated with Entophysalis crustacea, Calothrix scopulorum and Schizothrix species.

Anacystis montana (Lightf.) Dr. & Daily

Tokerau: Mataira (11373)

Gake : Teuriamote (11442, 11443, 11444)

Raro : Garumaoa (11118)
: Homohomo (11179, 11218, 11257, 11276, 11293, 11298, 11300, 11302, 11305, 11703, 11708)
: Oneroa (11557, 11649, 11663, 11665, 11666, 11668, 11671, 11674, 11677, 11679)

This species appears to be restricted to situations rather far removed from the direct influence of salt water. The thalli were often associated with Scytonema hofmannii and Scytonema guyanense in felt-like coatings on coral fragments and Cocos nucifera husks and trunks. The species will be discussed below with Schizothrix longiarticulata as a member of sediment binding associations.

Brachytrichia quoyi B. & F.

Raro: Garumaoa (11800, 11801)
: Oneroa (11675)

Brown coatings just below high tide mark on seaward conglomerate.

Calothrix aeruginea B. & F.

Kereteki: Tetou (11321)

At high tide line on conglomerate in front of the seaward gravel rampart.

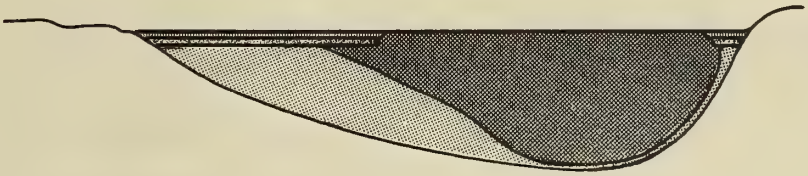

Figure 2

— Cartilagenous

— Sediment

— Algal layer with sand

— Water

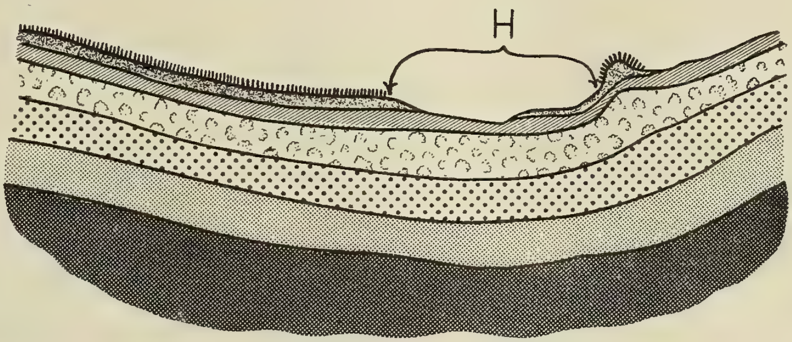

Figure 3

B→F = 6 mm.

— Green

— Algal

— Yellow

— Pink

— White

— Blue

H — Bluish grey rasped area with pink borders.

— White

Calothrix crustacea B. & F.

Gake: Teuriamote Iti (11429)
: Tikageri (11483)

Raro: Tahuna popo (11236)

Lyngbyaceous trichome portions associated with masses of other algae in quiescent saline pools.

Calothrix parietina B. & F.

Gake: Teuriamote (11443)

Raro: Garumaoa (11118)
: Homohomo (11290, 11296)
: Oneroa (11666)

Associated with other species in bound sand on both the lagoon and seaward beaches.

Calothrix pilosa B. & F.

Gake: Teuriamote (11433, 11434)

Kereteki: Tetou (11318)

Raro: Garumaoa (11981)
: Oneroa (11233)

Occurring occasionally as a felt-like stratum on gravel, boulders and beach rock just above the high tide line on both the lagoon and seaward sides of the islands.

Calothrix scopulorum B. & F.

Tokerau: Mataira (11373)
Vaituki (11371, 11372)

Gake: Teuriamote (11436, 11439, 11441, 11442)
Tikagera (11483)

Kereteki: Tetou (11320, 11332, 11832, 11878)

Raro: Garumaoa (11117, 11800, 11801)
: Homohomo (11143, 11144, 11145, 11147a, 11298, 11306, 11307)
: Korere (11308, 11309, 11311)
: Oneroa (11566, 11664)
: Tahuna popo (11236)

In all areas investigated where this species was found, it was associated with Entophysalis crustacea. Thalli of this species were present on all parts of the seaward beach conglomerate and in some instances appeared as a constituent of the sand binding associations discussed under Schizothrix longiarticulata.

Coccochloris aeruginosa (Nag.) Dr. & Daily

Raro: Oneroa (11674)

Associated with other blue-green algae in greenish non-bound lagoon beach ridge sand.

Entophysalis conferta (Kuetzing) Dr. & Daily

Raro: Garumaoa (11935b)

Epiphytic on Lyngbya semiplena attached to Garumaoa village wharf.

Entophysalis crustacea (J. Ag.) Dr. & Daily

Tokerau: Mataira (11373)
Vaituki (11371, 11372)

Gake: Teuriamote (11431, 11433, 11435, 11436, 11437, 11439, 11441, 11442, 11443, 11444, 11445, 11446, 11447, 11472)
Teuriamote Iti (11429)
Tikagera (11483, 11484)

Kereteki: Gavarivari (11922, 11929, 11932)
Kaea (11900)
Tetou (11318, 11320, 11321, 11332, 11333, 11832, 11865, 11871, 11875, 11876, 11877, 11878)

Raro: Garumaoa (11117, 11118, 11351, 11800, 11801)
Homohomo (11143, 11144, 11145, 11146, 11147a, 11284, 11285, 11286, 11289, 11290, 11291, 11292, 11293, 11294, 11295, 11296, 11298, 11300, 11302, 11303, 11304, 11305, 11306, 11307)
Korere (11308, 11309, 11311)
Kukina (11224)
Oneroa (11557, 11566, 11662, 11663, 11664, 11665, 11666, 11667, 11668, 11670, 11671, 11672, 11673, 11675, 11676, 11677, 11679)
Tahuna popo (11236)

This was certainly the most ubiquitous blue-green alga on the atoll. From high tide line, extending down into the reef pool on the seaward side and below low tide line on the lagoon shore, the species formed a slippery yellow brown coating over the calcareous substratum. From the high tide line upward through the splash area the rocks are blackish when dry, but when wet they are dark brown from growths of this species. It appears that the best growth, quantitatively, was in and just above the littoral zone. In and around the pools at the landward edge of the sea beach conglomerate the surface is darker or black when wet and gray when dry. Throughout all this conglomerate region the present species is associated with Calothrix scopulorum.

In no case was this alga found growing above the high tide line on other than a calcareous substratum.

The species was also a prominent member of the sand binding associations. The coral rocks and gravel covering most of the island surfaces are generally completely white beneath and gray on top (or black when wet) with a more or less green line around the under edge. The dark color imparted to the tops of these fragments and to the beach rock appears to be due to the discoloration of the sheath material of this Entophysalis by sunlight. Where shaded, as on the under edge of the fragments, the sheath material is hyaline and the protoplasts, having a greenish color in mass, show through.

Fischerella ambigua (B. & F.) Gomont

Raro: Homohomo (11284, 11289, 11290, 11292, 11294, 11307)
Oneroa (11583, 11663, 11672, 11673, 11674, 11676, 11677)

A common algal cover on inland coral fragments and vegetable debris. Specimens recorded under this name may very well be aerial growth forms of Mastigocoleus testarum.

Hapalosiphon pumilus B. & F.

Kereteki: Tetou (11844, 11870)

Green (in low areas) and brown (in raised areas) patches on mud surface of inland swampy section of the islet.

Hydrocoleum coccineum Gomont

Kereteki: Mahaki (11316)

Raro: Oneroa (11565)

Soft flat reddish sheets on Mahaki channel floor and at the low tide line in the lagoon at Oneroa.

Hydrocoleum glutinosum Gomont

Raro: Garumaoa (11342)

On stones exposed in the low tide area near the village wharf.

Hydrocoleum lyngbyaceum Gomont

Tokerau: Namunamukona (11470)

Kereteki: Mahaki (11313)
Tetou (11831, 11839)

Raro: Garumaoa (11945)
Homohomo (11342)

At and just below low tide line of lagoon, sea and channel shores.

Lyngbya aestuarii Gomont

Raro: Kukina (11815)

Attached to Porolithon onkodes and Microdictyon okamurai on surge ridges.

Lyngbya gracilis Gomont

Raro: Garumaoa (11944)

North (shaded) side of the village wharf just below low tide line.

Lyngbya lutea Gomont

Raro: Korere (11309, 11310, 11311)

Together with Entophysalis crustacea, Calothrix scopulorum and Microcoleus tenerrimus in a crust of coalesced sand and silt grains on the east end of the island.

Lyngbya majuscula Gomont

Kereteki: Tetou (11827, 12342)

Raro: Garumaoa (11227)

This species was a common member of the flora below low tide line in the lagoon. It was not found in the channels between the islands or on the sea reefs. At Tetou it grew up to low tide level on fine gravel along the beach shore and on rocks of the lagoon slope that extended above the low tide line. Here it was taken to be a good indicator of the shore edge of the sublittoral zone. In front of the village of Garumaoa it was growing in the lagoon to a depth of 3 to 6 meters.

Lyngbya semiplena Gomont

Kereteki: Tetou (11333)

Raro: Garumaoa (11935b)

Covering the bottom at the lagoon end of the blocked channel north of Tetou. Also at the high tide line on the Garumaoa village wharf.

Lyngbya sordida Gomont

Tokerau: Fakatomo (11376)

Kereteki: Gavarivari (11922)

Raro: Garumaoa (11064, 11944)
Homohomo (11104)
Oneroa (11513, 11526, 11553, 11572)

This species was often utilized by the shrimp Crangon frontalis (Milne Edwards) as building material for its characteristic tubes, appearing as described by Taylor (Plants of Bikini: 110-111, 1950) from the Marshall Islands. These tubes, sometimes reaching a length of 60 cm., were found on the sea reef flat and in channels of the leeward side of the atoll. Taylor discusses this interesting association of shrimp and alga and something of the history and distribution of this association between shrimps and algae. Prof. A. H. Banner, who identified our shrimp specimens, tells us that some of the Hawaiian species of Crangon have similar habitats. This seems to be unknown to the phycologists who have worked in that area.

Mastigocoleus testarum B. & F.

Gake: Teuriamote (11443, 11444, 11445, 11446)

Kereteki: Tetou (11318, 11320, 11871, 11877, 11878)

Raro: Homohomo (11146, 11286, 11291, 11293, 11295, 11298, 11300)
Oneroa (11557, 11664, 11667, 11669)
Tahuna popo (11236)

This species, marine in distribution, is a perforator of shells and other calcareous materials. At Raroia it was found within tidal limits and the splash zone and perforating the fragments making up the inland surface of the islets. The presence of this species quite removed from typical marine conditions suggests three possibilities.

1. The species is capable of at least passive existence under relatively fresh water conditions.

2. Enough salt is released by the condensation of ocean spray in inland areas to sufficiently duplicate marine conditions.

3. The inland fragments had been recently deposited by storm action and the specimens could be expected to die.

All the specimens examined appeared to be healthy and storms of such magnitude as to carry shore fragments far inland are seldom. Thus, the third possibility would seem unlikely. No choice can be made of the other two without extensive culture experiments.

Microcoleus acutissimus Gardner

Gake: Teuriamote (11443, 11444)

Kereteki: Tetou (11871)

Raro: Garumaoa (11218, 11936)

Intermingled with Oscillatoria corallinae on Garumaoa village wharf. Also found in damp inland habitats.

Microcoleus chthonoplastes Gomont

Raro: Garumaoa (11702, 11703, 11705)

On thoroughly algalated foundation of a village house.

Microcoleus tenerrimus Gomont

Raro: Korere (11309, 11310)

See Lyngbya lutea.

Nostoc commune B. & F.

Kereteki: Tetou (11887)

Forming thin olive membranaceous sheets on the ground and on tree trunks in Cocos groves. This species is a ground covering alga at Raroia, Takume, and Hikueru. Dr. Francis Drouet informs us that this species is also commonly found in North America where seepage and limestone occur together.

Oscillatoria corallinae Gomont

Raro: Garumaoa (11936, 11944a)

See Microcoleus acutissimus.

Phormidium crosbyanum Tilden

Kereteki: Tetou (11332)

Forming a cartilagenous coating over the bottom of seaward end of the same blocked channel mentioned above under Lyngbya semiplena.

Phormidium papyraceum Gomont

Gake: Teuriamote (11422, 11424, 11472)

See Anacystis dimidiata.

Plectonema calothrichoides Gomont

Kereteki: Tetou (11864, 11884)

On greenish soil and sand from above the high tide line along shore of the lagoon.

Plectonema nostocorum Gomont

Gake:	Teuriamote Iti (11429) Tikagera (11483, 11484)
Kereteki:	Kaea (11900)
Raro:	Garumaoa (11703) Oneroa (11662, 11668, 11673, 11674)

Growing within the sheaths of other blue-green algae in both aerial and marine habitats.

Plectonema terebrans Gomont

Gake: Teuriamote (11438, 11445, 11446)

Kereteki: Tetou (11320)

Raro: Kukina (11224)

Perforating shells and conglomerate at and just below the low tide line of channels and seaward reef.

Porphyrosiphon fuscus Gomont

Raro: Garumaoa (11218)
Oneroa (11665, 11671)

On coral fragments and Cocos nucifera stumps in inland areas.

Rivularia polyotis B. & F.

Gake: Tikagera (11483, 11484)

Kereteki: Gavarivari (11919, 11932)

Raro: Kakipuka (11558)

Slick yellow brown coatings on intertidal conglomerate of both lagoon and seaward reefs.

Schizothrix giuseppei Drouet

Raro: Homohomo (11304, 11305)

With Scytonema crustaceum on heavily algalated inland coral fragments.

Schizothrix lacustris Gomont

Tokerau: Vaituki (11372)

Gake: Teuriamote Iti (11429)

The distribution of this species is similar to that of Anacystis dimidiata.

Schizothrix longiarticulata Gardner

Tokerau: Mataira (11373)

Gake: Teuriamote (11436, 11442, 11443)

Kereteki: Tetou (11875)

Raro: Garumaoa (11118)
Homohomo (11292, 11293, 11294, 11296, 11298, 11302)
Oneroa (11557, 11665, 11672, 11673, 11677, 11679)

Sandy areas between gravel on the seaward and lagoon shores often had gray areas where the sediment was bound into a smooth crusty layer. Occasionally these areas had blistered surfaces bearing black moss-like clumps or knobs up to 2 mm. in diameter. These crusts were usually quite thin and fragile, breaking into fragments when handled. They were not so common inland as along the beaches. Schizothrix longiarticulata, Entophysalis crustacea, Symploca kieneri and Anacystis montana were the species generally found in such formations. The crusts with the small black knobs almost always had Calothorix scopulorum in addition to these four species.

Schizothrix longiarticulata also formed a greenish coating over the mud flat near the center of Tetou.

Schizothrix thelephoroides Gomont

Gake: Teuriamote (11443, 11444)

Raro: Garumaoa (11117)

Occasionally found in crusts as discussed above under Schizothrix longiarticulata.

Scytonema crustaceum B. & F.

Raro: Homohomo (11284, 11302, 11304, 11305)

On heavily algalated inland coral fragments.

Scytonema guyanense B. & F.

Raro: Garumaoa (11218, 11219)
Homohomo (11182, 11293)
Kukina (11176)
Oneroa (11665)

Present on rotten debris and coral fragments in humus areas around the bases of Cocos nucifera.

Scytonema hofmannii B. & F.

Tokerau: Opaneke (11379)

Kereteki: Tetou (11865, 11869, 11884, 11887)

Raro: Garumaoa (11118, 11257, 11706, 11707, 11708, 11257)
Homohomo (11179, 11183, 11276, 11283, 11303, 11685)
Oneroa (11598, 11603, 11649, 11662, 11663, 11668, 11671, 11674, 11679)
Teputaiti (11238)

Very commonly this species formed brownish to black felt-like patches on the moist roots, bark and husks of Cocos nucifera. It apparently grew best on the damp or exposed sides of the trunks of the trees. It was also abundant on algal fragments in the Cocos groves.

Spirulina tenerrima Gomont

Kereteki: Tetou (11831, 11839)

Raro: Garumaoa (11945)

This species was occasionally a member of KOPARA associations and was found intermingled with a Hydrocoleum species.

Symploca atlantica Gomont

Raro: Garumaoa (11063, 11758, 11935a)
Oneroa (11620)
Temari (11026)

Brown cartilagenous crusts in and just below the intertidal zone. Found in channels and on both seaward and lagoon reefs.

Symploca hydnoides Gomont

Kereteki: Gavarivari (11924)
Tetou (11331, 11836, 11853)

Raro: Garumaoa (11759)

Just below low tide line on all shores.

Symploca kieneri Drouet

Gake: Teuriamote (11443, 11444, 11445)

Raro: Oneroa (11666, 11668, 11673, 11676, 11677, 11679)

See Schizothrix longiarticulata.

Symploca laeteviridis Gomont

Raro: Oneroa (11662)

On coral fragments just above the high tide line in the lagoon.

Symploca muralis Gomont

Raro: Garumaoa (11703, 11708)
Homohomo (11257)

On Cocos nucifera trunks and cement foundation of a village house.

Section B

The blue-green algae appear to have either a direct or indirect role in bringing about a number of physical and chemical phenomena of the atoll.

Findings are in full agreement with the theory (Cloud: Atoll Research Bulletin No. 12: 28, 1952) that certain species may serve to bind sand and coral fragments prior to cementation in protected areas.

Apparently some blue-green species play a dual role in the removal of material from beach conglomerate and boulder surfaces of both lagoon and seaward shores. Protuberances, from the conglomerate rock and boulders of the reef flat in the intertidal and spray zones, were broken off in the field and appeared as shown in Fig. 3. It is postulated that as the cells of the blue-greens die, the water soluble pigments released move by diffusion into the water saturated rock and there become absorbed in their order of affinity for $CaCO_3$, etc.. The colored bands illustrated in Fig. 3, B-F are thus produced. No such stain was found in living reef-flat corals. The intertidal and spray zones are inhabited by Nerita plicata and Tectarius sp. (11115), the Nerita migrating up and down with the tides. Over large areas the snails had eaten away the algae, thus exposing the underlying pink and blue layers. Upon close examination, grooves caused by the rasping action of the snail's radulae could be seen. With recurring growth of the outer algal layer and browsing by the snails the conglomerate rock face is no doubt continually removed at a rather rapid rate.

It was noted that the surface of beach rock, particularly that covered by blue-green algae, was soft and porous. In some instances, it appeared that the algae were actually "boring" into the calcareous substratum. Perhaps the alternation of night and day, with subsequent solution and precipitation in relation to the CO_2 cycle (Emery: Marine solution basins: Jour. Geology, Vol. 54, No. 4: 209-228, 1946) of these photosynthetic organisms, accounts for this softness and porosity. It is possible that this "boring" may be a result of some product other than acid radicles (Koster: Notes on Javanese calcicole Cyanophyceae: Blumea, Leiden, 3: 243-247, 1939) excreted by the algae. In any case the calcareous material would be in a state that could be readily removed by solution or mechanical action. If this is so, the zone periodically covered by tidal water would be expected to wear down at a more rapid rate than the zone dependent upon rain to wash away the precipitated $CaCO_3$. This could be an explanation for the solution pools found on upper beach conglomerate surfaces and the nip in the intertidal zone of beach rock and sea reef boulders. The additional factor of fresh ground water seepage (Wentworth: Marine bench forming processes: II, Solution benching: Jour. Geomorph., Vol. 2: 3-25, 1939) in the intertidal zone may account for some of the undercutting of beach rock but would not seem to be as completely satisfactory an explanation for the nip in the boulders of the sea reef flat.

Of even more importance to the economy of the atoll, is the possibility that the blue-green algae act as agents in the fixation of atmospheric nitrogen. Even in the vegetated areas, the major portion of the ground is covered with algalated coral fragments and sand. There is seldom a humus layer of the ordinary kind. Since the higher plants are dependent upon previously fixed nitrogen, it is suggested that the need here is supplied by either blue-green algae, symbiotic bacteria living in their sheath material, or both. It has been shown that certain species of blue-green algae are capable of combining atmospheric nitrogen with organic compounds. It is suggested that the blue-green algae have a hand in initiating the nitrogen cycle and that the decomposition products of blue-green algae bearing nitrogenous compounds are made available to higher plants through leaching. Whether the species present on Raroia are capable of performing this function and in a quantity sufficient to supply the needs of the other organisms remains to be answered.

Part 3

ECOLOGICAL AND FLORISTIC NOTES ON THE BRYOPHYTA OF RAROIA

by Harvey A. Miller & Maxwell S. Doty

The mosses and liverworts from the atolls visited pose several interesting problems. At present there seem to be about 7 species present, representing approximately that many genera. All of these are previously unreported for Raroia.

The localities given may be found by reference to Figure 1 in Part 1 of this Atoll Research Bulletin No. 33.

There was striking correlation between disturbance of the land and vegetation by cyclones and man and the abundance of mosses. The older people claim that the ground of the village was covered with mosses before the cyclone of 1903. They also claim that after the cyclone such plants as tomatoes, which they had either not seen before or which were unusual about the village, became abundant. Few of the islands regularly had mosses on the ground. Indeed on the ground, mosses were to be found only on the drier areas having more humus and there were very few such areas at Raroia. The principal habitat for mosses was tree trunks.

No ethnic interest was found for these organisms by our questioning, in the Tuamotus or in Tahiti. Mosses are possibly used as boat caulking in Micronesia, but this is only a rumor and "moss" might have meant algae or other material.

In the following list note the repositories for specimens: BISH = B. P. Bishop Museum; USNM = U. S. National Museum; NY = New York Botanical Garden.

MUSCI

Calymperes tenerum C. Mueller. Linnaea 37: 114, 1871-1873.

On rotten wet *Cocos* husk in the transect area across Homohomo (11181-USNM, BISH, NY).

On transect at Tetou (11888-USNM, BISH, NY), Kereteki, VIII-21-1952.

On *Cocos* along transect just north of village of Oneroa (11582a-BISH), on *Cocos* husk (11582b), mixed with liverworts (11651), on *Guettarda* (11657-USNM), Raro, VIII-7-8-1952.

On wet rotten *Cocos* stump with conspicuous balls of propagulae at the leaf tips, central part of island along transect across Homohomo (11180-USNM), VII-12-1952.

Distribution: Oceania, probably the most frequently occurring moss in the Pacific Islands.

Calymperes tuamotuense Bartram. Occ. Pap. B. P. Bishop Mus. 10: 6, 1933.

On Cocos husk at Oneroa (11648-USNM-BISH), Raro, VIII-8-1952.

On south side of Cocos trunk, sometimes overgrown by the lichen, Coccocarpia cronia, at Kukina (11174-USNM, BISH, NY, 11171A-USNM), VII-10-1952.

Distribution: Tuamotu Archipelago, Pitcairn Island, Henderson Island, Austral Islands, Mangareva Islands.

Brachymenium melanothecium (C. Mueller) Jaeger. Adumbratio Fl. Musc. p. 576, 1875.

Oneroa (11584-USNM, NY), Raro, VIII-7-1952; Kukina (11175-USNM, BISH, NY), Raro, among rocks beneath Cocos, VII-10-1952; ground cover in village of Garumaoa (11259-USNM, BISH, NY), VII-21-1952 and (11718-USNM, BISH), VIII-13-1952.

Where best developed forming a turf over the ground in association with Eragrostis amabilis and Pilea microphylla.

Distribution: Frequent in Society and Tonga Islands.

Trichosteleum pygmaeum Bartram. Occ. Pap. B. P. Bishop Mus. 10: 9, 1933.

On rotten wood south of the village of Oneroa (11556-USNM, BISH, NY), Raro, VIII-5-1952.

Distribution: Endemic to Tuamotu Archipelago. Reported previously from the type collection from Makatea.

HEPATICAE

Cololejeunea minutissima (Smith) Schiffner in Engler & Prantl. Natur. Pfl.-Fam. 1(3): 122. 1895.

On the transect at Tetou (11843-USNM, BISH), Kereteki, VIII-21-1952.

Distribution: Practically world wide in warm and warm temperate regions.

Ptychocoleus pycnocladus (Taylor) Stephani. Spec. Hep. 5: 52, 1912.

In more heavily wooded area just south of Oneroa, (11651-USNM, BISH, NY), on Guettarda (11658-USNM, BISH, NY), Raro, VII-8-1952.

Distribution: Widespread in Oceania and Indo-Malaysia.

Frullania sp.

On Guettarda bark in more heavily wooded area just south of village of Oneroa (11659-USNM, BISH), Raro, VII-8-1952.

Part 4

ECOLOGICAL AND FLORISTIC NOTES ON THE PTERIDOPHYTA OF RAROIA

by Kenneth Wilson

There were essentially only two ferns outside of the village. These are the Microsorium, often not distinguished from Polypodium, and the Psilotum keyed out in the key on page 14 of this Bulletin. Asplenium nidus being present as only two plants was certainly not cultivated. It is considered as a plant not well established.

The localities cited may be found on the map appearing as Figure 1 in Part 1 of this Atoll Research Bulletin No. 33.

At Anaa, the guide, a local man, told the collectors that the rhizome of the Microsorium was pounded to a pulp and given to children in the eastern Tuamotus who were suffering from what was interpreted to be some nervous cramping condition. At Raroia the people are reputed to boil parts of this fern and drink the fluid for some reason or other. No definite uses were discovered.

Asplenium nidus L. (Opakea, 11769-BISH, USNM)

Two plants of Asplenium nidus were found growing on Opakea near a former village site. Both of the plants were growing on a fallen rotten trunk of coconut, and were about two meters from each other. This fern is probably of recent introduction into the atoll since it was found only at this locality. Its proximity to a former village also supports this point of view.

It appears that it may be called OAHA by the Raroians, but this name is possibly a corruption of the Tahitian O'AHA, and not Tuamotuan at all.

Microsorium scolopendria (Burm) Cope. (Opakea, 11173-BISH, USNM; Kukina 11791-BISH, USNM; Kukina, 11793)

This is the most common of all the pteridophytes on the atoll. It occurs on nearly all the vegetated islands of the atoll, even the drier parts. It grows in coconut groves around the base of the coconut trees and also beneath trees of Guettarda speciosa. When growing under Guettarda speciosa the fronds were noted to have a striking orientation perpendicular to the sunlight.

Also found at Takume (12318-BISH, USNM).

During late July (11263-USNM) and early August (11607-USNM) two collections of what appear to be primary leaves and gametophytes respectively of this species were made.

This species is very commonly reported as Polypodium scolopendria. The local name was KIKIPA.

Nephrolepis biserrata (Swartz) Schott var. _biserrata_ (Garumaoa 11824-BISH, 11720-USNM)

A village plant.

Nephrolepis biserrata (Swartz) Schott cultivar _furcans_ Hort. (Garumaoa 11823-USNM)

Both these _Nephrolepis_ varieties were found only in cultivation in the village.

Psilotum nudum (L.) Griseb. (Opakea 11792-USNM, Oneroa 11555-USNM, Homohomo 11004-BISH, USNM)

Psilotum nudum was far more abundant in the more humidified areas. As a rule it was found growing only on trunk bases of _Cocos_ and _Guettarda_; as an epiphyte up to 50 cm. tall. Occasionally it appeared to be growing on the ground; then usually near either of these two trees. This fern was found also at Takume (12323-BISH, USNM).

Native name: TUMETUME, TUMETUME FENUA, or TUMETUME HENUA.

ATOLL RESEARCH BULLETIN

No. 34

Animal Ecology of Raroia Atoll, Tuamotus

Part 1. Ecological Notes on the Mollusks and Other Animals of Raroia

by J. P. E. Morrison

Part 2. Notes on the Birds of Raroia

by J. P. E. Morrison

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Part 1

ECOLOGICAL NOTES ON THE MOLLUSKS AND OTHER ANIMALS OF RAROIA

by J. P. E. Morrison

The molluscan fauna of Raroia Atoll in the Tuamotu Islands, French Oceania, is fundamentally similar to that of the other atolls personally studied in the northern Marshall Islands (Eniwetok, Bikini, Rongelap, and Rongerik Atolls). Where there is no widespread silt or mud habitat to compare with the clay or mud habitats of the shores of higher (volcanic rock) islands, there is necessarily a reduction in the total number of marine species present. With the simplification or restriction of the atolls to fewer types of habitats, there are fewer molluscan species living on and around the atolls than for example on such complex shores as those of the Philippine Islands. With fewer species in the total picture, it becomes a little less difficult to observe or evaluate the ecological preferences of those species. It should be clearly understood however, that the more than one hundred molluscan species whose observed ecology is briefly mentioned or outlined here, constitute only one-fifth or less of the total number of species of mollusks known to be living on such atolls as Raroia. When the classification and determination of all the forms collected at Raroia are completed, the total number of species is likely to pass six hundred.

The writer wishes to express his sincere appreciation of the unparalleled opportunity to be a member of the Pacific Science Board Atoll Research team sent to Raroia in 1952. This team, under the auspices of the Pacific Science Board, of the National Research Council, under contract with and supported by funds of the Office of Naval Research, received the fullest cooperation from the government of French Oceania. Particularly to be acknowledged is the excellence of the transportation furnished through the good offices of the Governor, The Hon. R. Petitbon, to and from Raroia Atoll.

I also wish to acknowledge fully the unfailing help received from others, particularly Austin H. Clark (Echinoderms), F. A. Chace, F. M. Bayer, and L. B.. Holthuis (Crustacea and other Marine Invertebrates), D. M. Cochran (Reptiles), D. M. Johnson (Mammals), without whose identifications the non-molluscan notes contained herein would be valueless; lastly, but not least is the aid received from my colleagues in Mollusks, H. A. Rehder and R. T. Abbott.

The single most characteristic molluscan species of the oceanic or outer reef edge on the windward side of Raroia Atoll, is the white-cat's eye shell Turbo setosus Gmelin. Associated with it on and in the zone of the algal ridge are the two commonest species of spiny rocksnails Drupa morum Röding and Drupa ricinus Linnaeus. These have the aperture purplish, and white, respectively. Also along this outer reef edge is to be found the fuzzy-red-legged hermit crab Aniculus aniculus Herbst.

Behind the algal ridge, the reef diminishes in height in the zone of the small boring sea urchins Echinometra mathaei Blainville and Echinometra mathaei oblonga Blainville. In these short tunnels in the surface of the reef rock, the Drupa species, the brown mitre shell Mitra columbelliformis Kiener, and a few species of cowries such as Cypraea (Arabica) depressa Gray and Cypraea (Ponda) ventriculus Lamarck, take refuge during the day from the light, and from the strong wave action present on windward oceanic reefs.

A few yards nearer shore the pool zone of the reef flat begins. In these pools there are only a few corals present on the rock surface covered, otherwise, with a thin film of foraminiferous sand. Here in no great abundance, are several species of the smaller cones, such as Conus sponsalis Hwass, C. ebraeus Linnaeus, C. chaldeus Röding, and C. nanus Sowerby, along with occasional Drupa ricinus Linnaeus, the very small Mitra litterata Lamarck, and the common black rock-snail Morula granulata Duclos. As one proceeds further shoreward in the study of the reef, the Conus sponsalis, Mitra litterata, and Morula granulata are usually to be found in greater abundance. Here under the larger coral blocks may be discovered a few black poison sea urchins Diadema setosum Leske, the small poison cone Conus retifer Menke, a small byssiferous pearly oyster Isognomon perna Linnaeus, a small black-spotted white ark-shell Arca maculata Sowerby, and two small snails, one speckled Maculotriton digitalis Reeve, and one pink Columbella pallida Deshayes, that may be considered characteristic. Closer to the island shores, at just about, or just below the low tide water level, Vasum armatum Broderip appears commonly, along with Thais hippocastaneum Linnaeus, and occasionally Cronia cariosa Wood. Both the Thais and the Cronia species have been found feeding on the Nerita snails in the lower edge of the intertidal zone.

In the intertidal zone, Nerita plicata Linnaeus is most characteristic, sometimes present in great numbers, on and under the coral rocks and gravel. Above it in level is the widespread white littorinid snail Melaraphe coccinea Gmelin, in great abundance on some of the dry rock flats ("Pakokota"), wet only by spray from the ocean in normal weather, but active with the humidity every night and during and after every rain. Above it in normal tide level relations, the spiny littorinid snail Tectarius grandinatus Gmelin was found about 4 to 5 feet above high tide level, but only on the solid rock of the largest reef-blocks (cast up by storm action) scattered across this windward oceanic reef flat. The coral gravel and loose rock of the island shores here is apparently not suitable for them. The windward island shores facing the ocean are rather barren of mollusks. In most cases the coral gravel and cobbles along the actual islet shore lines of this part of Raroia Atoll are inhabited principally by small hermit crabs. There are usually the younger stages (smaller sizes) of one or more species of Coenobita.

Many of the windward islands have large areas of dry rock-flats on the oceanic side. Where these flats are covered with low but very dense growths of Suriana and Pemphis, particularly around pools and incomplete channels across the islands, there are many individuals of the large land-crab Cardisoma carnifex Herbst, called "Papaka Tupa" by the Raroia natives, to be found. The burrows of these land-crabs were all over the lower ground of some islands; at night when they are most active, these crabs may range all over the higher ground as well, a considerable distance from any water. The brackish (or sometimes fresh ?) groundwater of enclosed ponds on the lower areas of some of these islands, and the groundwater exposed in the burrows of these "Papaka Tupa" are one of the sources of a considerable population of bird mosquitoes (Culex spp.). Another source of this mosquito population is the ever-present large number of rain-filled broken or half coconut shells lying around on both high and low ground, on and around the coconut groves. This secondary coconut shell habitat of the mosquito larvae dates only from the time the coconut palm was brought to Raroia by the Polynesian natives.

Under the Guettarda and other trees on the higher sandier ground of the islands, and in the leafmold of the coconut groves also, there are a few species of very small land snails. These include the ubiquitous, tiny white Gastrocopta pediculus Shuttleworth, a tiny reddish species of Nesopupa, Lamellidea serrata Pease, Lamellidea oblonga Pease, and two species of Opeas. In certain places on the islands, near the sites of former villages, there is a small yellow and red land-operculate snail, Orobophana colorata Pease. It seems likely that this helicinid snail and both the species of Lamellidea were carried to Raroia with the plants brought there by the Polynesian natives. Around one of the brackish (or fresh ?) groundwater ponds was found another land-operculate, a species of Syncera (or Omphalotropis ?), white in color, that seems distinct from its gold-colored relative found along the salty lagoon shores in certain places. All of these small land snails are facultatively xerophytic; that is they can withstand considerable heat and drought between rains and during the dry season. Their shells are small, so that micro-shelters in the upper soil and leafmold layers are sufficient. The aperture of their shell is small in proportion to its volume, in resisting desiccation, and in the case of the pupillid snails is still further restricted by lamellae within the aperture. These pupillids, Gastrocopta and Nesopupa are probably also protected from the tiny Ants, Pheidole spp., by their lamellate apertures, at least in the adult stage. In the leafmold, and under the coconut detritus also, various species of ants, a couple of species of cockroaches, and a small short-tailed scorpion are sometimes to be found in abundance. This species Hormurus australasiae Fabricius, has a wide range on many Pacific islands, and may also have come to Raroia with the Polynesians. The sting of this small scorpion is not regarded as dangerous by the natives. In addition, it does not seem to be very aggressive in its natural habitat at Raroia, so that people are very seldom stung by it.

The two species of earthworms found on Raroia are active in the lower leafmold, and upper soil layers, in breaking down plant detritus into richer soil. They were to be found only in the deeper leafmold layers of lower more moist ground, and in the denser stands of Guettarda and other trees, away from the presently cleared coconut groves. Both these species of earthworms Pheretina montana Kinberg and Pheretina upoluensis Beddard, are extremely active when disturbed, and will flip or "jump" out of one's hand if care is not taken when collecting them. These earthworms also are known to have been carried from island to island in the Pacific by the natives. They undoubtedly came to Raroia in soil on the roots of plants brought by the Polynesians generations ago.

There are two species of rats on the islands of Raroia Atoll. One, Rattus exulans, the small reddish species commonly known as the Polynesian Rat, has no fear of man or his flashlights, lives on various seeds, and has been seen feeding on the flowers of Guettarda. This species probably arrived at Raroia with the coming of the Polynesian people, perhaps two centuries before they brought the coconut palm to Raroia Atoll. Rattus exulans is not known to affect the crop of coconuts or copra. The second species (Rattus rattus alexandrinus), larger and grayish, runs away and hides when discovered at night, and actively feeds on the coconuts. It gnaws a hole in the side of small green coconuts on the trees to eat out their contents, causing them to drop off later and be lost; it also gnaws a hole into ripe coconuts on the ground, and eats the coconut meat out of them. Crop production figures have been gathered on Tahiti, in the Society Islands, that show that this species of rat may destroy up to 40% of the copra crop from those coconut trees that are not protected by a sheet metal band of sufficient height and smoothness to prevent the rats from climbing the tree trunks, and reaching the green coconuts. Also, this gray rat species travels from tree to tree across the touching and/or overlapping coconut leaves where the trees are crowded and not isolated. This larger grayish rat has apparently completely displaced the small reddish Polynesian Rat on those islands of Raroia Atoll the gray rat now inhabits. According to the people of Raroia this gray rat appeared on Raroia Atoll only after the development of the commercial copra trade began about a century ago. On Opakea Island, Raroia, this gray rat was found to be parasitized by the spirurid worm Mastophorus muris.

On those islands of the Atoll not yet, or not now inhabited by any rats, a large species of gecko Gehyra oceanica is particularly abundant. Here they may be commonly seen at night at any and all levels off the ground, on the Guettarda, Messerschmidia, and coconut palm tree trunks. In the presence of a population of rats, these geckoes are abundant only high on the trees, particularly on the underside of the leaves of the coconut trees. Two or three small species of lizards (skinks) are common on many islands at Raroia. They are most evident in the bright sun at the edges of coconut groves, and on and under the fallen leaves of Guettarda and other trees. A shorter, spotted species Ablepharus poecilopleurus seems to inhabit drier, rockier, more open places than the long-tailed (sometimes blue-tailed) skink Emoia cyanura. Only one specimen of a third species, Leiolopisma noctua, was collected on the island just north of the ship's pass, Tenuku Haupapatea Island. It was taken in company with, or at least in the same general habitat with, both the other two species of skinks.

The lagoon shores of the windward islands such as Tetou are almost barren of mollusks on the sandy beaches. However, wherever beach conglomerate is exposed along the shore, the characteristic Nerita plicata is evident, sometimes in extreme abundance. Everywhere in this habitat it shows the extreme variation of color of shell from all white, to pink, to striped black, and to an almost completely black shell in a few individuals. Also in this intertidal zone, in the crevices of the beach conglomerate, but otherwise exposed to the sun whenever the tide is out, may be moderate numbers of the small byssiferous relative of the pearl oyster, Parviperna dentifera Krauss. The color of this Parviperna varies also from blackish, to black-fringed, to a pale yellow overall, in different local areas. On the lower edge of the Nerita plicata zone on the rocks, one may find the carnivorous Muricid snail Cronia cariosa Wood, which feeds on the flesh of the Nerita plicata. The greater numbers of the Cronia are characteristically to be found in the zone just below the low tide water level. Under and on the rocks (beach conglomerate slabs) along this lagoon shore are a few money cowries Cypraea (Monetaria) moneta Linnaeus, purple rocksnails Peristernia nassatula Lamarck, and a cerithiid Rhinoclavis sinensis Gmelin, usually a little below the low tide line. Under some of the rock slabs along these lagoon shores are found small rock crabs, such as Cyclograpsus longipes Stimpson and Cyclograpsus parvulus DeMan. Also here under the rocks, but usually closer to the high tide level, are certain small ellobiid snails, Allochroa conica Pease and Laemodonta mordax Dohrn.

Brackish water lagoons are present in certain places on Raroia Atoll. These are micro-lagoons or ponds usually appearing as incomplete channels between islands or small embayments close to the lagoon of the atoll, and more or less completely cut off from the salt water of the lagoon by sand barriers. With the separation of these micro-lagoons or ponds from free access to the oceanic or lagoon salt water, the addition of rain or brackish groundwater brings about the brackish, or at least materially reduced salt water habitat. Such ponds offer a habitat in which only a few low salt tolerant species seem to flourish. Conspicuous here is the small rugose venerid clam Circe (Crista) pectinata Linnaeus, the cerithiid snail Cerithium breve Quoy & Gaimard, and the shrimp Palaemon debilis Dana. In lesser numbers, but nonetheless probably more common in these brackish water ponds than in any other habitat at Raroia were found Neritina bensoni Recluz and the extra large or giant form of Planaxis zonatus A. Adams. In the search for greater numbers of the Neritina bensoni, some larger coral blocks, partly imbedded in the muddy sand bottom, were turned over and accidentally revealed the habitat of some small pink cap-shells not seen before. The habitat, or at least the daytime refuge of these small false limpets, Phenacolepas sp., was on these coral blocks under the muddy sand line, near the shore of one of these enclosed brackish water ponds. In life these animals were very pink, color showing through the thin but tough shells, and were so active that the great numbers present could not all be picked off the coral block, before some of them had disappeared to the bottom side of the turned-over coral block. They did not drop off when the block was taken out of the water, they simply started gliding in a hurry for the lower under side of the block. It was not determined if they came out and were active above the muddy sand line at night, but they were certainly light-fugitive in the bright noonday sun.

Dredging in the lagoon at Raroia to collect the deeper water species of mollusks and other animals was not very productive. Little time was available for the dredging, and each try indicated a generally distributed rock-pavement bottom, with only a very thin sandy cover between the numerous coral clumps growing thereon, in the places sampled. A small shrimp, Palaemonella denticulata Nobili, some small clams, Tellina species, and a cerithiid snail, Rhinoclavis procera Kiener, were taken in 40 feet or more of water on such sand covered bottoms. This Rhinoclavis procera Kiener, and a related species Rhinoclavis asper Linnaeus are characteristic of such sand-covered rocky bottoms in the lagoons of many of the Pacific islands where they are recorded as living.

On and around the coral patch reefs in the lagoon, which at low tide are or are almost exposed, the green cat's-eye shell Turbo petholatus Linnaeus, a large spiny oyster Spondylus varius Sowerby, and a blackish plicate oyster Ostrea sinensis Gmelin, are among the most conspicuous species of shells. The small species of giant clam Tridacna maxima Röding is also present in shallow water on these patch reefs. Here also was seen an occasional individual of the large "leather urchin" starfish Culcita novaeguinae Müller & Troschel. The economically important commercial pearl oyster Pinctada margaritifera Linnaeus lives here in the lagoon along with the Spondylus varius, and the black oyster Ostrea sinensis, usually in water 20 to 30 or more feet deep, on the coral of the slopes of these patch reefs. Living in the mantle cavity of the pearl oyster is the commensal shrimp species Conchodytes meleagrinae Peters, a pair (male and female) in each large individual of the molluscan host. In exactly the same type of relationship, a pair (male and female) of the commensal shrimp species Pontonia hurii Holthuis may be found in each large individual of the large spiny oyster Spondylus varius. Time did not permit a detailed study of the many other smaller species of mollusks and other types of invertebrates undoubtedly present on and around these patch reefs. The commercial pearl oyster is actually living from a few feet below low tide line, to depths of more than 100 feet in the lagoon. There is no commercial pearl shell diving at Raroia because of the danger of sharks in the open lagoon, but at Takume Atoll a few miles to the north, with a closed lagoon and no dangerous sharks, they are taken during a carefully controlled open season under strict size regulations. The pearl oysters are important as an extra cash crop for the Polynesian natives.

The fauna of the lagoon patch reefs is very similar in appearance to that of the well developed lagoon reef along the shore of most of the islands on the leeward side of Raroia Atoll. In places on the steep lagoon face of this reef, the large flat ark shells, Barbatia complanata Bruguiere, and the byssiferous clam, Pedum spondyloideum Gmelin are conspicuous, living in pockets in living massive corals on the almost vertical face of the reef. On and near the edge of the reef, the brightly colored animals of the smallest giant clam, Tridacna maxima Röding, of large size for the species (10 to 12 inches) are also conspicuous. At first glance, it may seem completely absurd to have the smallest of the three known species of giant clams with the scientific specific name of maxima. Regardless of how the name may have been originally given, perhaps even accidentally, it is definitely not a wrong name. This is the smallest species, but with its shallow water, sometimes even partly intertidal habitat on the reef surface, it is subject to the greatest forces of wave disturbance, of any of the giant clams. With such ecological requirements, it possesses the maximum holdfast or byssal attachment. In this concept, the name maxima may be considered completely appropriate.

Inconspicuous at the surface, but nevertheless common here are a few species of clams, boring in the extremely hard coral rock. The commonest of these is the widespread Indopacific species of boring mytilid Lithophagus (Lithophagus) teres Philippi. Another is its relative Lithophagus (Diberus) mucronatus Philippi. A third, smaller species found here, which is probably Gregariella (Tibialectus) bakeri Dall, Bartsch & Rehder, has been found only in the Hawaiian Islands, and here at Raroia. If it is not the same species it is one very close to, but distinct from the Hawaiian form. Boring sea urchins Echinometra mathaei oblonga Blainville and black (banded-spined) poison sea urchins Echinothrix diadema Linnaeus are present, but not common, on these lagoon reefs. There are two species of crustaceans that are commensal here on the Echinothrix diadema. One is the commensal shrimp Stegopontonia commensalis Nobili, which lives generally over the surface of the sea urchin, between the spines, while the other is a small (spider ?) crab Eumedonus convicter Bouvier & Seurat, which lives on the anal plate region of this sea-urchin. There may be one on each of these urchins of large size. Both the commensal shrimp, and this little commensal crab are very inconspicuous in their habitat, being of almost the same color as the very dark greenish-black sea urchins.

In the small sandy pockets between corals the poison cone Conus textile Linnaeus, a small white cerithiid snail Cerithium nesioticum Pilsbry & Vanatta, and a small sand clam Tellina species, are present, along with a species of balanoglossid worm. Not collected, but obviously of necessity present here are numerous small annelid and other worms that make up the food of such carnivorous species as the "cloth of gold" poison cone Conus textile.

Inside this lagoon reef proper, the bottom is eroded somewhat, with pools (1 ft. deep at low tide), and covered with coralline and/or foraminiferous sand in a thin layer, or it is coral gravel and rocks, with sand filling the interspaces. On and under the gravel and coralline rocks, money cowries Cypraea (Monetaria) moneta Linnaeus (of small size), black rock snails Morula granulata Duclos, purple-mouthed snails Peristernia nassatula Lamarck, Pollia undosa Linnaeus, and a few other species may be found in abundance. On the under side of the larger coral blocks on the lagoon reef flat may be found the byssiferous clam Isognomon perna Linnaeus and two characteristic species of ark shells, the small black spotted white Arca maculata Sowerby, and the small brown Barbatia parva Sowerby. The struggle for space in this habitat under the shelter of the coral blocks is occasionally keen enough to provide some astounding examples of crowding. On the under side of one such coral slab of medium size was a complete ring of individuals of the byssiferous Isognomon perna. Every one of these individuals of fair size for the species was oriented in the same direction around the circle, leaning against the right hand neighbor, and leaned on by the left hand neighbor. In other words a complete line of these clams was formed around the periphery of the underside of this slab. As they grew, they all leaned in one direction (by chance ?) until, as the crowding progressed, there was no longer any beginning or end to the line of clams, but a continuous circle, achieving the absolute maximum use of space available to them under the slab. Deeply sunken in "nests" or pits ground into the under surfaces of some of these coral blocks are numerous specimens of all sizes of the large turkey-feather ark shell Arca ventricosa Lamarck. On these coral blocks, particularly on those that extend up to about high tide level, are also found money cowries Cypraea (Monetaria) moneta Linnaeus, and the eastern gold-ring cowry Cypraea (Ornamentaria) obvelata Lamarck (here practically intertidal in habitat), along with a species of the pulmonate sea-slug Onchidium, and the green-colored half-shelled tectibranchiate sea-slug Smaragdinella calyculata Broderip & Sowerby.

Commonly found most active at night along this lagoon shore, at or just below the low tide line, are a number of crab species, including the rock-crab Eriphia scabricula Dana, red-eyed rock-crab Eriphia sebana Shaw & Nodder, Lydia annulipes Milne-Edwards, white rock-crab Xantho exaratus Milne-Edwards, speckled rock-crab Xantho gracilis Dana, the small rock-crabs Grapsus longitarsus Dana and Pachygrapsus planifrons DeMan, young individuals of the common large red-clawed land hermit-crab Coenobita perlatus Milne-Edwards, and the smaller hermit-crabs Calcinus laevimanus Randall, Calcinus latens Randall, and Calcinus seurati Forest.

Perhaps less than a hundred yards away, on the sandier portions of this reef area, Strombus mutabilis Swainson, Strombus gibberulus Linnaeus, Cerithium columna Sowerby, and Conus eburneus Hwass are conspicuous members of the fauna.

The Conus eburneus were seen only at night; apparently they remain burrowed under the surface of the sand during the day. Under the rocks in this area are occasionally seen the small rugose venerid clams Circe (Crista) pectinata Linnaeus, while under every coral rock deeply imbedded in the sand, are annelid worms with needle setae that painfully stick in the fingertips at the slightest touch. This pink species of annelid with golden setae must be handled only with forceps. Widely ranging over the inner reef flats are two large species of hermit-crabs, one white-eyed Dardanus deformis Milne-Edwards, and the other giant red Dardanus megistos Herbst. Both these species are fast-moving and difficult to collect. They do not withdraw into the large snail shells such as those of Turbo, Charonia tritonis Linnaeus, and Lambis truncata Humphrey, that they use, but scurry rapidly away whenever disturbed or approached with a light in their nightly wanderings.

In the shallow tide pools that remain in some of the lower parts of the intertidal flats along the lagoon shore, and even hiding in the white sand film over the rock pavement of these flats are found certain swimming crabs, such as Portunus (Cycloachelous) granulatus Milne-Edwards and Portunus (Hellenus) longispinus Dana. In other spots, where there is only a thin crust of the conglomerate rock at the surface of the flats at just about the low tide line, there may be seen fiddler crabs. They are active whenever the tide is down, but scurry for their holes through the rock, if they are disturbed. Because their holes go through the thin places in this conglomerate rock, and their burrows are beneath it, they cannot be dug out, but must be surprised, and caught "off base" so they can't get back to their burrow, in order to be taken. The fiddler crab species found at Raroia in this particular habitat is a truly handsome creature, Uca tetragonon Herbst, with its whitish general color, and truly brilliant crimson-orange "fiddler" claw. Sometimes there may be great numbers of the tiny marine water-striders stranded on such rock flats at low tide. While each individual of this kind of insect (Halobates sp.) is very tiny, the aggregate of great numbers may add to the food available for scavengers in this intertidal zone.

Wherever there are extensive rocky pavement flats in the lower intertidal zone or lower to middle intertidal zones, there is evident a small but very characteristic group of molluscan species on these rocky pavements or slabs, that are exposed with every tide, and remain almost dry for a few hours each time. Here we find the small relative of the pearl-oysters that looks more like a sea-mussel at first glance, than anything else. This little bivalve Parviperna dentifera Krauss is well named. It is one of the very few members of its family that possesses even rudimentary hinge teeth. It may well have retained this primitive character of the shell because of its need for a more tightly locking shell in its more exposed habitat on top of intertidal rock surfaces, than that of Isognomon perna Linnaeus its relative which lives under rocks and has no hinge teeth whatsoever. In fact the family up to now has been described as being completely without them. So here we have another example of a species on the atolls, more primitive in certain ways than any of its relatives, living in a niche nothing else of its type is competing for. Is it too much to assume that such primitives still surviving on the outlying island habitats (atolls) might not be oldest or least changed of their kind still living? Much less conspicuous, in fact easily overlooked unless the rock surface is critically scanned, is the tiny golden trochiform littorinid Peasiella conoidalis Pease. Cerithium breve Quoy & Gaimard is often exceedingly abundant in the crevices and hollows on these intertidal rock flats, but is not limited to this zone.

In the upper intertidal zone, particularly on those shore lines composed largely of coral gravels, there is usually present an enormous population of rather small sized individuals of the common and widespread Nerita plicata Linnaeus. On the lower edge of this population, the carnivorous muricid snail Cronia cariosa Wood may be found in numbers, feeding on the Nerita plicata at night, and also occasionally in the daytime. Unlike some of their relatives, in this case the Cronia attack and eat the Nerita animals out of the aperture of the shell. Specimens of the Cronia were collected in the later stages of the act of eating Nerita animals, on several occasions. Apparently the Cronia have no difficulty in feeding on this particular species of Nerita because the operculum is only a very thin horny plate. They do not drill or otherwise mark the Nerita plicata shells. Normally the population of Nerita plicata retreats with the incoming tide, both day and night, and rests often in the daytime just at or above the normal high tide line for the next night's period of greatest activity.

On those shores of coral gravel with sand interspersed, another species Nerita polita Linnaeus is a conspicuous member of the fauna, but only appears at night when the tide is out. In the daytime they remain burrowed under the sand, as they do when the tide is high. These Nerita polita characteristically live in the zone just below the more visible population of Nerita plicata on these shores. With a thick calcareous operculum, the Nerita polita are apparently not subject to the depradations of the carnivorous Cronia snails, even though they live in the same shore line zone.

On the sand beaches of these lagoon shores may be seen the burrows and mound of the Pacific ghost crab Ocypode ceratopthalma Pallas. In the daytime they remain burrowed down to the moist sand layer, but at night when the tide is out, they are the most active and most conspicuous animals along the sand beaches. On those lagoon shores along which beach conglomerate rock is exposed, a brown rock-crab Geograpsus crinipes Dana is characteristic. Along with it may be found lesser numbers of the rather ubiquitous red-spotted shore (rock) crab Grapsus tenuicrustatus Herbst, and other smaller rock-crabs such as Grapsus longitarsus Dana, and Pseudozius caystrus Milne-Edwards.

The sub-marginal land zone at and just above the high tide line is the habitat of a few individuals of the common whitish shore line littorinid snail Melaraphe coccinea Gmelin, the tiny golden snail Syncera lucida Pease, and a considerable and very characteristic population of ellobiid or salt-marsh snails. This habitat is particularly well developed (and filled with snails) along these lagoon shores of coral gravel and rocks where there is more or less accumulation of drift material from the lagoon. In the absence of any salt marshes on such atolls as Raroia, these "salt-marsh" snails live in their other known type of habitat, that is under rocks, cobbles, or gravel along the salt water shores. These ellobiid snails feed on the decaying plant materials of the drift zone, or on the algae on these coral rocks, or both. They can survive under this apparently barren coral gravel, under the full heat of the sun, without shade, because of the insulation from the tropic sun afforded them by the numerous gravel and air (interspace) layers. In the daytime they remain at or on or partly buried in the sand level 4 to 8 inches below the sun-heated top layer of gravel on the beach slope, or just about at the crest of the beach ridge, if that is not too high above the normal high tide line. These most primitive land snails, the ellobiids, are limited to the sub-marginal or shoreline zones of the land by their life-history requirements, according to the latest information. The eggs, and the pelagic young larval stage of an American species have been recently discovered. Proof of the required pelagic stage in the life-history, which is probable for many members of the family, logically explains why this primitive type of pulmonate (lung-breathing) land snail has not been able to fill other land habitats, and at the same time furnishes a possible explanation for the extremely wide geographic distribution of some of the species that belong to this group. The three largest of these ellobiids from Raroia, Melampus luteus Quoy & Gaimard, Melampus violus Lesson, and Pira fasciata Deshayes, are known to be living over a vast geographic range in the Indopacific region, all the way from the South African (Natal) coast or from Mauritius, eastward to the Tuamotu Islands and Easter Island. In addition, there are smaller species belonging to other genera, Allochroa conica Pease, Laemodonta mordax Dohrn, Pedipes species, and Microtralia lucida Pease, living at Raroia under the rocks and coral gravel of the lagoon shores. Many or all of these species may be living together in the same spot. Also found here is another species, a smaller Pira, namely Pira mucronata Gould, whose ecological habit has hitherto kept it in the category of misunderstood and doubtful species. The Raroia studies have resulted in the re-discovery of this species, which seems to be restricted to the Tuamotu Island region, and with the finding of large populations, the ecology is clarified. Pira mucronata apparently lives at all times under the coral gravel pieces along these steeply sloping lagoon shores. It does not normally leave these covered interspaces under the gravel even at night, when all its relatives come forth and wander all over the top surface of the rocks or gravel, as far as necessary to feed on the drift material. The species Allochroa conica and Laemodonta mordax seem to prefer larger blocks of coral rock along the shore line for their habitat. The Laemodonta is sometimes inordinately abundant in the small pits or pockets on the underside of such larger coral rocks, just below the normal high tide line, along with another type of snail, the widespread Planaxis zonatus A. Adams. Two small species of crabs, Pseudograpsus albus Stimpson, and Cyclograpsus longipes Stimpson, are living in the same habitat under the coral gravel and cobbles, where the Melampus and Pira are so abundant.

The fauna of the leeward islands of the atoll is essentially a repetition of that of the windward islands of Raroia, with a few modifications. These leeward islands are usually more evenly level and sandier, hence the large land-crab "Papaka Tupa" Cardisoma carnifex Herbst is much less conspicuous. In its place the conspicuous Crustacean land fauna consists of large land hermit-crabs. The commonest species here is the large red-clawed species Coenobita perlatus Milne-Edwards. Less common is the purple-clawed, more active species Coenobita brevimanus Dana, and a second rougher, purple-clawed form Coenobita rugosus Milne-Edwards. All three of these land hermit-crab species utilize the shells of Turbo setosus Gmelin and Turbo argyrostomus Linnaeus for their protection, as adults. Of all the common shells at Raroia and many other similar atolls, only these species of Turbo have shells large enough and heavy enough to last very long for these large land hermit-crabs to keep indefinitely as protective shells. The large coconut crab Birgus latro Linnaeus is present, but rare at Raroia, simply because the Polynesian natives eat every individual they find, and there is no opportunity for the accumulation of a population of any size on any of these inhabited atolls. Also present on the leeward islands is a true land-crab Geograpsus grayi Milne-Edwards, seen principally on the leaf covered forest floor of the groves of Guettarda and other trees.

The small lizards (skinks) Emoia cyanura and Ablepharus poecilopleurus are less evident around native habitations than they are on the uninhabited windward islands of Raroia. There is a small species of gecko that is more or less abundant in and on the walls of every native house or hut. This smaller gecko Lepidodactylus lugubris seems to thrive around the native habitations, laying in wait even on the ceilings, or in the thatch of the temporary coconut-harvesting huts, for the numerous flies. The larger gecko present at Raroia Gehyra oceanica is only seen commonly at night on the under side of the leaves on the coconut trees. Because of the present location of the native habitations on the leeward islands, and the greater activity in all the major coconut groves of burning all the coconut and other detritus off the limestone soil, the normal fauna of the land is very much reduced on most of the leeward islands. This is particularly true of the normal inhabitants of the leafmold such as the land snails, and the earthworms. Both the species of rats present on Raroia are most uncommon around the native village. The villagers' cats and dogs, which are mostly allowed to forage for themselves, serve to keep the population of rats at a minimum and under cover (strictly nocturnal) on every inhabited island.

The sandy oceanic soil line of such leeward islands at Raroia as Ngarumaoa, is barren of living mollusks, but highly productive of drift shells. Here may be found samples of almost all the species living on the outer or oceanic shore and/or reef, including a number of deeper water inhabiting species never seen alive at Raroia. Locally the sand slope may change to a rampart of coral gravel or coral cobbles. Without any major shelter, this sand slope is traversed nocturnally by hermit-crabs, but in the daytime shows no animal activity. Seaward of the sand slope is a more or less level, but rather rough rock flat, known by the Polynesian natives as the "Pakokota". The only characteristic inhabitant of these rock flats is the littorinid snail Melaraphe coccinea Gmelin. These snails are active only in the high humidity at night, and during and after rains, apparently feeding on the algae that grow in and on the surface of the "Pakokota" rock. These snails, pinkish white in color, are conspicuous in the daytime resting with the aperture sealed against the leaden gray rock, either in the crevices, or on the top surfaces of these flats. They are not reached in this habitat by normal salt spray, living as they do 25 to 50 yards or more shoreward of the normal high tide line of water on this rocky shore.

The actual shore line may be characterized by the presence of the common red-spotted shore-crab Grapsus tenuicrustatus Herbst. Tectarius grandinatus Gmelin is locally abundant on the higher rocks of this shore line, a couple of feet above the normal high tide line, but obviously in the upper spray zone. Mostly below all the Tectarius, but sometimes a little overlapping, is the population of the common Nerita plicata Linnaeus, just above the high tide line. The carnivorous snails Cronia cariosa Wood and Thais hippocastaneum Linnaeus are here in moderate numbers in the zone at just about the mean or ordinary high tide line and a little below. Locally, and particularly on the higher blocks of coral rock cast up by storm action and standing on the reef near shore, the

Tectarius and Nerita plicata may be conspicuous. In addition on these blocks, there is a pulmonate sea-slug Onchidium species, and a green-colored half-shelled tectibranch sea-slug Smaragdinella calyculata Broderip & Sowerby, living in the upper intertidal zone, just at or a little below the high tide line. It is not clear what predator or ecological condition would allow these two sea-slug species to be locally abundant on these reef blocks standing isolated offshore on the reef flat, and at the same time prevent their occurrence or survival on the shoreline rocks of the same tidal zonation, just a few yards away. There did not seem to be any readily observable ecological difference to explain the restriction of the sea-slug species to these isolated rocks. Locally abundant here also is a small species of shore-crab Grapsus longitarsus Dana, at the edge of the water at low tide.

The molluscan fauna of the eroded reef flats, sometimes more deeply pooled near the shoreline, is the most easily collected, and the largest in number of common species of all those studied at Raroia. Here may be found locally in abundance several small species of Cerithium, with Pusia nodosa Swainson and other Pusia species (which probably feed on these small Ceriths), the small mitrid Imbricaria punctata Swainson, Strombus maculatus Sowerby, and Modulus tectum Gmelin. The most common and characteristic species of this inner zone of the oceanic or outer reef on the leeward side of Raroia are Vasum armatum Broderip, the small lettered mitre shell Mitra litterata Linnaeus, the black rock-snail Morula granulata Duclos, a whitish rock snail with purple mouth Morula uva Röding, and the little red-flammulate cone, Conus sponsalis Hwass.

In many places the Vasum armatum seemed to be all of a more or less uniform size, but small for the species; in other places on the reef flats, there were two sizes evident in the population, the commoner small size, and a large size almost twice the dimensions. Evidently we are here dealing with a species that with two size groups in the total population at one time, must have a growth of at least two years to reach full size. Some of the largest and hence oldest of the Vasum shells exhibited abandoned scars of formerly attached horses'-hoof shells Sabia conica Schumacher of large (adult) size, to corroborate the idea that the Vasum had lived longer than a whole generation (at least one years brood) of the Sabia snails. Uncommon, but characteristic here are the carnivorous frog-shells Bursa granularis Röding, the toad-shell Bursa bufonium Gmelin, and the small white frog-shell Bursa producta Pease. The first two of these are widespread in the Indopacific, while the third, Bursa producta is only known from the eastern atolls, from the Gilberts to the Tuamotu Islands. Also present locally in abundance are the Hebrew cone Conus ebraeus Linnaeus, the Chaldean cone Conus chaldeus Roding, the flesh-colored Conus miliaris Hwass, and the darker flammulated Conus coronalis Röding. The Hebrew and Chaldean cones, both named because of the resemblance of the markings on their shells to ancient writings, have often been considered as varieties of one species. Their presence here in one habitat in considerable numbers, of all sizes and ages, living together without any intergrades whatsoever, gives us biological proof that these two are distinct species. By the same proof, we know that the two others, Conus miliaris and Conus coronalis, although often confused, are absolutely separate and distinct species.

Under the larger coral rocks in this zone may be found the beautiful but dangerous (poison) Conus retifer Menke, the tiny speckled Maculotriton digitalis Reeve, the small pink Columbella pallida Deshayes, small black-spotted white ark shells Arca maculata Sowerby, and an occasional individual of the large horse's-hoof cowry Cypraea (Peribolus) mauritiana Linnaeus, along with numbers of very young hermit-crabs of various species in many kinds of tiny snail shells. Under every such rock, the black poison sea urchins Diadema setosum Leske take refuge in the daytime, moving out at sundown to feed. Living on some of these Diadema individuals is a small commensal species of crangonid shrimp. Also found characteristically under these rocks is a long black sea cucumber that remains always partly under the rocks, but stretches out a considerable distance to feed. Another species, the largest and most conspicuous animal in the open and evident in the daytime in this zone is the common black sea cucumber, usually at least partly covered with sand grains. These common black sea cucumbers may be as abundant as 15 or 20 to the square metre over the rock surface where it is coated with a thin film of foraminiferal sand.

Because of their more rapid and wider ranging movements, the crabs of the outer reef are more difficult to localize into narrow or restricted zones, so that their exact or complete ecology is not necessarily well indicated by the collection of a few specimens. However, the following several species of crabs were definitely recorded from the inshore, more pooled area of the leeward outer reef at Raroia. These included Cryptodromia canaliculata Stimpson, Dynomene spinosa Rathbun, Micippoides angustifrons Milne-Edwards, Thalamita picta Stimpson, Carupa laeviuscula Heller, Actaea superciliaris Odhner, Chlorodopsis areolata Milne-Edwards, Cymo deplanatus Milne-Edwards, Eriphia sebana Shaw & Nodder, Lophozozymus superbus Dana, Lybia tesselata Latreille, Lydia annulipes Milne-Edwards, Xanthias lamarckii Milne-Edwards, and Pachygrapsus plicatus Milne-Edwards (common also on the reef blocks). Also here are the red-fuzzy-legged hermit-crabs Aniculus aniculus Herbst, and Clibanarius corallinus Milne-Edwards, the brilliant blue-legged hermit-crabs Calcinus elegans Milne-Edwards, the ordinary appearing white-legged hermit-crabs Calcinus laevimanus Randall, Calcinus latens Randall, Calcinus seurati Forest, and the feathery appearing red-banded shrimp Stenopus hispidus Olivier. One individual of the red-eyed rock-crab Eriphia sebana Shaw & Nodder was seen in the act of feeding. When collected it was in the act of crushing the shell of a small cone Conus sponsalis Hwass in its crushing claw, and starting to eat the animal. At just about dusk, this crab was active on the exposed inshore reef flat, out of water at low tide.

The middle zone of this oceanic reef is thickly dotted with small coral growths, under which the many black poison sea urchins Diadema setosum Leske take refuge diurnally. On some of these sea urchins may be found a small commensal, a species of crangonid shrimp. The "squilla" (Stomatopod Crustacean) Gonodactylus chiragra platysoma Wood-Mason, is characteristic of the zone, but was never seen in abundance at Raroia. In and under these corals are commonly found money cowries Cypraea (Monetaria) moneta Linnaeus (of large size), the snake's-head cowry Cypraea (Ravitrona) caputserpentis Linnaeus, the whitish-tan colored sand cowry Cypraea (Ponda) schilderorum Iredale, the cones Conus lividus Hwass and Conus miles Linnaeus, and less commonly, the large Turbo argyrostomus Linnaeus. Also found here, but not commonly, were the tiny spotted cowry Cypraea (Naria) irrorata Gray, and the small blue-tipped, red-speckled starfish Linckia multifora Lamarck. Many of the individuals of Linckia collected here were in the act of regeneration of parts, some even regenerating the other four (tiny) new arms (and the body disc ?) from what was apparently only one ray or arm. Not common, but only found in this zone at Raroia is the round, short-spined sea urchin that covers itself with pieces of algae or other debris (Tripneustes gratilla Linnaeus).

Living in the coral rock formed at the base of certain of these corals (Acropora spp.) is the characteristic white coral-boring snail Magilopsis lamarckii Deshayes. These snails live in a flask-shaped cavity in the coral similar to the boring of certain coral-boring clams such as Lithophagus with the head of the snail directed toward the small opening to the exterior, and the spire downward in the widest part of the chamber. In some of these Magilopsis borings were found some small commensal clams; one of the clams Barclayia incerta Deshayes living alongside the living Magilopsis lamarckii snail in the boring, in each observed instance of this commensalism. It is interesting to note here that the snail and the clam of this commensal pair were both originally described from the same locality (Reunion Island) in the Indian Ocean by Deshayes. The discovery of the true commensal relation of the two species at Raroia Atoll indicates that this commensal clam is also present all the way across the range of the boring snail; in other words, all the way from Reunion Island thousands of miles eastward at least as far as Raroia Atoll, in the Tuamotu Islands.

Living in "nests" or depressions on the surface near the base of some of these corals is the uncommon but very characteristic coral-snail Coraliophila violacea Kiener. This species holds its eggs in capsules under the shell of the female until they hatch, and the pelagic young swim away just as is known in the case of the hipponicid snails (Sabia conica) at Raroia. In a similar fashion, the eggs of the coral-boring Magilopsis lamarckii are held in capsules in the boring chamber until they hatch, and the pelagic young swim away to find a new host coral in which to start their boring. Also living on the bases of corals here is the second type of coral-snail Quoyula monodonta Blainville.

In the patches of the middle of the outer reef that are almost devoid of coral, there is a more or less wide expanse of rock pavement, over which sifts a very thin film of Foraminiferous sand. Locally abundant on these pavement areas, but most inconspicuous because of their camouflage coating of small coralline algal (Goniolithon) growths and foram sand the same as the pavement, is the golden-mouthed rock-snail Drupa grossularia Röding. What is probably an undescribed species of bonelliid worm was seen here at Raroia, but never chiseled out of the rock and collected. This appeared as a thin ribbon like a nemertean worm, but in the shape of a capital T with the ribbon about two or three millimetres wide, and the T outstretched about 4 by 6 inches, with the base of the T disappearing into a hole in the pavement about three millimetres in diameter. In a cavity beneath the hole is the large sac-like body of the bonelliid worm, which is protected by the hard rock of the pavement.

Along some of the outflow areas of the narrower parts of the leeward outer reef at Raroia, the outer edge of the reef is lacking any definite algal ridge, so that the "pavement" may simply end with the beginning of the outer slope or buttress zone. On such flat pavement areas, near but not actually on the outer reef edge, may be found patches of "soft corals". In some spots locally abundant, these are not true soft corals, but are colonial zoanthid anemones, which are retracted and appear like sandy grit-filled patches of dirty grey-white parafin or candle drippings about an inch thick, when they are exposed out of water at each low tide interval. What may be the rarest animal in point of numbers, that is, least abundant in individuals at Raroia, was found here. It is a species of Baccalaureus, a symbiotic barnacle that lives inside the colonial zoanthid anemone. This symbiotic barnacle is without external appendages, and is so much reduced from the normal appearance of a barnacle, as to be difficult to place in any animal group, on the basis of visible characters. Its general shape is similar to that of the old greek discus, with a symmetrical helicoid spiral ridge on each face. The two sides or faces, and the helicoid ridges are right and left hand mirror images of each other.

In the boring sea urchin and/or Amphiroa algal zone, the reef is perforated with the burrows of the small boring urchins Echinometra mathaei Blainville and Echinometra mathaei oblonga Blainville. These borings, about two inches in diameter, and four to six inches deep, sometimes simple, but more often branched or irregularly Y or U shaped, furnish shelter for a number of other animals besides the subcylindrical urchins, which travel up and down (sideways) in these short burrows. They usually stay near the bottom of the boring when the tide is low, but always come right up to the surface end of the burrow when the first water of the incoming tide reaches them. Living on some of these boring urchins is a small commensal species of crangonid shrimp. Most of the other animals found here in these borings are simply taking shelter there until the next night's period of activity. Only seen at night, or more abundant out on the surface of the reef in this zone at night are the spotted cowry Cypraea (Arabica) depressa Gray, a few species of medium sized mitre shells Mitra spp., and another spotted cowry Cypraea (Arabica) histrio Gmelin. This last, the histrio cowry, has a blackish smudge on the base of the much higher arched shell, and is much more rare at Raroia than is its close relative depressa. Also found here but rarely is the widespread and elsewhere common tiger cowry Cypraea (Cypraea) tigris Linnaeus. Several very colorful sea-slugs (Nudibranchs) are characteristic of this part of the reef. These include at least two species of the genus Glossodoris; one about two inches long with red ring-spots on a blue-black general color, very similar to, but probably distinct from Glossodoris ransoni Pruvot-Fol recently described from Hikuero Atoll, 100 miles southward of Raroia Atoll, and another of the same size, but of an opaque milk-white color all over. One species of crab of medium size, rough surfaced, and of the same color in general as the pinkish purple Porolithon growths of algae, is especially characteristic of the boring sea urchin zone of this leeward outer reef at Raroia. This species of crab Daira perlata Herbst was seen only in or around these borings. With both the color and surface texture resemblance to the coralline algal rock, they were less commonly noticed than many species that were much less abundant, but much more easily visible in the same habitat.

As mentioned before, the crab fauna of the outer reef is harder to correlate into narrow zonation than are some of the slower moving molluscan species. The "outer reef", that is the general outer half of this reef along the lee side of Raroia, is the hunting ground of the natives for night-time fish spearing, and for the gathering of many species of crabs they use for food, whenever the tide is out. The edible species taken here by the natives, with the aid of torches in the early days, but now with the aid of kerosene or gasoline lanterns, include the swimming crab Charybdis erythrodactyla Lamarck, the xanthid crabs Atergatopsis signatus Adams & White, Carpilius convexus Forskal, Carpilius maculatus Linnaeus, Etisus (Etisodes) splendidus Rathbun, Juxtaxanthias tetraodon Heller, Lachnopodus tahitensis DeMan, Zosimus aeneus Linnaeus, and the plagusine crabs Percnon abbreviatum Dana, and Plagusia speciosa Dana, the shovel-nosed lobster Parribacus antarcticus Lund, and the spiny lobster Panulirus penicillatus Olivier. A small species of goose barnacle was found here, commensal on the mouth appendages of the shovel-nosed lobster Parribacus antarcticus Lund.

The top of the algal ridge is the characteristic habitat of Patella stellaeformis Reeve, which lives here in little sockets on the surface. When the ridge is exposed at low tide, each of these limpets is discernible only by the outline of its shell, the surface of the shell and the rock around it both being covered by the pinkish algal ridge. The limpets must be pried out of their individual homing positions or sockets. If they move around much they apparently return or "home" at each low tide to the same socket or pit which exactly outlines the shell. Also most characteristic here, resting in any large crevices available, is the large, heavy-shelled white cat's-eye shell Turbo setosus Gmelin. On every large Turbo shell are numbers of the hipponicid snail Sabia conica Schumacher which grows into sockets it erodes on the Turbo shells near the aperture. Apparently these small snails which seem to be scavengers, feeding on the scraps or droppings of the Turbo, have a shorter life span than does the Turbo. The oldest Turbo shells show full adult size scars of Sabia animals that have lived, died and dropped off, and in these old scars are small Sabia of the next generation living. Three spiny species of rock-snails, Drupa spp., are found here. Drupa ricinus Linnaeus, white-mouthed, may be found in small numbers scattered clear across the reef from the shore outward, but seems most abundant at the outer reef edge. Drupa elegans Broderip & Sowerby, white-mouthed with a bright red line ringing the aperture of adults, is less common, but restricted in habitat to the outer reef edge. These studies at Raroia proved elegans to be a separate species rather than a color form of ricinus, with young and adults of both species readily distinguishable. The purple-mouthed species Drupa morum Röding is typically restricted to the region of the algal ridge at Raroia, just as was observed for this species on Bikini and other atolls in the northern Marshall Islands. Actually the largest and most conspicuous animal of the algal ridge zone is the purple slate-pencil sea urchin, Heterocentrotus trigonarius Lamarck. Also present, but much less common at Raroia is a second, more reddish species Heterocentrotus mamillatus Linnaeus. Commonly present on the slate-pencil urchins is a small species of crangonid shrimp, which is also purplish in color, matching the general color of the urchins on which it is commensal. Much more rarely found at Raroia is the parasitic snail Stylifer species, which attaches itself to the oral side of these slate-pencil sea urchins.

In certain places, very local and restricted in area on the lee side of Raroia Atoll, are small stretches of what has been called "dead reef". Here the first impression is that the erosional forces are in the ascendency, with the reef being eroded simply as if it were only rock of inorganic origin, and not actively maintaining itself in balance or increasing, by the growth and the calcareous deposition accomplished by the Porolithon and other calcareous algae. In such places, the helmet or "pavement-spined" sea urchin Colobocentrotus pedifer Blainville is the conspicuous animal of the reef edge, living in the pockets they hollow out in the reef rock. Complete studies of these areas will undoubtedly show that these are not dead reefs, but areas of the reef where the forces of deposition and erosion are in a different balance, than is the case of the other stretches of reef at Raroia. In fact it is entirely possible that the presence of the helmet urchins Colobocentrotus is one of the factors in the modification of the reef to a different, but yet a true balance, in these areas of so-called "dead reefs".

Along these areas fronted by the helmet urchins on the reef, it seems as if there is a slightly different or modified zonation of the molluscan species, a zonation that was particularly evident in the case of the species of Thais present here. In this modified reef zonation, the large pinkish Thais armigera Link was near the reef edge; Thais intermedia Kiener was in the middle zone or pot-hole area; and the commonest Thais hippocastaneum Linnaeus was in the shoreward zone, without any apparent overlapping of these Thais populations under these conditions. Over the commoner type of reef with the algal ridge on the leeward side of Raroia, the Thais species were not so markedly set off in discreet or separate zones. In addition, the Thais tuberosa Röding was also present in the middle section of the reef flats, while the small narrow pink species Thais affinis Reeve was locally common on the middle and the shoreward areas of the reef, overlapping and mixed with the Thais hippocastaneum population near but not at the shore line. These Thais specimens from Raroia demonstrate that, contrary to the opinion of Pease, the large pink armigera and the small narrow pink affinis are completely distinct and separate species. Young of armigera and adults of affinis, of identical dimensions, are readily separated on the basis of the large knobby spines on the periphery of the whorl; in armigera there are two equally prominent, in affinis only one, just above the periphery is of major prominence.

Not evident on the surface, but very characteristic of the area of the Porolithon, and often living under the surface level of the reef, on the sides or on the under side of the small rounded "heads" or lumps of the Porolithon growth, are such species as the horse's-hoof snails Hipponix (Antisabia) foliacea Quoy & Gaimard, Hipponix (Cochlear) barbata Sowerby, and the small trochid snails Stomatia spp., and Gena rosacea Pease. The habitat of these hipponicid snails is completely different from that of the similar, but generically distinct Sabia conica Schumacher, which at Raroia and elsewhere on the atolls is restricted to a (commensal ?) habitat on larger snail shells. Drupa clathrata Lamarck, the brown chestnut-burr rock-snail is characteristic of the lowest normal low tide level on the outer slope of the algal ridge, always in reach of the surf. Only found on this outer slope also was a small red chiton, the only member of its group seen at Raroia. Also recorded from the coralline algal ridge of the outer reef, or from the reef margin just beyond, are the crabs Actaea cavipes Dana, Actaea rufopunctata Milne-Edwards, Carpilodes rugatus Milne-Edwards; the fuzzy-red-legged hermit-crab Aniculus aniculus Herbst, and the smaller hermit-crab with the brilliant blue-banded legs Calcinus elegans Milne-Edwards.

From the surge-channels in the buttress zone just beyond the algal ridge, two species of shrimp were taken, that apparently make this their home. These species, _Rhynchocinetes hiatti_ Holthuis, and _Brachycarpus biunguiculatus_ Lucas, were not seen in other habitats at Raroia.

The buttress zone of the reef and the coral shelf, outside of the edge of the surface reef, with up to 10 meters of water over its outer slopes, are undoubtedly the normal habitats of many of the species of mollusks that are recorded (as shells) but that have never been seen alive at Raroia. Most conspicuous among this group are the small but very beautiful abalone shell _Padollus pulcherrimus_ Gmelin, the umbrella-limpet _Cheilea equestris_ Linnaeus, the rare endemic _Drupa speciosa_ Dunker which was only found as a hermit-crab shell, and the handsome spotted cylindrical cowry _Cypraea_ (_Arabica_) _scurra_ Gmelin. It seems probable that the little abalone and the _Cheilea_ are living somewhere on the outermost algal slopes in the buttress zone.

The _scurra_ cowry was more abundant in the shoreline drift on the lee side of Raroia Atoll than at any other place personally visited in the Pacific. It must be common and characteristic of the offshore coral shelf of the atoll, living under and around the many and varied coral growths of this zone.

Only seen rarely at Raroia, undoubtedly cast up over the atoll rim by storms, were a few shells of the medium sized scaly giant clam _Tridacna noae_ Röding. It must also be living only on these outer slopes of the atoll. Lack of sufficient time, and the extreme reluctance of the Raroian natives to dive here in the known presence of all the dangerous sharks of the region, prevented the study or even the collection of living specimens of mollusks or other invertebrates from this outermost zone of the atoll ring.

Part 2

NOTES ON THE BIRDS OF RAROIA

by J. P. E. Morrison

The birds are not narrowly restricted to special habitat zones, as are many of the invertebrates living on and around coral atolls. With their powers of flight, any zonations of bird populations observed are more positively zonations of habitat preference than is necessarily the case with less motile species. In general terms, there are only four feeding or habitat zones for the birds to occupy on the low coral atolls. This limitation of possible habitats, and the geographic location far out in the middle of the Pacific Ocean, both serve to limit the number of bird species present on Raroia Atoll. There was a total of only 18 species of birds present on Raroia at the time of these studies. Ecologically the birds may be classified as:

(1) sea birds that feed out to sea, and roost on the atolls,
(2) sea birds that feed in the shallow waters of the atolls,
(3) shore birds, feeding on exposed reefs and island shores,
(4) land birds, feeding on vegetation covered island areas.

The sea-birds may or may not be limited to diving for fish in the open ocean near the atolls, or in the shallow waters near or over the reefs of the atoll ring. Food of the sea-birds is ordinarily composed entirely of fish, though on occasion both the species of boobies and some of the terns may capture and eat squids. In general appearance the sea-birds might also be separated into two groups on the basis of size of the individual birds. The larger sea-birds, mostly oceanic in food habits, include two species of boobies, and two species of those pirates of the sea, the frigate or man-o-war birds. A tropic bird was also recorded as an accidental or occasional visitor at Raroia.

The smaller sea-birds are represented on Raroia by only one type, the sea-swallows or terns. There are seven different species of terns in this island fauna; six of these species are resident here throughout the year. Some of these species of terns such as the white-capped noddy often fish a distance out to sea, in company with larger sea-birds such as the red-footed boobies. Other species such as the crested tern do not often leave the shallow waters of the reefs, getting all their catch of small fish near the island shore lines. Two of the less common, smaller terns are apparently restricted to certain areas on the atoll or its lagoon, instead of being generally distributed as are most of the bird species. Known special habits or zonations of each species of sea-bird are given in the annotated list of species that follows.

The shore-birds of Raroia include only one species of heron and three of the plover and sandpiper group. The reef heron, widespread on many islands of the Pacific, and the wandering tattler, are both resident here. The other two species, the bristle-thighed curlew, and the Pacific golden plover, are migrants, breeding far to the north in Alaska or Arctic America. Food of the shore-birds is generalized, including small fish, crustacea, marine worms, and other miscellaneous invertebrates recovered from the reefs at low tide, or picked out of crevices, or the line of drift materials along the island shores.

The land birds are extremely limited here. There is only one such species, a small warbler, that is resident here. This member of the Old-world family of wood-warblers (Sylviidae) is endemic on atolls of the Tuamotu Island group. With such limited land area, the total population of these small birds is probably small on any single atoll such as Raroia. They probably have no effective enemies to limit their numbers except disease, starvation due to limited food resources, and the rare hurricanes with their attendant tidal waves. The only other land bird of Raroia is a migrant species. The New Zealand long-tailed cuckoo scatters far and wide over the Pacific atolls to spend its winters. On islands such as Bikini in the northern Marshall Islands, and here at Raroia in the Tuamotu Islands, small numbers of this cuckoo tap an otherwise unused reservoir of insect food. The cuckoos thrive during these winters on Raroia and get fat on the larger insects such as numerous moth-caterpillars that are available.

Parasites of the birds observed at Raroia were mostly species of the ectoparasitic hippoboscid flies. One larger species Olfersia aenescens Thomson was found on four species of sea-birds, that fish out to sea in large part. This fly was collected from specimens of both the red-footed and brown boobies, and of both the common and the white-capped noddy terns. A second large species of hippoboscid fly, Olfersia spinifera Leach, was found on the Pacific frigate bird. A small hippoboscid species, Ornithoica pusilla Schiner, was found on the reef heron, and on both nestling and adults of the fairy tern. The only internal parasite of birds seen at Raroia was the species of ascarid worm, Contracaecum granulosum, recovered from the stomach of a male Pacific frigate bird.

Problems of the utilization of the birds of Raroia as a supplementary food resource for the natives are discussed under the species concerned, in the following annotated list.

Identifications of the bird species collected at Raroia were made by the ornithologists of the Division of Birds, U. S. National Museum. I wish particularly to thank Drs. Alexander Wetmore, Herbert Friedmann, and H. G. Deignan, for their continued help in the writing of these notes. The hippoboscid flies were determined by Dr. Joseph Bequaert of the Museum of Comparative Zoology at Harvard University.

ANNOTATED LIST OF THE SPECIES

White-tailed tropic bird, Phaethon lepturus dorotheae Mathews.

The TAVAKE HOPETEA was not seen alive at Raroia during the summer of 1952. It must be classed as an occasional visitor, however, since one skeleton was recovered. This was the remains of a bird of this species found in the drift on the lagoon side of Tahuna riri Island. It may have drifted ashore from the open ocean to windward.

Red-footed booby, Sula sula rubripes Gould.

One small colony of the KENA or KARINGA HOPETEA was present on Raroia Atoll in 1952. About twenty adults were seen returning to roost each night on the small stand of Pisonia trees on Kahongi Island in the northwest sector of the atoll. They leave before daylight breaks at dawn, to start out to sea (downwind) for the day's fishing. I say was present advisedly, because this strictly colonial species will not persist here much longer unless the natives of Raroia can curb their appetites and exercise strict conservation measures on behalf of the KENA. On this same island, Kahongi, were found parts of at least 12 skeletons of this species, which some of the natives had feasted on a year or so previously. I strongly advised and tried to impress on the natives the importance of conservation if this species is to remain as a food resource at Raroia. Surely if a dozen or more birds are killed and eaten each year out of a known total population of about 35 individuals present in 1951, the colony will disappear with shocking suddenness. The saddest feature of this picture seen in 1952 was that one of the three largest Pisonia trees of this small stand on Kahongi had been felled (apparently at night ?) to secure the birds eaten on the occasion of the feast in 1951. If the required roosting and nesting trees, the Pisonia, are cut down to get the birds to eat, the environment will be depleted as well as the population of the birds. If there is no stand of Pisonia trees, no new colony of the red-footed booby could be located on Raroia even by chance (as it would have to be) in future years or centuries. Hippoboscid flies, Olfersia aenescens Thomson, are on the red-footed boobies here at Raroia.

Brown booby, Sula leucogastra plotus (Forster).

The KARINGA was present in small numbers at Raroia, as would be expected, but it was not determined if any nested on the atoll. This ocean-ranging species was characteristically seen at Raroia resting on the coral blocks (out of water even at high tide) on certain patch reefs in the Raroia lagoon. These coral blocks, like the more numerous ones seen on the outer reef flats of Raroia and other atolls in the Tuamotus, were undoubtedly broken off and cast up on the patch reefs by violent storm action. The KARINGA is everywhere more wary of man than is its relative the red-footed booby, and so is seldom taken and eaten by the Raroian natives. The dozen or so individuals of this species estimated as the resident population at Raroia were ordinarily seen only at a distance from human habitations. On occasion they were seen fishing (diving) in the ship's pass at Raroia, particularly in the area of the strong tide rip where the outflowing lagoon waters meet the waves of the (lee) outer reef line. Adults of a species of hippoboscid fly, Olfersia aenescens Thomson, and a puparium of this fly were collected from a female shot in the pass.

Pacific frigate bird, Fregata minor palmerstoni (Gmelin).

A considerable number of KOTAHA were apparently resident on Raroia Atoll. Ordinarily the majority of these birds were to be seen soaring over the windward side of the atoll, but at least a few of this larger species of the two present were in evidence more or less regularly along the leeward side of the atoll as well. Perhaps a half dozen of this species were seen to roost on the Pisonia trees, in company with the small colony of red-footed boobies, on Kahongi Island. Like the boobies they left before the crack of the first light of dawn, to start the day's fishing (or pirating ?). In the absence of Pisonia trees, this species uses the coconut palm for roosts, as seen at Puhiota Island on the windward (northeast) sector of Raroia. A pair (male and female) collected at Puhiota Island were found to be infested with hippoboscid flies

Olfersia spinifera Leach; while the male of this pair was found to have several ascarid worms Contracaecum granulosum in the stomach. This larger, Pacific frigate bird is the species called KOTAHA HIVA by the Raroian natives. At least the white-headed immature plumaged female birds were so identified for me. The KOTAHA UMA MEA (of red breast) must be the breeding male of this species, since males of the smaller species F. ariel do not have the red gular pouches that are so characteristic of the males of F. minor.

Least frigate bird, Fregata ariel ariel (Gray).

Sixty or more of this smaller species were seen together in one flight, on the eastern (windward) side of Raroia Atoll on one occasion. Ordinarily all frigate birds are known as KOTAHA at Raroia, but this least species is also called KOTAHA PORO by the natives. This least species is also possibly the one referred to in the Tuamotu chants as KOTAHA UMA PEKA (of crossed breast). The adult females show two lateral patches of white on the belly, in contrast to the all-white belly of adult females of F. minor, so it is possible that the adult or perhaps slightly immature plumaged females might be considered as cross-marked on the breast. Ordinarily most numerous on the windward side of Raroia, at times of continued high winds, numbers of these KOTAHA PORO were observed for hours continuously soaring or simply holding their position over the lagoon shore of the village island (Ngarumaoa) on the leeward side of the atoll. At Opakea Island, near the southern end of the atoll, six or eight least frigates appeared regularly overhead several mornings at about 7:00 a.m. each morning. It was considered possible, but not determined that this species (these individuals) were coming to Raroia each morning from some uninhabited atoll to the south. It may be significant in this connection to note that Tekokota Atoll, only about 70 miles (less than two hours flight) southward was found by Townsend to have a larger population of frigate birds in October 1899 than any other Pacific island visited on that voyage of the U. S. Fish Commission steamer "Albatross".

Reef heron, Demigretta sacra sacra (Gmelin).

The KOTUKU was characteristically seen on the shorelines of Raroia, both oceanic or outer reef shores and those along the lagoon. The majority of individuals observed at Raroia (probably more than 60%) were of the dark or blue phase. The all-white phase of plumage was far less prevalent here than it was observed to be in the northern Marshall Islands such as Bikini, where nearly all the herons seen in six months in 1946 were completely pure-white in plumage. Only one (immature ?) individual showing strong mosaic (checkerboard) dark and white patch coloration was seen at Raroia. Unfortunately it was not collected. In the village area, this species was occasionally seen to roost in the crown of coconut palms. On small uninhabited islands on the windward side of Raroia it was found roosting near the ground, in the Guettarda trees. A small hippoboscid fly, Ornithoica pusilla Schiner, was collected from a male of the blue phase shot along the outer reef early one morning.

Pacific golden plover, Pluvialis dominica fulva (Gmelin).

The TOREA normally migrates out of the Tuamotu Islands to its nesting grounds in the north during the southern winter months of late June, July, August, and early September, when Raroia was under study in 1952. Only one individual of the golden plover was seen at Raroia, one day in early July. This adult male was late in migrating northward, and when it flew out of the village area after I missed a hurried shot at it, the reason for its delay became evident. Attached to one foot or lower leg in some way, as if hanging on a string or fiber that was snagged around the foot, was a white object about one by two inches in size. This white object appeared at the distance of observation to be a small clam; it obviously was a drag on the flight of this bird. In spite of the handicap, this male plover flew out of sight over the tops of the coconut palms. It was never seen again, even though an intensive search along the shores of Ngarumaoa and the islets to the northward was immediately carried out. No golden plovers had returned to Raroia by the 7th of September, 1952.

Bristle-thighed curlew, Numenius tahitiensis (Gmelin).

The Tuamotuan name KIVI is a good representation of the call-note of this Pacific island curlew. With care and skill, they may be "called in", to land very close to a hidden observer. As is known for other atolls such as Bikini and others of the northern Marshall Islands, here at Raroia it is also probable that some individuals (perhaps the old individuals ?) do not make the long flight to northwestern Alaska to breed. At any rate a few of the KIVI were to be seen at Raroia all through July and August of 1952, throughout the time of their (northern) breeding season.

Wandering tattler, Heteroscelus incanus (Gmelin).

This little sand-piper, known in the Tuamotus as the KURIRI, is often seen as a solitary individual flying from point to point, or casually picking its way along the coralline rock or the sands of the island beaches. It also may be seen in small flocks of six or more travelling and feeding together, on the exposed areas of the outer reefs, whenever the low tide period comes in the early morning. One of the most amusing incidents in all the scientific work done on Raroia followed the shooting of the first specimen of the KURIRI near the village, in front of a considerable audience of natives. This bird created much hilarious diversion when it was discovered that it had only one leg! There was not even a stump of the other leg, just a spot on the unbroken skin of that area. On another occasion a second one-legged KURIRI was seen, but unfortunately was not collected. The second one was apparently missing the opposite leg. It would be truly interesting to find out why some of these birds have just one leg. Is it because one was undeveloped by an accident of nature in the embryonic growth, or, is something responsible for clipping off one leg of the young chick? If so, how does the bird survive such injury, and eventually carry on in apparently normal fashion as an adult?

Spectacled tern, Sterna lunata Peale.

The OREORE was uncommon at Raroia Atoll. It was typically seen only in small groups, feeding in the eastern or windward half of the lagoon. When a small flock is actively diving and fishing, they pay little attention to the natives' boats or outboard motors, simply moving with the school of small fish, as the school travels along. The problem of observing or collecting specimens of the OREORE was not one of approach; it was one of location of the small groups. Either because of its scarcity, or because of differential ecology, it was never seen flying near the leeward shores of the lagoon, during the ten weeks of observation at Raroia in 1952.

Sooty tern, Sterna fuscata oahuensis Bloxham.

The KAVEKA was not positively known to nest on Raroia Atoll in 1952, although the natives had hopes that they might be starting a new colony there. Since the Raroian natives prize the eggs of this species as a good seasonal food resource, they have set themselves under strict regulations not to bother any sooty terns that may nest on Raroia, so that if possible a colony may be established and increase, before any eggs are taken on Raroia. The sooty tern was breeding on Tekokota Atoll, a small uninhabited atoll about 70 miles south of Raroia, near the end of June, 1952. It is also known to nest on five other atolls in the Tuamotu Islands. It is an occasional visitor at Raroia, after the breeding season. For example, 7 individuals were seen flying over the leeward reef near the ship's pass on July 22. No specimens were secured on this occasion, however.

Crested tern, Thalasseus bergii cristatus (Stephens).

This large tern called TARA, or sometimes TARAPAPA, by the Raroians is very common and familiar to all the natives. It habitually patrols the island beaches, fishing in the shallow waters over both the lagoon and outer reefs during most of the day. There were always a few resting on the poles set up by the natives as patch reef (channel) markers near the village. Whenever or wherever the fishing was good, a score or more of the TARA seemed to congregate in a short time, where there were only one or two visible previously. They must be called in by the cries of the fishing terns, whether it be along the lagoon shore in front of the village, or on the outer reefs far from any human habitations.

Blue-grey ternlet, Procelsterna cerulea teretirostris (Lafresnaye).

The NGANGA was seen only on the southeast side of Raroia. It is apparently uncommon here, but still well known to the native fishermen to be always on the windward (KERETEKI) sector of the atoll. They apparently fish along the windward outer reef and the windward island shores. At midday, they may occasionally be found resting on the wide coral gravel flats seaward of or between the vegetation patches on these windward islands of Raroia. Unless one sees these small blue-grey terns alight, they become effectively and completely invisible when on these grey gravel stretches of barren land above normal high tide line, near Patapata Island. The heat waves arising from the tropical sun's heat on the surface of these dry gravel flats also materially obscure their discovery.

Common noddy tern, Anous stolidus pileatus (Scopoli).

The NGOIO is resident and generally distributed over the islands of Raroia Atoll, except near the native village on Ngarumaoa. This is a noisy bird, particularly in the roosting areas. Some individuals are active at all hours, a few even all through the night. This was particularly true at Tetou Island on the windward side of Raroia, where a number were observed flying actively just after dark. Flying at this time just above as well as around and between the coconut palms, they appeared to the uninitiated somewhat like bats flying in the dusk.

White-capped noddy tern, Anous minutus minutus Boie.

This smaller noddy with a longer bill is just about as common, but less commonly observed on the islands than is the larger species. The KIKIRIRI, as it is known at Raroia, fishes farther out to sea than at least most of the individuals of the common noddy do. The KIKIRIRI was apparently most abundant in the neighborhood of Kahongi Island, roosting near the small colony of red-footed boobies. Most any day, however, small groups of the white-capped noddies could be seen "patrolling" or fishing, possibly searching for schools of small fish, just outside the line of the outer reef on any part of Raroia Atoll. They did not seem to fish in the lagoon to any great extent.

Fairy tern, Gygis alba candida (Gmelin).

KIRARAHU is the Raroian name for this familiar white tern. It is very curious, a few often hovering a few feet over the head of anyone who is walking across any island on which they roost and nest. At Raroia, as observed elsewhere, the eggs of the KIRARAHU may be laid in small numbers almost throughout the year. In the middle of August, months from the normal or maximum breeding season, there were a few eggs to be seen. These were laid in the characteristic manner in slight depressions on the top of horizontal bramches, or in a crotch depression of the Guettarda or other similar trees, without the formation of any nest. One nestling was collected at this time for the breeding record. Small hippoboscid flies, Ornithoica pusilla Schiner, were seen on adults of the fairy tern, but were not captured. One found on the nestling collected was captured however, and so the identity of this small fly was established.

New Zealand long-tailed cuckoo, Urodynamis taitensis (Sparrman).

The KUREVAREVA is present throughout the southern winters on Raroia Atoll. It was not seen in numbers, but occasionally only, and always solitary. As at Bikini in the Marshall Islands, this cuckoo is here silent except for its sharp alarm-note. This is usually given only when it flies away, so the collection of specimens in their winter habitat on the coral atolls is largely a matter of lucky chance. One of the two male specimens collected at Raroia was shot in the middle of a very dense thicket of Suriana bushes in the late afternoon. At this time of day (4:30 p.m.) it was still feeding actively. When the specimen was in hand it was found to have the stomach distended, so tightly packed with insects as to feel like a large stone in the bird's body. These cuckoos apparently thrive on the abundant supply of caterpillars and other insect life readily available on these atolls during their winter season, since they have so little competition from other land birds here.

Tuamotuan warbler, Conopoderas atypha atypha Wetmore.

These little warblers are not uncommon at Raroia, but are little evident around the inhabited areas. The males of the KOKIKOKIKO are the only ones ordinarily seen (or should I say heard and located) even on the less frequented, uninhabited islands. On Raroia Atoll, the seven males collected showed considerable variation in the amount of yellow on the underparts. Some of this variation is undoubtedly due to differences in age of the individuals. Also, there is a probable, but unproven, difference in age of males indicated by the differences in song observed. It seemed as if the older males sang much louder and with more varied notes, because they had more experience (and confidence ?). During the winter season the females are simply not evident at Raroia. Without a song, they cannot be located as can the males. Fortunately for the record, the only female seen in ten weeks was collected. It seemed much more curious than the other individuals seen, and was taken for that reason, after a halt had been called in the taking of any more male warblers. As the only resident land birds, these solitary warblers are continuously moving through the coconut tree tops or through the thickest Suriana and Pemphis thickets. Their song brightens to a considerable degree these otherwise silent islands.

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Interrelationships of the Organisms on Raroia Aside from Man

by Maxwell S. Doty and J. P. E. Morrison

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Having in previous sections of this report (Atoll Research Bulletins Nos. 18, 31-34) enumerated and given the geographic distributions of the individual kinds of organisms, and discussed the physical environment we can logically proceed to a more synecological discussion. At least we can report our major ecological observations and the syn- and autecological hypotheses derived from these observations.

To facilitate the gathering of information for this phase of our study of Raroia a number of areas (transects) were chosen for more intensive study. All of the members of the field team participated in these studies, and their aid is herein acknowledged. The locations of these transect areas on the atoll may be seen in Figure 1. In the transect areas a search was made for the living organisms present. These have been reported in Atoll Research Bulletins 18, 33, 34. Across each transect area a profile was studied in reference to the distribution of the physical and biological features of the transect. The profile positions in the transect areas are shown by the lettered solid lines within each area. The letters correspond to the profiles on Figure 2.

In this discussion reference is made to Figure 3. This is an idealized profile diagramming the typical elevational features met with in crossing the atoll ring. Essentially, it illustrates that which can be walked upon. This profile is a summary of Figure 2, the proportions are similar though no particular scale has been followed.

The description is organized as a discussion of the ecological units of the atoll under the following headings:

I. Sea Reef in general and pools

II. HOMOHOMO profile study

A. Sea shore

1. Spurs and grooves
2. Algal ridge
3. Amphiroa zone
4. Heliopora zone
5. Pool zone
6. Excurrent area
7. Intertidal and spray-wet shore

B. Sea beach

C. Guettarda forest

D. Lagoon shore

1. Lagoon shore above high tide line
2. Lagoon intertidal shore
3. Lagoon subtidal shore

III. A comparison of the other six profiles studied

A. Sea shore

1. Spurs and Grooves
2. Algal ridge
3. Reef flat
4. Intertidal and wave-wet shore
5. Spray-wet shore and sea ramparts

B. Sea beach

C. Guettarda forest

D. Lagoon shore below high tide line

IV. Reef patches

V. Vertical distribution

VI. Channels

I. SEA REEF IN GENERAL AND POOLS

The reef flats (Fig. 3) of Raroia are narrow (Fig. 2), usually less than 100 meters wide, and in general the pool of water on the reef flat was deepest near the shore. This, when considered in relation to the algal ridge, is in the position of the back-ridge trough of the much wider Marshall Islands reefs. The whole reef flat being only perhaps a hundred meters wide leaves little place as a rule for the inner area of reef flat characteristic of reefs having a greater width between the margin and shore.

The water comes in over the reef margin (Fig. 3) with each wave, except at low tide during calm weather. The water movements on the reef flat just as the tide began to rise (Fig. 4) were determined by watching the movement of dye spread on the surface. The water coming in over an algal ridge passes in toward the shore and to the right and left (Figs. 4B, C, D, E, F), and then out over the reef margin where it is low. This general pattern was consistent but at extremes of tide, and presumably at times of other extremes such as wind or the course of large waves, the details varied. As an example, at rising mid tide when a lot of water was coming in and out over the reef edge, a dye patch followed course "F" in Figure 4 rather than an *a priori* selected path parallel to "C".

The reef can be divided, by recognizing extremes, into *incurrent* and *ex-current* areas on this basis of direction of water flow after coming in over the reef margin. The excurrent areas are devoid of algal ridges. The incurrent areas usually have an algal ridge but this may be absent, the reef edge merely being higher here, or it may be a low cuesta in form. The leeward reef flats are such alternating incurrent and excurrent areas.

Excurrent areas rather consistently appear opposite the channels between the islands, but as the more leeward reef is approached, incurrent areas and excurrent areas alternate with one another even opposite island masses. Excurrent areas are much reduced as the more windward parts of the atoll are approached and in the most windward reef areas may be absent even opposite the channels, which are much more abundant (Fig. 1) here. In such cases the algal ridge is nearly continuous and the water normally passes across the atoll rim only in the direction of the lagoon. At least the water flows over the edges of the windward reefs and into the lagoon without the regular tidal reversal of direction characteristic of water flow in leeward channels.

The reef flat was far more intensively studied on the leeward transect north of the village of Garumaoa (Fig. 5). Locally speaking, the transect ran across the pieces of land known as Tomogagie and Homohomo. The profile of this transect (Homohomo) appears as figure 2G. Here evidence was gained that seems to indicate the reef may be divided into areas that become uncovered with the lowest tides and areas which do not become uncovered. The areas that become uncovered become uncovered rather quickly after the waves cease breaking over the algal ridge and once the tide rises so sufficiently that the waves again begin breaking over the algal ridge the whole tide flat is rather soon again covered with water from the reef ridge line inshoreward.

At high tide water does in part go back out over the ridge in incurrent areas even in regions having a rather high algal ridge. By standing at various distances out on the reef flat it was determined that the approximate point of division between where the water, at high tide, moves back toward shore after coming in over the algal ridge and where it moves back out over the algal ridge is the approximate location of the reef ridge line; though this varies out into the Amphiroa dominated algal-coral zone under some circumstances. Dyes dumped into the water on the reef flat at various stages of tide level revealed rather consistent circulation patterns over the reef flat. The water regularly moved as described, <u>in</u> toward the pool zone, <u>laterally</u> toward the excurrent areas, and <u>out</u> over the excurrent areas.

Water, in early July, coming in over the reef edge in the morning was near, or a little below, 26 degrees Centigrade. Twenty meters inshore, in an incurrent area the water would be between one half and one degree warmer and this warming of the water continued into the outer edge of the pool zone where the maximum temperatures were observed. In this case, they could be expected to be in the order of a degree to a degree and a half warmer than those obtained at the sea's edge.

Toward the inshore edge of the pool zone, the temperature dropped again. The lowest temperatures were measured in rills of water running out from the island conglomerate. In one case the temperature of a small pool near high tide line, but connected to the channel of the pool zone, was 29 degrees Centigrade in its central part, the inner edge, where the water was about 1 inch deep, was

27.8 degrees Centigrade, and with the bulb just covered in a sandy incurrent rill of water running into the pool from under the island conglomerate the temperature was 27 degrees Centigrade. Note in this connection the path of dye patch "A" in Figure 4.

As the channel along the inshore edge of the pool zone was followed toward the excurrent area, typically the temperature of the water was observed to increase in temperature about one degree. Then as the reef flat was crossed again, following the excurrent area out to the sea again, the temperature increased perhaps another degree, until at the most the temperature was about 30 degrees Centigrade. It was just in this area of maximum temperature that a certain soft coral was found. Beyond this point the repeated inwash of cooler water with each wave quickly lowered the temperature to that of the sea beyond and outside the reef.

There are essentially two kinds of pools associated with sea shores, both of them are calm ever-submerged habitats. The simplest is the classical tide pool with its continuous rim. Such pools may be thought of as being constant-level tide pools in consideration of the fact that when exposed by the receding tides, waves or spray, their level remains constant, except as it may change through addition of rain water or by evaporation. The second type consists essentially of areas with a restricted drainage. The surfaces of this type, when exposed, slowly lower and may be thought of as a non-constant-level type. Around the former of these two types there is often a sharp change in the biota associated with the surface level. Such a change is absent at the high water level in the latter type.

Tidepools are convenient places in which to make observations. They attract biologists for they are often centers of considerable biological activity. Recently, for the reason that this biological activity is of geological importance, the interest of the geologists (e. g. Emery, Bull. Geol. Soc., 1946) has been attracted. All of the tidepools can perhaps be differentiated to a certain extent by their position in respect to tide level, as supralittoral, littoral, and sublittoral tidepools.

The constant-level pools of the island conglomerate are supralittoral pools often of low salinity or of high salinity. These have been discussed at length under the blue-green algae in Part 2 of Atoll Research Bulletin No. 33.

Littoral pools are nearly absent except for the reef flat and the channels both of which are non-constant-level type pools. They are discussed below in greater detail.

Sublittoral pools of the constant-level type are nearly absent, unless one wants to consider the whole ocean as one pool. The concentration of biological materials around the shores of the sea favors this classification. Certain surge channels, the incomplete channels between the islands and especially the lagoon, itself, are essentially sublittoral tidepools of the non-constant-level type. However, on downwind lagoon shores where there is a reef, the gross aspect, like the littoral shore of the ocean, is that of a constant-level tidepool.

II. HOMOHOMO PROFILE STUDY
(Figures 2G, 4 and 5)

A. Sea Shore

1. Spurs and Grooves. The so-called "surge channels" and "ridges" received considerable, but entirely superficial, attention. Classically it is here that the atoll rim is growing upward and advancing the surface of the atoll outward. Newell has seen the same features in limestones which were of an oolitic sort formed inorganically. In Hawaii, on the basaltic materials under water where these are partially covered with sand, the sand and basaltic material show to an observer in a plane or boat as radially arranged elongated areas. Thus must be eliminated the explanation that the spurs and grooves have formed entirely as ridges growing between the now present channels. All of this points to an erosional origin of these spurs and grooves as Cloud (Bull. Amer. Assoc. Petroleum Geologists, 1952) has claimed.

At Raroia the spur and groove area appeared (Fig. 5) to be a mass of Porolithon onkodes with only traces of other coralline algal species. Coral animals were few. In the heads of most of the grooves there were to be found colonies of a Millepora, which extend down about one foot and out from approximately the outer edge of the algal ridge and the level of the reef flat inside the algal ridge. These Millepora colonies form their own small pools by their reticulate pattern of upgrowth. (See Figure 2 in Tracey, et al, Bull. Geol. Soc. Amer. for 1948.) Centroceras clavulatum coated many of the highest parts of the spurs beyond the algal ridge. Rarely were other than coralline algae present; however, among these rarities was a Caulerpa (a variety of pickeringii or an undescribed species) and Microdictyon okamurai Setch., and spots of blue-green algae. In a very few places rather well under even the lowest tide levels there was an increased abundance of Pocillopora on the tops of the spurs.

The grooves beyond the algal ridge at Homohomo dip sharply (Fig. 3) or may even be somewhat overhanging at their heads. Often the heads of these grooves are broadened and filled with what might be referred to as huge algalated lumps. While no effort was made to determine more than the nature of the superficial material of these it appeared that they might be fragments of reef rim broken off and lodged in the heads of the grooves and then cemented in by the growth of such algae as Porolithon onkodes and Lithophyllum species. From the rounded shapes of the groove bottoms and their containing rounded boulders and pebbles as well as their generally very smooth regular contours it was assumed that in the grooves there was a lot of abrasion. This was insinuated further by the frequency of spherical clumps of algal materials (Microdictyon okamurai) found there. Around these irregularly arranged huge algalated lumps in the channel heads the broadening seen appeared to be what one might expect from the abrasive action of particles being washed around their sides. In some cases the heads of grooves were nearly confluent as though by extensive overgrowth of the lodged reef fragments by coralline algae. A prostrate Gelidium and an extremely fine partially corticated Ceramium, recalling Ceramium avalonae Dawson but with longer nodes and more slender throughout, grow in small concavities of the Porolithon onkodes along with Herposiphonia tenella (C. Ag.) Naegeli (Male thalli were found displaying the assymetrical nature described by Boergesen).

It should be emphasized again that there was little macroscopically visible on the walls of the grooves. The actual surface was usually covered with a characterless pink layer of coralline algae, which insofar as we could tell, was always morphologically undeveloped.

Here at Homohomo the opinion was developed that perhaps Porolithon onkodes is different from other crustose species of coralline algae in being able to develop rapidly, stand the brilliant illumination (other crustose corallines were usually restricted to cavities or shaded areas) and a certain amount of emergence with its attendent elevated temperatures and the osmotic changes inherent with desiccation. Furthermore, since this species was apparently extremely important in the life of the reef it was interesting to entertain for a time the idea that such a species suddenly arising and spreading very rapidly would aid in explaining some of the uniform characteristics of coral atolls.

2. Algal Ridge. The algal ridge at Homohomo was discontinuous (Fig. 4), being highest in what are being called incurrent areas and absent in what are being called excurrent areas. The surface of the reef, however, was a uniform pink coating of Porolithon onkodes throughout. Seaward the algal ridge descended from its maximal heights of eight or ten inches by a gradual slope (Figs. 2G and 3) onto the spurs and into the heads of the grooves. Inshoreward similarly it descended to the reef flat by a gentle slope, often a bit steeper than on the seaward side.

But few animals were to be found on the algal ridge. On the sea side, the most conspicuous of these was Turbo setosa, which as a substitute for a good breakfast was certainly reason for the relative scarcity of this species near the village. In numbers the animals on the surface here were principally a limpet (Acmaea, Siphonaria, or Helcioniscus sp. 11067*), a small barnacle (Balanus sp., 11068) and various worm or gastropod tubes which protrude through the algal cover which tends to overgrow all these animals. Microdictyon okamurai is the most conspicuous non-coralline alga and appears on both faces of the algal ridge. Particularly on the inner face of the algal ridge, but on the outer too, small spots of a blue-green alga appeared.

The inshore side of the highest part of the algal ridge at Homohomo was deeply pitted with many of the pits being occupied by pencil urchins (11088). These holes which the urchins were in were holes such as are "typically bored by sea urchins".

The smooth Porolithon onkodes cover of the algal ridge extends horizontally inshore from the base of the algal ridge from a few inches to a few feet ending in a rather definite border. This border, which usually could be located within a few centimeters, was called the reef ridge line (Fig. 3). It was one of the most consistent marks on the sea reef. Even opposite relatively large excurrent areas where no ridge was to be found this reef ridge line could be identified. In Figure 3, the algal ridge is shown in its full expression. Beneath the ridge four dotted lines are labeled a, b, c and d. These indicate the contour of the algal ridge in relationship to a groove bottom as one progresses from a strongly incurrent area to a less decidedly incurrent area, a, where the algal ridge is an almost level topped cuesta. Further along toward an excurrent development, such as the large excurrent area at the sea end of the Homohomo transect, successively profiles b, c and finally d could be expected.

*Doty & Newhouse collection numbers.

Throughout the algal ridge area one gained the impression that Porolithon onkodes was dominant, overgrowing everything. At its outer edge there were a few boring urchins (Echinometra species) but the holes on which these urchins were found were often nearly overgrown. The sea edge of the algal ridge was often cavernous in structure when broken into; as though the Porolithon had overgrown whatever was previously there and then the material had disappeared perhaps by solution. Perhaps, the superficial reef ridge material in time itself may disappear through weakening by such solution or boring and break away during storms. The cavernous areas were the habitats for a host of different species of fish and of crabs and other invertebrates rarely seen out on the reef in the daytime.

3. Amphiroa Zone. The reef ridge line is the position distinguished by a transition from the smooth Porolithon onkodes surface dotted here and there by patches of a blue-green alga to a surface dominated by an Amphiroa. This Amphiroa (11103, 11061) is similar to Amphiroa annulata Lemoine, but is somewhat larger. From observation this zone (Figs. 3 and 4) has three major characteristics: 1) form and position; 2) structure; and 3) its peculiar biota.

In form the Amphiroa zone is a flat that is quite like a turf and consists principally of but this one species. It formed a zone about five to fifteen meters wide.

It was observed that at low tide the Amphiroa community was out of the water. The remainder of the reef flat or reef pool area constantly submerged. At high tide the water coming in over the reef edge "divided" here. The water inside the inner edge of the Amphiroa zone passing on in over the reef flat and that over the Amphiroa and outside the reef ridge line surging back outward. Essentially the feeling was gained that this was the highest growing form insofar as tide level is concerned on the reef flat away from the high tide line at the shore itself. It was widest inshore of incurrent areas and most narrow, absent (or nearly so) across excurrent areas.

There was in a few places some development of this association to the seaward of the algal ridge on the largest and flattest topped spurs. For a series of such flat topped spurs see Figure 5 opposite the third island from the right, Kumekume, and just outside the line of breakers.

In structure the Amphiroa zone is a turf about three centimeters deep over a room and pillar structure (diagrammed in Fig. 3) about ten or fifteen centimeters thick. The cavities are the habitats for a myriad of invertebrate species and small fish. The important inhabitant insofar as the solid structure of the reef is concerned appeared to be a black "boring urchin", Echinometra (11095). This urchin can be postulated as being responsible for boring the holes in which it is found and thus causing the removal of algal material. Whether it consumes this material or not is unknown but should be looked into. The tops of the chambers or rooms of this portion of the reef are open to the surface. However, this opening is increasingly closed by Porolithon onkodes which tends to convert the reef flat here into a smooth pavement like that of the algal ridge area. The Amphiroa grows on top of this perforated algal pavement.

This zone is perhaps distinct vertically but is not so distinct horizontally. The biota here beyond the Amphiroa itself is not seemingly restricted to this zone, except for Caulerpa urvilleana which appeared with some frequency opposite incurrent areas as green patches in the otherwise pink Amphiroa turf. Corals such as those more abundant in the next zone inshoreward were present here with lower frequencies. Especially opposite incurrent areas Heliopora appeared most frequently. The Porolithon beneath the Amphiroa and especially the animals in general in the cavities below the active growing level of the Porolithon are essentially those of the next inshoreward and lower zone.

Turbo argyrostoma was rather sharply limited inside the reef ridge line and the major distribution of this species on the Homohomo transect was in holes near the surface of the Amphiroa zone. It did, however, occur in much lower numbers in the next zone shoreward. In the Amphiroa zone the boring urchins (Echinometra) were predominantly black urchins and in the more inshore zones a similar pink urchin became predominant. A most interesting association between the shrimp, Crangon frontalis, and the alga Lyngbya sordida, discussed with the other blue-green algae, (Atoll Research Bulletin No. 33), was most abundant in the cavities under the Amphiroa though occurring both out in the grooves and more inshore in the next adjacent zone.

4. Heliopora Zone.* At Raroia there was only what might be said to be an analogue of the Heliopora zone (Fig. 3) reported by Ladd, et al., (Jour. of Geol. 58, 1950) at Bikini. At Raroia, Heliopora (11107) was nowhere conspicuous and was found with any frequency at all only on the sea reef at Homohomo and there with regularity only inside the most incurrent areas. Perhaps, it would be better to term this a coral animal zone, without being too specific as to whether or not a hyphen should be placed between coral and animal.

This coral animal zone or Heliopora zone (Fig. 3) was essentially a band inshore of the Amphiroa zone achieving its maximal breadth opposite the incurrent areas and being absent opposite excurrent areas. On the Homohomo transect this zone was about 20 meters broad at its broadest.

In general the lowest levels in this region were fifteen or twenty centimeters below the level of the highest levels. The whole zone could be thought of as a series of holes with more or less incomplete rims. At the seaward margin the holes were smaller and more nearly closed over as the Amphiroa zone was approached. Inland, the holes were larger and the rim portions less conspicuous. Rim portions that reached the level of the Amphiroa zone were populated above with species of the Amphiroa zone. Essentially, perhaps, this coral animal zone extended right under the Amphiroa zone at least to the reef ridge line (Fig. 3).

The depressions or holes in this area were connected so as to drain toward the shore. Toward the seaward edge of the zone these drainage chains were inconspicuous. Inshore the holes were deeper, larger and more conspicuously continuous and almost no solid material reached the elevation of the Amphiroa zone. The impression gathered was that the rim material of the holes was more in the nature of the remains of coral organisms that had grown and died there, rather than being of the nature of material such as island conglomerate that has been removed by one process or another.

* [This is the "Montipora belt" of Newell, Atoll Research Bull. 36. Ed.]

The organisms identifying this zone by their distribution are Diadema (11093), Pocillopora (11069) and Acropora. Abundant, but less conspicuour are the same black Echinometra (11095) and such gastropods as Drupa ricinus (11069) and Cypraea moneta (often in pairs in small holes).

Essentially this zone is not exposed to emergence at low pool water level. The organisms in it extend upwards to the lowest water levels. Those which are mobile move so as to remain submerged. As an example, Diadema became rather active as soon as the spines became emergent. The spines were actively tilted this way and that until they came under the water surface or nearly under it. In correspondence with this observation is the observation that the size of the specimen is as a rule no larger than the depth of water at the lowest level in the particular pool area in which organism is stationed. That is to say the height of the animal was equal to the depth of water at low pool level. Seaward the specimens are smaller in correspondence to the smaller holes, which we presume to be due to the greater rate of algal replacement of the material removed by the boring of the urchins and other forces.

A rather interesting series of observations on the relation of the nonmobile animals, e. g. Pocillopora, Heliopora and Acropora, was made. These organisms apparently grow upward during periods of higher low tides and the corresponding higher low pool levels. On July 7 and 8 there was at Raroia, in correspondence with favorable weather, a series of exceptionally low pool levels (and tides). At this time, it was noted that the Pocillopora (11101) were more damaged by the exposure of their uppermost parts than were close by Acropora colonies (11101). The effect is one of killing the more exposed parts of these colonies. In correspondence with the direction of the prevailing wind and the sun the more northern edge appeared to be killed to a greater extent than the southern edge. Thus, one could find what appeared to be the dead base of the coral animal colony extending away along the reef to the north and at the southern end a crescentic living edge. This is illustrated in our specimens and photographs of Pocillopora (12168) and Acropora and another as yet unidentified coral animal (12169).

Not only are the animals killed at times when the pool water level is low but inducement of the turf-like nature of the algal cover over the highest portions of this zone is encouraged by the killing of algal tips. Caulerpa urvilliana, as well as the Amphiroa of the next seaward and elevationally higher zone appeared the next day after one such exposure with all the longer tips yellow or white and presumably dead.

It was in this coral animal or black urchin zone that the only living Fungia was seen on the sea reef. In this zone the black boring urchin, Echinometra, gives way in predominance to a very similar pink one (11905, 11130). This led to some discussion as to the distribution of these small boring urchins. To gather more information the transect method was resorted to and the populations of these small urchins in meter squares were counted. The results were, in brief, at the innermost meter square 2 black boring urchins and 13 pink ones (11131). At station #72, in this coral animal zone, there were 48 black ones to 9 pink urchins (11130). At this point the counting was discontinued for counting further out into the Amphiroa zone revealed the fact that the pinker boring urchin there had shorter thicker spines than the similar pink one discussed from nearer shore. Whether this was a third species of Echinometra, or a color form or an ecological form could not be decided and the most our results gave us was the information that there is only a gradual change in numbers across coral animal zone and added support to the idea that the area under the Amphiroa zone is closely related to the present area.

5. Pool Zone. Between the coral animal zone and the low pool level at the seaward edge of the land is the deepest part of the reef flat. In this region, there are few objects that protrude at low pool level. Essentially, this pool zone (Fig. 3) is a shallow channel fifty to sixty meters wide gradually deepening inshoreward to within a few meters of the shore and then further deepening gradually as it passes along the reef from behind the incurrent areas toward an excurrent area. The water flows downhill (Fig. 4) toward the excurrent areas. At low tide, the water is warmest in central regions of the pool zone (by about a degree on the Homohomo transect). It is colder at the inshore edge in correspondence with the cold water percolating out of the shore at low tide and again colder at the sea edge, but not usually as cold there as at the inshore edge. At high tide the water temperatures over the reef flat are rather uniform. The bottom is covered with a generally pink sandy layer. This, as at Bikini, was predominantly coralline algal material, mostly juvenile crusts, and sand. The sand itself consisted of foraminifera and clastic fragments presumably of the organisms living further out on the reef flat.

There was little in the way of algae sufficiently mature that could be identified, with the exception of some few clumps of Caulerpa urvilliana (11094) despite the fact that the pink color of the region seemed to result from a predominance of coralline algae. As sand increased, and the areas became less pink, it was pointed out by Morrison that there was a corresponding increase in micro-species. And in such sandier parts Strombus sp. became perhaps the most abundant of the larger gastropods. In less sandy parts where the corallines were more developed, perhaps the best molluscan indicator of this region was to be found in Drupa grossularia. This species of Drupa was quite distinct by its low form and yellow lip. With it, especially as these two species occurred nearer the excurrent areas or down the channel, Goniolithon sp. (11106) appeared as an epizootic coralline alga on top of this Drupa. Similarly this same Goniolithon appeared in the centers of the small (30 cm or so) microatolls resulting from death of the center of coelenterate coral heads.

It is of interest to list some of the other animals of this region. They all appeared to obtain their food from the algal species directly or indirectly. Heliopora (11107) was present in small numbers. Diadema (11093, 11092) was present in larger sizes and lower numbers. The largest appeared in the deepest parts of the pool very near the shore, there being fewer, however, in the middle of the pool zone. Perhaps, this was related to the distribution of water temperatures. Pocillopora and Acropora appeared here but in lower numbers. Near the seaward border, but very indefinitely so, there occurred a brain coral the colonies of which were so scattered that its distribution was very difficult to determine. Thais, a species of the armigera-group, was found here. Cypraea moneta, perhaps a better indicator of the next zone out was also abundand here. Cypraea helvola and C. caput-serpentis were here. Naria irrorate, a wee speckled "Cypraea" was suspected of living here, but its shells were usually always found empty and cast up with the coarser sand or in with little gravels in holes in the island conglomerate. Cypraea schilderorum in various forms or sizes was perhaps most typical of this pool region. Various cone shells such as Conus miles, C. debraeus and C. miliaris and a couple of others were most easily found here too, but were probably in more seaward regions equally but there harder to find at least in the daytime at low tide.

Toward the inner edge of the pool zone a tawny Porites thrived even in the rock basins in the island conglomerate where sand predominated, but always at least just below the lowest pool level. This species was so consistently placed that it was used along with a black Holothurian as an indicator on the shore of low pool level. Several other animals were conspicuous just below this lowest pool level too; such as two gastropods, a Vasum sp. and the very interesting small red marked Conus sponsalis. A pipe fish, which seemed to be an undescribed species of Corythorichthys was typically found here, especially in the larger of the pools at the edge of the island conglomerate.

As this inner edge of the pool zone is reached the color of the bottom becomes more brown and is more sandy in nature but is still definitely pinkish in contrast to the brown of the intertidal regions above.

6. Excurrent Area. Logically a discussion of this region (Fig. 4) follows the discussion of incurrent areas which have predominated this specific discussion of the sea end of the Homohomo transect so far. The largest excurrent area studied can be approached, for the sake of description, most logically by continuing our discussion as though passing along the pool zone, following the course of the water which flows through the pool zone and out through this excurrent region. As one moves from the pool zone opposite an incurrent area toward the lip over which the water pours out of an excurrent zone the bottom becomes increasingly smooth and toward the lip becomes longitudinally furrowed as though by gravel scouring.

We speak of little else other than bottom for the shores of excurrent areas are the incurrent areas to each side and the intertidal island shore area to be described below. This bottom is a pink pavement of what seems largely to be undeveloped Porolithon. It is, especially seaward, a bright pink; though inshore it is more buff to brownish. The low pool level of the excurrent area is marked with the same species of Porites and the deeper areas with Diadema.

It is the relatively inshore portions of the excurrent areas that we found the greatest development of Heliopora in formations termed by other atoll workers, microatolls. The centers of these microatolls were covered as a rule by coralline algae which are of the genus Goniolithon. Unfortunately the thalli are so oddly developed, or underdeveloped, that these knobby crusts could hardly be identified to species as specific determination demands not only fertile material but "normally developed" thalli.

Thus far, we have been discussing what might be called the "pool zone" of the excurrent area and it has in it all the organisms characteristic of the pool zone elsewhere but they are for the most part much less abundant. The little association of Goniolithon and Drupa grossularia, however, is more conspicuous here.

At what we considered the "pool edge" the bottom (Fig. 3 at "e") was quite flat and just beyond began dipping more sharply toward the sea. On this lip was a sea-facing arc of yellow soft coral colonies (Zoanthids) in a single series, spaced about eight or ten meters apart. And here the water level was least, even zero at lowest pool levels, and the water temperatures were highest. Beyond this level, there was rather constant mixing with insurging waves and the temperatures were measurably lower.

At the pool edge, the increase in slope toward the sea was accompanied by the longitudinal grooving described above. These grooves were various in size and while coursing in a general way parallel to one another they were to a small degree tortuous and anastomosing. As a rule, they were neither more than a foot broad nor a foot deep. Their bottoms were broadly rounded like pot hole bottoms. In the bottoms of these grooves, there was little other than the pink of coralline material. The ridge tops often had the same Amphiroa as described for the incurrent areas or a few of the other species of incurrent areas arranged in the same general serial order inwards from the sea.

Aside from the organisms mentioned already, Porolithon aequinoctiale appeared in such excurrent areas on the ridges between these grooves. It was very characteristic of such places and might be said to have been the best indicator organism. While not strikingly developed at the sea end of the Homohomo transect it was much more developed at the sea end of the large excurrent area associated with the channels at Kukina Rahi, at the south end of the same island and the islands called Kukina and Rare. Here it tended to close over the tops of some longitudinal grooves entirely. At Homohomo the thalli of this species were rarely more than mere undeveloped buttons perhaps four centimeters in diameter at best and two or three centimeters in height. Those in similar positions at other stations developed from bases of similar diameter but specimens returned to Honolulu were up to twenty centimeters tall and twenty-five to thirty centimeters in diameter at the flat top.

At the seaward end of the reef pool lip just discussed, the bottom pitched deeply and abruptly into the groove heads with little in the way of the overhanging development found so often in incurrent area groove heads.

No study of one of the channels between the islands (Fig. 5) was made in connection with the Homohomo transect. Channel information is collected in section VI.

7. Intertidal and Spray-Wet Shore. The intertidal region (Fig. 3) proper is approximately 22 centimeters high.* The solid conglomerated material is brownish in color, contrasting with the pinkish sandy, otherwise similar shore slope of the pool zone. This region varied in width as the slope of the beach changed all along the shore of the island and transect at Homohomo. Otherwise, it was relatively uniform in character. Thus, it and regions inshore of it were at times considered separately as an "onshore area" in contrast to the "incurrent" and "excurrent" areas. The surfaces here were in general rounded and convex in contrast to what they were in other places.

This approximately 22 centimeter band was usually a gently sloping shore rather continuous in slope with the pool floor. It was terminated inshore by

* [According to Newell's measurements 35 centimeters. Ed.]

a steeply pitched step or bench of island conglomerate (loosely speaking "beach rock").

In some places there were outliers of island conglomerate or pools cut to pool zone levels in the seaward edge of this island conglomerate bench. The outliers were in some cases apparently of the island conglomerate, but in other cases they were very obviously, from the uniform orientation of the fossils in them, fragments of reef. The outliers were found in various stages of undercutting with this 22 centimeter zone recognizable physiographically and biologically. In general as one moved up them vertically their surfaces were similar in biota to the shore.

Continuing inland and upwards above the intertidal zone above what may be mean high tide line the rock rises almost vertically for about two feet. The surface then levels off at about 100 centimeters above the low pool level. When rather dry, at times of low tide, this area is blackish and appears from the air (Fig. 5) as a black line around the island. It provides a good point of departure in interpreting aerial photographs (Fig. 5); as the seaward edge may be taken as high tide line.

The organisms insofar as algae are concerned were microscopic forms mostly unstudied yet. Those studied and identified have turned out to be blue-green algae, with some exceptions, and for the most part forms of _Entophysalis crustacea_ (see discussion under Myxophyta in Atoll Research Bulletin No. 33). This organism was spread all over the general area under discussion and was responsible for the black coloration of the rocks.

Between the low pool and level and about three fourths of the way to high tide line the common gastropod _Morula granulata_ with another gastropod, _Thais hippocastaneum_, occupied the remainder of the intertidal region up to the mean level of high water.

Migrating so as to remain just above the water's low surface between waves and especially conspicuous at night was _Nerita plicata_. This species could be expected as the predominant living organism of macroscopic size upwards for perhaps forty centimeters above the water where it overlapped the lower levels of the range of a _Tectarius_. Just below the levels of the _Nerita_ a carnivorous gastropod, _Cronia cariosa_, fed on the _Nerita_. The ecological implications here, especially in reference to migration of the _Nerita_, are most interesting.

Tectarius did not seem to be a species which migrated with the tides and its intertidal range was rather high. In fact, it was what might be called a spray zone, or low spray zone, habitant. It ranged at the sea end of the Homohomo transect about thirty-six centimeters above the ordinary wave splash line with the general lower level of its distribution being about thirty to forty centimeters lower.

Perhaps the most conspicuous feature of the supralittoral zone, or the shore just above high tide line, is the blackness of the island conglomerate induced by a heavy growth of blue-green algae. Both _Nerita_ and _Tectarius_ appear to feed by ingestion of this blue-green algal material. The animals living directly or indirectly upon this material were to a large extent migratory.

As discussed in greater detail in the floristic report on Myxophyta these blue-green algae appear to have several very important roles in the determination of the nature of the edge of this island conglomerate shore. Briefly, though one should consult the section mentioned for the details, these roles seem to be such as: softening of the limestone rock; inducing rasping by the snails; elevation of temperatures; protection of the rock from rain; protection of the rock from the buffering action of sea water while shifting the pH locally; and locally affecting the solution or deposition of calcium carbonate through their metabolic activities.

Inshoreward over the island conglomerate the black line so sharply distinct at the sea edge of the island conglomerate in the aerial photographs (Fig. 5) fades to a grayness over the exposed surface of the rock. That this is superficial was determined by breaking out fragments. The fragments were white where not previously exposed to the light. Similarly the undersides of stones lodged or laying on the surface of the island conglomerate were gray on the exposed surface, this faded to green just under their edges and the remainder of the under surface being white. For a discussion of this phenomenon see under Entophysalis in the section on Myxophyta.

The island conglomerate on the sea shore of Homohomo was a bench (Figs. 2G and 3) about two feet above high water line and sloped, with ridges parallel to the sea, somewhat toward the island mass. The Tectarius population dwindled soon inshore of the seaward edge of the rock and there was nothing found in the way of macroscopic life for a distance of perhaps fifteen meters. Inshore of this in crevices, shaded places and under rocks for the approximately twenty meters of the more-inshore remaining portion of the exposed island conglomerate what was taken to be Melaraphe coccinea, a littorine, was abundant. The same Entophysalis crustacea was abundant in the regions where the littorine was abundant, along with other blue-green algae, but there was nothing else macroscopic in the way of living material other than the larger transient animals such as man and birds.

B. Sea Beach

At the seaward extreme one saw only sand, at the landward extreme only bushes (Fig. 3). At first glance, one is inclined to distinguish two zones, one of beach and one of shrubs or bushes.

The edge of the vegetation on the Homohomo transect sea shore is not what was expected. There was no Ipomoea pes-caprae at all and Scaevola frutescens, so common on sea beaches on atolls elsewhere, did not extend out onto the beach. Indeed, though a search was made for it, Ipomoea pes-caprae was found on neither Raroia nor Takume. Superficially there appeared a zone of sand as a gently sloping beach extending inshore about 20 or 25 meters and rising about two feet. This is, perhaps, the area of which Wm. R. Taylor (Plants of Bikini 1950: 162) says "on the upper beach there was nothing" in the Northern Marshalls Island areas he studied.

A vegetation of Suriana maritima, Pemphis acidula and Messerschmidia argenta bordered this sand beach (Fig. 3) which was apparently so barren of living things. However, the small tropical lizards we know as geckos were to be found under the larger rocks that sat on the sand where its seaward edge ran out onto low places in the island conglomerate. Minute Suriana plants were to be found in surprising abundance growing scattered about on this sand, but were only found upon close observation. The surface of the sand was a buffy white near the sea edge and more gray at the inshore edge. It was indeed superficially apparently devoid of life. However, around footprints in the sand, a pale green edge could be seen about two millimeters under the apparently sterile surface. This proved to be a layer of blue-green algae (largely Anacystis montana and Entophysalis crustacea) two millimeters thick.

There seemed to be little else in this sand until one dug down about two more centimeters, where the sand was found to be damp, and where one was confronted with a maze of rootlets one to two millimeters in diameter. After digging one of these for a half hour and following it many meters one of our helpers, Tetohu, was put at following the root. After exposure, the irregular course of that particular root was from within two meters of the sand's seaward edge to the tree some forty-four meters away. From sampling of the sand area, it was decided that the roots of this particular tree, Messerschmidia argentea, occupied all the nearby sand area. This led to the postulation of root dominance of Messerschmidia over the many minute Suriana plants. This was an amazing dominance of the area for the roots spread over 40 meters, radially, while the tree top was only about two or three meters at most in diameter and height. The depth and diameter of this root and distance from the base of this tree are given in Table 1.

Table 1

Distance from tree in meters	Depth of root in centimeters	Diameter of root in centimeters
0.15	25	6.5
1.0 (?)	20	17
4.	29	3.5
10	25	2.8
22	18	1.8
30	14	1
35	8	0.6
40	-	0.4
44	2	0.1

Temperatures in the sand were measured and the coolest area in the sand was some few centimeters below the surface. The sand was hotter at the surface and at about sea temperature below this level. Table 2 is a resume of temperatures measured at different depths in the beach where Messerschmidia was growing.

Table 2

Position of thermometer bulb	Temperature in degrees Centigrade
Air above sand	29.5
Just covered with sand	33.5
Below the surface 2.5 cm	30
Below the surface 12.5 cm	26
Below the surface 21 cm	25
Below the surface 120 cm (pushed into wall of well dug one day previous)	25.5
Below the surface 90 cm (pushed into wall of well dug a few hours previous)	26.5 & 27

Temperature and related phenomena may be significant in controlling succession in the sere leading to what one finds on an atoll islet. Thus it is of interest to learn something of the temperatures tolerated by such pioneers among the bushes and trees as Messerschmidia, Suriana and Pemphis. According to Wm. H. Hatheway (personal discussion) Messerschmidia may be the only tree-like plant to occur natively on Canton in the Phoenix group. It seems likely that it may be the pioneer of this sort elsewhere as well. Thus we are prone to attach some significance to the lower temperatures found at about the level of the largest Messerschmidia roots. Certainly their significance, as well as the significance of such factors as water (set sand) and oxygen should be taken into account in studies of root biology in such beaches as this. Our apparatus, laboratory grade thermometers, did not justify any more detailed study of this possibly very important aspect of the environment.

The vegetated area at Homohomo and generally elsewhere too, was bordered by what could be called a bush zone. Actually extending over the bare ground between and even beyond the bushes in some places was Heliotropium anomalum but this was infrequent here. The bush first found upon approach from the sea was certain to be Suriana. It even extended out onto the island conglomerate at the end of the island. It extended over the sand of the beach, often as plantlets only a centimeter to two in height, to the inland edge of the sea shore island conglomerate (Fig. 3 and 5). In a short distance from the vegetational margin, but often this was hard to determine, one was certain to find Pemphis. Often a bush of Pemphis would occur surrounded by several bushes of Suriana.

Inshore of the Suriana and Pemphis one often found an almost exclusive zone of Messerschmidia. Again the Messerschmidia was diffused among these bushes or the most seaward other large plants.

The observed relationship of these two plants at Raroia appears to contrast somewhat with the observations of Fosberg (Atoll Res. Bull. No. 23) and Hatheway (op. cit. 16), but it may be that at Raroia the exposed conglomerate is a remnant exposed by hurricanes and the situations are only superficially comparable. Apparently Suriana could develop under rather rigorous conditions, in the sand and on the island conglomerate and tolerate the high temperatures, salt and lack of water experienced in such locations. However, it did not seem to be able to develop in the presence of viable roots of Messerschmidia. Indeed, on the beach where Messerschmidia was present there was apt to be no small nearby Suriana, only mature large plants. Thus, on the beach Suriana tended to be clumped separately from the Messerschmidia. Since we rarely found Pemphis isolated by itself, we gathered the impression that perhaps it or the seedlings were not tolerant of the high temperatures of the open sand and island conglomerate and was, thus, not such a pioneer. Apparently, there was not the antagonism between Pemphis and Suriana roots and the Pemphis may have been favored by the shade and lack of competition with Messerschmidia roots found in Suriana areas.

As the upper part of the beach was reached the particle size of the sand increased to that of small pebbles (IRIIRI) and gravel (KONAU KOREREKA). At the same time, there was a change in color from the buff color of the surfaces nearer the sea to grey and blackish near the trees. The color was not uniform, however. In the shade, as for example under bushes, there was less darkening and out in the open the sand was in places completely bound into a blackish cake by Entophysalis crustacea. The temperature here under the midday sun was 33.5° C. just under the algal mat. This was at least 1.2 meters above high tide line and far into the bush zone, thus, not one of the phenomena of beach rock formation, though perhaps related. Gravels and rocks in the sandy open areas in the Suriana belt tend to be whiter on top than those from further inshore and the sand between them was greenish below as in the case of the beach sand. The coloring material in all these cases seems to have been derived from Entophysalis crustacea with others, such as Calothrix scopulorum, Mastigocoleus testarum and Fischerella ambigua, contributing lesser amounts.

At the inner edge of the bush zone on the seaward end of the profile at Homohomo there was a gap covered by gravel and then various areas of Messerschmidia and finally the next to be discussed zone of Guettarda. The barren rocks from just out from under these trees and bushes are black-topped in general. Again the blackening was algal, and again in this case, Entophysalis crustacea and Calothrix scopulorum.

An interesting variation of this situation was studied on the leeward (sea) side of the Guettarda. The further from the Guettarda, the less black the rocks. This appeared to be like the reverse of a rain shadow. Perhaps, it was due to the protection from wind and thus lessening of desiccation in the "rain shadow". That it was not entirely an effect of exposure of the rock surface itself was indicated by the distribution of greenness on subsurface rocks. Under the blackened rocks near the Guettarda, rock surfaces were greenish to a depth of about seven centimeters, about four centimeters halfway across the (ca. 15 meter broad) area and only two centimeters at the seaward edge of the area, where the surface was but grey. Collections of these rocks were uniformly soaked in the laboratory to make sure the color differences observed were not due to immediately local field conditions.

Messerschmidia argentea, where bushes or small trees were present, arbitrarily was accepted as the innermost limit of the sea beach. The soil, such as it was, was the blackened gravel described above. This small tree was in general most dense near the Guettarda forest boundary and less dense toward the beach where it was irregularly scattered as isolated bushes. In this connection it is to be noted that on the transect area at Raroia Messerschmidia not only sprouts readily from stumps but layers readily from decumbent branches. The relationship between this zone and the next is described with the Guettarda forest.

C. Guettarda Forest

The greatest elevation of the Homohomo transect area was about eight and a half feet above high water line. In general the transect area was covered with Guettarda speciosa from just seaward of the highest part of the island to within perhaps five or ten meters of the high tide line on the lagoon shore, or perhaps more truly almost to the lagoon shore high tide line. This area (Figs. 2G, 3, 5) is the area supporting coconuts where planted. It should be noted that this area was a main source of Guettarda as structural timber for houses, outriggers, etc., in the village. However, the Economics of Raroia (see Danielsson in Atoll Research Bulletin No. 32) is another chapter and can not be taken up here.

Upon rare occasions Messerschmidia trees of relatively enormous size (one foot trunks and tops 25 feet high) were found in the Guettarda forest. More often mere skeletons of such trees were found. Around the edges of the Guettarda forest on the Homohomo transect while investigating the soil under Guettarda we found rotten prostrate stems of Messerschmidia. These were at a stage easily disintegrated by foot: similarly-rotten roots bound them to the ground. Such stems could be followed towards the edge of the Guettarda thicket, a distance of over twenty feet, and as the stems were followed they became less rotten and finally alive and revealed themselves to be the living though prostrate trunks of the Messerschmidia bushes that so tightly and characteristically here underly and protrude from the edge of the Guettarda vegetation. Undoubtedly the Messerschmidia is very intolerant of shading and it is this that results in its beachward displacement by Guettarda though the Messerschmidia grows best inland away from the beaches. Furthermore, since the Guettarda is further from the sea shore than from the lagoon shore and only on the highest ground one is led to the conclusion that it is not very tolerant of salt water.

The large leaves of Guettarda accumulate under the trees for a time, though there was little in the way of humus. Since they are cupped they often hold small pools of rain water. Having constantly in mind the mosquito and elephantiasis problems of the Society Islands (though these were respectively, neglegible and absent at Raroia) a great many of these small pools were investigated as possible breeding places of the mosquitoes. No mosquito larvae were found in the large number of such pools looked at. Similarly there seemed to be little in the way of pools formed by empty coconut husks or in the bracts of coconut inflorescences.

The profile (Fig. 2G) of the transect indicates a low spot in the center of the island. This corresponded to what was apparently a partially filled channel crossing the island mass and transect at this place. There was essentially little change in the vegetation other than a quantitative reduction though the rocks forming the soil were larger here on the surface. The bottom of this trough of gentle profile was covered with stones largely three to eight inches in major diameter. All were heavily covered with algae (Entophysalis crustacea, Fischerella ambigua and Schizothrix longiarticulata, 11292). Much of the gravel surface under the more dense stands of Guettarda was covered with leaves of this plant with occasional larger boulders (up to 2 feet in diameter) protruding through the leaf cover. The rocks at ground level, or perhaps more properly gravels since they were usually less than three inches in major dimension, were in these areas rather barren as were the tops of the larger boulders protruding through the leaf cover. However, on the vertical sides of some of the larger rocks black rather nostocaceous lumps appeared, probably due to Anacystis montana 11302 and 11304 with the algae apparent nearer the ground as browner patches of this algae and Anacystis montana, Schizothrix giuseppei, Entophysalis crustacea, and Scytonema crustacea, 11305. In less shaded and less leaf covered regions the rocks forming the surface layers of the soil and the sand had more in the way of discoloration by Calothrix parietina, Fischerella ambigua, Entophysalis crustacea, and a fungus (11290) but still the discoloration was nothing like that found nearer the shores.

The seaward beach consists of foraminiferal sand at its seaward edge. At the inshore edge it is coarser and has much fine gravel in it. Just inside the bush zone on the seaward edge the sand may be bound by an algal coating as described. Inside this region the sand is gone as though it had been washed out of the gravel. The gravel is coarser at this seaward edge and becomes increasingly fine as the lagoon shore is approached. At least there is, toward the lagoon shore, an increasing predominance of sand and smaller gravels; the larger gravel is perhaps there too. However, the sandy material toward the lagoon shore above high water line has a different appearance from that on the sea shore. This lagoon shore appears to be of clastic material, largely broken coral fragments in the broadest sense. The foraminiferal sand type is found in abundance toward the center of the island lagoon shore and below high tide line, but not toward the end of the island and the channel which separated the island across which our transect ran from the next island. In Figure 5 this change is indicated by the breadth between the trees and dark intertidal zone.

The sandier soil toward the lagoon shore was beset with pebbles closely placed on the surface. Blue green alga of rather gelatinous consistency (Entophysalis crustacea, Schizothrix longiarticulata, Anacystis montana, and Scytonema crustacea, 11302) coated the soil. While grey at the surface below about a depth of about 2 millimeters, where not covered with pebbles or rocks, the sand is green down to about the 2.5 centimeter level. This appears to be sheath material of Symploca kieneri (?), Entophysalis crustacea and Scytonema hofmannii (11285). The pebbles which cover the sandy soil in certain small discontinuous areas were thoroughly algalated with Scytonema hofmannii and Entophysalis crustacea (11303), often so much so that they appeared black.

Inshore of the lagoon storm ramps and around the nearest dug well shown (Fig. 2G), occasional nearly buried stones were exfoliating either from natural causes or because fires had burned over them. The exfoliated chips were uniformly covered with such algae as Entophysalis crustacea, Fischerella ambigua, Schizothrix longiarticulata and Scytonema crustacea (11284) on their outer surfaces. Perhaps these algae play some role in the breakdown of land laid rocks, e. g. in "boring" into the rocks and inducing softening or increasing the water-permeability of the rock. Other rocks that protruded in an otherwise more or less algal sterile area of soil that had been burned over were heavily covered with Entophysalis crustacea, Scytonema crustacea and Schizothrix guiseppei (11304). In fact these were the most heavily algal-covered rocks on the land. Rotten woody debris found here was heavily covered with Scytonema ocellatum (11297).

The soil on the Homohomo transect has been described in its superficial aspects above. Humus could be distinguished toward the lagoon shore. Even toward the center of the profile in a small rather dense coconut grove an upper A-1 zone of humus could be distinguished in which the only living things detected were fungus filaments (11288) and a lower brown sand zone, an A-2 zone, of little or no humus with the same fungus filaments (11287). Toward the sea the plants seemed to grow just as well without such humus, the surface being covered with the relatively coarse gravel described to a depth of a foot or more. The geological members of the party pointed out that this was very likely due to the finer material having been washed out by the hurricanes. It was suggested that the remaining algal covered coral fragments may substitute for the "A" soil zone. Roots were not found in the superficial few inches of gravel which were discolored by algal material but there were lots of them below a depth of about fifteen centimeters where pinkish-buff sand fills in between the coral fragments. Perhaps the essential products of this rare type of "A" zone was dark and about three centimeters thick.

A considerable amount of time was spent attempting to estimate the specific distributions of the various smaller plants along the Homohomo profile and in this transect area. The area had apparently been burned over repeatedly through the years, with the various irregular burned areas overlapping. This was both an advantage and a disadvantage in attempting to devise tentative explanations for the distributions observed. Perhaps the most clear observation was that Microsorium scolopendria, the ever common Polypodium-like fern, was coextensive in range with Guettarda, often growing on it and all about under it. It seemed to grow as well with the coconuts.

Other plants were less clear in their roles and distribution. Scaevola frutescens, which one normally expects on beaches and the common Euphorbia atoto, grew throughout the burned-over areas, with the Euphorbia apparently appearing first and perhaps being restricted to the Guettarda area. The Scaevola did extend beyond the limits of where Guettarda grew, especially toward the channel between the island across which the transect was studied and the next island, Tomogagie.. It did occur in numerous forms with different flower colors and leaf shapes and as large shrubs with 4 cm stems up to ten feet high. The forms in dense shade seemed more attenuated and viney and weak, while the best development was toward the more brightly illuminated margin of the Guettarda zone, where the Guettarda had been removed by burning or cutting, and in the inner areas where Messerschmidia could be expected to be most prominent otherwise. Morinda citrifolia was most dense in an irregular zone 30 meters broad, the lagoonward edge of which was about 30 or 40 meters from high tide line. Portulaca johnii occurred on this transect area where there was the most humus.

D. Lagoon Shore

1. Lagoon shore above high tide line. On the lagoon beach (Figs. 3 and 5 (between trees and first lagoonward dark line)) of the transect area it seemed clear that other things being equal there would be a condensed version of the transition from Guettarda to Messerschmidia to the bushes Pemphis and Suriana. However here local variations in the composition and form of the beach were more pronounced comparatively as this whole transition appeared to be restricted to a band about five to fifteen meters broad. The lagoon shore (Figs. 3 and 5) appeared here to be one that was building up and extending into the lagoon for there was loose material accumulated in front of the vegetation and an active reef below low tide line. Messerschmidia was present, however, only near the end of the island.

Morphologically the surface covered by flowering plants sloped gently toward the lagoon from an elevation of about three feet. This surface was rather solidly of the clastic sand and small gravels described above. While under the edge of the Guettarda or Messerschmidia the gravels were blackish and the sand dark grey, toward the lagoon the surface became lighter grey. This was due to a coat of Mastigocoleus testarum and Entophysalis crustacea (11286). The individual pebbles are darker on their upward facing surfaces with increasing prominence of Scytonema hofmannii (11303) and lighter on their surfaces facing the lagoon ridges and facing down.

The most inland rampart or lagoon beach ridge (Fig. 3) is flat topped and sloped uniformly down on both the landward and seaward faces. The top of the rampart is whitish in aspect and consists of mixed gravels mostly smaller than three centimeters in their largest dimension. The lagoon facing side of this upper storm rampart above the whitened gravels below high tide line are grey in gross aspect. Individual gravels are grey on their long exposed surface, brownish on their edges and greenish under their edges, fading away to white in the center if the lower surface is sufficiently large. Such stones were turned over just above high tide line and left in order to determine if this typically-grey coating would appear during the approximately two months we were to be there. These stones remained in appearance quite as when turned over.

The top of this major lagoon beach rampart (Fig. 6) is as uniform as though it were a small man-made grade and is the principal walkway along the lagoon shore. Below the lagoonward base of this rampart were two or three smaller ramparts of whitish gravels. The surfaces of these 2.5 cm minus gravels are harder than those of the grey gravels above when tested with a knife. It was observed that these gravels are worked over vigorously at times of high tide coincident with onshore winds at the lagoon shore. Thus it was concluded that the algae and any surfaces softened by weathering are kept ground off. There was little in the way of algae apparent here other than minute brown patches in cavities in some of the pebbles. Melaraphe, however, is common to such lagoon gravelly beaches just above high tide level.

2. Lagoon intertidal shore. The intertidal region (Fig. 3) of the lagoon shore on the Homohomo transect consists of a gentle slope of centimeter-minus gravels about 3.2 meters broad. Its extent was recognizable by the brown color induced by blue-green algae. It appears as a narrow dark irregular band in Figure 5 in the transect area, the inner sharp margin of which is separated from the trees by the light colored beach area. Away from the end of the island the size of the gravels was much less and Nerita polita migrated back and forth over it just landward of the usual wash of the waves as the tide rose and fell.

Behind each embayment in the lobed lagoon reef the intertidal area and lesser gravel ramparts above it were concave in form.

The only fishes seen here over this part of the shore were mullet at high tide. One red and brown shore crab was common here in the intertidal region. These crabs were often poised just outside the reach of the waves. The scientists and children delighted in their response to being tossed into the water. The crab, hesitating a moment and then orienting with the wave motion, would hurriedly scramble back up on the beach out of the water.

3. Lagoon subtidal shore. Along the lagoon shore, except where there was a gravel bank opposite a channel opening into the lagoon, there was a reef bordered by active coral animals. This reef shows as a linear irregular dark area opposite the island lagoon shores in Figure 5 between the intertidal region and the lagoon bottom. For the sake of discussion this reef can be divided into a number of zones, enumerated here as "A" through "G" and illustrated in Figure 6. They are taken up here as they were most extensively studied in conjunction with our study of this transect.

Geographically and morphologically "A" regions (Fig. 6A) are intertidal, and have been described above.

"B" regions are very variable and consist of a coralline algal pavement (Fig. 6B), coralline algal nodules or gravels. If unconsolidated the "B" regions consist of an even more gently sloping slope than "A" regions and are covered by gravels. Here, however, there are more small and more flat pieces and the gravel is coral chunks covered with coralline algae. This area was six meters broad on the profile. Other "B" areas to be noted are the Porolithon (11357) algal pavements which are quite flat (see below) in nature.

In this "B" area Cypraea obvelatawas found in association with the coralline algae. Latirus sp. was found active on the rocks at night in both the "B" and "C" zones. It was not found on the sea reef. Mullet on occasion swam over such areas as the "B" area and over the more lagoonward areas as well. Just below low tide line a holothurian was especially common in cavities in the coralline algal pavement and the coralline algae covered, fragment areas (Fig. 6B "N" and "O"). Under the rocks in this area is a white Isonomon along with an Arca (of the A. noae group (turkey feather ark shells)). Perhaps here hypo- and epibioses should be considered separately. Most of the animals found here are hypobiotic.

"C" regions are sand dominated flats (Fig. 6C) and are essentially the bottoms of reef pools. They show up in Figure 5 as the lightest colored region on the lagoon reef. A few living corals are found on rock chunks with a few holothurians (11361, 11363). This region on the profile is about four meters broad. This is the deepest part of the lagoon reef flat, but rarely over a foot deep at low pool level here at Homohomo.

Often Halicaries (a small wrass) hides among the coralline nodules or coralline covered rubble. Perhaps these fish are truly characteristic of this "C" region for the other fishes seen here occasionally are largely species much more abundant elsewhere.

While on the outer reef Strombus maculatus is common in the sandier parts of the pool channel region, in the sandy pool region or reef flat (Zone "C") of the lagoon shore two different species are common. These are Strombus varabilis and S. gibberulus. S. variabilis is quite similar to S. maculatus differing in having only obscure striations and these only in the central portion of the outer lip. In S. maculatus this striation is rather uniform and distinct all along the yellowish outer lip. Conus tulipa was collected alive in the deeper parts of the "C" region which were in connection across to the sand beyond the reef edge at about the "D" or "E" level, horizontally speaking. Conus eburneus is found with the two Strombus species mentioned above.

Beyond the "C" area one stepped up abruptly onto what we may call a "D" area (Fig. 6D) of dead coral the upper surfaces of which were often silt covered. This area was 2 meters broad and dominated by sandy patches, the coral occupying less area than the sand. In Figure 5 the "D" area is the light grey shoreward edge of the grey lagoon reef margin.

This was followed by an "E" zone (Fig. 6E) that was essentially an eight meter belt of the same Pocillopora (largely) as in the "D" and following "F" zones. Sand bottomed areas between patches of Pocillopora are minor in area covered. Living Porites was found around the edge of each Pocillopora patch. The aspect was often that of the inside of a microatoll top with many small Tridacna specimens and a general surface veneer of algal material. It is over this heavily "algalated" inner reef edge that Acanthurus triostegus (the convict surgeon fish) is most abundant. It does appear commonly both inshoreward and further offshore but in reduced numbers. It seems to feed on the noncalcareous algae that cover dead Pocillopora branches with a brownish coating. These algae are fine reds and Zonaria. In the sand-bottomed channels between the larger patches Acropora was common but the heads were small.

An "F" zone is to be distinguished (Fig. 6F) as a dense mass of coral fingers, again the same Pocillopora, alive at least on the lateral upper edges and not closed over at the surface. However the tops were veneered with algae, often of filamentous Rhodophyta. No sandy areas are to be seen in this three meter broad region. The spaces between the coral animal fingers were often plugged a few inches down with algal material, often Zonaria or Rhipilia.

Finally the very dark and narrow (Fig. 5) irregular edge of the lagoon reef was distinguished as a "G" area. While about 0.5 meters broad (Fig. 6G) the living coral was largely distinct heads on the reef margin and gently sloping downward from the level of "F". There was no algal veneer on the surface.

In the corals here there was found an Anomia-like clam boring like a Lithophaga. Leather urchins (related to the sea stars, Asteroidea, because of their ambilacral grooves) can be reported from here. On the reef patches these were found further in from the reef margin; perhaps in what is referred to as the D-zone above. Over the edge on protruding lobes of the lagoon reef the drop-off was vertical or even locally overhanging, but in embayments in the reef the drop-off was at about forty-five degrees to the sand or sediment covered bottom six to ten feet below.

The numbers of Acanthurus and Pomocentrus common inshore and on top of the lagoon reef are considerably reduced as one drops over the edge of the nearly vertical reef edge. This is ichthyologically the most varied habitat in the way of species and the most productive in the way of numbers. Surgeon fishes cruise along with the large parrot fishes audibly nipping off chunks of coralline algae. Accompanying them are often various large wrasses which, while they feed with the parrot fishes, have small teeth and seem to search for invertebrates among the algae. Unlike the parrot fishes, which always dash for open water or herd along the shore when disturbed, the wrasses may hide in caves or under overhanging ledges. The surgeon fishes common in this area too will hide in such places. They are frequently seen to swim along the face of the reef above a cave or overhanging place and right on under the roof or ledge. The observer is bound to be somewhat disturbed by the picture of the several different kinds of surgeon fishes then swimming along the overhanging surface wrong side up, or on their sides.

A cave fish fauna appears here of fishes which more or less continuously occupy these places in which the wrasses and surgeon fishes merely hide. Most conspicuous of these are the brotulids and large sea basses. Along with one of these sea basses there often moves a trumpet fish, an Aulostomus or a Fistularia. The unwary observer may swim down to take a close look at a brightly colored yellow trumpet fish and upon very close approach suddenly become aware of the very large well tooth dark colored fish alongside which the trumpet fish was hiding. Often just at that moment one is inclined, though the sea bass are harmless, to go to the surface for air.

A perhaps even more interesting association of two fishes is seen in the case of a blenny and the large parrot fish (TINGATINGA). Now most proper blennies are residents of the bottoms or piles of rubble, but this one accompanies the parrot fish swimming in an odd leaping fashion, shomewhat like a finch in flight. This blenny (commonly called a tick fish) is furthermore unusual in having broad longitudinal stripes of blue, black and red. When the parrot fish feeds the blenny presses alongside the parrot fish and cleans off its larger companion's beak-like jaws, teeth and head area.

In all there are more fish in the way of numbers and species here than on all the other parts of the lagoon end of the transect put together.

The edge of the lagoon reef, the "G" areas, drop abruptly (Figs. 3 and 6) to the fine white gently sloping lagoon bottom three to seven meters below. This lagoon bottom shows in figure 5 as a white area dotted with brownish (black in the figure) patches of coral and coral rubble. There was little in the way of life on this white surface.

In the sand bottom of this region fish rarely seen by others than ichthyologists dominate. These are fish which are quite peculiar to this region such as burrowing gobies and eels (Echidnidae, Moringuidae and Echelidae). In places of seclusion in coral rubble are many small blennies and the young of the larger wrasses and of the various eels, such as the unpleasant morays. Perhaps some of the most characteristic forms of the whole flat sand area are the lizard fishes. The water area of this region is characterized by many kinds and large numbers of transient forms most of which are apt to move out of the area as one approaches. This habit of the inhabitants makes them difficult to obtain by any but very careful placement of fish poison if they are to be taken at all by poisoning.

The area between the reef edge and the first lagoon patch reef (Fig. 3H) is essentially a channel frequented near the upper surface by the needle gars and half beaks which are also common to the areas further lagoonward. These forms are unusual shoreward of the reef edge. Further down in the water cruise various sharks. An occasional remora causes the swimming observer to look around nervously for its normal and more voracious shark buddy. Nearer the bottom characteristically there cruise carangids and large lutjanids.

One of the more ludicrous ichthyological wonders available to the swimming observer in this area is Dascyllus, a small black and white fish of the Pomocentridae. This fish swims in schools about the occasional branched coral heads at the bottom of the reef edge and out on the fine sand bottom. When some danger is anticipated, as from a suddenly thrust outward set of fingers on an arm, the whole school dashes into the seclusion of the branched coral mass only to drift out almost together in a few seconds cautiously and ready to sink into the coral should the pretended danger still threaten.

Along the vertical face of the coral patches and lagoon shore reef there is a bright blue small (4 cm long) fish, Chromis, which in small schools behaves in somewhat the same manner, but is more venturesome...getting as much as six or eight meters out in the lagoon.

A consideration of the distribution of variations on the lagoon reef as one might see them from the air (Fig. 5) is most valuable here. As seen from this Figure 5 the lagoon reef is not a regular band along the shore but a series of irregular lobes with, in the transect area, the lagoon face flattened and the flat face tending to face the wind. One of these is diagrammatically illustrated both in profile and as seen from above in Figure 6. This same lobe shows in Figure 5 as the third from the north end of the island. Even a very brief study of these regions and the reef in the lagoon reveals great similarity between the two. The individual lobes of the lagoon shore reef may best be considered as patch reefs of which the island shore forms one edge. As one goes toward an embayment between such shore-bound patch reefs, or lobes of the lagoon reef, there is a conspicuous change depending upon whether one is moving toward the end of the island (and the channel there) or along the shore toward the island center. The "C" areas are essentially separate pools and in line with the wind induced surface currents these drain out toward the center of the island lagoon shore over what is essentially a "D" area. The "C" area is closer to this down current edge of the shore bound patch reef, e. g., here the "D", "E", "F" and "G" areas are narrower or absent.

The "A" and "G" regions were the most consistent in composition and general character. The other areas varied widely from place to place, and cannot be characterized by any single profile study. In all positions in reference to these shore bound patch reefs the "A" zone remains approximately the same except for the change in particle size noted. The most conspicuous difference is in the qualitative character of that region termed here "B". At upcurrent sides of the reef patch (Fig. 6B "O") the "B" area is largely coral fragments covered with a coralline algal coating (11357 (but also see 11352)) and there are many holothurians between these fragments. Even further upstream, or between adjacent shore bound reef patches, there is a pavement (Fig. 6B "M") of coralline algal material (11364) just below low pool level. This pavement is about one meter or a meter and a half wide and nearly horizontal. Usually bordering this pavement on its offshore side and downstream side was an area (Fig. 6B "N") of close-lying coralline algal nodules (Porolithon 11366, 11365 and 11364). In Figure 5 the lagoonward margin of this pavement shows as a very faint dark line across the shore edge of the second reef lobe south from the channel north of the transect area. Usually over the upstream "D" and "C" areas there was a pink sandy layer over the tops of fragments, coral heads and microatolls that may be the same coralline algae (11361) as that forming the pavement in the "B" area, but very much less well developed.

Algae were found, further, under stones in the "C" areas where they were usually forms such as completely prostrate crustose Peysonnelia species and Ectocarpoid species such as (11353, perhaps really from "B" sandy areas). Spots of Sphacellaria were obtained here as well. Apparently such algae form the food for certain of the fishes, but no exacting food chains were worked out. Rhipilia, probably R. geppii Taylor, was common both under such boulders in the "C" zone and between the phalanges of the Pocillopora of more lagoonward areas "D" to "F". This species seemed active in trapping and binding sand in crevices and holes and may play an active role in solidifying of the reef material below the surface: the corallines being far more active, however, than Rhipilia right at the surface. Zonaria species, again, play a role if nothing else in overgrowing the sides of the coral animals and perhaps killing them by cutting off their food supply.

Along the lagoon shore further from where the active reef is near shore, that is near the center of the island shore where the "A" and "B" areas are sandy and indistinguishable from the "C" areas, there are little sandy points upon occasion. These (Fig. 5) are usually in line with reef edge configurations or beach rock outliers or other offshore features. The bases of these points while sandy themselves are often accompanied on each side by patches of Jania (11351 (see also 11350)). Where further offshore the consolidated reef flat was not so strongly overlain by sand there was a coating of Gelidium (11029) everywhere. Characteristic tufts of Lyngbya majuscula and Caulerpa serrulata (11010) are about the only macroscopically recognizable subtidal algae on the lagoon shores otherwise. Above low tide line on rocks are recognizable what appeared to be Ectocarpus indicus and some of the little ubiquitous but almost unidentifiable tropical Enteromorpha species.

Only about ten species of fish were to be found from the high tide line to the outer edge of the shore reef. This is a generally non-fishy area. Over the coral edge of the shore reef or as one approaches the edge there is a great increase in the number of the little (10 cm) black Pomocentrus nigrigans which with its head protruding from almost each hole in the coral greets the observer with a pair of very cold dark eyes. This small four-inch fish is common in fewer numbers outward and down over the face of the reef as well.

III. A COMPARISON OF THE OTHER AREAS STUDIED

To avoid needless repetition of observations the differences between the seven transect areas studied are recorded below in one series of sections rather than putting in descriptions of each transect area. The location of these areas and the profiles through them may be found in the diagrams, figures 1 and 2.

A. Sea Shore

Animal coral was not a conspicuous element anywhere visible from the surface of the reef. In general the Village or Raro reefs were the sea reefs having the most coelentrates on them. The sea reefs of other areas had far fewer. Nowhere were they apparently dominant and leading to increase in mass of the reef flat or reef margin; this seemed to be an algal activity. However, it appeared that a majority of the gravels and stones making up the islands were coelenterate coral material. Foraminifera were major contributors of the coarser sand found.

1. Spurs and Grooves. Flying just offshore along the windward reef from Kaea to Tahuna Maru provided the only opportunity of seeing much of the windward spurs and grooves. Occasional fleeting observations were made from the top of the algal ridge but these gave us at best but a qualitative appraisal. The reef flat, perhaps in correlation with the higher general surf level, seemed higher in elevation than that on the lee side of the atoll. The spurs in our photographs and from the shore at Tahuna Maru and Kaea appeared to be relatively broad and flat. Often they appeared to be narrowed toward their inshore end and thus the grooves between widened. They pitched on a rather even slope into the sea from the seaward edge of the algal ridge. Between the lowest wave trough levels aerial photographs indicate a rather rough and broken pasture of small coral knolls and very irregular channels.

The view obtained by swimming seaward down the gradually widening grooves was very different on the sea shore of Motufano (Tokerau), Homohomo (Fig. 5) and Oneroa. In these latter places at least for fifty yards seaward the grooves gradually widened and deepened. The surface of the spurs seemed to be sloping more steeply than the floors of the grooves. This gave the impression that these two features would blend into a coral plane a few hundred yards off shore.

While little sampling was feasible, the surfaces of the grooves and spurs everywhere seen were pink as though covered by Porolithon. Certainly those of Tokerau, Raro and the village area investigated by swimming were covered by this genus. In a very few places Pocillopora was found on the inshore tops of the ridges below low tide line.

While almost all the Porolithon observed appeared to be P. onkodes in one place on a ridge top below low tide line a specimen of P. aequinoctiale was obtained. This is an interesting record, though considered anomalous at the time, for this species appears to be a dominant species in similar areas at Johnston Island (Novelty shoal).

At Gake and in a few other places the spurs in addition to P. onkodes had Amphiroa (11488) on them if their shoreward end was broad. There are rare patches of poorly developed P. ?gardneri (11485) on these ridges and what appears to be the same species still more poorly developed occurs behind (inside) the algal ridge.

The surge channels in places extend through the first of the ridges of "beach rock." In places they are very broad (10M) between the algal ridge and the exposed island conglomerate and they are ca $\frac{1}{2}$ to 1M deep. Their bottoms are scoured but wide places have corals in them. Coral were not conspicuous otherwise on this transect area. Essentially the same situation prevailed at Kaea, but here the algal ridge was less often cut through by the grooves. The grooves themselves left us with the impression of being shallower and more numerous, and from the aerial photographs, more irregular in their courses.

2. Algal Ridge. The reef ridge area was defined on the profile as the surfaces of the reef margin above low pool level. The ridge as a whole protruding from the pool bottom level might be an at least equally useful unit. It is felt that at Garumaoa, the level of the reef ridge line and the upper level of the boring urchins or the seaward edge of the Amphiroa zone (Fig. 2E) is at the base of any reef ridge that may exist as defined in the field. Perhaps the pool impounded by a well developed algal ridge changes the habitat so as to favor the urchins which seem to be the most active agents in destroying especially the inshore edge of the algal ridge.

At Gake, and Gagieroa there seemed to be a so-called "backridge trough" rather than the flat Amphiroa zone recognizable elsewhere (Fig. 3) at Raroia. This was often true elsewhere in Kereteki and to some extent at Gake, Takume. This seems to imply that perhaps the reef ridge should be defined as the seaward raised area on the reef which impounds a pool and gives the reef flat the characteristics of a tidepool.

As one proceeds along the reef ridge at Gavarivari (Fig. 1), the general level of the top of the reef ridge changes. Centrally along the island shore on the profile (Fig. 2A) the ridge was about 30 cm high (above low pool level). That opposite the northern half of the island, while not sharply lower than opposite the southern half is about a foot lower. This lower reef ridge is more thoroughly "algalated" from its pool edge to below its seaward edge. Still from a distance it is uniformly pink in appearance.

The outer half of the Gavarivari reef ridge is covered with P. onkodes (11926). Microdictyon okamurae and a fine Jania sp. are characteristic epiphytes on the P. onkodes. A Laurencia-like alga (11926) is common in small hollows and holes. The more eroded inner half of the ridge is higher than the outer half and appears to be more actively covered (11925) by non-calcareous algae at the surface than by P. onkodes. Cypraea depressa (11927) and C. mauritiana (11927) were found on the inshore slope of the reef ridge down to within 15 cm of the pool level. The genus Drupa was represented by numbers of D. morum and D. ricinus. Many vermetids (11919 = J.P.E.M. 2221) were seen. It seemed that even Turbo setosa was much more common on these inshore slopes. The latter delightfully comestible species as well as the purely scientifically interesting species were not searched for diligently on the seaward slope of the reef ridge for the usual reasons applicable to research on windward reefs.

The higher reef ridge generally opposite the south half of Gavarivari, was in correlation with somewhat different appearance. The inshore half of this ridge was yellow brown in color. This coloration is given by what appears to be blue green algae, at least in part Rivularia polyotis (11919) on erect spines of rock left by the erosion of the ridge material. In places the algal coating is sufficiently developed to look not unlike that covering the sometimes similar spines of rock just above the pool level at the inshore side of the reef flat or inshore margins of the reef pool.

There was little or no general algal cover of the rock here. The only algal materials at all common were isolated tufts of a Dictyosphaeria and a Microdictyon (11919). On the larger Drupa shells and dead Vermetus shells there were obviously fine algae but these forms did not cover to such an extent that the ridge appeared to be dominated by non-calcareous algae (and different species were involved) as on the inshore part of the reef ridge further north at Gavarivari.

Similarly there were few living animals in sight. Drupa ricinus and Drupa morum were found only on reef ridge pot hole bottoms and on their sides.

Low on the inshore edge of the ridge the reef is pink with various algae, but predominantly P. onkodes. (Amphiroa (11917) is not a meadow hereabouts but is found in frequent patches or tufts irregularly two to four centimeters across. This is the only area on the atoll where Centroceros was recognized in the field as a consistent dominant and these areas were small bright red patches of uniform appearance. Laurencia formed skimpy coatings and small tufts in the hollows and holes of the general P. onkodes cover.

The seaward half of the higher ridge area is, at most, perhaps 9 to 12 centimeters lower than the inshore half. This outer reef area was bright pink in area and a priori appeared to be a suitable area for the surf dwelling P. gardneri and related forms. However, in no place at Gavarivari or Gagieroa was there any trace of living Porolithon gardneri or similar species. On Gavarivari, however, were found the greatest concentration of boulders in the island structure which were fossil remnants of such species.

One "clump" of what appeared to be P. aequinoctiale was lost when pried loose in a surge channel bottom. Turbo setosa was common on this higher ridge as elsewhere. No living Cypraeas were seen on this higher part of the ridge either on the inshore or offshore half. A medium sized dead vermetid (11919 = J.P.E.M. 2220) was abundant coiled flat on the reef ridge pavement. It was different from the vermetid (11927) on the lower reef further north.

The algal ridge at Gake (Fig. 2E) has large (25 cm) pits that are interpreted as evidence of erosion by solution.* The outer high part has fine algae (Laurencia 11487, 11491) and arches or domes of P. onkodes (11486). The algal ridge at Gagieroa was not only pitted on top but it appeared as though it had been a rather high ridge now truncated by erosion.

In general as the Garumaoa village area was approached from Gake through Tokerau the algal ridge became less ridge-like and more of a cuesta. While still more often little other than a cuesta, as one proceeded southward to Oneroa a ridge was often present. This ridge when present was very often deeply pitted on the inshore side by holes often occupied by pencil urchins. There was little algal cover in such places beyond a general pink calcareous coating taken to be undeveloped P. onkodes.

The sea reef in front of Tetou (Figs. 2B and 2C) is covered with non-calcareous filamentous algae. While it seems to possess an impressive algal ridge the only calcareous alga in sight that appears alive is a fine Jania intermixed with the non-calcareous filamentous algae.

As one progresses along this ridge northward there are some clear but inconspicuous changes seen. Firstly, there is an increasing abundance of Bryopsis pennata (in 11851-11852) until it forms conspicuous turfs of a square meter or so in area. This then gradually became less conspicuous and a branched matted Codium (11860) became common only to disappear as there came into prominence in turn Neomeris (11857 etc.). While at first found only in holes, a tenth of a kilometer further on it lined many of the larger cavity rims. This species was small and ringed and when small hardly calcified. A half kilometer further along the Codium was gone and Neomeris is scarce. Then a Dictyosphaeria (1 cell thick and hollow) became common. At about this point almost 3 km. north of Tetou, there were the beginnings of a conspicuous display of P. onkodes (11859). This was first seen around low edges of excurrent channels, but further on, it extended to local algal ridge prominences. The P. onkodes was never conspicuous though and possibly because of extreme erosion here it was on its way out (i. e. here there was merely a less dead Porolithon ridge than directly opposite the village of Tetou).

One kilometer south of Tetou the algal ridge has P. onkodes (11846) showing in about the same degree as 2 or 3 kilometers north described above.

At Kaea the reef ridge area and more seaward areas were pink with P. onkodes. Turbo setosa was common. Little else was visible. In one of the deepest of the excurrent channels through the algal ridge a few coelenterate corals were to be seen; none was seen on the reef flat, the algal ridge or elsewhere. The algal ridge (Fig. 2D) was sloped very gently into the pool on the reef flat. A few miles south, at Tetou, the reef ridge was much the highest seen and there covered with a coating of non-calcareous algae and sharply distinct from the reef flat area. Here at Kaea the inward edge of the algal ridge area was hard to locate because of the gentle even slope and the lack of macroscopically distinct indicator organisms. The rather uniformly high edge was cut into from the seaward face by numerous low surge channels, only a very few of which extended through.

* [Considered by Newell to be mainly an effect of gravel scour. Ed.]

At Mataira and in the same geographic area of Takume Atoll the margin of the reef gradually sloped upward resembling "Reef type II-B-(1)" at Bikini as depicted by Tracey in his figure 1 (Bull. Geol. Soc. Amer. 59, 1948). Here likewise were found the only good cases of grooves extending into the reef flat and overgrown at the surface to any extent. One of these into which we could dive was perhaps 20 meters long, five meters deep and from 0.1 to 2 meters broad.

3. Reef flat. The reef flat (Fig. 3) is considered to be a tidepool biotically related to the sublittoral region. The seaward edge of the black coating of blue-green algae seen in aerial photographs is the inshore margin. This margin is broken (Fig. 5) by the complete channels between the islands. The seaward wall of this pool is the algal ridge.

The narrow heads of grooves frequently extend from the sea through this wall on the windward shore. These are, then, related to small localized excurrent areas. More generalized larger excurrent areas connect the reef pool to the sea as the village and pass area are approached. It may be the single pass rather than the leewardness of the village area that is responsible for this difference in connection between reef flat and sea on the windward and leeward shores.

At Gavarivari there is no division of the reef flat into Amphiroa, or boring urchin zone, etc. The whole reef flat is characterized by the lightly sanded pink pavement and black holothurians to be expected in channel pool areas. This outer part of the reef flat at Gavarivari could be interpreted as a situation where there was a poorly developed back-ridge trough. No corals at all were seen on the reef or reef flat there. Only two Diadema specimen were found and a very small black shrimp was found under circumstances that led us to believe it had come from around the bases of the Diadema spines. The common black-tipped sharks so timid near the village would move right in head on when they first sighted (smelled) something. They were relatively easily repelled, however, if one jumped on them.

In this zone at Tetou, just inside the reef ridge Symploca hydnoides was found as soft wisps with gelatinous centers.

At Gavarivari the inner part of the reef flat was distinct from what has been described above as the pool area. Under rocks near the shore edge of this area are many large boulders 30 to 100 centimeters in diameter and usually rather thin proportionally. Under these there is an aggregation of small gravel and even sand. These particles were found to be variously cemented to the large boulders, to the reef pavement, and to each other. These shaded surfaces are often coated green and often supported various non-calcareous algae (11922) which seem to be but poor developments of those species found on the reef margin or algal ridge.

As animals perhaps the most abundant macroscopically was Morula granulata (M. tuberculata in Tinker's very useful book). Under rocks was a variety of small Cerithium-like gastropods among which Planaxis? zonatus was the most common of these "smaller than usual collecting size" shells. One shell of Morula uva (called M. nodus in Tinker's book) was obtained. One shell of Imbricaria punctata was found. This was unusually plain white but the appperture had the violet anterior tip to the columellar surface characteristic of this species. One small specimen, about one centimeter long, of Conus miliaris was found under a stone. The above six molluscs (MD 11923) are in the U. S. National Museum under the number JPEM 2218.

Locally near the shore at Gavarivari and Gagieroa there were clusters of Chama half-shells protruding from the reef pavement. No living Chamas were seen here. Few of the other characteristic animals of such regions were seen alive. For example, after some searching, a few Conus sponsalis were seen but of the shells found only one was alive. Few other gastropods were found here (11923).

Drupa grossularia, common in leeward reef pool zones at Raroia was not found at all on the windward reefs of Raroia. This species was also uncommon on the windward reefs at Bikini, only about a half dozen specimens being found according to Morrison.

As hermit houses (11931 = JPEM 2222) Bursa bufonium, Thais hippocastaneum, Vasum sp., Strombus gibberulus, S. mutabilis were common. Both Strombus gibberulus and S. mutabilis normally at Raroia are lagoon specimen but Morrison found that at Bikini S. mutabilis occurs with S. maculatus on the sea reef flat. Cronia, Tectarius, Nerita, Cerithium, Polia, Morula and Mitra litterata occurred. The last four, while hermits, are characteristic when alive of the inshore portion of the reef pool area. Cronia, Tectarius and Nerita are characteristic of the shore between tides or above the tides in the case of Tectarius. Vasum and Bursa are probably characteristic of the more seaward pool areas.

On both the Mataira (Figs. 1 and 2F) and the Gake (Figs. 1 and 2E) transect areas the inshore edge of the reef flat was, in general more shallow than the outer part. The bottom near high tide line was conglomerate rock with large shallow pits on the surface. In these there was very often a flattened stone. As the observer moved seaward these pits were more and more frequently fused forming chains of pools through which the water drained as the pool level lowered. Toward the seaward edge of the system the walls of the individual pools gradually were reduced to merely sharp pinnacles a decimeter or two high. At Mataira, these disappeared about halfway across the reef flat. The outer part of the reef being smooth to its sea margin.

At Gake the inner half is so irregular in elevation that one has the effect of a series of incomplete small reef pools 25 to 60 cm in diameter. The bottoms tend to display the reef pool characteristics of being covered with a fine coating of sand and what is taken to be juvenile encrusting coralline algae. On this bottom there were to be found many specimens of such species as the Strombus maculatus, Conus ebraeus and C. sponsalis characteristic of the pool area of the sea end of the Gavarivari transect. Cypraea moneta and some of the characteristic Drupa species (and D. grossularia as hermit shells) were also seen. The walls of these pools and the lowest of the ridges by their color and general appearance seemed to represent the shore between high tide level and low pool level.

In contrast almost the whole reef flat at Kaea was a pool zone with little other than a smooth coating of coralline algae visible. At Kaea there were many relatively small reef boulders, but they were not as numerous as they were at Gavarivari where there were larger ones as well.

4. Intertidal and Wave-wet Shore. This area is divisible in general into a lower yellow zone and an upper black zone. The junction between them was considered after observation to be high tide line. In general on solid shores the intertidal or yellow zone was a gently sloping consolidated shore about 20 or 30 centimeters high and two meters broad. The black zone above was usually a precipitous drop of 115 centimeters (Matajra, Fig. 2F) or so over the edge of a consolidated rock bench (PAKOKOTA). The black zone also extended as a coating inshore over the upper surface of this bench for a variable distance.

At Kaea (Fig. 2D) this yellow intertidal zone was largely coated (11900) with Entophysalis crustacea and Plectonema nostocorum. At Tetou (Figs. 2B and C) this yellow zone was coated with the same Entophysalis and in addition Calothrix aeruginea (11321). At Tetou the yellow zone rocks were in places covered by a fine brown fuzz (11322).

On the transect area at Gake the walls of the pools dominating the shoreward part of the reef flat protruded from the low pool level water surface. The algae (11483), Entophysalis crustacea, Rivularia polyotis, Plectonema nostocorum, Calothrix scopulorum and C. crustacea, coat this protruding rock a yellow brown. Thus, these protruding points and pool walls were listed as intertidal. The presence of a few specimens of Thais hippocastaneum as hermit homes on the pool bottoms and the presence of Morula granulata support this hypothesis. The bottoms of these pools were the sandy pink of reef pool areas.

On the Oneroa transect (Figs. 1 and 2H, I, J), while there was no specific or definite "high tide line" fish fauna otherwise at Raroia, there was in the splash region on the reef boulders a species of blenny during low tide periods. This blenny was loath to return to the aquatic environment even when disturbed. Perhaps the restriction of this fish to such a region is an indication of a different species of algal food though a priori it might as well be some other restrictive factor.

The fauna in the intertidal regions was perhaps richest in the village area (Garumaoa) and poorest at Oneroa. Gake held an intermediate position, for example, the blennies and gobies were those of the above stations, but some species were absent...i. e. the fauna was attentuated from that at Garumaoa but richer than Oneroa, both in reference to numbers and species. No fish were found intertidally in the Gake sea reef region other than the common white spotted rather innocuous Gymnothorax picta which moves in and out with the tide as did Acanthurus triostegus. However, rare this eel was, it was definitely more aggressive or curious here and at Kaea. It would follow a passerby and go so far as to bump its nose into a proffered shoe sole before scurrying for a rock to hide. At Gake none of the "splash zone" blennies could be found. On bolder sea and channel shores a sea slug (Onchidium sp.) and a greenish half-shelled tectibranch are to be found in the lower part of the intertidal area above the pool level near shore. While seen only at Oneroa and Garumaoa it is presumed that these two occur in similar places all around the atoll.

At Mataira (Fig. 2F) the large pits of the reef pool gave way to small pits with relatively blunt topped walls in the intertidal zone. These were the sizes thought bored by the resident gastropod species. Above high tide line, in the black zone, the wall tops on these holes were sharper.

Above high tide line the black or spray zone may be recognized by its color when dry. On Oneroa (Fig. 2H and I) this was largely algal material (11675), Entophysalis crustacea and Brachytrichia quoyi, that is dark brown when wet. Here at Raroia (11675), in Massachusetts (7273) and in the Philippines (10937) and elsewhere this Brachytrichia appears just above high tide line, often with the ecologically related Calothrix species.

Three phenomena are notable in relation to the "black zone". 1) At Mataira there were numerous pools of fresh water on the surface, often about forty centimeters broad and four to six centimeters deep. These were fresh water at the time of observation, though within ten meters of the sea edge of the rock platform. 2) Many large reef fragments, up to 100 cubic meters in size, were strewn on the rock platform here. Some had several kinds (Timonius polygamus, Portulaca johnii, Boerhavia diffusa, Heliotropium anomalum) of flowering plants growing on them. Inshore from each there extended a bar of small gravel. 3) From the sea edge the platform so sloped down toward the lagoon that it would have about reached the lagoon level at the lagoon shore. At the sea edge of the unconsolidated island material the surface of the platform was leveled and found to be 30 cm lower than the sea edge. This slope was commonly, but not always, observed in other areas of Raroia.

The highest protrusions of the inshore reef flat pool walls at Gake, often only the size of a fist, above a certain level were colored black. Such black "algal" material was collected (11484) and proved to be Entophysalis crustacea, Rivularia polyotis and Plectonema nostocorum. This same black algal material, predominantly Entophysalis crustacea and Calothrix scopulorum (11439), covered the so-called spray wet zone (Fig. 3) on both the beach boulders and gravel (Entophysalis crustacea alone 11437) near the shore. This was accepted as evidence that these protrusions were in essence above high tide line.

The blackness of the black zone at Tetou (11318, 11320) is a coating, in addition to the dominated Entophysalis crustacea, composed of Calothrix pilosa, C. scopulorum, Mastigocoleus testarum, and Plectonema terebrans.

At Gake only a few specimens of Nerita were seen; too few to decide upon their zonal affinities. Tectarius was observed only on the beach boulders in the upper part of the black zone. The shore was a gravel ridge and this nature of the shore in the vertical range of this species (and perhaps as well as Nerita) might be cause for the apparent absence of the species there. Much of the splash zone gravel is white at the seaward foot of the high gravel ramps, probably due to movement with each wave that washes this high.

An interesting habit was noted at Gavarivari and elsewhere, among the hermit crabs. One is puzzled by local accumulations, often of one species of empty gastropod shell. Often these are of but one size. They are found on rocks a few centimeters above high tide level. There were many such accumulations at Gavarivari. But here it was found that many of the shells had hermit crab occupants and many of these were aperture side up. Just what the explanation is is not clear, but it did seem that the hermits had crawled up themselves, perhaps just to sun themselves. It is to be noted in passing that the common red land hermit crabs similarly accumulate.

The black zone at Gavarivari (Fig. 2A) and Kaea (Fig. 2D) is very broad and the surface, while plane, slopes gently toward the high tide level down about seventy centimeters. The grey beach-rock flat inshore is essentially level. The black zone here instead of being essentially the outer edge of a consolidated beach rock platform as usual, is composed largely of loose and semi-cemented-in-place flat stones embedded in sand, each of which tilts into the sea. The blackened material (11928) appears to be Entophysalis crustacea. The stones tend to be green around their sand embedded bases and on their undersurfaces when loose. The whole is apparently seated on a consolidated platform of homogeneous rock at about the pool channel bottom level. This is revealed in the exposure of such material in the frequent small pools in this black region. The basement rock, though, instead of being pink and sanded over as in the pool channel is blueish and rather clean. The blueishness is about the same blueish color as that to be seen around snail borings in the black zone, for example, in the PAKOKOTA at the sea end of the Garumaoa transect. At Kaea much of this boulder covered flat extended up to levels where the rock was only grey.

While their shells were found elsewhere no living Tectarius, Nerita or Melaraphe were found at Gavarivari; though a brief fruitless search was made for them. Tectarius was found 4.5 feet above the pool level on the reef boulders though and these specimens (11931) were turned in to Morrison (JPEM 2222) for identification. Various gastropod and pelecypod shells (11931 = JPEM 2222) were found in this region and on them were various small algae (11930). On the rocks at and just above the high water level were found (11932) Rivularia polyotis along with the ubiquitous Entophysalis crustacea.

Above high tide line in the black zone at Mataira and also at Oneroa (Fig. 2I) exfoliation was common. The exfoliated pieces coming off were from a few centimeters to almost a meter across. Exfoliation was noted elsewhere along the lee atoll shore but was not recorded from the windward shore.

At Gake and occasionally elsewhere on windward or exposed shores the black zone was bordered inshore by a gravel rampart. These were most interesting. The sea facing base of the gravel rampart was filled with sand. This sand in the uppermost part of the black zone was bound by Mastigocoleus testarum, Plectonema terebrans and, as might be expected, Entophysalis crustacea (11446). This growth was permeated by numerous fungus filaments. Flat areas of beachrock seaward of the gravel ramparts, where these curved shoreward at their ends, were often covered by fine sediment bound into pinkish crusts. These were quite stony when nearly dry. The algal material (11436) which was the biological part of these crusts was largely Schizothrix longiarticulata, Entophysalis crustacea and Calothrix scopulorum.

5. Spray-wet shore and sea ramparts. Arbitrarily the areas (Fig. 3) between the algally blackened spray wet region and the vegetated areas are biologically treated here as "sea beaches." These differed greatly in nature from place to place from loose gravel ramparts to boulder fields to conglomerated rock benches bordered shoreward by sand or fine gravel. In the aerial photographs (e. g. Fig. 5) the beaches appear white, sometimes dotted with black indications of shrubs. The rock benches appear as radially striated greyed areas just shoreward of the black zone.

In the Tetou and Gake transect areas the sea beaches were gravel ramparts at their seaward edges. This was also true of the more southern more exposed ends of Garumaoa and some of the larger islands in Raro. As an example note the successive profiles J, I and H in figures 2 and 9 of Oneroa. Figure 2J represents the profile at the exposed part, the bend, of the island. Figure 2I a mid region further north. Figure 2H a profile across the northern protected end of the island. As this series was passed through (Fig. 3) the sea beach became less gravelly and at the seaward edge it became a conglomerate bench (PAKOKOTA).

The top of the gravel ridges, or ramparts, everywhere is grey and there was (except at Tetou) only a gently curving slope inshore to the tree-covered area. The whole beach area was dominated by unconsolidated grey gravel to inshore areas where _Suriana_ became dominant. Only one flowering plant was ever found on the gravel ramparts. This was _Ipomoea tuba_ at Tetou. The local people insisted that some of these trailing plants had blue flowers but none other than the typical _I. tuba_ was seen. _Ipomoea pes-caprae_ was not found on either Raroia or Takume and a special search was made for it.

South of Tetou at Gagieroa and Gavarivari, a large amount of the sea beach was small (25 to 50 cm) boulders. These were cemented at lower levels onto the consolidated platform described above. At higher levels they were loose. A large proportion of those (e. g. 11845) far inshore had the appearance of a _Porolithon_ of the _P. gardneri_ type. No such forms were seen on the reef margin even after repeated search. Such algal boulders were not at all conspicuous on the lee shores (Tokerau, the village area, or Raro).

The black zone organisms spread over the consolidated bench (PAKOKOTA) to variable distance shoreward. Splash from waves was seen to wet this area upon occasion. During rains the area is washed quite free of salt and small pools of fresh water accumulate (determined by taste). In the vicinity of the sea edge these pools last noticeably longer than those formed further inland where the PAKOKOTA is merely grey. Whether this is due to greater porosity of the rock, higher temperatures or lower humidity or some other cause as the sea edge is left behind was not determined. The floor of the pools near the sea edge at Mataira were coated by a black soft scum called KOPARA (11372, _Calothrix scopulorum_ B. & F., _Entophysalis crustacea_ (J. Ag.) Dr. & D., _Anacystis dimidiata_ (Kutz.) Dr. & D., _Schizothrix lacustris_ Gom.) or a floating soft mat. Around the pools at the landward edge (Q in fig. 9) of the beach rock, at Oneroa, the surface was grey when dry and black when wet with _Entophysalis crustacea_. The blackish coloration of the alga found on seaward edges of the rock surface (R in Fig. 9) was the ubiquitous _Entophysalis crustacea_ and _Brachytrichia quoyi_.

Occasional boulders on the shore were sometimes sufficiently large that land vegetation occurred on them. At Mataira one such boulder attracted attention in particular. It was about five meters high, six meters wide at right angles to the shore and six or seven meters long. This boulder (KONAU TOREU) was at least 100 meters inshore from the reef edge. It must have taken a tremendous wave to break it out of the reef edge and carry it up that far. On its gray top there was growing Timonius polygamus, Heliotropium anomalum, Portulaca johnii and Boerhavia diffusa. A most odd observation was that the upper half of this boulder appeared to be composed of Pocillopora faced upward and the lower half of Porolithon onkodes faced downward. Nowhere did anyone on the team see either of these organisms growing in any other position than facing upward.

While no loose gravel was seen on the sea edge of the PAKOKOTA or in the "rain pools", further inshore increasing amounts of loose gravel appear. This gravel is in general of smaller size as one proceeds shoreward. Nearest the sea it was almost all either on pool bottoms or in bars behind large boulders. Inshore it formed a general litter obscuring the surface of the PAKOKOTA, e. g. at Mataira.

At Gavarivari there was an extensive black-zone boulder field extending up, inshoreward, into the grey zone or PAKOKOTA levels. At Kaea the similar boulder field was much more in the grey zone. These boulders were found in varying degrees of cementation to the solid reef material. Perhaps if covered by sand they could have become cemented into the island conglomerate benches seen. These benches where we saw them were exposed by hurricanes ripping the vegetation and much of the islands away.

B. Sea Beach

The vegetational margins and the sandy areas between the spray zone PAKOKOTA (island conglomerate) and trees seem to be related. This was decided after a study of root areas at Homohomo. In general Pemphis acidula and Suriana maritima were the plants associated with PAKOKOTA areas and Messerschmidia appeared with the presence of sand.

If the present extensively exposed island conglomerate was at one time productive land, then about ten times as much productive land was present at one time at Raroia. Local history records a great deal of destruction of land but we do not know how much. A reduction of the human population by a factor of ten is related in the history correlated with European civilization of the area.

There was little to be found in the way of sea beach biotic elements on the PAKOKOTA other than for an occasional bristle-like tuft of the grass, Lepturus repens. At Tetou Lepturus repens appeared on both the PAKOKOTA and the sand. As at Homohomo and each place where this point was investigated the sand for the first three millimeters below the top one millimeter of whitish sand is greenish near the sea edge of the beach (Fig. 9I) with various blue-green algae. However since they cannot be distinguished even as to genus with the unaided eye and because some of them grow well further seaward they do not serve as indicator organisms.

While at first glance the sea beach seemed to be rather barren, close investigation always revealed roots or seedlings or the tufts of Lepturus or other plants (in one case geckos) and this seaward limit of such macroscopically recognizable biotic elements became accepted as the seaward limit of the sea beach beyond which was the spray wet zone. This was essentially true also at Oneroa where Pemphis and Suriana became dominant. Under the Pemphis in particular the sand is solid and well packed, i. e. not the loose sand of the sea beaches. From the seaward edge of the bushes, some 45 meters from the beach rock where the sand was less packed to the inshore edge of the bushes essentially the same blue-green algae were found as were found at the sea edge of the beach. This seemed to indicate there to be no real difference in the surface soil conditions between what might be called the sandy beach and the bush-covered areas.

At Tetou Ipomoea tuba was also found growing at the edge of the Guettarda area on the sand and often growing as a climber into bushes of Pemphis, Suriana and young Guettarda. The largest patch, about 20 meters long and 4 meters broad, occupied the inner surface and top of the gravel rampart illustrated in Figure 2B. This was the only thing like the expected growth of I. pes-caprae seen on Raroia. I. tuba is apparently the only species to be found; though our local resident assistant thought this particular patch of Ipomoea to be blue flowered until shown differently.

The bristle-like Lepturus became abundant inshore and Suriana became more frequent and larger until it dominated the landscape at Tetou.

While Messerschmidia was common at the landward edge, and indeed on one profile it was conspicuous at the outer edge of the "land" behind the gravel rampart (Figure 2C) it was not what one could call a strong element in the population from a purely observational standpoint. Inland one can draw on a map an arbitrary line between the seaward edge of the Guettarda and the inland edge of the bush zone coordinately dominated here by Suriana and Pemphis. One element (Hibiscus tiliaceus var. sterilis, 11833) found only at Tetou appeared in a very narrow zone just seaward of the Guettarda. This species was a bush usually just less than two meters tall with rather stiffly erect or patent branches. It was interesting to note that the young, more terminal, leaves wilted at a much greater rate than the old leaves...and to note also that the leaves apparently did not remain on the stems very long. This was evidenced by their appearance in clusters at the tips and the great frequency of leaves at the bases of these clusters with "autumnal" foliage coloration, as well as the accumulation of leaves on the ground.

It should be noted that Messerschmidia is to the local people a very valuable mulch forming plant. In this connection it was noted that leaves of Suriana and Pemphis accumulate to a considerable degree under their respective bushes. Along with the leaves of the above Hibiscus these are all probably very active plants in the humification of gravel platforms such as that here at Tetou inasmuch as humus is formed.

With the region outlined to the seaward by the Hibiscus at Tetou and by the bristly form of Lepturus, the ground is covered by stones (5 cm) that are blackened (Mastigocoleus testarum and Entophysalis crustacea, 11877). On transects elsewhere than at Tetou one could expect a coincidence of the successful coconut plantings and outer, seaward limit, of Guettarda. In windward areas under the Guettarda there was little Euphorbia atoto or Scaevola frutescens in comparison to other areas studied. These two plants were far more abundant on the leeward side of the lagoon. Similarly on and beneath the coconut trees Microsorium and mosses were common in windward areas but not as abundantly so as on the leeward side of the atoll.

As in the case of other islands along the windward side of the atoll Gavarivari displayed (Fig. 2A) a broad area between the vegetated area and the sea. There were also several gravel ramparts in the structure of the seaward part of the vegetated area separated from the lagoonward gravel ramps by low areas most of which were swampy. The more seaward gravel ramps (Fig. 1) tend to be strongly covered by gravel that is coarser than that which covers their seaward uppermost and lateral (exterior) faces.

Various of the islets north of Tetou were investigated as to their flora. Lepturus repens and Heliotropium anomalum appeared alone on many of the islets that were hardly more than sand spits. These were the smallest vegetated islets at Raroia. On islets that had a fair cover of these plants there were coconut trees but nothing else was to be seen in the way of flowering plants.

There seemed little transition between islets having the aforementioned vegetation and those having additionally Pemphis, Suriana, and Guettarda. However, there were a number of flats which were little other than Pemphis-Suriana thickets without Guettarda. This latter genus appeared only on islets where there were elevations distinctly higher than the usual levels at which Pemphis and Suriana were to be found.

It appears that these beach edge plants are thus pioneers and that a water supply is available under their cover that will at least support Cocos. Cocos is planted. Since Cocos does not bear and do well in the above places it is not normally planted in regions supporting only the Messerschmidia seral stage. It can be postulated that the reason for the absence of Messerschmidia from such islands at Raroia is the length of time required for Messerschmidia to become distributed to such areas, germinate and grow naturally.

A preliminary assumption is that Cocos will grow in sand with little or no humus if there is a satisfactory water supply. Similarly, it may be that Guettarda, which seems to follow Messerschmidia, requires the water suitable to Cocos but in addition more soil or shade during development of its younger stages. The absence of Guettarda seedlings in some of the burned Guettarda areas at Opakea substantiates this. Perhaps Messerschmidia growth sets the stage, serally, for Guettarda.

Kaea (Fig. 2D) presented another case of Suriana and Pemphis, and also Timonius polygamus, on the island conglomerate and beach gravels. Hedyotis romanzoffiensis was there too, but as most common it was more conspicuous as the channel shores of the island were approached.

C. Guettarda Forest

Skeletons of large Messerschmidia trees (7 meters tall) were found on Kukina. At Opakea (Figs. 1 and 2K) in central regions relatively recently destroyed by fire, among the skeletons of fire-killed Guettarda, seedlings of Messerschmidia had appeared in profusion. At Garumaoa and generally elsewhere Guettarda appeared on islands, on the sea side, about 2.2 M above high tide line. That it does occur lower, for example, was observable at Oneroa (Fig. 9) where on the lagoon shore, one trunk was based on the sand sloping to the water's edge. It was perhaps a foot above high tide line, but dead roots protruded into the sea water of the lagoon at high tide.

The Homohomo transect area, upon which so much time was spent, was a very muchly disturbed area and not so desirable for an analysis of the vegetation as Oneroa. Oneroa too is a coconut plantation, but it is an old one in which somewhat of a balance between the pre-plantation conditions and plantation conditions may have become established, and it appeared to be typical of what we found in coconut plantations at Raroia. Three profiles across this area were leveled with a hand level and paced. These three profiles were through an exposed part of the particular island (see figure 1J), through a moderately exposed part of the island (Figure 1I) and through the least exposed part, that is the part most protected from windward influences (Figure 1H). These profiles are illustrated in detail in Figure 9. A sample of the distributions of the species can be had by study of Figure 9 and reference to the species found at each of the locations indicated by the letters A through R. The relative abundance of the species is indicated by its position in the lists of species... the most abundant being given first. The taxonomy and certain specific information on these organisms is given in Atoll Research Bulletins No. 33 and 34.

Fine sand dominates the sea edge of the Cocos area at Oneroa and this is largely covered by algae (Fig. 9G) binding it into stony moss-like tufts. Suriana and other bushes appeared with the most seaward coconuts at Oneroa. The coconuts had been planted further seaward here than they are usually planted, and the most seaward trees had not developed well and did not seem to bear nuts. In this area (Figure 9F) at one or more places fragmentary channels show as depressions in the surface of the island. In these depressions sometimes Suriana dominated. The sand under the shrubs was either covered with a layer of Suriana leaves or the complement of algae indicated in Figure 9 at F. These algae form an almost continuous series of dark lumps, 0.5 to 1 cm. in diameter, over the surface. Further toward the center of the island and at higher elevations (Figure 9P) boulders of 1/3 to 1/2 meter in diameter were frequent. These were quite black on their upper surfaces when wet but only plain grey when dry. This algal layer of Symploca kieneri and Schizothrix (?) longiarticulata was particularly developed in surface depressions on the boulders and diminished on parts more exposed to the air. While we did not turn over the larger boulders the smaller rocks and gravel near the center of the island tended to be more completely white beneath and grey on top, or blackish if wet. They had the same complement of algae (see list on Figure 9 for N and O, though not listed some Schizothrix longiarticulata and Nostoc muscorum was present at this latter site) as found on similar gravels on the lagoon storm ramparts (beach ridges), and a more or less green line around the margin of their white under surfaces. Toward the center of the island the surface is in general buff gray and while the sand and small gravels are not bound together or cemented they are certainly well packed. After a rain algae (figure 9E) cause these same surfaces to become greenish.

At Gavarivari, Guettarda appeared on the nearly level top of the outermost ramp and continued on all but the lowest areas across the island. Even on the outermost ramp some of these were as much as 0.6 meter or more thick toward the base below the major limbs. Most of these large Guettarda trees had light grey bark. Our measurements indicate about 920 hectares of Guettarda forest area on the atoll about 580 of it planted to coconuts.

The trees on the seaward edge of the vegetation at Tetou were coated on their windward faces with Trentepohlia (11842). This green alga formed a bright yellow orange coating on the tree trunks and limbs as it does elsewhere in the world in such habitats. The larger limbs of Guettarda on this seaward face were coated beneath with a whitish coating of fungus material (11841).

Morinda citrifolia was most often more abundant just within the edge of Guettarda areas. It did occur at Garumaoa rarely outside this cover on the seaward side of the island in a muchly disturbed area. On the atoll of Anaa, it similarly was seen seaward of the major tree covered area on a raised area. It was most frequently seen along the lagoon shore, but one usually walked near the lagoon shore or along the algal ridge. There is no central road or, in fact, much of any regular trails at all at Raroia. At Tetou within the seaward edge of the Guettarda area there is an unusual amount of Morinda and this extends, largely as seedlings without much in the way of branching and less than 3 meters tall, to "x" in Figure 2C where they stop rather abruptly. Grass in this area is only spotty and the soil is largely obscured by the grey algal-coated small gravel (11876) discussed above. Morinda seemed to be well able to grow in the shade but only away from the salt water. In the southern Marshalls, Morinda is about the only tree reputed to survive under the dense shade of Artocarpus (breadfruit). Artocarpus seems to grow well only far away from salt water at Raroia.

Special note should be made of the hermit crabs (Coenobita brevimanus and C. perlatus) found on the highest parts of the islands. One comes upon fifty to a hundred clustered about the base of a single tree and there will be no others in sight for fifty meters or so in any direction. The tree is sometimes a small one or an odd one. One aggregation at Gavarivari was on the ground around where a downward growing Guettarda limb touched the ground. The limb then curved upward so that it touched the ground only in this one place. In the occasionally occupied villages these same hermit crabs may accumulate almost entirely in just one of the abandoned houses. A human occupant, if wise, will confine all his decapod contenders for the period of residency to a bucket or box...throwing them out of the house only being the stimulus setting them in motion to a noisy return.

In passing, it should be noted that Birgus latro, the coconut crab, was a highly prized article of food found rarely in unpopulated Guettarda areas. The only specimen shot was from Kahogi where it was molesting a Pandanus fruit. This island was just north of the pass, and was an island visited infrequently. It had the only large Pisonia trees seen at Raroia.

Pandanus was a most variable entity in form. In habitat it was found on the highest parts of the islands. Usually it was surrounded by Guettarda. However, some of the small, yet highest, islands such as Kaea on the windward side of the atoll and Temari, just south of the pass, had this tree growing in exposed situations. At Gavarivari Pandanus occurred on some of the high windward ramparts and was there quite unprotected by other vegetation. The trees in this habitat were nearly a solid leaf-filled masses and thus most typical in appearance.

Though little such land was available for study the coconuts were in general not growing above a level (determined with a hand level) of 3.2 meters above high tide line. The surfaces above such levels were of coarse gravel and occasional flattish boulders (up to 0.75 meters in diameter).

Essentially it is in the Guettarda area that most all the flowering plant species are to be found. The aerial photographs well illustrate the extent of this area on the individual islands. This is the stippled area on the map accompanying the report by Newell on the geological work at Raroia. In going from Garumaoa northward toward Gake the flora in general became increasingly depauperate; though the general situation as described for the Garumaoa transect area persists. After leaving Homohomo one can almost count each individual tree of any species other than Cocos, Guettarda, Messerschmidia, Pemphis acidula and Suriana maritima.

Scaevola frutescens nowhere at Raroia grew out onto the beaches as it does in Hawaii, in the Marshalls and elsewhere. As a rule it was a plant of the inland Guettarda dominated end areas but appeared to be much more intolerant of shade. When growing in the shade Scaevola developed as a viney plant with slender parts and creamy flowers having no purple wavy petal edge or corolla base.

Euphorbia atoto seemed to be more shade tolerant than Scaevola and was the predominant herb (isolated and usually approximately 30 cm tall) in most coconut groves. It likewise may either have a shallower root system or be more tolerant of salt than Scaevola for it extended nearer the lagoon and often nearer the hurricane-disturbed island ends than did other members of the Guettarda forest community and even Scaevola.

While discussing shade it should be pointed out that under the Cocos and Guettarda cover there were usually many small saplings of Guettarda. The possibility that these might shoot up quickly and fill an opening in the forest canopy comes to mind.

At Raroia it was Suriana maritima rather than Pemphis acidula that seemed the most hardy pioneer form on sand and rock. This is in contrast to reports from other atolls and it may be that at Raroia this apparently unusual situation was due to the hurricane-disturbed nature of the northern part of the village area where this relationship was observed. In some places at Oneroa (Fig. 9) Suriana did grow in abundance well inland on a sandy area as described above. Inophyllum calophyllum was present only as a single small tree at Vaituke outside the village, Garumaoa.

In the village area only one tree of Cordia subcordata, a small one, was found. This was at Kumekume. North of the pass on Kopuano there was one Cordia, a small tree along the southern edge of the coconuts not far from the water in the channel. On another island, also called Kopuano, the name essentially of the estate to which it belonged, were two rather large Cordia trees (TOU) and many small ones forming a small grove.

On Kahogi the largest Pisonia grandis, GATAE, was seen. This was some 0.8 meters in diameter (but not DBH) and fourteen meters high. There are several trees just slightly smaller and many very small trees. It, thus, appears that this species was reproducing. Though there were no guano deposits identified on the ground there were red-footed boobies nesting in the trees. Terns similarly made the area their home. One tree about 0.3 of a meter in diameter was found in the eastern part of the Gake region. At Paparoa there was one other Pisonia (11506). No reproduction of this tree at Paparoa was seen and neither bird nests nor guano were seen to be associated with it or its environs. No seeds were to be found though flowers were collected. Except for perhaps a dozen or so trees of uniform size with small ones underneath at Opakea no other Pisonias were found.

While rare, south of the pass, except in the village, Lepidium bidentatum was scattered along the islands to the north. Here it was withered beyond the fruiting stage or juvenile, no fruits or flowers being seen. On the windward side of the atoll fruits and flowers were common, e. g. at Kaea.

Timonius polygamus was rare north of the village to the pass. One plant being found on Tomogagie and two on Takeke. North of the pass this species was common; as it was in Raro and Kereteki.

Hedyotis romanzoffiensis, like Timonius, was most commonly found along the channel ends of islands, the former often on rather thinly covered consolidated rock and the latter usually on the more gravelly soils. Hedyotis was found occasionally in widely different forms. As a vine it resulted in tangles near the sea beach at Oneroa and near the lagoon beach formed rather tall spindly plants. These two with the bushy plants of island ends were so different that they were thought at first to be different species.

North of the pass mosses and ferns soon became insignificant and were not found at all from Mataira through the Gake area.

Such plants as Fleurya ruderalis grew in profusion on some of the long undisturbed Guettarda areas of, e. g., Kaea, where no coconut trees were growing. Portulaca johnii here seemed most succulent and with the largest flowers. The land area of Kaea appeared to have been reduced about nine tenths by a hurricane in 1903 but since had vegetationally quite recovered so as to be a somewhat open Guettarda forest. There were on the island many whitened remains of pre-hurricane trees, probably Guettarda. The seaward remnant high portion of Kaea (Fig. 2D) had a generally vigorous growth of Guettarda. Suriana and Pemphis were present around the margins but Messerschmidia was little in evidence. The highest portion of the island, that end nearest the lagoon, in addition to Guettarda, as is often true of the islands at Raroia, was largely populated by Pandanus distinctus. Lepidium bidentatum formed the major ground cover with a grass (11896).

Ximenia americana (RAMA) was scattered along the midline of the large island at Opakea as about six bushes, Forsythia-like in their viney habit. This was in general a shady habitat in the freshest ground water area of the island. It had the same position at Kopuano (Tokerau), where it was identified only as a burned dead stump with nuts scattered about on the ground.

Without analyzing it further there was an increase in floral variety in reference to approaching long islands near the southern end of the atoll.

To this point we have been discussing the Guettarda vegetational area essentially of the highest part of the island. As one approaches the lagoon the land consists of finer particles. On short islands the island surface in the Guettarda area may be entirely of gravel. Toward the lagoon the surfaces of long islands are of sand that is finer toward the midpoint along the lagoon shore. In both cases there are usually traces of storm ramparts of essentially these beach materials near and parallel to the lagoon shores. The lagoon base of these storm ramparts is essentially high tide line and is identifiable by a shift in color, slope and biota.

Perhaps in correlation with the finer particles and lower permeability, coconuts and Guettarda grow closer to the high tide line along the mid lagoon shores of the islands. Toward island ends the storm ramparts were gravelly in nature and occupied by, essentially, the bushes. Of these Messerschmidia, drops out first as the center of an island is approached, then the Pemphis and Suriana, leaving Guettarda, Cocos and grass on the sandy ramparts in mid-shore areas. Sometimes where the lagoon beach ramparts were broad as at Gavarivari (Fig. 2A), this was the only area thoroughly planted in coconuts.

Between the lagoon and seaward storm ramparts there is (Fig. 2) often a low area (Fig. 3), a swale. In southern Kereteki (Fig. 2A) often there was a series of these low areas. Elsewhere (Fig. 2) there was usually but one. This has been termed here "swale". In some places the swales had been in the past used as taro pits. No taro was found at Raroia and it is believed to be extinct there.

At Tetou the swale proper was a muddy area thickly beset by coconut trees. At Gagieroa and Gavarivari, Suriana and Pemphis were common in these troughs between the ridges. In these swampy areas Pemphis dominated the picture, Guettarda being absent. Likewise in these swampy areas Pemphis and Suriana formed cane-like trees up to 16 feet tall, the trunks of which were only six or eight centimeters in diameter. At Tetou in the swale a very shallow well (APOO KOMO) had been dug (Fig. 2 C, "y") about 48 cm deep in which at high tide there were a few inches of water. The water had a salinity of 4.1 parts per thousand salt at high tide and the surface of the water was about 20 centimeters below ground level. On the mud bottom of this well the unicellular green alga, Gloeocystis grevillii (11901), formed a delicate coating.

The seaward slope up to the crest of the island was of coarser material than the lagoonward margin of the swale. At Tetou this was covered by Lepturus repens of the same form as that found on the downslope to the mud flat from the lagoon. Actually this cover extended over the beach ridge to within a few meters of the lagoon. Portulaca johnii of low stature and occasional tufts of Eragrostis amabilis were intermixed with the Lepturus. Many of the partially burned pieces of Cocos trash had the blue-green alga, Scytonema hofmannii on them. On soil swept bare here there were occasional developments which in mass appeared to be green algae (11884).

The beach ridge was bordered with an irregular zone about 3 meters wide, the ground of which was grassless, relatively loose, sand or fine gravel. The sand (11864) and fine gravel (11865) were somewhat greenish when damp and grey when dry. This color was induced by the presence of the blue-green algae Entophysalis crustacea, Scytonema hofmannii, Mastigocoleus testarum, Coccochloris stagnina and Plectonema calothrichoides.

The very plane surface of the beach ridge sloping gradually toward the central swale region at Tetou is very variable in shape. Rather consistently it is a slope covered with complete cover of Lepturus repens (11866). This form of Lepturus is soft and in loose spreading tufts which do not run conspicuously. The highest density of Vernonia cinerea was seen here. The tallest plants were often 0.7 meter high.

Out on the swale flat itself at Tetou toward the center of the island, Pemphis and Suriana were essentially absent. The surface was level and of mud. On this mud surface the general color is "blackish". The temperature was found to be 26° C. about 3 cm beneath the surface. The surface had the same temperature as the air. Temperatures of the nearby lagoon water were 26 to 26.5° C. Over the surface were strewn large numbers of Strombus gibberulus characteristic of the lagoon. They were present here in rather larger numbers than would have been expected just from hermit crab carrying. On this surface, too, there are localized scatterings of small stones which are quite yellowish green with a mixture of the Gloeocystis grevilli and fungus filaments (11874). In some intensely lit areas the surface of the mud could be seen to be greenish and covered by a thin coating of Hapalosiphon pumilis (11870). On the flatest surfaces there were two sorts of raised areas. One, while very low, was arched upward and while solid was rather dry and non-stony internally. This brownish surfaced material was a dense development of the same Hapalosiphon pumilis (11844). The other sort of raised surface was black and plain as to contour. Such areas were out two or three millimeters raised and were in texture adjudged to be nearly the same in texture as the nearby Hapalosiphon-covered mud or black and higher (3/16") and often quite stony. This stoniness was that of dry mud and probably the area was not stony beneath its somewhat dry surface. This material (11871) proved to be the Hapalosiphon and a mixture of Entophysalis crustacea, Microcoleus acutissimus and Mastigocoleus testarum. There was a rock formation around the roots of many of the coconut trees on this mud. No biological materials other than the roots were seen to be associated with this hard material.

Here in this central region of Tetou there was an aggregation of cryptogams growing on the trunks of coconuts (11872, 11873, 11868, 11885, 11886, 11887, 11888, 11889). Physciaślorediosa, P. integrata and Antracothecium ochraceoflavum were the lichens. Blue-green algae such as Nostoc commune, Scytonema hofmannii, Plectonema calothrichoides and the green alga Gloeocystis grevillii were found. The moss Calymperes tenerum was common on these trees as well. Outside of this swale area these cryptogams were far less abundant.

The lowest swampy areas had the best developments of soil. By measuring the elevation of the surface above the level of the water-saturated sandy soil in land crab excavations at Gavarivari it was estimated that such swampy areas were about 0.5 meter above the upper level of the Ghyben-Herzberg water lens.

The lagoonward rampart ridges at Gavarivari were at least covered by sand and small gravel, e. g. covered with materials consistently smaller in size than those which covered and seemingly composed the seaward ramps or ridges. Algal growths here bridged between the individual particles and thus more of a soil was simulated. Under the coconuts in this area Lepturus repens formed a meadow but for burned areas and leaf trash. This situation at Tetou prevailed lagoonward to within a very few meters of the sandy lagoon beach edge where the grass dropped out and the land surface was more definitely sandy. Coconuts thrived right to the edge of the lagoon beach on windward and Raro shores where land and beach graded together without an erosional bank showing. In contrast at Tetou and Oneroa, where coconut trees were being washed into the lagoon an erosional bank showed. From Kereteki (Fig. 1) through the village area and northern Raro, downwind lagoon shores, the coconuts were not as conspicuously close to the water's edge as they were on the more windward shores.

While the lagoon side of the beach ridges in sandy intertidal areas are of clean well washed sand rather devoid of any conspicuous vegetation the sand of the inshore sides of these ridges at Oneroa is often bound algae (Fig. 9B). These generalized bound areas are interspersed with loose sand areas and areas bound more or less distinctive in one way or another. One such different area type is smooth surfaced and rather light grey. This (Fig. 9C) was found to be largely a binding by fungus filaments. It extended with considerable frequency far into the coconut area. Behind and on top of the lagoon beach ridge much of the bound sand over relatively large areas was brownish grey and somewhat lumpy on the surface. A long list (Fig. 9D) of algae was found intermixed here with the same dominant Symploca keineri, as dominated the generally bound "B" areas.

On the slope (Fig. 9N) from the lagoon beach ridge into the swale most of the gravels and rocks become very black after a rain. They are more strongly grey when dry and most darkly colored near the sand line with what may be a typical island "large gravel" association of algae. The unbound sand (Fig. 9A) of the lagoon beach ridge crest areas assumes a greenish cast from the activities of the largest variety of algae found closely intermixed on the atoll. Occasionally about the village of Oneroa and on the ridges (Fig. 9M) some stones were green even when dry. These were found to be coated with Mastigocoleus testarum and Entophysalis crustacea.

D. Lagoon shores below high tide line

In general the upwind atoll lagoon shores, such as those of Gake and Kereteki, were of sand (GAERE) or fine sediments. As one approached the village area through Tokerau and Raro more and more gravel was to be found on lagoon shores and the particle sizes and high tide storm ramparts were larger.

A major exception to this rule was the lagoon shore of the longer leeward islands. Toward the midpoint of such shores the intertidal region, as well as the supratidal region above it, became a sand or sediment beach. Nerita and the ghost crabs mentioned above were the major biological forms of these beaches as well. Stones low on the intertidal shore at Tetou were coated with Symploca hydnoides (11863). The small gravels or stones to be found at low tide line, at high tide line and just above high tide line (Fig. 9J, K and L respectively) were similarly grey green at Oneroa. Because of the constant submersion of the low tide stones, the intermittent regular submersion of the high tide stones and rare wetting by rain or spray of the above-high-tide stones we were surprised to find in general the same algae predominating on them.

In a few places beach rock was observed. Biotically this was interesting for it, with the town wharf, provided about the only stable areas on which intertidal zonation could be studied. This topic is expanded below in section V.

The lagoon beach at Gavarivari was for the most part typical of agrading lagoon beaches on the windward side of the atoll. There was lots of foraminiferal brown sand in the upper intertidal region. The beach between tide levels was large plane in profile between extreme tide limits. Upward it rounded off gently into the lagoon ridge. Below it rather abruptly changed pitch to the plane even more gently sloping lagoon shallow water flat.

At Kaea the brown sand (11897, a Calcarina?) or small pelecypod shells formed the beach. In any case there was little in the way of macroscopic algae on the lagoon shore other than an occasional patch of Caulerpa urvilleana near channel mouths and certain corallines (11334-11338) on coelenterate coral fragments. Here at Kaea the lagoon terrace, while of the usual slope, had perhaps more Acropora and less Porites than other Gake or Kereteki lagoon beaches. There was no evidence in this region of any lagoon reef or beach rock at all.

Ghost crabs appeared on such sandy shores at low tide at night. These were not to be seen in the daytime. The land hermit crabs appeared to make some regular visits to these shores. Algae were essentially absent.

Subtidal lagoon shores can be readily divided into reef regions and unconsolidated shores. The reef regions have been described as to major variations in our description of this area at Homohomo above. The unconsolidated shores are almost continuous through Kereteki and Gake as an almost flat sandy area. At Gavarivari, Tetou, Kaea and Gake the sandy flat was occasionally interrupted by a mill-stone-like colony of Porites. At Gavarivari on this flat there was more coral development than elsewhere in Kereteki or Gake. However, there was no intimation of a coral lagoon reef on windward lagoon shores. In one embayment at Gavarivari there was a rather broken up example of an algal reef pavement like the "B" zone on the lagoon shore of the Homohomo transect. This (11916) was seemingly the same alga as collected at Oneroa (on the flat south of village) forming a flat pavement or growing up around Vermetus (11915 = JPEM 2219) tubes in such a way as to stimulate a branched Porolithon in form. A number of species of shells were collected (11915). Cypraea moneta was found both on the sea reef and on the lagoon reefs in this same "B"-zone association with a Porolithon species. It was not found at Oneroa, however, in essentially similar places, but may have been overlooked. At Gavarivari two Isonomon species are found, the black one from intertidal regions on beach rock and the white one from beneath rocks below low tide level. Very small shells of Arca turned up in the same collections, and a fragment of the shell of Conus pulicarius was found filled with cemented lagoon rock material. Rhinoclavis sinensis was found alive below low tide line but near shore. Shells of the clam Asaphis were common but perhaps had come from nearby channels.

At the most lagoonward edge of this shallow water flat the pitch of the fine sand (silt, sediment, etc.) changes rather abruptly to a steeper angle. This is the innermost line drawn on the maps reproduced in this report. The depth here is often near 6 fathoms. On downwind lagoon shores where a reef is present, this same line represents the lagoon edge of the reef. It is at about the lowest lagoon water level.

Mullet, of two species, schooled in the channel between the sandy lagoon shore and the shore reef (KAOA) at Oneroa. Common in this micro-lagoon area were various of the coronet fish species (Fistularia sp.) that would drift slowly near to investigate any operation and flopped around most confusedly upon realizing the situation. The convict surgeon fish, Acanthurus triostegus, with vertical black stripes was a common visitor in the area.

Attention is called to the reefs paralleling the lagoon shores at Oneroa (Fig. 2H and map). These had the biology, apparently, of shorebound and other reef patches. The inner was essentially similar in morphology to that illustrated in Figure 3. And like lagoon reefs in general termed PAPAE. The offshore reef was more or less connected to the shore at its (northern) end only and thus was a KAOA.

The PAPAE differed little from other lagoon reefs in the fish to be found and, indeed, there seemed to be little in the way of a specific fish fauna at all. Acanthurus triostegius was common here and as a new element found in our progress lagoonward the very common very dark brown Pomocentrus nigricans peered back at the onlooker from many of the crevices between the corals. No information was obtained on populations of the deep area between the PAPAE and the KAOA.

The barrier reef, or KAOA offshore, had little in the way of a fish fauna on its top. Two different labrids, however, were considered typical. The outer edge of the KAOA had a myriad of several species of parrot fishes feeding on or among corals and the algae there. It was in general morphology and population like a lagoon reef patch.

IV. REEF PATCHES

Under this heading the shore bound patches, or lagoon reefs, and the lagoon reef patches isolated from the shore were considered. Other terms for these latter are patch reefs, coral heads and coral patches. The reef patches of both subcategories were essentially of the morphology of the shore bound lagoon reef in the Homohomo transect area. The actual distance and proportions varied, except that in general the active coral edges or reef margins were uniform.

Two extensive areas of shorebound reef patch were studied outside the Homohomo area. These were the reefs at Oneroa and those between the town wharf and the old small boat harbor and wharf at Garumaoa. The former reef areas were so similar to the Homohomo transect area and the lagoon reef patches that they will not be discussed here in detail. Some of the features of the Garumaoa village area reefs should, however, be pointed out. While the living coral edge is about the same horizontal width as on the Homohomo transect the drop-off lagoonward to the sand below is in the neighborhood of 20 feet. Passing inshore from the outer edge there is little in the way of a dead coral zone (Fig. 3, D and E) and instead there is a pavement. This pavement seems to be of rounded pieces and grooved solid areas; as though eroded by moving sand. This might have been a development of such an algal pavement as "M" (Fig. 6) in the "B" zone on the Homohomo transect and at Gavarivari. It has patches of algae having the same appearance as 11831 from Tetou. This eroded pavement area is in general seven meters or more wide. It has cavities so arranged that one suspects loose chunks or coral growths have been overgrown by the pavement-making organisms. Inshore of the pavement area is a shallow sand flat which is quite extensive and, at least in the places seen, at a lower elevation than the pavement itself. This sand flat appears to slope up toward the low tide level on the shore and then slope more steeply through the intertidal region to high tide line. White tipped slender but dark colored sharks about five to seven feet long persisted in cruising around so that diligent exploration of the drop-off over the edge of the living coral area seemed unattractive. Sharks and fishes, particularly trumpet fishes (Fistularia sp.) were more abundant at Tetou and other Kereteki stations than elsewhere perhaps in relation to fishing intensity.

One case of fish work was seen on a Porites colony (but on less active parts?) growing on the pavement in the "D" or "E" zone. Other Porites colonies were unaffected; though many were looked at in this connection.

The lateral surfaces of stones, especially where they lay close together, as well as holes, were often outlined by a Gelidium (11928). Where this species was exposed to the light it was mostly quite yellow. It was in color a pale yellow green to green and browner where less exposed to light. Under the edges of the same stones what appeared to be this same Gelidium was dark red, but far under the stones where the fronds were longest the Gelidium appeared brown.

On the surface below intertidal levels little living was visible. Most of the algae to be found were growing under but near the edges of stones. Some stones there were ringed with Gelidium and a Codium (11980). Struvea was seen in one such place in the field. Microdictyon was common as was a coarse cladophoroid alga (11990) that may have been Rhizoclonium hookeri. Conspicuous on the lower surfaces of such stones were tunicates and encrusting sponges. However their area was exceeded by the incrustings of coralline algae (11985) and Zonaria (11984).

Shells (11982) and bones of a turtle plastron (11983) on the bottom near shore were conspicuously green with an algal coating as yet unidentified.

Morrison put out about 30 large shells of Lambis truncata to clean on July 31. He put them in a subtidal pen-like area, the unfinished end of the town wharf. They were taken up and brushed off and packed on August 27. At this time the algae were scraped off and preserved (11993, 11994, 11995). Jania, Cladophoropsis, Gelidium, Ectocarpus, Sphacelaria, and other genera were recognized. There were crustose coralline algal pink crusts up to 2 mm in diameter. There were several animal corals on the Lambis shells. The largest of these was about 0.5 cm tall and 2 or 3 cm in diameter. While this coral was rather whitish it seemed to have a slimy coating over the surface and was thus judged to be alive and to have grown during the one month immersion. A further study of this material will give us better ideas of growth rates on the lagoon reefs.

The lagoon reef patches that are free from the shore were among the most interesting biological features of the atolls seen. The Tuamotuan terms applicable to these are given by Danielsson (Atoll Research Bulletin No. 32).

At Raroia it was apparent from the air that as one approached the more upwind parts of the lagoon the reef patches were smaller and perhaps less closely placed. This seemed to be true of the atolls of Makemo and Tahanea as well. In the lagoons of both Raroia and Makemo the reef patches further downwind were often more elongate or tear-drop shaped.

The lagoons in the Tuamotus which were more open to the sea appeared to have more reef patches in them. Such closed rings as Hiti or nearly closed rings such as Tuanake, Tepoto and Taenga, appeared to have no reef patches. Nearly closed atolls having no good boat pass, such as the pearl shell atolls, Hikueru and Takume had far fewer coral patches than Raroia, which is relatively open. Other correlations between "openness" and "closedness" of the atoll ring became apparent to the team as time wore on.

Not only are the copra schooners able to bring in their blessings and curses through the ship passes, but the sharks come in through them, too. In working at Raroia, the team members who spent any amount of time in the water were run out many times by sharks. These were nearly all surface sharks, only two midwater sharks being caught during the summer. These were a seven-foot white shark feeding in a most unlikely place and manner in about two feet of water along the lagoon shore on a sand bottom. It was miles from the pass through which it had probably come in. The other midwater shark was a four-foot blue shark caught in the pass. The algologists' canoe man, Vaea a Timaeva, earned the undying gratitude of two workers by heaving his none-foot fish spear some twenty-five or thirty feet into a bothersome soup fin shark, some species of Galeorhinus. Probably the most exciting shark story is to be told by the ichthyologist, who avoided one possibly only curious elasmobranch by pretending to be a very sessile crust in a surge channel concavity while the shark drooled by, mouth open. The ichthyologist did not report the kind of shark beyond insisting that it was one of those with teeth. One rarely went more than a few minutes in the water at Raroia without being investigated by a shark. One member of the team worked at Takume, a more closed atoll just north of Raroia, for over a week and essentially saw no sharks. As a result while there is a lot of valuable pearl shell in many of the open atolls such as Raroia, only the essentially closed atolls such as Hikueru and Takume are also sufficiently free of sharks to make pearl shell fishing seem worthwhile. These shells are characteristic of the sides of reef patches.

Coelenterate corals, Pocillopora and Acropora and genera of similar appearance, dominate the edges of the reef patches. This edge comes just about to the low tide level of the lagoon. Often the edge appeared a bit better developed on the windward side. This led to a week of vigorous discussion during the summer relative to the origin of the elongated shape of the more downwind coral patches. During tradewind periods the water is calmer on the windward, or upwind, side of the lagoon. Could it be that this is correlated with the shape differences? Perhaps the normal higher effective tide level in downwind regions and larger waves, induce the development of the reef patches to greater elevations. Abnormal calms would then equalize the effective tide level over all the lagoon, leaving the downwind coral patches more exposed to air at low tide. Thus one could expect more death on downwind coral patches, especially on their lee sides where wave action would be least effective. Not only would one expect these lee sides to break down more, but the strongly calcareous detritus from the upwind sides could be expected to be carried over the lee sides as a suffocating blanket. The material from both edges would be deposited in the lee of the reef patch forming a substratum on which more corals could grow in that direction. The elongated patches would result. Numerous tests of this hypothesis were suggested. One was to view the contours of the patch reefs to see if there was a predominance of accumulated detrital material on the downwind side. Another was to note the nature of the patch reef surface for evidence of such greater breakdown and lateral growth of this leeward rim. In most cases only the most contrary conclusions could be drawn from the observations.

Reef patches in the lagoon were seen to be of all sizes and forms. The general forms are outlined in Figures I & II of Danielsson's report on Topographic terms (Atoll Research Bulletin No. 32). The smallest KAPUKU might be said to consist of one coral, usually a coelenterate, growing on a bit of shell or a tree limb or other solid particle on the bottom such as an old shoe or bottle. In some instances it appeared that the coral had grown to such a size that the base had been upset, the coral head toppled over; the lateral surface then coming to serve as the substratum where several forms had developed. Indications that this toppling process was repeated several times were seen variously, and KAPUKU were seen from a foot or so in diameter to those as large as a barn. If these develop sufficiently near the surface so that they can be seen, they are called MARAHI. Those coral patches at the surface depending upon size are called TIRARE, if small, PUTEU, if medium in size, with KARENA being the name for the largest, often as much as 100 meters across or over.

The smaller categories of coral patches are very irregular mounds. The large coral patches were in general in deeper water and in overall aspect truncated cones. However, in more intimate detail the upper twenty feet was apt to be quite vertical and the upper three or five feet an irregular, overhanging shelf. The vertical walls were likely to be densely covered with various species of Caulerpa. Sandy ledges below ten feet down could be expected to be covered with Halimeda. The sloping bases were to a large extent covered by fine white sediment, dotted with irregular chunks of coral material such as might have broken off the rim of the reef patch. On these chunks coelenterate corals and Caulerpa were abundant.

The surfaces of many of the reef patches reached low water level. There were no terrestrial forms on any of them though a very few had chunks of dead coral so placed that they protruded from the water even at high tide. Such appeared to be blackened by the same blue-green algae as cause the blackening of spray zone rocks along the sea reef shores.

The reef patches that approached the surface were flat on top. The smallest (TIRARE) were more or less alive completely across their tops. If one visits a succession of increasingly large reef patches one finds that they are progressively like micro-atolls in that the center is more apt to be a pool a few feet deep and the edge a rim a few feet wide more or less complete and higher, just below low tide line. Coral patches of intermediate sizes (PUTEU) were apt to have several smaller sand-bottomed pools in place of the one large pool area of big reef patches (KARENA).

Large reef patches had a rather consistent external anatomy. They were very much like the lagoonward edges of the lagoon reefs. The margin of the rim was usually irregularly rounded and almost entirely of animal corals; corresponding to the "G" zone of a lagoon reef. Horizontally this area was regular in form, usually less than one meter wide. Inwardly it could be expected to yield to a uniform flat region. Here the odd coral animal, Fungia, could be taken as an indicator organism. The branches of coelenterate corals, which at the edge of the patch top were separate, dendritically branched forms, were here (on "E" or "F" zone) a nearly solid mass of branches with but small cracks between. When near the surface these small cracks were filled with (or the branch surfaces encrusted with) a prostrate Zonaria and other similar algae.

Algae were not conspicuous on reef patch tops at Raroia, except locally near the rim edges where sometimes prominent areas of Polysiphonia (11015), Lophosiphonia (11016 and 11014), and Bryopsis (11011) were to be found. These populants were particularly abundant on windward edges. The windward rim edges were sometimes more loose in structure, often having holes through them, and often more overhanging than the lee rim edges.

The micro-lagoons, or pool areas in the reef patch tops, were as a rule s sand or sediment floored and a foot to a meter deep (as in the lagoon reef "C" zones). Scattered about could be expected dead coral animal fragments, often with living coral growths similar to the smallest reef patches (KAPUKU) described above. The inner edges of the rim (essentially equivalent to lagoon reef "D" zones) were full of small caverns, nasty looking eels and a host of other fishes. Algae such as Rhipilia choke many of the smaller holes among the dead animal coral branches, and through binding of sand grains tend to fill these holes in such a manner that a rather solid mass results.

At Raroia from the air it often appeared that the reef patches were in lines as though separated from each other by circulation cells radially arranged in reference to the downwind shores. On the map these show conspicuously on the most southwest lagoon shore near Oneroa. That their direction is radial or in reference to the prevailing winds is seen by the arrangement of the most southeasterly reef patches shown. Unfortunately, we did not have sufficient flight time available to take photographs of the lagoon itself and thus this was not followed through.

Piscatorially the reef patches were like the shore bound reef patch faces but neither so rich in species nor in numbers. The squirrel fish are rather common to the patch reefs and are the notable new element in the fish fauna as one passes from the shore out into the lagoon.

Phycologically the vertical faces of the reef patches were unique for Raroia. They were often covered by great quantities of a large-jointed Halimeda and by masses of relatively simple forms of Caulerpa pickeringii. Masses of Caulerpa bikinensis were favored pastures for turtles. Pendant from overhanging coral shelves one found upon occasion six to ten feet down Pseudotetraspora antillarum home. This in the field looked not unlike a thick gelatinous sheet of Ulva irregularly four to ten centimeters across.

V. VERTICAL DISTRIBUTION

Aspects of vertical distribution were pursued both on the land above and into the water of the reef edges in the lagoon and on the sea shore below the intertidal region. In respect to the intertidal regions we were particularly anxious to see whether or not there was a correlation between tides and the observed distribution of living things.

The intertidal region is a common point of departure for elevational studies and thus the tides received consideration first. It was quite apparent that determining rise and fall of the tides beyond the sea reef would be quite a feat with the materials at hand, thus a tide stick was set up on the wharf in the lagoon. It was very quickly determined that while the time factors were not so muchly affected the vertical components of the tide curve were very much affected by the wind and sea roughness. This was presumably a result of the water piling in over the reef and piling up against the lagoon shore more with some winds than others, the outlet through the pass remaining the same. It was determined that the mean tide range in the lagoon was probably a little over one foot. Our impression, and it was only an impression, was that the tidal variation of the sea outside the atoll was between two and three feet or about double that in the lagoon. Tides are reckoned from Apia, about a thousand miles away across certain factorial nodes. There was at least as much as fifteen centimeters difference in successive high tide levels, and similar differences between successive low tide levels during our period of observation.

The three basic zones observed (Figs. 7 and 8) can be called from convention, supralittoral, littoral and sublittoral. Upon occasion divisions of these or variations from this pattern were observed, but the observations were few, rather closely placed geographically and no accurate leveling means were available, and thus little can be said justifiably as to what these anomalous situations might signify.

Below the lowest levels exposed by the tides at the reef margin the biota was dominated by a smooth coating of Porolithon onkodes. This extended downwards at least eight meters (no one measured this) and covered over 95 per cent of the surface. On flatter tops of spurs an occasional area was conspicuously dotted with Pocillopora. This whole region dominated by Porolithon can be considered an upper sublittoral zone.

A coral animal zone below this level was reported by the geological members of the party. Such a zone would be a lower littoral zone, and correspond to what has been observed elsewhere by others and in general referred to as a ten to twenty meter terrace covered with a forest of coelenterate corals.

Vertical distribution along the sea shore near Garumaoa (Fig. 5) was noted sufficiently that the sequential events are rather certain. However, there are special problems involved in studying the vertical aspects of distribution on a coral reef. Firstly the sea breaks over the very irregular edge of the reef almost constantly. At low tides on calm days the reef pool is likewise calm with no waves. As soon as the tide is high enough that the waves are not completely broken at the sea reef edge they run across the reef flat and there is considerable wave action along the landward edge of the reef. Nowhere on the reef margin does there appear to be a regular sine relationship between effective water height and time.

In Figure 7 we have presented a summary of observations on the Homohomo transect sea shore and reef. To take account of the tide pool like nature of the reef and the desirability of different vertical scales the figure has been broken in the middle by an "unscaled" portion. For that portion of Figure 7 concerning the algal ridge and the spurs and grooves this unscaled portion includes the positive and negative changes in elevation met in passing up over and back down beyond any algal ridge (Fig. 3) or cuesta that may be present and the elevational changes within the pool itself.

The algal ridge and the organisms living on and in it can stand emersion but also are found dwelling constantly immersed. The algal ridge is thus considered to be a sublittoral fringe. As examples, the upper sublittoral fishes may feed here on the algal and other materials of the intertidal area but they are always immersed in the water. They, themselves, are not considered to belong properly to the sublittoral fringe.

Porolithon onkodes is a fine example of a typical fringe zone organism for it lives better here in this subzone under the unique circumstances of surf, aeration and bright light than elsewhere, though it is widely spread in its major zone, the sublittoral zone. It occurs below low pool level on the reef flat, in the channels, on the lagoon shore and beyond the algal ridge as a coating of the grooves and spurs down to a depth of at least four to eight meters.

The *Amphiroa* zone is regularly exposed by the low tides but briefly. It has, therefore, been treated here as manifest of a lower littoral fringe or more simply a lower littoral zone. The species of *Jania* found were in always-submerged localities. The *Amphiroa* species forming this turf at Raroia and Takume seems to be an elevational correlative to such jointed coralline algal species elsewhere as *Corallina gracilis*.

At the shore edge of the reef pool the fauna is not the same on the upper and lower parts of the brown intertidal area. For the present we accept the lower area occupied by *Morula granulata* as being equivalent to a sublittoral fringe. *Thais hippocastaneum* occupies the upper part of this shore area. The sea reef areas typified by the occupancy of Thais and Amphiroa have been (Fig. 7) considered as the lower littoral areas on the sea shore. It may very well be that this region should be treated as but a single bionomic zonal unit. There is not the clear break between them one usually finds between sublittoral and littoral zones and it would perhaps be better to treat this whole region as sublittoral fringe.

Higher in the intertidal area on the shore *Nerita plicata* ranges essentially over the lower edge of the black zone dominated by *Entophysalis crustacea*. Tectarius is higher on the black zone. Respectively these two have been taken (Fig. 7) as indicators of mid- and upper littoral zones. *Melaraphe coccinea*, on the grey rocks, was thought to be an indicator of a supralittoral fringe (Fig. 7).

Above the intertidal zone the atoll was covered with a rather ubiquitous coating of blue-green algae. These bound the sand or formed a grey to blackish coating on gravels and rocks, and even on bark and dead wood. The macroscopic vegetation was at its margin a bush zone. This had been described in our description above of the sea beach (Section B) and the lagoon shore above high tide line (Section D).

The bush zone was a wedge-shaped encircling zone, perhaps two meters high on the sea shores and one half to one meter high on the lagoon shores. On lagoon shores this zone was sometimes absent along the central portions of long islands. It occurred to us that the bush zone and sea beach might represent the horizontal extent of variation in the position of the Ghyben-Herzberg fresh water lens margin. This fresh water lens has been found on other atolls to approach or extend under high tide line on the lagoon shore. We presumed this to be true on some parts of Raroia, e. g. at Oneroa, for in such places the coconuts and Guettarda are found right at high tide line. In such places a supralittoral fringe is absent as well as the bush zone or lower supralittoral zone.

One must note here that the above explanation considers the trees as appearing at high tide line, though their roots must extend into the fresh water lens below. It is thought that the lagoon mean water level was higher in elevation than the sea. In correlation the intertidal zones were shifted upwards, but without the conspicuous fringe zones of the sea shore the final result being adjacent littoral and supralittoral zones without a place for the fringe organisms. Speaking of genera this means an absence of *Melaraphe*, *Messerschmidia*, *Pemphis*, and *Suriana* toward the centers of the lagoon shores of the longer islands. This is in line with the observations made on the distribution of these organisms.

Above the bush zone, or the intertidal zone where the bush zone was absent was the vegetational area normally occupied by Guettarda speciosa. Guettarda forests at Raroia and Takume and most other Tuamotuan atolls have been displaced by man with his coconut plantations. As a rule all but the highest parts of the islands were covered with coconuts. However, the smallest islands that were relatively very high showed in their highest regions a shift in vegetation to Pandanus distinctus. Only the smallest islands, e. g. Kumekume, Temari and Takeke in Figure 5, reached elevations over ten feet above high tide level, the elevation at which the coconuts dropped out.

At Takume it was noted that Pisonia grandis was restricted to the highest parts of the island, the ridges between the very large taro pits, and was thus at elevations of plus 15 or 20 feet. On Raroia the islands upon which Pisonia was growing were probably not as high. Similarly Cordia subcordata was found on the higher parts of islands, but the elevation of none was measured with the hand level.

The incomplete channels and lagoon shores presented but few opportunities for vertical distribution studies. Unconsolidated shores predominated and, e. g. at Mataira, were brown intertidally (probably Entophysalis crustacea) but little grew in such places that could be related to vertical distance. The village wharves and occasional conglomerate rock areas made a few sets of observations possible.

At Garumaoa (Fig. 8A) the lagoon beach had several rock outliers which while not continuous gave, when taken as a whole, a fairly continuous picture of the vertical distribution to be found on such a sandy shore. The highest marine algae were found in a small tidepool on the surface of a rock area on the shore. The sand in the bottom of this fifteen centimeter deep small pool was bound by algal filaments (11339). This pool was above the uppermost limits of macroscopic algal growth. About 15 cm below its edges a green alga covered the rocks followed lower by other organisms at other levels. Figure 8B illustrates the zonation on one of the few rather large isolated boulders found in the sand along the lagoon shore.

The vertical zonation found along the shores of an incomplete channel at Gake is illustrated in Figure 8C. As the black gravel (11431) extends along the shore of the channel lagoonward it gradually becomes smaller in diameter and less conspicuously gravel, e. g. the gravel graded into sand. At the lagoon end of the channel the shore was of sand and a black zone was no longer to be distinguished. The coarser sand of the lagoon shores (11440) seemed predominantly fragments of what may be Porolithon gardneri of the sea reef.

The Garumaoa village wharf provided the best opportunity for studying intertidal vertical distribution in the lagoon. Distribution was observed to be somewhat different on the two major sides of the wharf. Likewise there were some differences laterally along the wall the significance of which were not clear. Figure 8D illustrates such vertical distributional differences by the slopes of the lines.

In Figure 8 a five-zone arrangement of the biota can be inferred as a general rule. Where solid materials extend sufficiently high, a supralittoral zone can be said to be represented. The littoral zone below this is essentially divisible in turn into upper and lower zones; though in one case (Fig. 8B) where the size and position of the rocks prevented a real analysis, three littoral zones may have been evidenced, or the Sphacelaria may represent more truly a sublittoral fringe. A little consideration of the exposure of the habitats in reference to waves and wind leads us to suspect that the variable elevations of the breaks illustrated between the zones are due to wave action.

Two lower zones (Fig. 8) were in some places evident. These were considered to be a sublittoral fringe and an upper sublittoral region. While the biotic elements of these were present, they were in places not well sorted into separate zones. On the shores of the incomplete channels, only one zone, an upper sublittoral zone, could be found.

The coelenterate corals were active in lagoon areas in what is accepted here as the upper sublittoral zone. Beginning a very few meters below the surface Caulerpa bikinensis, C. pickeringii, Halimeda sp. and Pseudotetraspora antillarum became evident. These covered the sides of lagoon reef patches essentially to their bottoms. It was felt that these species were indicators of a mid- or lower sublittoral zone. Below about six meters, there appeared to be an increased abundance of individuals of Spondylus, Tridacna, etc. Whether this was a natural distributional phenomenon or due to fishing is questionable.

VI. CHANNELS

The areas between the islands dotting the reef are channels. These are seen in the illustration (Fig. 5) to be of two kinds. The three islands on the right are separated completely by one kind, complete channels. These are waterways connecting the sea with the lagoon. Toward the center of the figure three of the other kind, incomplete channels, show. They are water filled at their lagoonward ends but do not separate the above-tide land into separate islands and connect to the sea reef flat. Incomplete channels are related to the various pond types found on the atoll and described here below.

The bottoms of complete channels are essentially plane surfaces but often have protruding islands of conglomerate material in them. In general at low tide the channels are but perhaps thirty centimeters deep at the sea end, but deepen gradually toward the lagoon until at the lagoon end of the solid bottom they may be two feet deep at low tide level. The Raroians refer to the reef flat as AKAU and to them the AKAU continues between the islands insofar as the bottom is solid and has the general character and population of reef flat regions. Lagoonward of the solid bottom the channels deepen to a few meters and are in character, then, like the shallow lagoon bottoms. In downwind areas the mouths of such channels are often closed at their lagoonward ends by a bar of gravel, sometimes apparently capped with coral rock. The gravel bars as shown in Figure 5 interrupt the shore bound reef patches, or lagoon reef. In windward areas the lagoon mouths have sandy similar bars and there is no shore bound patch reef to interrupt.

Particularly near the edges of the complete channels there are often numbers of rather flat rocks under which there is almost always a population of grey spotted moray eels (Gymnothorax picta). These eels, common to the reef pools, were at most clearly timid, as were the black-tipped sharks (Eulamia) common to the same channels and pool areas. The same Goniolithon species as in the sea reef pool zone apparently, and Porolithon aequinoctiale are knobby corallines almost always found relatively undeveloped. The smooth general cover of everything that does not move, below low pool level, appears to be Porolithon onkodes, but this, too is undeveloped. Such organisms as Chama and the corals common to the inshore edge of the reef-flat pool area are likewise common biotic elements in the channels.

In the deeper of the complete channels there is a greater representation of corals and such other elements as Diadema and Porolithon aequinoctiale and a greater profusion of species. The Vermetus and Drupa species typical of the reef pool areas occasionally appear in the channels. In the channels near Gavarivari toward the lagoon fragments of coral were found with some surfaces actually covered with vermetids. Some channel areas just north of Tetou were entirely blackened with what was probably this same vermetid on their bottoms at the sea end. The same or a similar small vermetid grew in an interesting relationship with the coralline alga forming a shore bound pavement like that in the "B" zone of the lagoon transect at Homohomo.

Around the boulders on the bottoms of more central regions of the channels near Garumaoa (Fig. 5, e. g. between the three islands on the right) there were often Caulerpa urvilleana colonies (and e. g. at lagoon end of the channel at Kaea, 11890). Nearer shore what was apparently the same Microdictyon okamurai was the most conspicuous alga and under the edges of rocks below low pool level but very near shore what appears to be Dictyosphaeria cavernosa was the most abundant macroscopic alga. The more or less vertical intertidal shores other than for being coated more thickly with a brown scum of blue-green algae are like the shores of the sea reefs.

Incomplete channels appear to be closely related biotically to the lagoon. Certain typical lagoon species of clams and such gastropods as Cerithium breve were found commonly. While the holothurians common to low tide line elsewhere were seen again here, the yellow Porites common at this level on the sea reef was absent. In fact no living coelentrate corals were seen in the incomplete channels though they did appear on the gravel bars at their mouths upon occasion.

A rather detailed study was made of ponds and incomplete channels at Gake and a classification of them devised. These pond and incomplete channels associated with the lagoon shore were distinguishable as a series of biolcgically or physically distinguishable types. The most isolated of these (Type 1) were flat damp spots often covered by green strands of Phormidium papyraceum or Anacystis montana (11423). These spots were in the gravel between the sea beach rampart and the heads of incomplete channels, apparently considerably above high tide level.

One pond or damp spot (Type 2) near the lagoon shore end of the Gake transect was apparently water filled at exceptionally high waters (the collections had salt on them) or during rains. On the most moist bottom parts there was little other than a gelatinous yellow-brown coating (11433). On the most soil-like drier but protected areas were wefts of Calothrix pilosa incorporating Anacystis dimidiata and Entophysalis crustacea (11432). Moss-like tufts and coats of Calothrix pilosa (11434) in pure stands covered most of the remainder of the pond bottom. This pond was perhaps one left in a gravel hook more or less made permanent by a growth of Suriana maritima and Pemphis acidula on the sand beach front and between it and the lagoon.

About fifty meters inland from the center of the lagoon shore was a pond (Type 3) about 8 M by 20 M long. This was a freshish water pond. Newell says that sand along the lagoonward shore of this pond indicates that it may have originally been a low spot in the island shore cut off by shore sand and thus isolated from the lagoon. There were several similar ponds seen. The fine silt in this pond was consolidated at the surface into an orange red cake of Schizothrix lacustris, Entophysalis crustacea, Anacystis dimidiata, Plectonema nostocorum and Calothrix crustacea (11429). The Pemphis crab was common in such ponds.

A shallow (15 cm deep) pond (Type 4) was selected as belonging serially here. It was covered on the bottom by an orange algal crust and around the edges by more of this colored algal crust. Though probably not regularly receiving tidal water; the same mullet was found here as in the following pond type, Type 5.

The island areas of Teuramote and Tikagera were separated by an incomplete channel. This channel (pond Type 5) was shut off from the lagoon by a sand bar on which grew a number of Pemphis and Messerschmidia bushes. The pond thus formed was brackish. It was a repository for refuse and excrement. The water was green; as though with a chlorophycean algal bloom. No equipment was available for study or preservation of this plankton. The bottom (maximum depth of 2 meters) was covered by about 15 cm of very soft sediment over gravel. On this sediment were occasional patches of very soft brownish purple Phormidium papyraceum (11422). On the flat and near water level shores were large areas of the orange red algal coating discussed variously above. On beach rock isolated as a ledge in the pond was a fine green alga. Under water and on the beach rock around the edge of the pond there was an abundance of soft (Newhouse said "fluffy") orange material (11424). Gravelly sand shores in places in the water's edge had a dark colored blue-green algal mat that was in places broken into small pieces approaching balls in form but still somewhat angular in outline and distinctly dorsiventral.

On places where gravel and beach rock shelved into this pond there was a multitude of the small gastropod, Cerithium breve. In more sandy areas, similarly just below low water level, there was an abundance of one small clam. One sipunculid worm, perhaps peculiar to this environment, was found a few times. At night, and only then, a myriad small (2 cm) colorless shrimps were attracted to any slight disturbance at the bottom. A small crowd of one species of fish (Mugilidae) lived in this area.

Toward the east end of this wooded series of land areas a somewhat less isolated pond (Type 6) was discernable by the addition of Albula vulpeo, the mild fish, to the fish fauna described for the above ponds. The same clam and gastropod (Cerithium) were in abundance. The daytime investigations revealed none of the shrimps observed in the Type 5 region. Brackish water gastropods were generally abundant. The only two Raroian records for two species were obtained here. One of these was a Neritina found just beneath the then current water line. The other was a very active pink cap shell (not unlike the Hungarian cap-shell) found at similar levels on coral fragments somewhat buried in sandy mud.

It should be emphasized that none of the ponds in this series so far appeared to be a pond that ever has a free exchange of sea water other than perhaps by storm waves that sweep over the land to them over levels well above the highest tide levels.

Pond Type 7 as selected was of small ponds near one of Type 8. The Type 7 ponds were apparently in connection with Type 8 and the lagoon at the very highest tides through channels lying above the usual high tide levels. Though these were small relatively shallow ponds Acanthuridae appeared in the fauna in addition to the previously mentioned fish.

Pond Type 8 is represented by ponded channels regularly having a channel opening to the lagoon with the higher tides. Coral growth appeared meagerly here near the lagoon entrance. In addition to the previously mentioned fish fauna there were additionally members of the Scaridae. Not only was the fish fauna population distinctly larger there but the individuals, for example of Albula, were large. Balls of healthy Jania (11490), a filamentous green (11492) and a small clam (11493) were to be found. The water, though no measurement was possible, was seemingly nearly of the same salinity as the lagoon water.

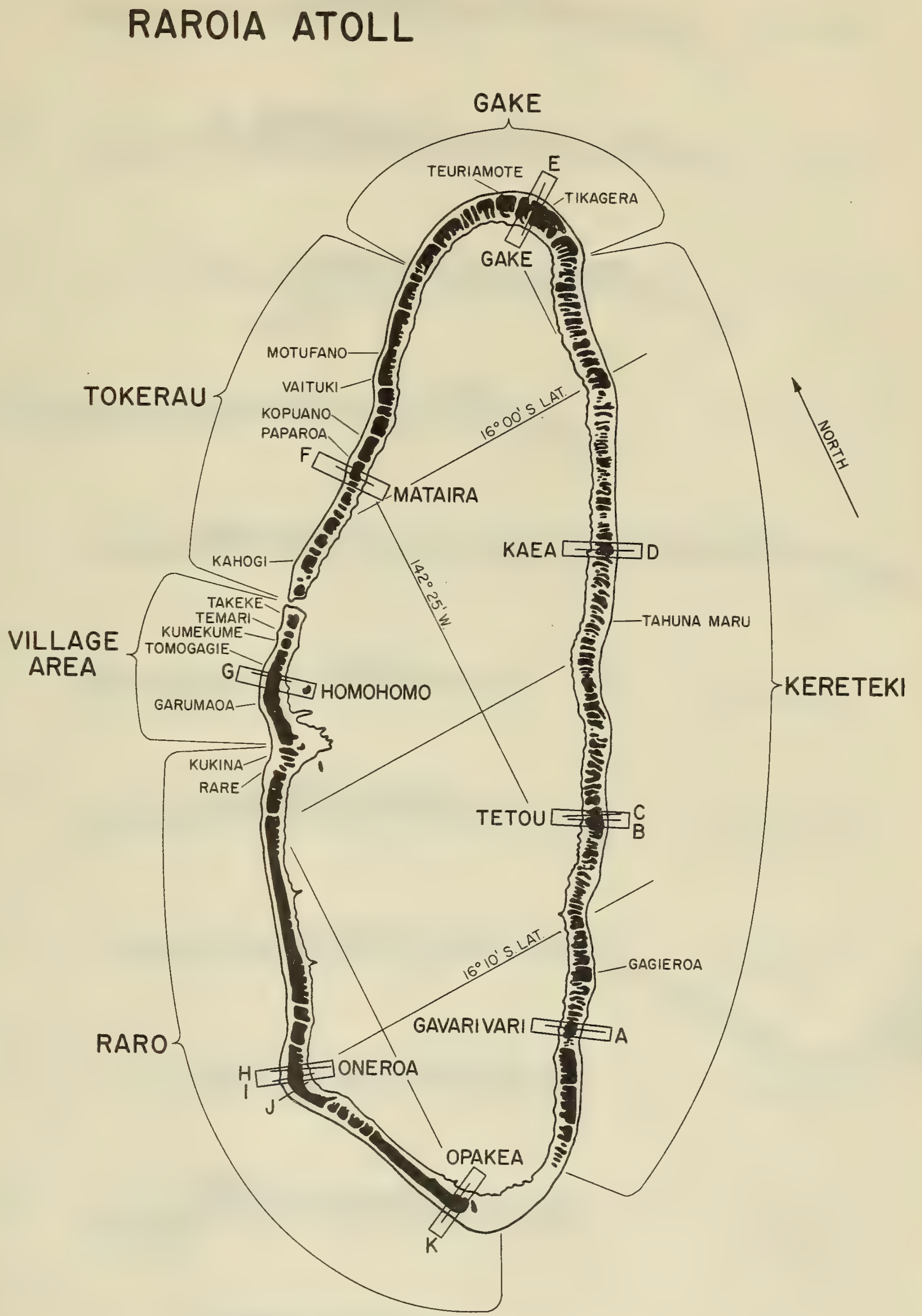
Incomplete channels open at all tides to the lagoon appeared to the next type, Type 9, distinguishable biologically in the series. Here particularly near the lagoon end corals were abundant and there were some holothurians. The fish population was broadly variable but typified by a neon blue damsel fish (Pomocentrid) with a conspicuous yellow tail.

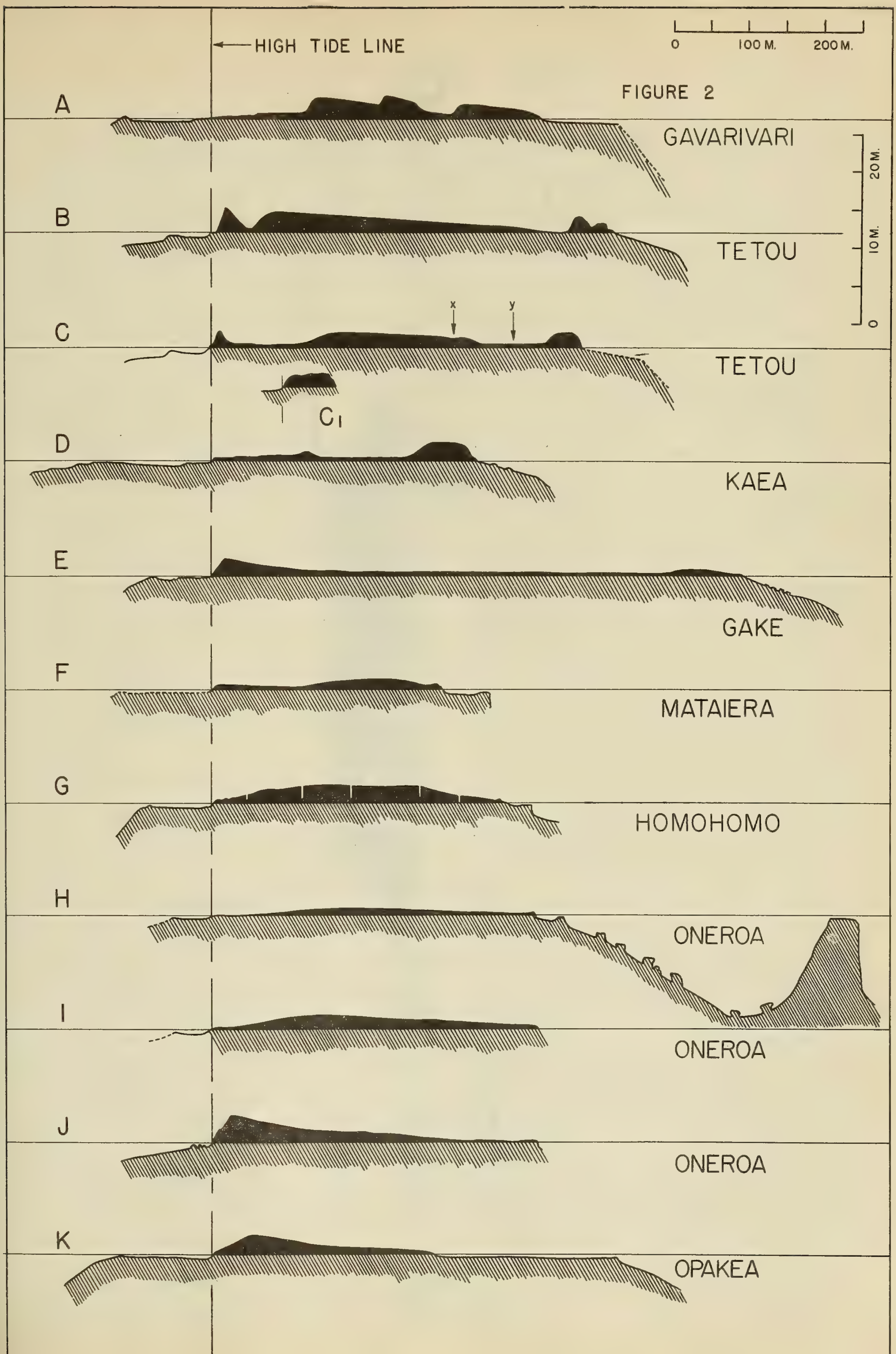
The more strictly intertidal region toward the heads of incomplete channels (pond Type 9) is dominated frequently by the red mud of Entophysalis crustacea (11435). Along the sides of such channels in flat areas probably covered by highest waters are crusts that seem to be transitional to rock. These are dominated by Entophysalis crustacea, Symploca kieneri, Mastigocoleus testarum, Plectonema terebrans and associated fungus filaments (11445). Lower and approximately one-third of the way to the mouth of such a channel the region below blackened by Entophysalis crustacea (11431) may be forming beach rock one form. This surface is a mixture of the "red mud" described above and stones that are predominately yellow brown with, again, Entophysalis crustacea (11447). On lower surfaces of one such stone were to be found 1 mm disc-like patches of blue-green algae (11448). Further toward the mouth of the channels this zone is entirely gravel, coated yellow brown with Entophysalis crustacea and Calothrix scopulorum (11441) on top and clean beneath. This forms a zone 20 cm broad vertically. At the lagoon ends of some such channels there is a transition to sand as in the case of the black zone; and there this yellow brown zone can be distinguished no longer. The channel below low tide line insofar as observed was sand, coral or boulder bottomed.

Above the black zone inside the channels of pond Type 9 the shore areas are dominated by gravel and sand, bound by such blue-green algae Anacystis montana, Calothrix scopulorum, C. parietina, Schizothrix longiarticulata, S. thelephoroides, Entophysalis crustacea, Symploca kieneri, Microcoleus acutissimus and what was taken to be a form of Mastigocoleus testarum (11442, 11443, 11444), there was a sandy-gravelly soil with little humus on top. Neither ferns nor mosses were observed here.

The lagoon shore itself may well form a terminal member, Type 10, in the local series of aquatic habitats associated with the lagoon shore. An additional discussion of this terminal member in the series is to be found under the discussions of the lagoon shores. The shore at Gake was covered by very find sand, has a fish population that most immediate to high tide line is characterized by the fish Chromis coeruleus, black-finned mullet and black-finned sharks. Two octopods were collected at Gake in the very shallow (15 cm) water as was one of two remoras seen.

FIGURE 1


RAROIA ATOLL
GAKE
TEURIAMOTE
E
TIKAGERA
GAKE
MOTUFANO
TOKERAU
VAITUKI
KOPUANO
PAPAROA
16° 00' S. LAT.
NORTH
F
MATAIRA
KAEA
D
KAHOGI
142° 25' W.
TAKEKE
TEMARI
TAHUNA MARU
VILLAGE AREA
KUMEKUME
TOMOGAGIE
G
HOMOHOMO
KERETEKI
GARUMAOA
KUKINA
RARE
TETOU
C
B
16° 10' S. LAT.
GAGIEROA
GAVARIVARI
A
RARO
H
I
ONEROA
J
OPAKEA
K



HIGH TIDE LINE
0
100 M.
200 M.
FIGURE 2
20 M.
10 M.
0
A
GAVARIVARI
B
TETOU
C
x
y
TETOU
C1
D
KAEA
E
GAKE
F
MATAIERA
G
HOMOHOMO
H
ONEROA
I
ONEROA
J
ONEROA
K
OPAKEA

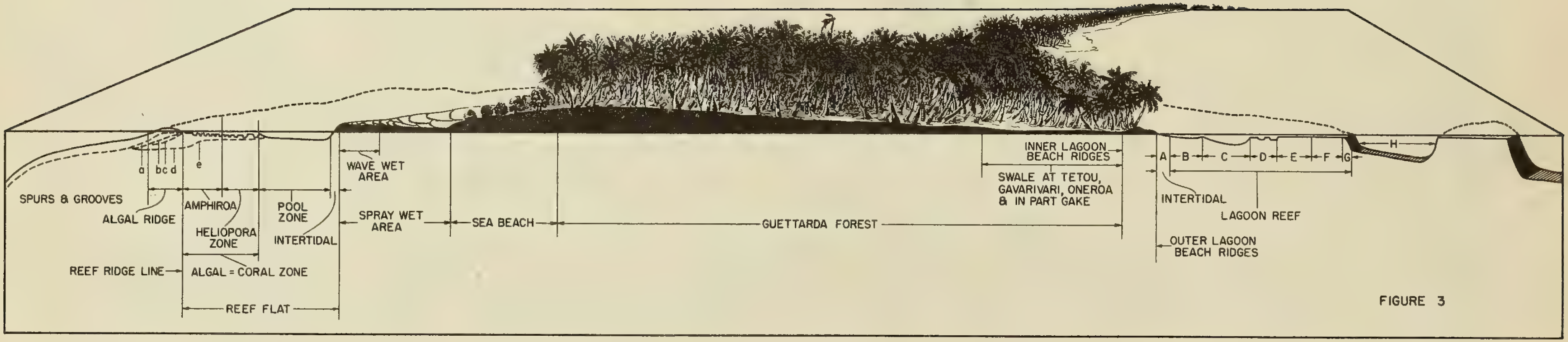

a
b c d
e
SPURS & GROOVES
ALGAL RIDGE
AMPHIROA
HELIOPORA ZONE
POOL ZONE
INTERTIDAL
REEF RIDGE LINE
ALGAL = CORAL ZONE
REEF FLAT
WAVE WET AREA
SPRAY WET AREA
SEA BEACH
GUETTARDA FOREST
INNER LAGOON BEACH RIDGES
SWALE AT TETOU, GAVARIVARI, ONEROA & IN PART GAKE
A
B
C
D
E
F
G
H
INTERTIDAL
LAGOON REEF
OUTER LAGOON BEACH RIDGES

FIGURE 3

FIGURE 4

ZONES AND WATER MOVEMENTS OVER REEF AT HOMOHOMO

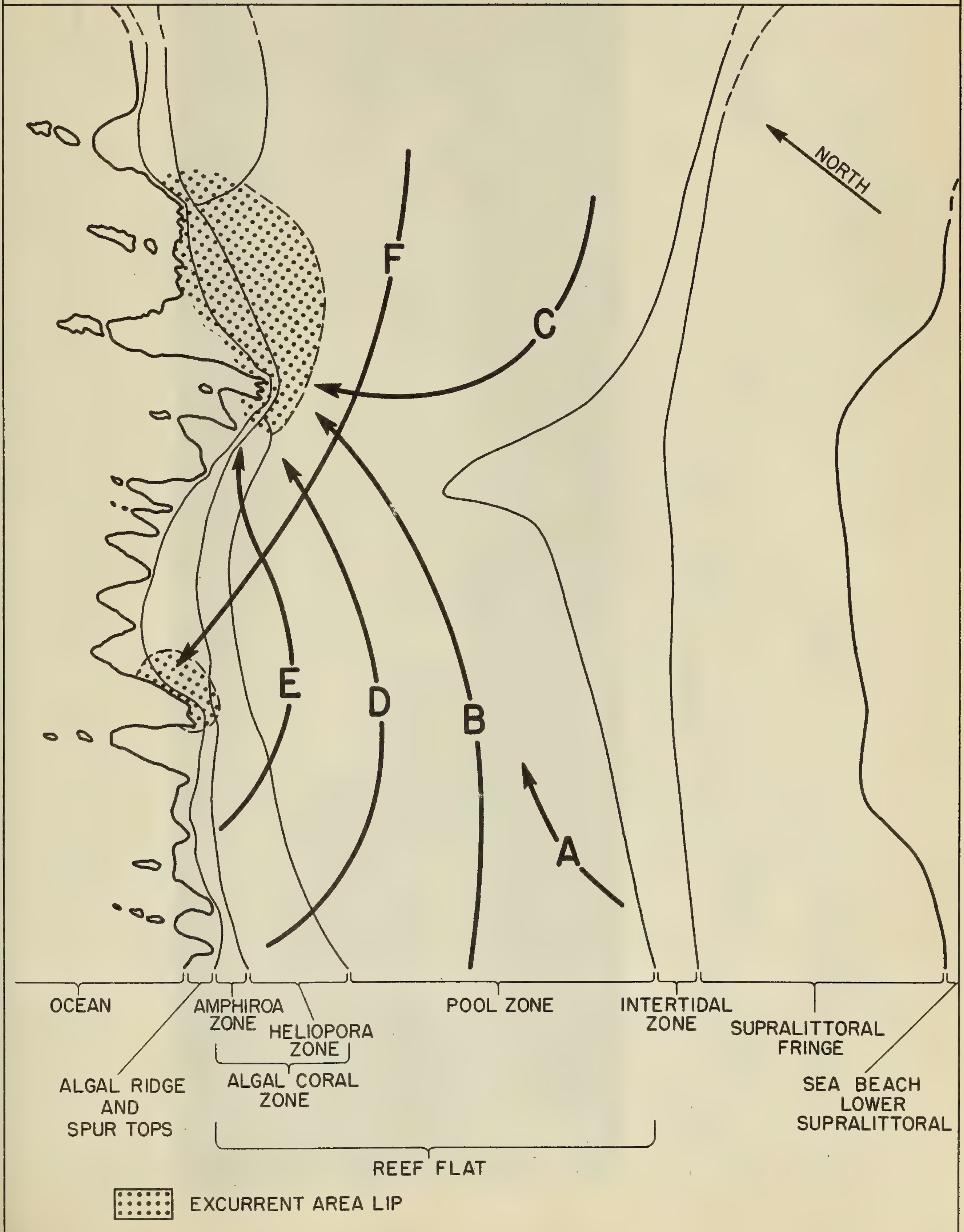
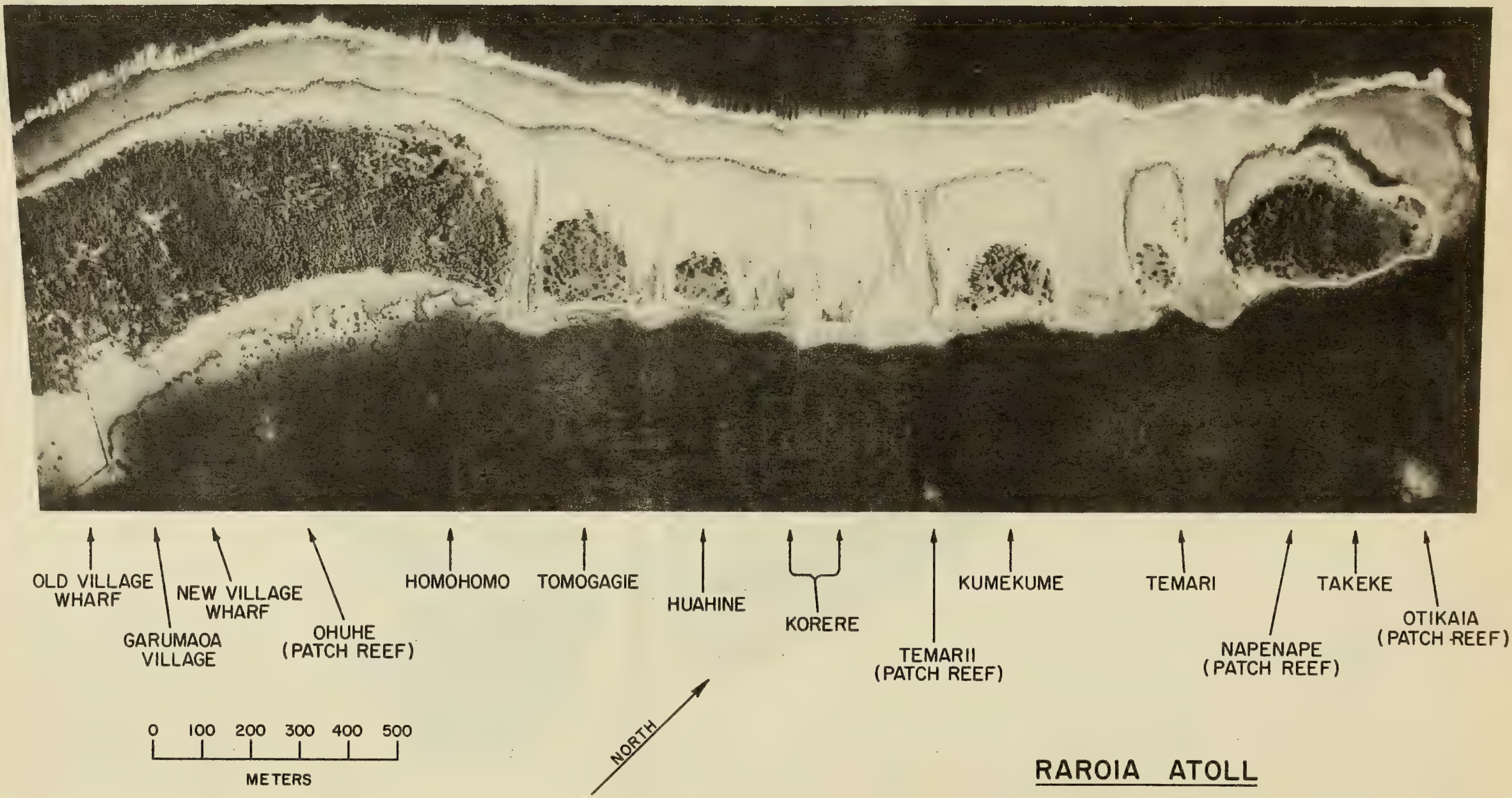


FIGURE 5



RAROIA ATOLL

GARUMAOA TO THE LEFT AND THE SHIP PASS AT THE RIGHT. LAGOON BELOW.

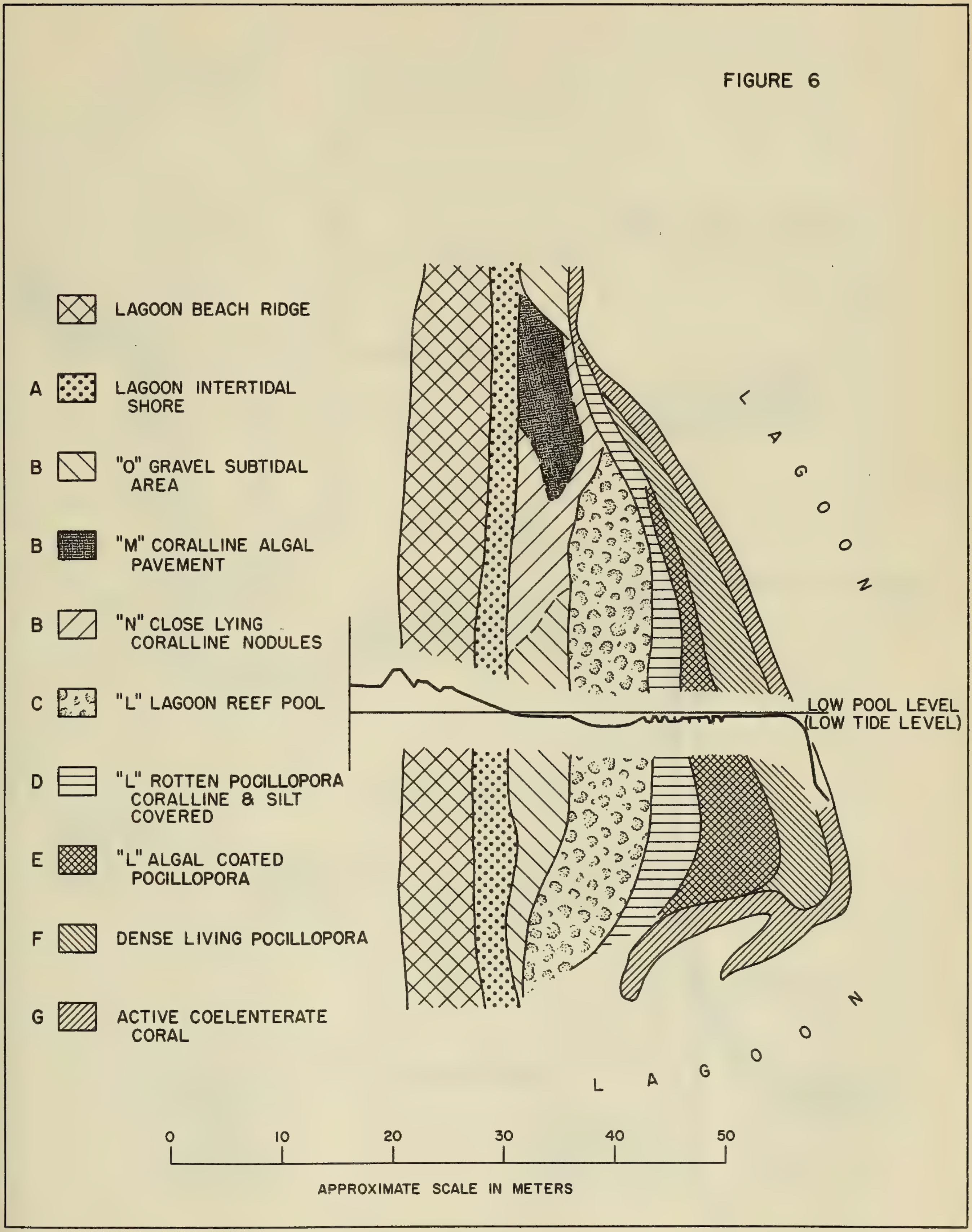


FIGURE 6
LAGOON BEACH RIDGE
A LAGOON INTERTIDAL SHORE
B "O" GRAVEL SUBTIDAL AREA
B "M" CORALLINE ALGAL PAVEMENT
B "N" CLOSE LYING CORALLINE NODULES
C "L" LAGOON REEF POOL
D "L" ROTTEN POCILLOPORA CORALLINE & SILT COVERED
E "L" ALGAL COATED POCILLOPORA
F DENSE LIVING POCILLOPORA
G ACTIVE COELENTERATE CORAL
LAGOON
LOW POOL LEVEL
(LOW TIDE LEVEL)
LAGOON
0
10
20
30
40
50
APPROXIMATE SCALE IN METERS

FIGURE 7

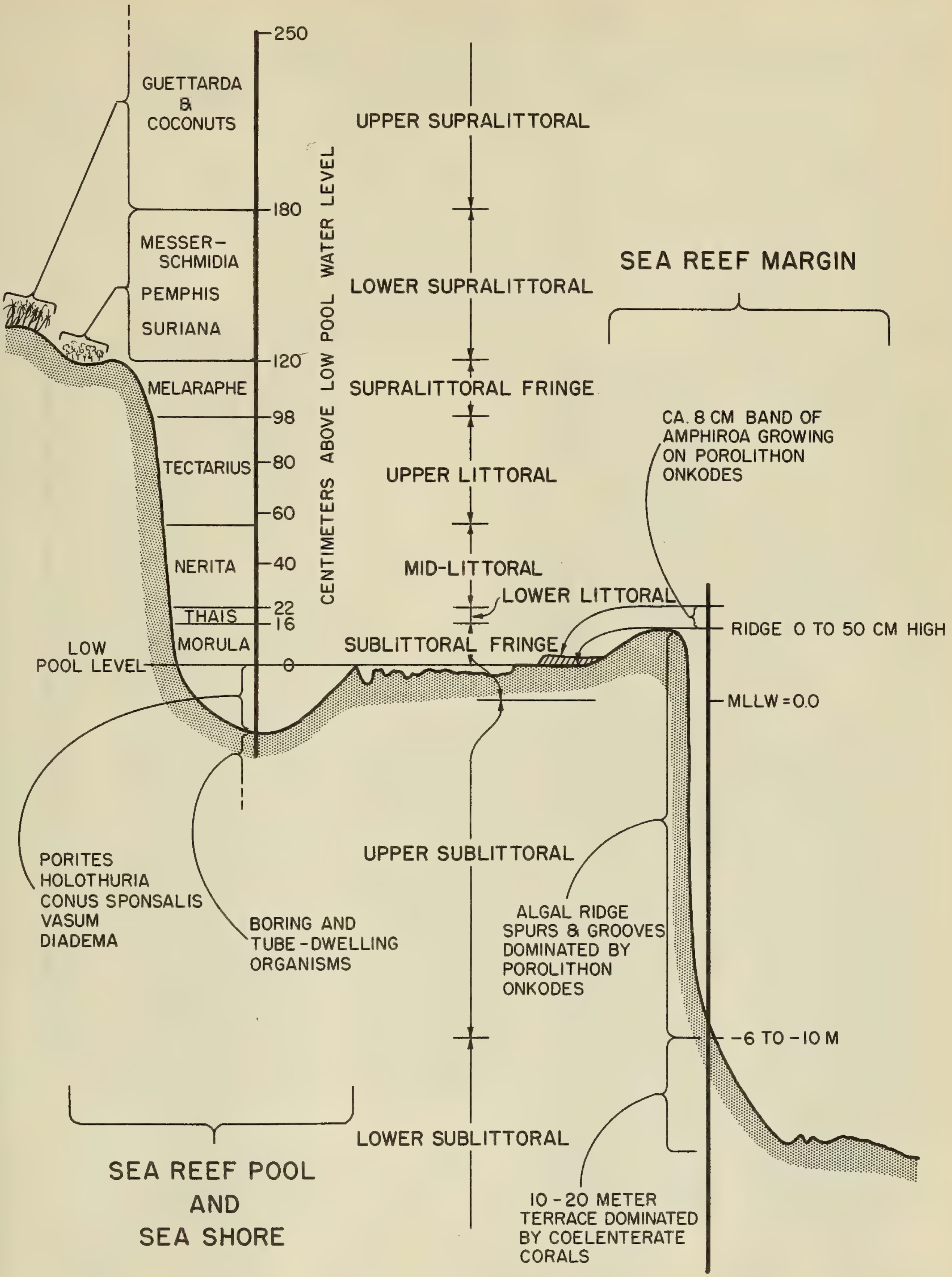
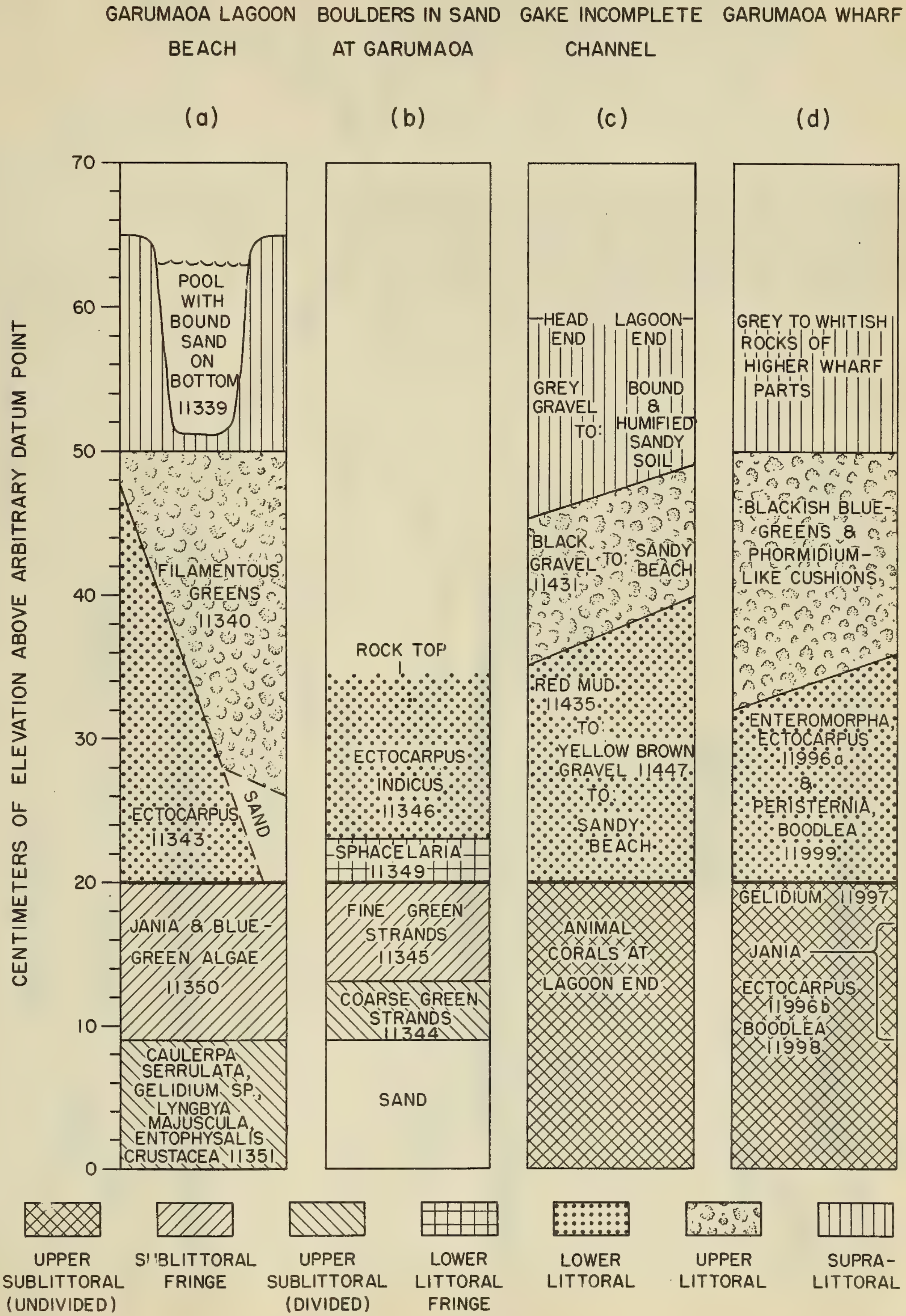

GUETTARDA & COCONUTS
MESSER-SCHMIDIA
PEMPHIS
SURIANA
MELARAPHE
TECTARIUS
NERITA
THAIS
MORULA
LOW POOL LEVEL
250
180
120
98
80
60
40
22
16
0
CENTIMETERS ABOVE LOW POOL WATER LEVEL
UPPER SUPRALITTORAL
LOWER SUPRALITTORAL
SUPRALITTORAL FRINGE
UPPER LITTORAL
MID-LITTORAL
LOWER LITTORAL
SUBLITTORAL FRINGE
UPPER SUBLITTORAL
LOWER SUBLITTORAL
SEA REEF MARGIN
CA. 8 CM BAND OF AMPHIROA GROWING ON POROLITHON ONKODES
RIDGE 0 TO 50 CM HIGH
MLLW = 0.0
-6 TO -10 M
PORITES
HOLOTHURIA
CONUS SPONSALIS
VASUM
DIADEMA
BORING AND TUBE-DWELLING ORGANISMS
ALGAL RIDGE SPURS & GROOVES DOMINATED BY POROLITHON ONKODES
10-20 METER TERRACE DOMINATED BY COELENTERATE CORALS
SEA REEF POOL AND SEA SHORE

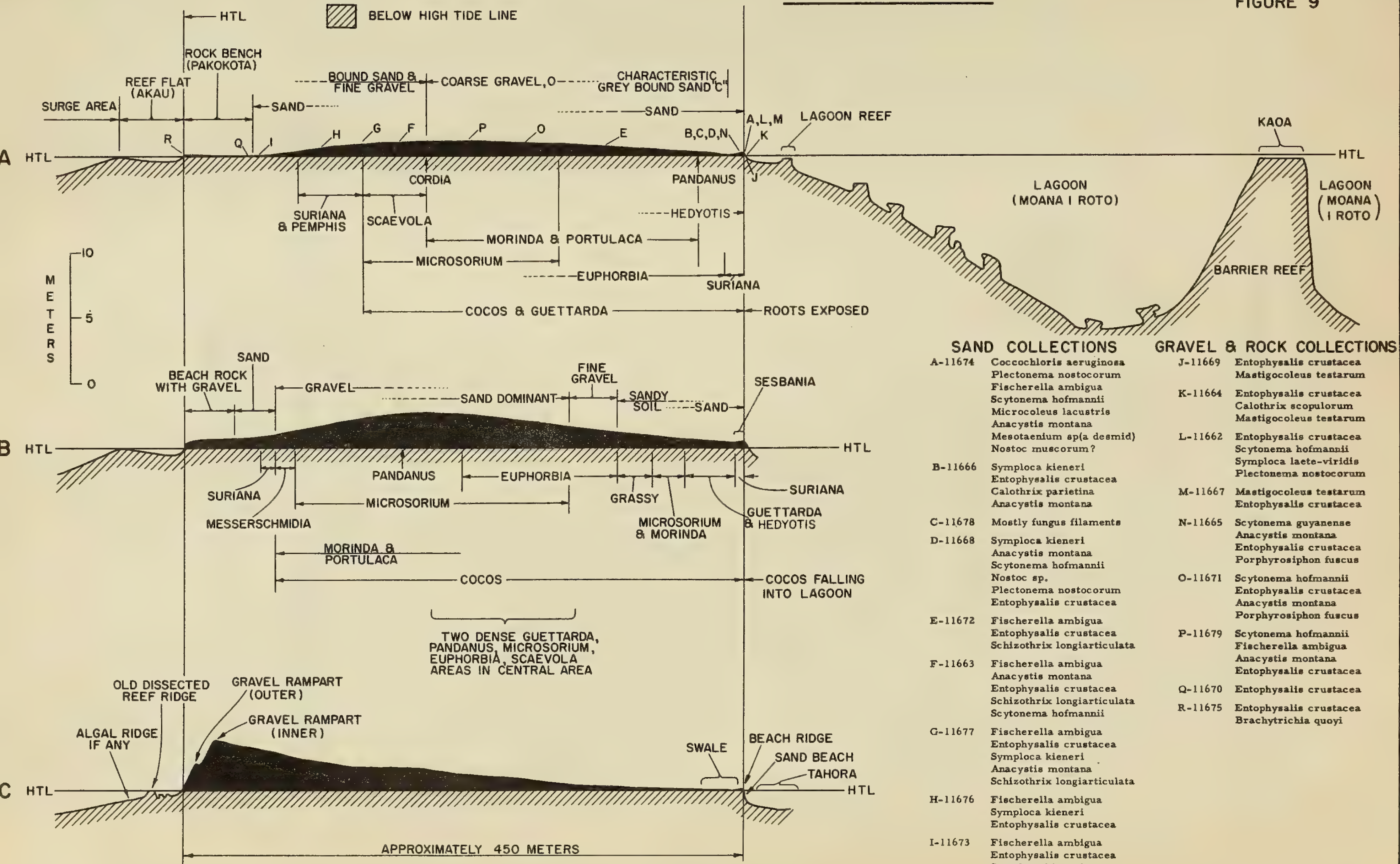
FIGURE 8

LAGOON SHORES



ONEROA PROFILES

FIGURE 9



SAND COLLECTIONS

A-11674	Coccochloris aeruginosa Plectonema nostocorum Fischerella ambigua Scytonema hofmannii Microcoleus lacustris Anacystis montana Mesotaenium sp(a desmid) Nostoc muscorum?
B-11666	Symploca kieneri Entophysalis crustacea Calothrix parietina Anacystis montana
C-11678	Mostly fungus filaments
D-11668	Symploca kieneri Anacystis montana Scytonema hofmannii Nostoc sp. Plectonema nostocorum Entophysalis crustacea
E-11672	Fischerella ambigua Entophysalis crustacea Schizothrix longiarticulata
F-11663	Fischerella ambigua Anacystis montana Entophysalis crustacea Schizothrix longiarticulata Scytonema hofmannii
G-11677	Fischerella ambigua Entophysalis crustacea Symploca kieneri Anacystis montana Schizothrix longiarticulata
H-11676	Fischerella ambigua Symploca kieneri Entophysalis crustacea
I-11673	Fischerella ambigua Entophysalis crustacea Symploca kieneri Plectonema nostocorum Schizothrix longiarticulata

GRAVEL & ROCK COLLECTIONS

J-11669	Entophysalis crustacea Mastigocoleus testarum
K-11664	Entophysalis crustacea Calothrix scopulorum Mastigocoleus testarum
L-11662	Entophysalis crustacea Scytonema hofmannii Symploca laete-viridis Plectonema nostocorum
M-11667	Mastigocoleus testarum Entophysalis crustacea
N-11665	Scytonema guyanense Anacystis montana Entophysalis crustacea Porphyrosiphon fuscus
O-11671	Scytonema hofmannii Entophysalis crustacea Anacystis montana Porphyrosiphon fuscus
P-11679	Scytonema hofmannii Fischerella ambigua Anacystis montana Entophysalis crustacea
Q-11670	Entophysalis crustacea
R-11675	Entophysalis crustacea Brachytrichia quoyi

ATOLL RESEARCH BULLETIN

No. 36

Reefs and Sedimentary Processes of Raroia

by Norman D. Newell

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REEFS AND SEDIMENTARY PROCESSES OF RAROIA

by Norman D. Newell
(including reports by John V. Byrne and J. Sperrazza)

ILLUSTRATIONS

REEFS AND SEDIMENTARY PROCESSES OF RAROIA

by Norman D. Newell

INTRODUCTION

Reef types of Raroia are about as diverse as those of other atolls. An outer, or sea reef (akau), is essentially continuous around the margin of the atoll, and it is somewhat different on the windward and leeward sides. Extensive slump sectors such as those of Bikini (Emery, Tracey, and Ladd, 1949) were not recognized.

There are indications that the rate of erosion of the reef front may actually exceed the accretion of organic material. The equilibrium among subsidence, reef growth, and erosion apparently has been disturbed recently by a rate change in one or more of the controlling variables. Crossland (1928, 1931, 1935) has concluded that growth of the reefs of nearby Tahiti and Moorea is not keeping pace with erosion. He tentatively suggests that the recent epoch of reef formation is drawing to a close as a result of world-wide decrease in vigor of the reef corals. The evidence as presented hardly justifies such a sweeping conclusion, and the implication of racial senescence does not have a place in modern evolutionary theory. Stearns (1945) has made the interesting suggestion that "decadency" in modern reefs is related in some way to recent negative shifts of the sea. That is, a drop in sea level would destroy the organisms of reef flats previously just awash near sea level and might thus lead to wave destruction of the exposed and shallowest parts of the reef. Such a reef might display extensive dead areas in the upper part. If, however, a reef in equilibrium to existing tide conditions were uplifted only a few centimeters, many organisms would quickly be eliminated because of exposure even though still regularly covered at high tide. Slight uplift may be responsible for observed conditions on Raroia.

Ranson (1952) makes the pertinent observation that the Marquesas Islands, which are almost lacking in reefs, and the Tuamotu atolls, although situated at low latitudes, are marginal with respect to suitable temperatures. The southern equatorial current, which bathes these islands, was quite cold as a result of up-welling at the South American continent where the Humboldt current swings westward across the eastern Pacific. The point is that these waters continually store solar energy during the westerly drift. Although the surface waters are warm at the longitude of the Marquesas and Tuamotu, the thermocline is doubtless much shallower here than at points farther west. Great storms may bring very cold waters to the surface with deleterious effects on reef corals. This promising idea requires study. It must be stressed, however, that reports of the feebleness of reef growth in the Tuamotu are exaggerated.

In the Raroia lagoon a discontinuous, generally narrow, shore reef lies along the northwest shore, where the prevailing sediment is gravel. This reef is exposed to the fetch of the prevailing winds, hence is the windward shore reef, even though it lies at the downwind shore of the lagoon. The sheltered, or lee shore, along the southeast side of the lagoon lacks a well defined reef, but small patches composed mainly of massive heads of Porites are common. The sediment here is mainly fine foraminiferal sand. An estimated 1500 to 2000 patch reefs[1] rise from all depths of the lagoon to the surface. The largest of these are termed karena in the Tuamotu language. Doubtless they are an important source of sediments in the lagoon. Coralla and rounded and irregular knolls are visible from the air over shallow bottoms, and results of dredging indicate that living corals are scattered over the deeper part of the lagoon but they generally do not rise far above the bottom.

Field identifications of the algae and mollusks cited in the following pages were made by M. S. Doty and J. P. E. Morrison, respectively. Names of corals were supplied by John W. Wells after examination of the collections obtained by the field party.

THE OUTER REEF

The sea reef (akau in Tuamotuan) is the peripheral reef zone outside the land areas and channels. It forms the outer part of the atoll rim. Since the reef is continuous around the atoll, it is hardly appropriate to refer to windward reefs and leeward reefs as though they were separate reefs. Wherever islands are lacking and the reef flat extends across the atoll rim, as at the southern end of Raroia, the inner boundary of the sea reef is not clearly delimited.

Reef front.-In some reef areas, perhaps in many, the most luxurient growth of corals is not on the reef flat or margin but lies on the reef front well below wave base of ordinary storms. This outer zone commonly is not conveniently accessible for direct observation because of the strong ocean swell. Nevertheless, as at Raroia, the bottom may be examined from a small boat by means of a water glass. This zone of maximum productivity of the corals is usually overlooked, or it is dismissed with a few words.[2]

It may be fairly argued that this rather than the algal ridge or the "spur and groove" zone is the front of the living parts of the sea reef. Almost certainly it is the chief producer of sediment at Raroia. The lower part of the reef front is an uneven, rather steeply shelving surface relatively free from loose sediment. It extends downward from approximately eight meters at the edge of the spur and groove escarpment to beyond the limit of vision at 34 meters. A terrace at approximately 20 meters (10 fathoms) comparable to

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1/ Patch reefs are flat above and reach the surface. I am reserving the term reef knoll, or knoll reef, for the rounded or irregular pinnacles that do not reach the surface. Many writers use "knoll reef" for all small, circumscribed lagoon reefs. On Raroia practically all of the visible small lagoon reefs are patch reefs.

2/ This outer zone has been recognized on the Great Barrier Reef, Andros Island, Bahamas, and elsewhere.

that at Bikini (Tracey, Ladd, and Hoffmeister, 1948) and the Bahamas (Newell, Rigby, Whiteman and Bradley, 1951) is visible on aerial photographs of Raroia. Our handline soundings in the agitated outer waters are not, however, very reliable.

The visible bottom in front of the reef spurs is blanketed by robust living corals, some of which are unlike those elsewhere on the atoll. Of the species apparently limited to this zone most conspicuous is a great flabellate Acropora (A. conigera) which locally covers as much as 25 per cent of the bottom. This coral forms irregular horizontal plates up to two meters across and one-third of a meter thick. They are attached by a short thick trunk at the center of the lower surface or directly at one margin. The species supplies most of the coral slabs scattered over the reef flat and at least 30 per cent of the slabs of the island conglomerate. Another species, unrecognized elsewhere, is a robust staghorn, a Pocillopora, which rises more than one meter above the bottom as bushy clumps with stout stalks seven or eight centimeters in diameter. This form is richly represented in the island rubble, of which it comprises an estimated 10 per cent of the smaller fragments.

Great heads[1/] up to two meters in diameter of a massive Porites are common as is a robust species of Fungia. Several of the coral species of the reef flat also occur on the outer slope, especially corymbose species of Acropora and several species of Pocillopora besides the staghorn referred to above. The abundance of material in the island rubble derived from the reef front indicates that an estimated one-half to three-fourths of the island debris was derived from this zone during hurricanes.

Groove and spur system.-Raroia atoll is surrounded by a conspicuous, groove and spur zone some 50 to 100 meters wide at the top of the reef front. The outer edge of this zone forms a low escarpment at a depth of about eight meters. Landward the crests of the spurs form a terrace surface which rises rapidly to about the extreme low water level at the algal ridge. The terrace is traversed by rather regularly spaced vertical walled gorges or grooves (koehae) which extend seaward at right angles to the margin of the atoll. Generally these grooves terminate at the algal ridge, but a few cut across the ridge and extend across the reef flat as "surge channels." The groove and spur zone is very like the "seaward slope" of Bikini, which has been interpreted as the advancing margin of the reef, composed mainly of algal deposits (Ladd, Tracey, Wells and Emery, 1950, p. 412). Many reef features of Raroia clearly combine both erosional and depositional processes, and it is probable that this is also true of reefs in general.

The outer grooves of the sea reef were investigated in several places at the surface and by means of a swimming mask and the Browne diving mask. Characteristically the deeper gorges descend precipitously from the head at the algal ridge to a depth of six or seven meters; then flattening gradually to a depth of about 10 to 15 meters they debouche on the lower slope of the reef front beyond the spurs. The grooved terrace is rather uniformly dissected, the

1/ A coral "head" as used here is a hemispherical corallum, not a knoll or patch.

deepest grooves of which terminate beyond the terrace; but many of the shallower grooves do not extend completely across the terrace but instead terminate on the terrace surface.

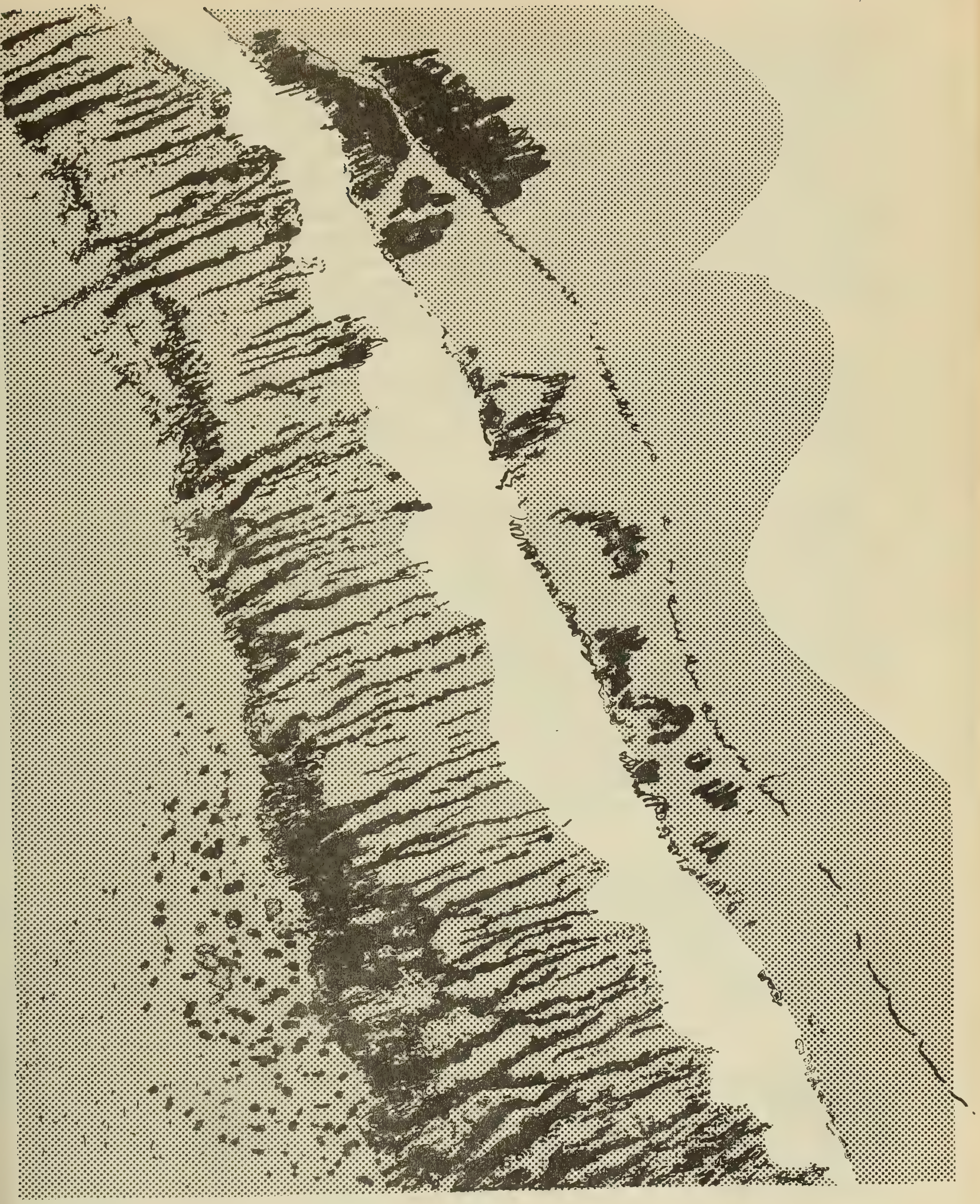
The walls and floor of the grooves generally are smooth and free from all but scattered very young colonies of corals. The rock surface is pitted, rounded, and scoured smooth, and the floor is uneven and ungraded except near the mouth where there usually is an accumulation of boulders and gravel. Here and there on the floor of the grooves are hemispherical shallow potholes of varying size more or less filled with rounded pebbles and cobbles. In some instances the potholes attain diameters up to about two meters and are occupied by boulders of worn Porites that could have been derived only from the outer slope. A few of the gorges are quite narrow, only one meter wide where they are as much as seven meters deep. For the most part they are deeper than wide at places of maximum relief but a few are as wide as they are deep near the mouth. Many of the grooves divide near the head, producing a rough dendritic pattern of tributaries. Rather capacious rooms often are formed at the confluence of these tributaries. Others show effects of a kind of "stream piracy" where they divide seaward in distributaries. Much about these grooves recalls mountain gorges of high gradient cut in massive rocks.

Pothole formation by gravel and scour by sand clearly is the chief agency of erosion along the floors of these grooves. Gravel, which is trapped temporarily in depressions, cuts pits in linear series down the slope. These eventually form more or less straight furrows. The grooves are gradually extended headward by gravel scour, in many places reaching well onto the reef flat as very shallow, more or less bare, furrows, embryonic surge channels.

Part of the gravel responsible for scour in these grooves clearly is derived from the outer slope and this is the only possible source of the largest coralla. The remainder probably originates on the reef flat.

The grooves of the windward outer reef are somewhat narrower and more closely spaced than those of the leeward side. Otherwise they are about the same.

The ridges or spurs (tauta) between grooves form the general surface of the terrace. In many places the spurs are about as wide as the grooves, and with the latter form a comb-like pattern. In other places there are sectors of the terrace as much as 50 meters long that are undissected or incompletely dissected by grooves as the reef sector on Bikini illustrated by Ladd, Tracey, Wells, and Emery (1950, Pl. 3A). In these places grooves have not been formed. Where dissection is incomplete not all the grooves extend to the outer edge of the terrace (Fig. 1). This and the fact that the terrace has a very regular outer margin suggests that the form of both spurs and grooves are effects of erosion rather than construction. There is very little roofing of the grooves by algal deposits. The spurs are quite unequal in breadth. If they were simply buttresses of algal deposits being extended seaward against the surf, they would probably advance at unequal rates and this should produce a jagged, irregular margin.



Bikini Reef

1. Spur and groove zone of a Bikini reef. Reef front at lower left. (From a photograph published by Ladd, et al., 1950)

The tops of the spurs form a flat surface which slopes gently seaward. It is covered by a thin blanket consisting mainly of living brown Pocillopora elegans (25 per cent), and Porolithon onkodes (identified by Doty), which is most prevalent at the inner margin (50 per cent), decreasing rapidly seaward toward the outer ends of the spurs. Other abundant forms of the terrace are a green alga Microdictyon sp. and the gastropod Vermetus maximus. The boring echinoid Echinometra mathaei and a tufted coralline alga Amphiroa sp. are abundant in the shallowest water of the terrace. In addition to the ubiquitous small Pocillopora cited above, two or three species of small Acropora and small massive forms of Plesiastraea and encrusting Millepora and Montipora are visible. All of these forms are securely attached and do not project above the bottom more than 10 to 15 centimeters. This is an association of strongly turbulent shallow waters. It is evidently from this zone that most of the large reef blocks of the reef flat are derived.

The species of Porolithon and Pocillopora together form a rim which in places overhangs half a meter into the gorges and extends a few centimeters down the gravel scoured rock surface. However, under conditions now existing on Raroia these organisms are not significantly modifying the topography of the reef margin.

In summary, there is a well-defined shallow outer terrace which slopes gently seaward. This probably lies at about the wave base of heavy surf but above wave base of the greatest hurricanes. These inferences are drawn from the fact that all of the corals of the terrace are low and small, indicating that they are more or less constantly subjected to strong turbulence and are doubtless frequently decimated. On the other hand the slope in front of the escarpment formed by the spur ends carries large, in some cases, fragile corals which must be many years old. These evidently escape the violence of seasonal storms but during hurricanes they are stripped away to supply much of the island debris. The lower surfaces of the walls and the floors of the grooves generally are scoured free from algal deposits and corals. All of the corals of the rims of the grooves are small; a colony 20 centimeters across is exceptionally large. From this it must be concluded that these surfaces are rather frequently scoured clean by storm turbulence and that few planulae have an opportunity to form colonies.

The surface of the grooves, as those of the reef flat and tidal pools, is colored light pink by a film of Porolithon onkodes the "pavement Lithothamnion". This pigmentation evidently appears within a few days on fresh surfaces and does not require deposition of a heavy accumulation of calcium carbonate. Chips freshly broken from the walls and bottom of grooves and from the reef flat show that the rock is of heterogeneous origin, containing coral skeletons and foraminiferal sand. The algal deposits are quantitatively not significant although they may perform the function of cementation.

It is probable that the grooves are cut into the terrace and that both were formed more or less concurrently. However, it is clear that gravel scour so potent in the grooves does not affect the terrace, the surface of which is relatively free from loose material. As shown by recent work in the Bahamas (Newell, Rigby, Whiteman, and Bradley, 1951) grooves and spurs like those of Raroia may be formed in inorganic limestone free from the supposed influence of coralline algae, and Cloud (1952, p. 43) reports similar erosional forms in Hawaiian basalt. There is no indication that the spurs on Raroia are being extended seaward. On the contrary, abundance of reef blocks[1/], fragments of s spurs thrown up by storms, clearly indicates net erosion (Fig. 2).

The algal ridge.—[2/] There is a well developed, narrow ridge at the outer margin of the reef flat which separates the reef flat from the grooved terrace (see Figs. 6,7).[3/] The ridge commonly is from five to 15 meters wide and rises some 0.3 to 0.6 of a meter above the lowest part of the reef flat. The ridge crest rises at least one meter above the adjacent ends of spurs. In a few leeward sectors the reef flat rises gradually toward a steep seaward margin, terminating in a sort of cuesta that faces the sea. Elsewhere the ridge is more narrowly defined. At irregular intervals along the ridge a few grooves cut across the ridge at low places on the reef flat. At intermediate stages in the tidal cycle waves break over the ridge, building a head of water on the reef flat. Much of this water returns seaward in excurrent streams which issue at the gaps in the ridge. At low water stage the water of the reef flat, which in the daytime may be several degrees warmer than normal sea water and depleted of much of the dissolved oxygen, invariably drains seaward at the excurrent points. Because of less favorable living conditions in these areas the surface commonly is relatively bare of attached organisms.

In a sense the algal ridge is intertidal, but it may rise locally above mean high tide level. It is constantly bathed by breaking waves wherever exposed to the wind, but it is occasionally dry on the lee side of the atoll in quiet weather during low tides. It is difficult to determine the tidal range along a sea reef. For one thing the influence of the wind is considerably more significant in controlling the water level than are the tides. In any case the tidal fluctuation is small at Raroia, about 0.6 meter in the lagoon. The strong ocean swell, even on a windless day produces translation waves with amplitude of two meters and more along the south and southeast sides of the atoll, and perhaps half as high on the leeward or northwest side of the atoll. At low water stage with a moderately rough sea a sheet of water pours over the ridge with each breaker though the mean level of the sea has dropped well below that of the reef flat. The head produced on the reef flat in this way carries much of the water and suspended sediment to the lagoon except where blocked by islets. Opposite the latter the water returns to the sea in many well-defined excurrent streams. It is tempting to speculate on the circulation of reef flat water in the breaker zone during high water. The circulation may be somewhat like that at low tide, excurrent water passing seaward at the gaps in the algal ridge. It is probable that each groove in the terrace functions as an excurrent channel during times of great turbulence. Water laden with outgoing sediment tends to be channelled by the grooves. Circumstantial evidence that this is the case is described in subsequent pages.

1/ In spite of a natural repugnance for the inelegant term "nigger-head" or "negrohead" almost universally employed by students for these reef blocks, I would follow accustomed usage if there were justification on grounds of special aptness. There is none. Let us call a reef block a reef block.

2/ This term is preferred to "Lithothamnion ridge" because the dominant coralline is Porolithon onkodes, not Lithothamnion. The two are quite different structurally, though similar superficially.

3/ Figs. 6 and 7 appeared in Atoll Research Bulletin 31.

Mataira Islet

2. Seaward view of large reef blocks, leeward side of Raroia atoll. The block at the right is about 30 feet long, with an estimated volume of 9000 cubic feet.

Wherever the biota of the algal ridge is healthy and vigorous, the ridge is covered by pink blister-like crusts of Porolithon onkodes, with here and there small hemispheres of ramose Porolithon gardineri. The blisters of the former are often as large as a man's hand and they partially enclose open cavities, refuges of innumerable little crabs. There are many small patches of an encrusting blue-green alga colored light yellowish-green. A narrow belt of discontinuous patches of encrusting Millepora follows the outer flank of the ridge and extends around the heads of the grooves. A helmet urchin (Colobocentrotus sp.), acorn barnacles, limpets, and species of the gastropods Drupa and Turbo live here. A small brown Pocillopora elegans, one of the chief reef formers, and the green alga Microdictyon sp. extend upward over the outer flank of the ridge. Almost every fragment of rock taken from the algal ridge contains the remains of the Pocillopora, yet it is comparatively rare on the crest and landward side of the ridge. Presumably growth accretions on the algal ridge are mainly on the seaward face. Commonly the landward slope of the ridge is deeply pitted and eroded by the burrows of a large slate pencil urchin (Heterocentrotus sp.) and the boring urchin Echinometra mathaei. The latter produces a broadly U-shaped cleft several centimeters deep within which the animal moves back and forth in a plane nearly perpendicular to the surface. On the landward face of the ridge the urchin borings are but little modified by algal incrustation but on the crest and front slope the borings and barnacles are encrusted by laminae of Porolithon onkodes.

The landward face of the ridge, just below the crest, commonly is relatively free from encrustations except for a pink film of Porolithon onkodes. Here the rock, unlike the more active areas on the seaward side of the ridge, is solid. Inspection of broken fragments indicates that the spaces between algal laminae have been filled by foraminiferal sand which has since become firmly cemented by algal accretions.

In many places around the atoll the algal ridge is being reduced by erosion over most of the surface. This is especially the case around the southern end of the atoll from the elbow at Oneroa as far as the southernmost islets of the east side.

Persistent erosion of the algal ridge is in every case accompanied by sustained activity of Porolithon onkodes at a level a few centimeters to a meter lower around the heads of the grooves and over the crests of spurs. This fact might suggest a very recent drop in the relative level of the sea. If so, the drop cannot have been more than a few centimeters because the ridge is not exposed to view even on the leeward side of the atoll during times of high water. Erosion of the ridge is correlated with local depopulation of the coralline algae and corals. But the factors responsible for this are not clear.

Outer reefs of Bikini on which there is a low uninterrupted algal ridge were designated type I-A by Tracey, et al., (1948, pp. 870-871). On Raroia this is the dominant type on both leeward and windward sides of the atoll. It is noteworthy, however, that on Bikini this type of reef is poorly developed on the leeward side and is especially characteristic of reef segments between islands. On Raroia there appears to be no correlation between reef type and location of channels.

Surge channels.-In a few places around the sea reef on both windward and leeward sides of Raroia, the outer grooves extend through the algal ridge some 25 to 50 meters as narrow clefts. These are found chiefly in low areas of the reef flat. Because they are low, these places are also excurrent areas which drain seaward much of the time. In some examples the troughs are partially or completely roofed over by a thin crust of Porolithon onkodes and small corals. Spouting jets of water and hissing of air are characteristic phenomena at openings over the caverns thus formed. The channels, which form a special habitat for many reef fishes, are lined at the rim by small corals and blisters of Porolithon onkodes. The lower walls and floor, however, are scoured by sand and gravel like those of the outer grooves. Judging from the extensive deposits of coralline algae over and at the margins of the surge channels, it seems that this environment is almost as favorable for a few reef organisms as that at the front of the algal ridge. The coralline algae are not, however, very active in the gloomy recesses of the caverns where erosion clearly is dominant and accretion is at a minimum.

The surge channels are headward extensions of the outer grooves and they are now being cut and deepened by gravel scour. All of the Raroia examples contain pot holes filled with rounded cobbles and pebbles. Many extend within 15 meters of the shore.

None of the surge channels of Raroia is being filled or being displaced seaward by algal deposits. As the channels are extended headward and roofed over in the intermediate areas, they are widened toward the sea. Even where the surge channels are partly or completely roofed the cover is only a thin veneer over extensive caverns that clearly are being deepened and widened as they are extended headward. Reef sectors bearing surge channels were designated type I-B (2) on Bikini (Tracey, et al., 1948, p. 871) where they are best developed on the windward side of the atoll along convex arcs in front of islands. On Raroia surge channels are comparatively uncommon. They do occur, however, on both windward and leeward sides.

The reef flat.-This term is used in a purely descriptive sense for the flat rock pavement which extends from the algal ridge to the shore of the islands; or, where islands are lacking, as at the south end of Raroia, the reef flat extends almost to the lagoon, being practically coextensive with the atoll rim. All parts of the reef flat are not necessarily part of the reef and it may not be underlain everywhere by reef limestone. Probably the inner part of the reef flat of Raroia is an erosional surface cut in whatever rocks compose the islands. It appears to me improbable that atoll islets are always formed on a preexisting reef flat. Granted that atoll islets are ephemeral there is still little evidence that they are peculiar to the modern scene. It is more probable that island deposits (i.e., terrestrial rubble) may form an appreciable part of the interior structure of any atoll rim.

On Raroia the reef flat is a pavement which descends gently inward from the algal ridge to near low tide level opposite islands and one to three meters below low water at the lagoon margin between islands. The piling of water on the reef flat by breakers makes it very difficult to correlate water levels on the two sides of the algal ridge. The normal tidal range in the lagoon is about 0.6 meter, but the range on the reef flat of the leeward side of the atoll is about 0.35 meter as indicated by characteristic intertidal organisms and erosion forms.1/ This suggests that although the high water mark on the reef flat is probably at about the level of high tide, the low water mark may be as much as 0.25 meter above low tide. For this reason the reef flat continues to drain at low water state. As stressed elsewhere by Doty and Morrison (Atoll Research Bulletin No. 35), it is essentially a tide pool.

Characteristically, the Raroia reef flat is narrow, 30 to 150 meters, except at the south end of the atoll where there are no islands and the reef flat comprises most of the rim area. On the windward reef flat there are few attached organisms and most of these are sparsely distributed in low areas around surge channels where they are somewhat sheltered. The leeward reef flat is more populated, even though it is exposed for longer periods than the windward flat, and at many places there is an outer belt behind the algal ridge that is completely covered by a matte of small corals (especially *Pocillopora elegans*) and encrusting red algae. This coral-algal zone contains innumerable burrows of the echinoid *Echinometra mathaei* which retain water during emergence, hence provide shelter for a diverse and distinctive community of ophiuroids, crabs, gastropods and fishes. Shoreward, the corals are less crowded and the algal deposits more sparse. The coral fauna becomes specifically more diverse and extensive areas of smooth rock pavement dotted with Foraminifera appear between coral colonies.

Generally the coral colonies are small. Heads 25 centimeters across are large for most areas. From studies of growth rates in corals (Vaughan and Wells, 1943) it appears probable that the majority of the reef flat stony corals are not more than 15 or 20 years old, and probably none antedates the great hurricane of 1903. Rings of *Montipora* sp. one and a half meters across were observed on the leeward reef flat, but these are exceptionally large.

Wherever corals are abundant there is a rather well-defined differentiation into life zones probably determined mainly by the degree and length of exposure to the air and by the temperature conditions.

Large, brown slate pencil urchins (*Heterocentrotus* sp.) occur sparsely in a belt about two meters wide on the sheltered side of the algal ridge. For the most part these urchins occupy pits and depressions in the rock, similar to potholes, which they apparently have excavated. The surface in this zone is bare and smooth. There is little indication that these urchins and the much smaller *Echinometra* move about freely and it is presumed that food is brought to them by the circulating water.

From the pencil urchin belt landward for some 5 to 25 meters the reef flat is here and there completely overgrown by the small brown *Pocillopora* of the algal ridge and small colonies of *Acropora* spp. Many of these are heavily encrusted by *Porolithon onkodes* which generally is brownish, apparently moribund, and abundantly perforated by the boring urchin *Echinometra mathaei*. Some of the openings, however, are partly closed by algal deposits. In some areas there are as many as 50 to 100 of these urchins to a square meter. Most individuals are black but a few are brown. The superficial deposits over the reef

1/ According to Doty, the interval is less than this.

flat form a superstructure of coarsely cellular material 10 to 20 centimeters thick over a basement of solid rock in which pores have been filled by cemented foraminiferal sand. The open burrows and entrapped water provide shelter for a variety of ophiuroids, crabs, snails, fishes and octupi at low tides when much of the surface is out of water.

In a few places the surface adjacent to the algal ridge is overgrown by meadows of a purplish-red jointed coralline _Amphiroa_ sp. The black, long spined urchins (_Diadema_) range from the edge of the algal ridge (at high water) to the shore, migrating back and forth as necessary to remain covered by water.

Census of a square meter in Amphiroa _belt_

	Per cent of total area (estimated)
Porolithon onkodes, covered by _Amphiroa_ sp.	40
Pocillopora elegans (27 small colonies less than 12 cm across)	25
Echinometra (chiefly of black form)	20
Porites sp. (pavement type with _Vermetus_ sp.)	10
Alga, blue-green	5
	100

Census of another square meter in Amphiroa _belt_

	Per cent of total area (estimated)
Porolithon onkodes and _Amphiroa_ overgrowing dead corals	60
Pocillopora elegans (21 heads less than 12 cm across)	15
Echinometra (burrows of black form)	20
Acropora conferta (purple corymbose form) five colonies less than 12 cm across	2
Plesiastrea spp.? (five small colonies)	2
Porites sp. (two colonies)	1
	100

Corals become more varied as _Porolithon_ decreases in importance toward the inner margin of the coral-algal zone where the water is a few centimeters deeper and the surface is more continuously covered than the slightly higher surface near the algal ridge. A square meter in this part of the coral-algal area provided the following estimates.

Census of a square meter near inner margin of coral-algal area

	Per cent of total area (estimated)
Porolithon onkodes encrusting dead corals (mainly Pocillopora elegans)	58
Pocillopora (17 live colonies less than 20 cm across)	3
Echinometra burrows (black variety)	30
Porites (encrusting)	5
Acropora spp. (three colonies) less than	1
Montipora sp.	1
Massive coral (Plesiastraea sp.?) less than	1
Diadema setosa (six individuals) more than	1
	100

Shoreward from the coral-algal area the supersturcture of small ramose corals and Porolithon onkodes breaks up into scattered, more or less isolated coral colonies, separated by flat low areas of solid pavement. Porolithon onkodes is relatively unimportant here and forms only a thin pink film on dead corals and the pavement. Discoid Foraminifera (Peneroplidae) are abundantly scattered over the surface loosely adherent by their pseudopods. Dead tests may become permanently anchored by the algal film eventually to be incorporated in the rock of the reef flat. Serpulid tube worms are scattered over the rock pavement.

There are perhaps a number of environmental factors which prevent the extension of the coral-algal cover to the shore. Porolithon onkodes finds optimum growth conditions near the algal ridge. Reproductive activity of this alga apparently decreases rapidly away from the ridge, both seaward and landward. On the reef flat wherever conditions greatly reduce the number of coral colonies that can become established and wherever the coralline alga is unable to encrust dead corals and roof over the intervening space the superstructure does not develop. There are several factors near the shore that inhibit coral growth and limit the number of larvae that can successfully establish themselves. In the first place, there is a tendency for ephemeral deposits of sand and gravel to be accumulated temporarily near the shore, so that undoubtedly the effects of cover and scour are much more important here. Effects of scour, of course, are much more deleterious to larvae and very young colonies and the corals do rise well above the bottom where scour is most pronounced. A second unfavorable factor is the great temperature fluctuations found in the shore waters. Water draining from shore rocks and tide pools at night and early in the morning is cooled by evaporation to a degree or so below the general temperature of the reef flat waters. In the daytime, especially when low tides coincide with high air temperatures, excurrent water draining from the exposed areas of reef flat is heated to 32°C and more as compared to the (winter) temperature of 26° C of the incoming water which splashes over the ridge and flows shoreward over the flat.

Zonation, more or less parallel to the reef margin, is largely a consequence of the fact that the reef flat slopes shoreward from the crest of the algal ridge to a trough or pool some two-thirds to three-fourths of the distance from the reef edge (Figs. 6 and 7, Atoll Research Bulletin No. 31). The trough may be as much as 20 or 30 centimeters lower than the outer part of the reef flat. Because of this the outer part of the reef flat generally is drained before the slightly lower inner part; hence, during very quiet weather the latter is less exposed to the air. On the other hand, the outer part, corresponding to the coral-algal belt, is nearer to the source of normal sea water with its more abundant supplies of food and oxygen.

The most conspicuous feature of the middle area of the reef flat is low, irregular colonies of the coral Montipora spp., usually alive only around the periphery. These usually accommodate several individuals of the gastropod *Vermetus maximus* in the dead central area.1/ Several massive corals and one or two "brain" corals are better developed here than elsewhere. Individuals of *Diadema setosa* are common to abundant in this zone, but *Echinometra* is represented by relatively few individuals, and these are the reddish-brown phase rather than black. Tufts of the arborescent coralline alga, *Goniolithon* sp. are common here on dead corals. The *Montipora* zone /This is the "*Heliopora* zone" of Doty and of Doty and Morrison, Atoll Research Bull. 33 and 35. Ed./ ranges in breadth from about 5 to 30 meters, and it is limited to the leeward side of the atoll.

Census of a square meter in the Montipora belt

	Per cent of total area (estimated)
Rock pavement, covered with discoid Foraminifera, blue-green algae, and film of *Porolithon onkodes*	70
Montipora (a single colony)	5
Acropora digitifera (three colonies)	5
Acropora conferta (purple, two colonies)	1
Massive coral (*Plesiastrea* sp.?, nine colonies)	8
Porites sp., encrusting (four colonies)	5
Echinometra (burrows of brown form)	5
Diadema setosa	1
	100

1/ The term "microatoll" for these and other single colonies of corals is not very appropriate. Why not reserve the term for ringed patch reefs enclosing more or less dead central areas such as are so abundant in the Bahamas (Newell, *et al.*, 1951)?

Census of another square meter in Montipora belt closer to shore

	Per cent of total area (estimated)
Rock pavement, with surface film of discoid Foraminifera, blue-green algae, and *Porolithon onkodes*	76
Montipora (two colonies)	10
Acropora digitifera (three colonies)	2
Acropora (purple, two colonies)	1
Pocillipora elegans (five colonies)	2
Massive coral (spiny, *Favites*?)	1
Massive coral (*Plesiastrea* sp.?)	3
Echinometra (burrows of brown form)	5
	100

A shore strip of the reef flat some 15 to 30 meters wide, as well as the floor of many rock pools behind outlying masses of beachrock, consists predominantly of smooth pavement almost continuously inundated even at low spring tides. Most of the loose rubble of the reef flat and blocks broken from the shore passes over this zone and serves as tools for the excavation of numerous shallow potholes below the general surface of the reef flat. The entrances to small landlocked rock basins within the area of beachrock commonly lie 20 centimeters or so below the general level of the bottom.

The reef flat descends gently from the algal ridge to a low trough some 5 to 10 meters from the shore. The slope is the result both of upbuilding along the reef margin and erosion near the shore. The surface even near the shore is covered by a thin film of pink coralline algae, presumably *Porolithon onkodes*[1] and adherent discoid Foraminifera. As will be shown below, much of the inner part, at least, of the reef flat is an erosional platform cut in old island conglomerate.

Two species of large black holothurians are abundant in this area. One is sausage shaped and ordinarily is coated by adhering grains of sand. The other is extensible, living mainly under rock slabs and thrusting its oral crown out many centimeters in search of food. A large rock "oyster," *Chama pacifica*, occurs in some abundance here with several gastropods, *Morula* sp., *Conus sponsalis*, *Vasum* spp., and others. Flat, knobby encrusting plates of *Porites* spp. occupy as much as 30 per cent, locally, of the bottom.

1/ Maxwell S. Doty has made the suggestion to me that the algal film of the shore zone and the deeper parts of the outer grooves may be non-reproductive colonies of *Porolithon onkodes* incapable of secreting massive deposits of calcium carbonate.

The excurrent areas of the reef vary considerably around the atoll. They are alike in being appreciably lower than adjoining reef sectors. Some of these, as at the Garumaoa transect (Homohomo), may be nearly devoid of bottom organisms, although adjoining reef sectors are well populated. These areas commonly are furrowed by potholes and irregular shallow grooves converging, fan-like, toward the gaps in the algal ridge. The grooves are discontinuous and erratic. For example, a groove five meters long and a quarter-meter wide abruptly shallows from a maximum depth of 20 or 25 centimeters toward both ends and disappears, being continued a few meters farther on by another more or less aligned groove. The floors of the grooves are scoured clean by gravel and sand but are very uneven and interrupted here and there by gravel-filled potholes. These grooves are incipient surge channels, and like the latter they lead to outer grooves.

Some excurrent areas are populated by scattered corals; and perhaps because of the greater depth of water in these places, the corals attain relatively large dimensions as compared with other reef flat corals. They attain very frequently a lateral diameter of one-half meter and a height of 20 or 30 centimeters. In these areas more than two-thirds of the bottom is devoid of corals, and hardly any of the colonies are very small. Hence, an inference may be drawn that the area is most commonly unfavorable for planulae, perhaps because of sediment scour, perhaps because of unfavorable temperature conditions. On the other hand these areas are not too unfavorable for the continuance of colonies established under temporarily more favorable conditions.

On the windward reef flat the excurrent points are at rather shallow basins on the reef flat around surge channels. These basins contain a few small corals but the general surface of the flat is completely devoid of corals. The general barrenness of the windward reef flat is difficult to understand. This area is not subjected to protracted exposure to the air, in fact it is almost always inundated by piling up of adjacent waters. It may be that sediment scour is responsible for these special conditions.

Erosion of the reef flat.-Both the outer and inner parts of the reef flat are being conspicuously eroded over large sections of the sea reef. It is perhaps more accurate to say that the reef flat is being extended landward by planation of the shore to a level approximating the deepest parts of the reef flat. Aligned outlying erosion remnants of beachrock, elevated reef pedestals beneath reef blocks, and distinctive pitted areas all clearly indicate that the beachrock was formerly considerably more extensive seaward than at present and that the inner reef flat is being lowered by erosion. On the windward side of the atoll the shore has retreated at least 50 meters for long distances and on the leeward side at least 15 or 20 meters. Thus the reef flat has been extended by this amount at the expense of the land. Lacking facilities to excavate the reef flat in these places we were unable to ascertain whether the rock is composed of conglomerate or organic accretions. There is no indication that the beachrock and island conglomerate were welded to a preexisting reef flat.

In many places around the atoll the landward flank of the algal ridge shows generally a moribund condition of the reef builders and consequent erosion. Along the windward side and the southern end of the atoll the outer part of the reef flat, some 10 to 30 meters wide, is deeply pitted by potholes. Joints in the reef flat are clearly etched in relief. All evidence points to net erosion.

The same deep pitting occurs at the outer margin of the reef flat at many places along the leeward side of the atoll. Usually this zone is narrow, one or two meters wide, and it is not recognizable at all in a few areas of exceptional growth activity.

This evidence of erosion of the reef flat, taken in conjunction with the generally sterile appearance over great areas, suggests an appreciable very recent relative drop in sea level of perhaps 20 or 30 centimeters (the local relief of erosion remnants between excurrent channels) with attendant far-reaching effects on the life zones and acceleration of clastic sedimentation.

LAGOON REEFS

Lagoon shore reefs.-A discontinuous reef lies along the windward (northwest) shore of the lagoon (in Tuamotuan, *tahora*). Reef growth is inhibited or prevented at the mouths of channels and along the edge of the lagoon at the southern end of the atoll where there is active deposition of fine sediments. The leeward (southeast) shore lacks well-developed shore reefs but instead has innumerable coral heads (mainly massive *Porites*) and small patch reefs. The differences in lagoon reefs on the two sides of the atoll probably are attributable to 1) more effective delivery of oxygen and food to the windward shore, and 2) more favorable conditions there of sedimentation. The shore reefs rest on a shallow terrace which may correspond to the eight-meter terrace of the sea reef. Few of the shore reefs rise more than about six or seven meters above the bottom, and in most places the relief at the reef front, well inside the terrace rim is only three or four meters. An exception to this is found at Oneroa, where a small barrier reef extends across a broad bay in about 20 meters of water. Presumably this reef originated as a fringing shore reef and maintained upward growth during subsidence of the bottom.

Well-defined habitat zones are shown by the windward shore reefs. Commonly, the beach is formed of fine gravel which forms the border of a narrow reef flat. A black, sausage-shaped holothurian, presumably the same as one of those of the outer reef flat, ranges from the low water line at the shore outward to the outer limit of the reef flat pavement. The holothurians ingest Foraminifera and other particles not firmly attached to the pavement. Loose pebbles in the holothurian belt are commonly heavily encrusted by a knobby pink coralline alga, possibly *Porolithon onkodes* with a small commensal *Vermetus* sp., and an *Isognomon*.

A small club-shaped *Acropora digitifera*, a finger-like ramose *Porites mordax*, and *Chama pacifica* locally are numerous among the holothurians.

Two to 10 meters or so from the shore flattened hemispherical "millstones" of knobby *Porites* make their appearance. The largest of these heads is about one-half meter high and one meter across the disk, but the majority are less than a quarter this size. The massive *Porites* forms a favored habitat for a species of small *Chama*, a *Vermetus* of intermediate size, *Isognomon* sp., and burrowing pelecypods of several species (*Tridacna maxima*, *Lithophaga* sp., *Pedum* sp., *Barbatia* sp.).

Rather abruptly, within two to 20 meters of the reef rim a small brown Pocillopora elegans?, interspersed with a few small Acropora and massive corals of several kinds become abundant. Dead corals are in places overgrown by Porolithon onkodes and Zonaria sp., a brown alga which forms a superstructure 15 to 20 centimeters thick on the reef pavement, like that of the coral-algal surface of the outer reef flat. Here, conditions are favorable for the brown phase of the boring urchin (Echinometra mathaei). The black phase was not encountered in the lagoon.

The Pocillopora belt varies in breadth. It is replaced a meter or so from the reef rim by a more robust species of staghorn Pocillopora sp. and knobby massive coral (Plesiastrea sp.?) which extends down the reef front, forming heads a half meter in diameter. The front of the reef drops nearly vertically or with slight overhang a few meters to the sediment-covered terrace below (Fig. 3). Somewhat shaded from the sun beneath the rim is a coarse "brain" coral (Lobophyllia costata?) which forms massive surfaces. The most conspicuous of the reef-front corals, however, is a massive Montipora sp., most prevalent in the lower part of the reef face, composing a large part of the living surface. Small and fragile Acropora spp. are scattered over the front of the reef, extending over the bottom beyond the reef edge.

Opposite the south end of Garumaoa Islet the shore reef spreads far into the lagoon, forming the most conspicuous feature of the windward shore of the lagoon. The reef flat here is about 700 meters wide, occupied mainly by the holothurian association. There is circulation across the atoll rim through several shallow channels at this place, but these do not offer a clue to the exceptional development of the shore reef. The atoll rim swings inward here in an embayment, so directed as to form a sort of funnel to ocean swell from the northwest, the direction from which the strongest winds blow. It is probable that the expanded shore reef is built on a gravel fan or delta. The form of the reef suggests that this is the case.

At irregular intervals around the lagoon shore, especially on the northwest, there are slender tongues of the shore reef which extend into deeper water as spurs at right angles to the shore. These are termed kaoa in Tuamotuan and many are given distinctive names. Exceptionally the kaoa extend a half kilometer into the lagoon (e.g. Miramirau). Apparently they represent fusion of patch reefs with the shore reef by growth across the intervening gap. The consistent orientation of the reef tongues at right angles to the shore must be related in some way to the prevailing circulation of the lagoon waters. This problem will be again considered in the discussion of patch reefs.

The leeward (southeast) shore of the lagoon has very few shore reefs, those being quite small patches, and there is only one kaoa reef. The black holothurian which characterizes the near-shore belt elsewhere is abundant here below low water level. Pebbles are coated with deposits of Porolithon onkodes. Massive disks of Porites with all of their commensals are scattered abundantly over the sand. They are not attached to the substratum and can easily be turned over. A finger-shaped Porites mordax and a fragile Acropora implicata are occupants of the sand bottom.

3. Profile of lagoon shore reef at north end of Garumaoa Islet. 1, Reef flat pavement; 2, large disks of <u>Porites</u>; 3, <u>Pocillopora</u> sp. 1; 4, <u>Favia</u>; 5, <u>Pocillopora</u> sp. 2; 6, <u>Lobophyllia</u>; 7, <u>Montipora</u>; 8, <u>Acropora prolixa</u>

Patch reefs.-Viewed from an airplane the Raroia lagoon is impressive for the large number of patch reefs scattered over the entire lagoon, but somewhat less numerous toward the leeward (southeast) shore than elsewhere. Practically all of these are near the surface, just awash at low spring tides, and there are few coral knolls visible at intermediate depths although the water is sufficiently clear[1] for them to be visible from the air at 10 or 20 meters. Dredging shows that most of the bottom between patch reefs is covered by sand, gravel and corals rather than by fine sediments. Evidently the finest sediments do not accumulate in the lagoon. It seems justifiable to conclude from these observations that there are many low coral knolls on the bottom and many patch reefs, and that there are relatively few intermediate knoll reefs.

There are an estimated 1500 to 2000 patch reefs outside the shore zone in the Raroia lagoon. They range from circular patches three or four meters across to great streamlined reefs a half kilometer long and 200 meters across. Hand-line soundings indicate that they are characteristically steeper on the windward than leeward end and they have slopes of intermediate steepness on the sides. The margins down to about 10 or 15 meters are very steep with a few overhanging ledges. Most of the living corals are within this depth range. At greater depths the slopes flatten to angles less than 45 degrees.

Viewed from a boat, or better from the air, the windward margin of the patch reefs is invariably colored olive-brown by the living corals. The leeward margin is marked by turquoise-colored streaks of shallow water over gravel and sand. The loose sediments are shed mainly to the leeward through shallow channels or gaps between living corals, and in the larger patch reefs much of the leeward surface is occupied by gravel and sand heaped up by the waves.

The marginal and surface corals of the patch reefs form the same associations as those of the windward shore reef. Black holothurians live in the sand areas to the leeward of the summits of the patch reefs, and the associated corals are dominated by species of Porites and Acropora. Small Pocillopora elegans? become crowded together forming a marginal zone at the rim on the windward and intermediate sides. Coralline algae and the boring Echinometra occur with Pocillopora near the rim in some patch reefs, but for the most part the soft green algae Zonaria and Caulerpa are more conspicuous here.

In plan, some of the patch reefs are roughly equidimensional but many are four or five times as long as wide, elongate roughly in the direction of the prevailing wind. The majority of these show a tendency for the leeward end of the reef to taper more gradually than the windward end, streamlined in teardrop form.

In air views it can readily be seen that the patch reefs are not entirely distributed at random. Many are arranged in rows generally oriented downwind, but there is some deviation near the windward shore where the linear series of patch reefs gradually assume an orientation normal to the shore. The majority of reef tongues (kaoa) of the shore reef are aligned with and apparently are the terminal members of individual series. Probably the distribution of these reefs is controlled by wind induced currents, perhaps broken into many jets at the windward channels.

1/ An eight-inch Secchi disk was visible from a small boat down to 28 meters.

Unfortunately it was impossible to survey the lagoon by vertical photographs and a map of the lagoon from aerial oblique photographs has not yet been completed. It is expected that a map of the coral patches would lead to satisfactory inferences regarding their distribution and possible relationship of the patch reefs to channels.

The tendency for the reefs to lie in parallel rows suggests linear cells of turnover presumably with a counter-clockwise motion in accordance with the Coriolis principle. Plans to test this theory by means of fluoricine dye were frustrated by unavailability of transportation during suitable weather.

REEF BIOTA

Diversity.-Outer and lagoon reefs of various types are well developed and contain a flourishing biota probably more diverse than that of Tahiti and comparable to that of Samoa. The often cited attenuation of reef organisms eastward across the Pacific is much more marked between Hawaii and the Tuamotu group than between the latter and Samoa.

Reef builders.-The only quantitatively important reef-forming coralline alga on Raroia, according to Doty, appears to be Porolithon onkodes which has the unique ability to deposit extensive encrustations in the surf zone, especially at intertidal levels. This alga is most conspicuous on the algal ridge and around the heads of grooves and around surge channels where it truly is a rock-former, composing perhaps as much as 25 per cent or more of a very cellular rock. Pocillopora elegans perhaps makes up as much as 25 per cent here and the rest is represented by voids on a fresh example, or by foraminiferal sand in an old example. The alga effectively binds corals together in a rigid framework in the algal-coral belt of the reef flat, and on the unshaded crests and edges of the spurs to a depth probably not much greater than six or eight meters below low water level.

The innumerable reef blocks cast up on the reef flat by storm waves permit direct examination of reef limestone from the groove and spur zone of the reef. In most of the blocks examined the cellular rock consists mainly of tier above tier of small Pocillopora elegans with an occasional massive coral and a staghorn Pocillopora. On the surface, interstices between corals are unfilled. An occasional fresh fracture across a reef block reveals that the unweathered interior is compact and the space between corals is filled with lithified sand composed largely of Foraminifera. This sand "matrix" weathers away readily on exposure, leaving corals, almost unaffected, standing in relief. Besides interstitial material and voids the substance of the blocks generally is 50 to 95 per cent Pocillopora elegans. Porolithon onkodes rarely occupies as much as 15 per cent of the volume, and in many blocks we were unable to recognize algal deposits without microscopic examination.

Certainly Porolithon onkodes plays an important role as a building agent and its importance should not be underrated, but quantitatively it is a great rock builder only along the algal ridge. Algal deposits are rarely recognized in the island rubble.

About 600 pounds of corals representing the common shallow-water species at Raroia were transmitted for identification to John W. Wells who reports 53 species in the collections, of which only eight had previously been reported from the Tuamotus. Six species reported from the Archipelago are not represented in our collections.

PRELIMINARY LIST OF REEF CORALS COLLECTED AT RAROIA (identified by John W. Wells)

Pocillipora danae Verrill
P. elegans Dana
P. ligulata Dana
P. verrucosa (E. and S.)

Acropora conferta (Quelch)
A. conigera (Dana)
*A. corymbosa (Lam.)
A. danai (M. E. and H.)
A. digitifera (Dana)
A. exilis (Brook)
A. formosa (Dana)
*A. humilis (Dana)
A. implicata (Dana)
A. cf. nobilis (Dana)
A. procumbens (Brook)
A. prolixa Verrill
A. quelchi (Brook)
A. rayneri (Brook)
A. rotumana (Gardiner)
A. sp.
A. syringodes (Brook)
A. tubicinaria
A. variabilis (Klunzinger)

Montipora australiensis Bernard
M. venosa (Ehrenb.)
M. caliculata (Dana)
M. verrilli Vaughan
M. verrucosa
M. n. sp.

Astreopora myriophthalma (Lam.)

Pavona clavus Dana

Leptoseris hawaiiensis Vaughan

*Fungia scutaria Lam.

Fungia concinna Verrill

Herpolitha limax (Esper)

Porites australiensis Vaughan
P. lobata Dana
P. mordax Dana
P. n. sp.
P. superfusa Gardiner

*Favia stelligera (Dana)
*F. rotumana (Gardiner)
F. pallida (Dana)

Favites hemprichii (Ehrenb.)

*Plesiastrea versipora (Lam.)

*Platygyra rustica (Dana)

Cyphastrea serailia (Forskaal)

Leptastrea purpurea (Dana)

*Acanthastrea echinata (Dana)

Lobophyllia corymbosa (Forskaal)
L. costata (Dana)

Culicia rubeola (Q. and G.)

Millepora platyphylla Ehrenb.

*Previously reported from the Tuamotu group.

Other species reported from the Tuamotus but not found in the Raroia collections:

Acropora hyacinthus (Dana)

Favia favus (Forsk.)

Fungia cooperi Gardiner
F. paumotuensis Stutchbury

Pocillopora meandrina Dana

Pavona (Pseudocolumnastraea) sp.

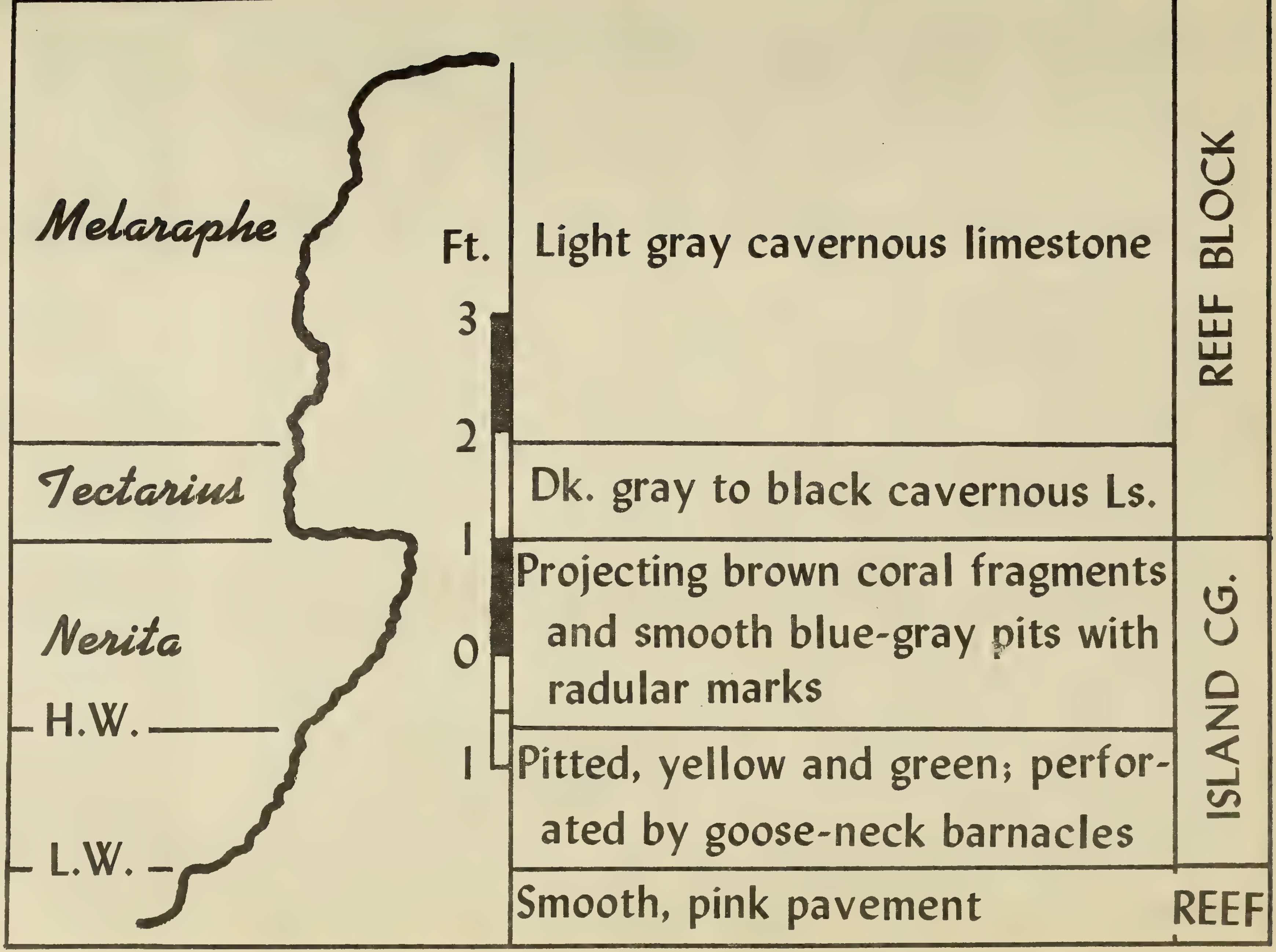
The shore profile.-A vertical succession of well-defined, narrow biozones occurs on the shore and outlying reef blocks around the atoll but these are best developed on the leeward side of the atoll. These zones are readily distinguished by the character of the surface and the color of the encrusting blue-green algae. Each zone is occupied by gastropods which feed on the algae or on the herbivores. In addition tube gastropods (Vermetus) and boring goose-neck barnacles are conspicuous on the reef blocks between high and low water marks. All of the animals are truly marine forms in that they pass at least the larval stage in the sea and their shore distribution depends on the varying degrees of their tolerance to exposure to sun, air and rain, and to competition and predator pressure. Probably to a lesser degree they show preference for various kinds of algal pastures.

At the bottom, always covered by sea water, is the scoured pavement covered by adherent Foraminifera and a film of pink coralline algae. The surface is smooth, undulating, or pitted by potholes.[1/] Foraminifera can be scraped from the surface where they cling to the bottom by means of their pseudopods. This is the holothurian belt of the reef flat. In some places it is bordered by a vertical rise of smooth, pinkish rock surface some 20 centimeters high to the clearly defined low water mark.

Above the low water mark the rock surface is yellowish-brown and scoriaceous through a vertical interval of 40 to 45 centimeters (a little less on the windward outer shore). Although this is considerably less than the normal tide range of 0.6 of a meter, it represents approximately the usual range between low and high water at the outer shore. A species of Turbo, a medium-sized Vermetus, a Drupa and a boring gooseneck barnacle dwell here.

This yellowish-brown surface grades into the lower part of a grayish surface above which is wet less frequently. This higher belt may be termed the Nerita zone from the dominant gastropod, Nerita plicata (Fig. 4). This form feeds mainly at night and ranges into the intertidal zone as the tide recedes. However, the species is most characteristic of the surface immediately above the high water level. The numerous pits of the Nerita zone are rounded and smooth and colored bluish-gray. The projecting coral fragments between pits are etched in relief by removal of intervening matrix. The projections are tan in the lower part of the zone, becoming brown in the upper part. The interior of the rock a millimeter or so beneath the surface is white, and the bluish-gray color of the pits, as observed in fresh fracture, is a stain which penetrates the rock below the algal film. Immediately outside the bluish-gray

1/ Emery (1946, p. 225) implies that potholes are more frequently deep and narrow than shallow and broad. At the beginning of excavation a pothole can be shallow as are many of the examples alluded to here.



4. Shore profile, reef block, leeward side of Garumaoa Islet.

layer, but covered by the superficial gray film, there often occurs a thin pink layer. Presumably these are pigments derived from the algae.1/ The bluish-gray pits are striated by radular marks of a gastropod, presumably Nerita plicata, the only abundant form in this zone. These gastropods feed on the surface algae and possibly also the algal filaments below the rock surface. The grooved surfaces over which the gastropods have browsed clearly have been modified by radular rasping. It is interesting that the projections between pits correspond to coral fragments and the pits to matrix of foraminiferal sand. The latter is relatively non-resident to the prevailing processes of erosion. As tested by scraping the surface with a knife blade, the pits are underlain by much softer material than the coral fragments, and it may reasonably be supposed that the pits have been excavated largely by the feeding activities of the Nerita plicata. Above the zone of Nerita plicata, moistened chiefly by spray, the rock is uniformly blackened by a film of blue-green algae.2/ This blackened area, reaching above high water some 20 to 60 centimeters or more is the feeding ground of a robust turbinate snail (Tectarius grandinatus). This gastropod does not scrape the surface deeply, although radular marks are plentiful, and there is little indication that it significantly modifies the rock surface. The Tectarius is rarely seen on the windward shore except on reef blocks. The blackened algal stain of this belt shows distinctly on aerial photographs as a narrow band at the shore on the leeward shore and a broader band on the windward shore. Apparently enough moisture as salt water spray reaches the surface to maintain an algal cover sufficient to color the rock and to supply pastures for the Tectarius. Immediately above the normal reach of spray the rock surface changes from black to gray, the color, as shown elsewhere by Newhouse, being derived from dessicated blue-green algae. On reef blocks this grayish surface is occupied by a small bluish gastropod, Melaraphe coccinea, which is most active at night and following rains when foraging is best. This species does not produce conspicuous effects on the rocks. Melaraphe coccinea ranges over the surface of the conglomerate platform to the edge of beaches or ramparts. Doty and Morrison have described the shore profile more fully on an earlier page in connection with ecological zonation.

Solution of limestone by sea water.-In spite of the well-known fact that tropical sea water normally is saturated or supersaturated with calcium carbonate a number of investigators have suggested that aerated sea spray and the sea water of rock pools may become sufficiently acid from CO_2 liberated by organisms to dissolve limestone (Emery, 1946). Kuenen (1950) has recently summarized these various views and cites quite a lot of evidence in support of the theory that sea water does dissolve limestone, particularly in the intertidal zone, even though attempts generally have failed to satisfactorily demonstrate that the water, excepting in small enclosed pools, is sufficiently acid to dissolve limestone. The topographic forms produced by rainwater above the reach

1/ Bergman expresses the following opinion about these color zones: "I believe that your original suspicion was right that the pigment is indeed of the porphyrin type, or the closely related bile-pigment group. It is probable that it is derived from the algal pigments, that it is acidic in nature, that it has penetrated into the lower layers where they form calcium salts (Werner Bergmann, personal communication 3/18/53). Newhouse has gone into this matter more fully in a preceding report (Atoll Research Bulletin No. 33).

2/ This film of blue-green algae was mainly Entophysalis crustacea.

of the sea are strikingly unlike those of the intertidal and spray zones and the bottom topography beneath low water is also different. Emery has shown that intertidal gastropods play an important, if unevaluated, role in erosion. Newell, Rigby, Whiteman and Bradley (1951) and Ginsburg (1953) have concluded that mechanical as well as biochemical activities of organisms are adequate to produce the distinctive erosion forms of the intertidal zone on limestone coasts.

On Raroia many of the reef blocks of the reef flat rest on deeply undercut pedestals. The pedestals in some cases consist of beachrock which is reduced by erosion more rapidly than the overlying reef rock and this tends to accentuate the distinction between overhanging cap rock and pedestal below. As pointed out by Kuenen (1933) these pedestal rocks are notched uniformly on all sides; therefore, it is unlikely that action of waves is particularly involved. If solution by sea water is the dominant process, then it follows that at times the waters of the entire reef flat must become sufficiently acid to dissolve the limestone, since undercutting is as pronounced on the reef flat as at the shore and the process is not peculiar to small enclosed basins.

Cloud (1952, p. 40) has found that at Onotoa the pH often rises toward a maximum of 8.6 in open shoal water and 9.1 in tide pools during the day when CO_2 is being diminished by photosynthesis. At night when the CO_2 content of these waters is increasing, pH falls to 7.3 or 8.0. He believes that it is probably at times of lowering of pH below about 7.8 to 8.0 that solution occurs (Op. cit., p. 40).

The solubility of calcium carbonate in sea water under natural conditions is rendered particularly complex by buffering effects and by great variations in CO_2 concentration. Unfortunately, pH determinations alone are not very helpful in determining whether or not calcium carbonate is being dissolved or precipitated, but these must be considered in conjunction with analyses for titration alkalinity (Smith, 1940; Emery, 1946). While precipitation is taking place, the pH will fall because of release of carbon dioxide from the bicarbonate, and vice versa. My plans to make alkalinity determinations at Raroia were frustrated by failure to receive essential reagents included in our strike-bound Los Angeles shipment.

A number of pH measurements were made with a Gamma electric pH meter in an enclosed high rock pool and on the outer leeward reef flat at Garumaoa with the following results:

Time	Large Rock Pool		Reef Flat	
	Temp.	pH	Temp.	pH
9:00 pm .	22.0° C	8.09	23.0° C	8.01
10:00 pm .	21.7°	8.02	23.3°	8.10
12:00 mn	21.5°	8.06	23.0°	8.06
2:00 am	22.5°	8.11	24.5°	8.20
5:00 am	25.0°	8.20	25.0°	8.20
7:00 am	23.5°	8.11	25.0°	8.10
9:00 am	26.5°	8.15	27.5°	8.20

At 5:00 am the rock pool was receiving fresh sea water. At other times it was isolated. Additional isolated measurements were made several times with the result that pH values were invariably above 8.00, too high for solution of calcium carbonate.

Rock surfaces of the reef flat and the land are generally covered by a thin film of algal vegetation (See Atoll Res. Bull. No. 33 on algae). Outlying blocks and shore rocks between low and high water levels are conspicuously colored tan to brown and are particularly roughened by erosion. A fresh fracture of this rock reveals that the filaments of blue-green algae penetrate the capillary fringe of the rock and the entire surface in places is blanketed by the algae. It seems likely that the carbon dioxide and possibly other acids liberated by plant metabolism and decay are brought into intimate contact with the substratum, providing an acid environment in which the rock is rather rapidly leached, much as a limestone surface is leached by a blanket of lichen, or a calcareous soil by plant roots. This would explain the marked solution effects in precisely the zone where blue-green algae are most active on limestone shores in the intertidal and splash zones. It also explains why solution effects are about the same on outlying reef blocks and in rock pools where pH conditions are generally different.

Organisms as agents of shore erosion.-We have inferred that the life processes of blue-green filamentous algae, which are especially active between low water level and the top of the splash zone, are responsible for the characteristic pitted surface of the rocks at this level. But it is noteworthy that the deepest part of the shore notch of the pedestal rocks of the reef flat on Raroia is not below or within the intertidal zone as might be expected if erosion were accomplished mainly by inorganic solution by sea water or solely by algal leaching. Instead it is at the high water level. Undoubtedly direct solution by sea water and algal penetration of the rock are both significant but not dominant factors. The zone of Nerita plicata occupies the deepest part of the furrow around the pedestal rocks (Fig. 4). Assuming that the growth of blue-green algae on and below the surface initiates erosion by penetration of algal filaments into the rock, it may safely be concluded that the rasping of the softened surface film by gastropod radulae accelerates the process of limestone removal. Newhouse, Doty and Morrison arrive at this same conclusion in earlier reports.1/ Erosion in the underlying intertidal zone is only a little less pronounced. The surface of the reef blocks, more rarely the shore rocks, is perforated deeply at this level by a boring gooseneck barnacle which, in extreme cases, removes as much as 20 per cent of the rock to a depth of two or three inches.

Exfoliation.-Erosion by organic agencies and by wave action have resulted in many places in a low escarpment one-half to one meter high at the edge of the island conglomerate. This is highest on the leeward side of the atoll. This bench breaks down by exfoliation along fracture planes which dip seaward at low angles ranging from nearly horizontal to about 35 degrees. The fracture planes cut smoothly through coral blocks and cobbles. Freshly broken tabular masses are shifted by the waves exposing fresh surfaces. These displaced slabs remain near the place of origin until a storm carries them onto the conglomerate platform.

1/ Atoll Res. Bulls. 33 and 35.

The exfoliation planes generally intersect the front of the conglomerate bench at the undercut notch near the high water line. It seems probable that the hydraulic pressure of storm waves concentrated below the overhanging rim of conglomerate is responsible for the fractures.

SEDIMENTATION

Introduction.-Presumably the outer slopes of Raroia at depths of several hundred meters are talus slopes inclined at the repose angle. Down to the limit of direct observation at 34 meters on the outer slope the bottom is covered by living corals and is kept relatively free of loose sediment. Gravel and large worn boulders of *Porites* more than a meter across are strewn over the floors of the grooves where they reach the outer slope. The size and constitution of the boulders indicate clearly that they are derived from the outer slope and are swept into the grooves by storm waves.

Sand and gravel of the outer beaches and ramparts accumulate well inland from the rock shore where they are deposited by storm waves of intermediate amplitude. This debris is composed partly of corals and Foraminifera that live on the reef flat. There is a direct interrelationship among degree of exposure to ocean swell, texture, and height of the ridges. The ramparts progressively become higher and coarser where the coastline forms a high angle or an embayment directed toward the prevailing storm directions. The sediment includes fine sand, composed mainly of brown Foraminifera (*Amphistegina lessoni*) and discoid Peneroplidae, the largest of which are about five or six millimeters across.

The prevalence of the brown Foraminifera gives the sand decidedly a reddish-brown color. The more conspicuous Foraminifera of the beach sand were all observed on the reef flat, where they cling to the pavement, to algae and dead corals. Detrital material is inconspicuous and subordinate to the Foraminifera among particles of sand size.

As discussed elsewhere, the land surfaces behind the outer rampart are covered by coarse gravel and boulders of coral, much of which clearly must have been derived from the outer slope at depths of more than eight meters. Much of this material is coarser than that of the rampart, hence it is judged to represent deposits left by hurricances. The outer slopes of the gravel ramparts are white in color, the normal color of bleached coral debris, but the surface of the moat and higher ground beyond the moat is stained dark gray by a film of blue-green algae, and this supports the view that these surfaces are disturbed only infrequently and by the greatest storm waves. The surface gravel becomes progressively finer toward the lagoon.

All evidence, including testimony of the inhabitants, shows that the sediments of the outer reef are driven overland across the islets or toward the lagoon through the channels by storms. Apparently there is relatively little migration of sediments seaward.

According to eyewitnesses the land is swept during hurricanes by great waves from both the sea and lagoon, but the sea waves generally are by far the greater, even on the leeward side of the atoll. Most of the hurricane winds, judging from inadequate records, strike Raroia from the westerly quadrants, normally the lee side of the atoll. These reports are borne out by the fact that the highest ramparts and the coarsest storm debris are found on the leeward side. However, it is clear that the southeast, or upwind, side of the lagoon receives more sediment than does the northwest side. The deepest part of the lagoon lies well to the northwest of the midline of the lagoon (see Atoll Res. Bull. No. 31, Fig. 5). This observation harmonizes well with the fact that most of the channels occur on the windward side of the atoll, and these flow lagoonward practically continuously.

The lagoon beaches are composed of sand to fine gravel and much of the finer sediment is idential with that of the outer beaches and ramparts from which it evidently was derived.

Dredging by hand for sediments in the lagoon turned out to be discouraging. Only five samples were obtained after 40 unsuccessful hauls, each involving laborious recovery of the dredge. In several attempts branches of the sand-tolerant Acropora prolixa were brought up from various depths in separate localities, leading to the inference that this coral is abundant on the lagoon floor. The sediment samples recovered consisted mainly of silt and sand-sized particles of calcium carbonate. Very few segments of Halimeda were observed. It is supposed that most of this sediment is the fine fraction winnowed from the lagoon shore sands.

General lack of mud-bottom areas in the lagoon suggests that the finest detrital fractions do not accumulate but are carried out the pass in suspension. The adjoining atoll, Takume, which lacks a ship pass, has extensive areas of mud bottom, as also is the case with Hikueru, Anaa, and probably other enclosed Tuamotu atolls. In general, those atolls of the Tuamotu group with lagoons more than 40 meters deep have one or two passes and the waters are clear.

Preliminary report on the sediments (by John V. Byrne).-Lack of proper dredging equipment and boats made the collection of lagoon sediments at Raroia extremely difficult. Nevertheless, more than a dozen lagoon samples were collected from depths greater than 10 feet by the use of a biological dredge, hauled by hand from an outrigger canoe equipped with outboard motor. Samples were collected at points evenly spaced along traverses between known locations on opposite sides of the atoll. Most of the dredge samples consisted solely of biological material, but several hauls containing sediments were made. The abundance of bottom coral was evidenced by the number of times the dredge caught on the bottom or returned with only fragments of coral. The dredge caught on bottom coral on approximately 90 per cent of the hauls.

The lagoon sediments consist of recognizable coral and shell fragments, Foraminifera, fine sand and silt, probably derived from the comminution of shells and coral fragments, echinoid spines and other organic skeletons. Halimeda is represented in the samples. However, unlike Bikini and other atolls of the northern Marshalls remains of this alga comprise a very small percentage of the total sediment.

Particles composing the bottom sediments range from fine silt to cobbles, but fragments of cobble size were infrequently recovered. Median diameters in the samples range between 0.08 mm and 0.74 mm. The average, based on 15 samples, is in the medium sand class, 0.36 mm. The sorting of most of the samples is good but a few of the exhibit medium to poor sorting.

Composition analyses were made in order to determine percentages of the major constituents of the sediment. The samples were divided under the microscope into shell, coral, Foraminifera, fine sand and silt, and miscellaneous. All material finer than 0.25 mm in diameter was classified as fine sand and silt. The miscellaneous classification includes echinoid spines, algae and other material not classifiable in the other groups.

Generally, fine sand and silt make up the largest percentage of each sample; in one case 79 per cent. The average percentage, based on 15 samples, however, is 42 per cent. Coral fragments are consistent in making up fair-sized portions of each sample, averaging 25 per cent, but comprising up to 60 per cent of some of the samples. Foraminifera, averaging 16 per cent, make up no more than 25 per cent of any single bottom sample. "Miscellaneous" material, including unrecognizable material, comprises not more than 10 per cent of any sample and averages 3 per cent for the 15 samples.

The beach samples have not been completely analyzed, but preliminary study indicates that sand is more than 75 per cent of the material. Sampling errors may be responsible for this high value, for field observations seem to indicate that material coarser than sand is more abundant than preliminary studies showed. It may be pointed out that Foraminifera make up more than 85 per cent of some of the beach samples collected.

The lagoon bottom samples obtained at Raroia are not adequate for the determination of distribution patterns; however, there are points of resemblance with the distribution of sediments obtained from previously studied atolls.

A traverse across Raroia lagoon opposite Garumaoa village shows that the percentage of Foraminifera is greatest close to shore on both sides of the atoll. Likewise, shell fragments make up a larger percentage of sediment near the islets than in the center of the lagoon. Deposits in the deeper parts of the lagoon are dominated by fine sand and silt which decreases toward the rim of the atoll. The relative abundance of miscellaneous material is fairly uniform throughout. The coral constituents, however, are irregularly distributed. The abundance of patch reefs throughout the lagoon may account for this lack of trend. The distribution of sediments, as suggested by the few available samples, resembles those observed by K. O. Emery for atolls of the northern Marshalls (personal communication). In fact, the only conspicuous difference between the two areas seems to be in the role played by Halimeda. In atolls of the northern Marshall Islands, Halimeda makes up a major portion of the sediment, particularly in deeper parts of the lagoons. At Raroia it is insignificant as a sediment producer.

The patch reefs supply much coarse sediment which tends to complicate the over-all pattern of deposition in the lagoon. In general it may be said that Foraminifera and shell fragments make up a larger per cent of the sediment in a zone around the outer edge of the lagoon than elsewhere. These constituents are probably equally abundant in the central, deeper areas of the lagoon where they are masked by fine sand and silt which accumulates there.

Lagoon-beach sediments on the windward side of the atoll consist primarily of fine material, mainly Foraminifera. Lagoon beaches on the opposite side of the atoll are more exposed. They are composed essentially of coarse shell and coral fragments. Where these fragments are abundant, they are usually deposited in small beach ridges. There are, however, areas on both sides of the atoll in which the above generalization is reversed. The seaward sides of the islands are characterized by coarse cobble and boulder ramparts and ridges, storm beaches behind beachrock areas, and well sorted accumulations of sand in depressions; both along the landward margin of the reef flat and on the island conglomerate behind the reef flat. In general, the more exposed shores are characterized by coarse material, whereas protected areas have accumulations of finer material.

<u>Distribution of Foraminifera</u> (by J. Sperrazza).-A preliminary survey of sediment samples from Raroia atoll reveals the usual tropical shallow water species of Foraminifera of the Indo-Pacific fauna. Many of these range from southeastern Africa to the Polynesian Islands. The Foraminifera are closely related to those of Samoa described by Cushman (1924) and those of the Kerimba Archipelago of southeast Africa covered in studies by Heron-Allen and Earland (1914). Several of the Raroia species are known from Hawaii, the Philippine region, the Malay region and Funafuti.

A check list and a table showing the percentage of foraminiferal content per sediment sample are presented in this preliminary survey. Volumetric measures were used in estimation of percentages. The Foraminifera were separated from a representative sample from each station and volumetrically compared with the total representative sample. The determinations are believed to be accurate within an error of plus or minus three per cent of the recognizable foraminiferal fraction.

The beach sands show varying percentages ranging from 0.1 per cent to 72 per cent in Foraminifera content, depending, probably, on the degree sorting by waves. Shoal reef benthonic forms of larger Foraminifera are abundant and generically represented by <u>Marginopora</u>, <u>Sorites</u>, <u>Amphisorus</u> and <u>Amphistegina</u>. <u>Amphistegina</u> is by far the most abundant form and appears in all samples. Small and large forms of Miliolidae are also common in the beach sands.

The dredge samples show a richly diversified fauna with depth. Families commonly represented are the Miliolidae, Amphisteginidae, Peneroplidae, Valvulinidae, Textularidae, Cymbalopoidae and Anomilinidae, with the greatest diversity of genera occurring in the family Miliolidae. Less abundantly represented are the Alveolinidae, Camerinidae, Heterosteginidae, Nonionidae, Lagenidae, Fischerinidae, Buliminidae and Rotaliidae.

Pelagic forms are present but of rare occurence. They are represented by <u>Globigerina</u> and the adult floating stage of <u>Tretomphalus</u>.

The tests of Foraminifera in lagoon sediments may be classed in depth zones as follows:

Zone 1. Depth range 0 - 6 meters

Abundant: Amphistegina lessoni
Amphistegina madagascarensis
Marginopora vertebralis
Quinqueloculina sulcata

Common: Acervulina inhaerans
Amphisorus hemprichi

Zone 2. Depth range 6 - 30 meters

Abundant: Amphistegina madagascarensis
Sorites marginalis
Archaias adunca
Clavulina pacifica
Clavulina difformis
Textularia candeiana
Anomalinella rostrata

Common: Acervulina inhaerans
Amphisorus hemprichi
Articulina sulcata
Gypsina globulus
Heterostegina depressa
Nubeculina divaricata var. advena
Quinqueloculina parkeri
Quinqueloculina tropicalis
Schlumbergerina alveoliniformis
Quinqueloculina samoaensis

Zone 3. Depth range 30 meters and over

Abundant: Textularia candeiana
Quinqueloculina samoaensis

Common: Bolivina tortuosa
Anomalinella

Percentage by volume of Foraminifera per smaple

Sample	Per cent of total	Location
7-9-1	22.0	Sand from small beach between seaward reef flat and beach rock at traverse north of Garumaoa village.
7-9-4	25.0	Outer beach sand just inside conglomerate platform at Garumaoa traverse.

7-9-5	13.0	Sand and gravel 10 meters inland from outer platform of beach rock; first zone of coarse material at Garumaoa traverse.
7-9-6	11.0	Sand and gravel 20 meters inland from outer platform of beach rock at Garumaoa traverse.
7-9-7	7.0	Sand and gravel inland from preceding station, Scaevola zone at Garumaoa traverse.
7-13-1		Gravel, lagoon beach, Garumaoa transect.
7-13-2	20.0	Beach sand from beneath large cobbles just below small ridges of gravel of sample 7-13-1.
7-13-3	24.0	Coarse sand from lagoon beach just north of Garumaoa village.
7-13-4	2.0	Fine sand taken near Garumaoa village on lagoon beach.
7-21-1		Pink forams on piece of drift (lagoon shore).
7-22-1	38.0	Sand from depth of 6 inches in test pit C(4).
7-23-1	7.0	Sand from test pit A(5) bottom 3 feet.
7-26-x		Lagoon beach samples collected south of Garumaoa village.
7-26-2	14.0	Lagoon beach south end of Garumaoa Islet.
7-26-3	16.0	From rocky point near sample 7-26-2.
7-26-4	4.0	Lagoon beach at embayment behind spur to south of Garumaoa village.
7-26-5	3.0	Lagoon beach south of Garumaoa village.
7-26-6	10.0	Lagoon beach south of Garumaoa village.
7-26-7	14.0	300 meters south of old pier, Garumaoa village.
7-27-1	7.0	At Garue pass, lagoon beach between gravel ridges.
7-27-2	20.0	Lagoon beach, north side of channel mouth south of Takeke Islet, south of Garue pass.
7-27-3	25.0	Lagoon beach, north side of channel south of Temari Islet, south of Garue pass.
7-27-4	10.0	Lagoon beach, north end Korere Islet, south of pass.

7-27-5	9.0	Lagoon beach, south side of incomplete channel, Korere Islet, south of pass.
7-27-6	12.0	Lagoon beach, 20 meters north of incomplete channel. Between Tomogagie and Garumaoa Islet.
8-5-1	0.1	Patch reef top near south end of lagoon.
8-5-2	14.0	Patch reef top near south end of lagoon.
8-5-3	20.0	Lagoon beach, Kakipuku.
8-5-4	55.0	Lagoon beach, Kakipuku.
8-5-5	72.0	Lagoon beach, Kahuruna.
8-7-1	8.0	Outer beach, Oneroa.
8-9-1	8.0	Sand patches between corals, lagoon pavement bottom, 10 feet of water, off second channel mouth north of Oneroa (Marie).
8-11-1	9.0	Dredge sample, lagoon half way between Oneroa and Garumaoa village.
8-11-2	10.0	Dredge sample, lagoon 300 meters east of Ohava patch reef, near Garumaoa village.
8-12-1	15.0	Dredge sample, lagoon 200 meters east of Ovete patch reef near Garumaoa village, depth 90 feet.
8-13-1	20.0	Dredge sample, lagoon, half way between Ohava reef and old wharf, near Garumaoa village, depth 65 feet.
8-13-2	5.0	Dredge sample, lagoon, 200 meters southwest of Kumekume Islet, depth 45 feet.
8-13-3	9.0	Dredge sample, lagoon, 400 meters southwest of Tomogagie Islet, depth 70 feet.
8-13-4	12.0	Dredge sample, lagoon, 100 meters east of end of Miramirau reef spur, south of Garumaoa village, depth 40 feet.
8-13-5	16.0	Dredge sample, lagoon, 400 meters southwest of Ovete patch reef, near Garumaoa village, depth 60 feet.
8-13-6	14.0	Same location as 8-13-4.
8-13-10	11.0	Beach sample, ocean side at extreme northern tip of Raroia atoll.

8-13-11	32.0	Beach sample, lagoon side at extreme northern tip of Raroia atoll.
8-19-1	6.0	Dredge sample, lagoon, taken off Nengonengo Islet; depth 150 feet.
8-20-1	40.0	Beach sample, lagoon side at Tetou.
8-20-2	10.0	Dredge sample, lagoon, 500 meters west of Pirikau-taringa Islet, depth 80 feet.
8-20-3	12.0	Dredge sample, lagoon, 1000 meters west of Rata, depth 70 feet.
8-21-1	10.0	Dredge sample, center of lagoon between Fakatomo Tahuna Maro, depth 110 feet.
8-21-2	4.0	Dredge sample, lagoon, 500 meters east of Tetou, depth 90 feet.
8-21-3	7.0	Dredge sample, lagoon, 1000 meters east of Tetou, depth 85 feet.
8-21-4	3.0	Beach sample, seaward side at Tetou Islet.
Bottle		Contains forams collected on seaward reef, Garumaoa Islet, at first transect.

In summary, the following conclusions may be drawn with respect to the Foraminifera of Raroia:

1. The lagoon and outer reef of Raroia Atoll support a prolific foraminiferal fauna.

2. Foraminiferal lime sands, silts and mixtures of these were found to be the predominant types of sediments in the lagoon.

3. All samples collected in and around the lagoon contained Foraminifera, ranging from .1% - 72%. The greater percentages of Foraminifera to other constituents occur along the shallow, southeastern or windward side of the lagoon and in general, the smaller percentages appear to occur at the greater depths of the lagoon and along the outer seaward reef.

4. The outer and inner block sands and patch reef sands contain six predominant species. They differ chiefly in relative abundance of individuals of those species. The tests may be largely derived from the reef flats.

5. In general, there is a decrease in relative abundance of Foraminifera with depth.

6. The sediments of Raroia lagoon contain a rich foraminiferal fauna consisting of 56 genera and 126 species. <u>Amphistegina lessoni</u>, was found to

be most abundant in outer and inner beach sands and on shallow lagoon bottom less than six meters deep. _Amphistegina madagascarensis_, which is common in the beach sands, is the most abundant form in the lagoon becoming rare only at the greatest depths. _Marginopora vertebralis_ is a common associate of _Amphistegina lessoni_ in the beach sands, and has a similar bathymetric distribution. It attains maximum dimensions on the seaward reef.

7. Of the total of 126 species, approximately 22% were found only in the beach sands of the inner and outer reef. These are indicated in the distribution chart. All of the species found in the outer beaches are also represented in the lagoon samples. This is to be expected since sediments are continually being swept lagoonward by storm waves.

Origin of Island Conglomerate and Beachrock.-
The solid rock of the islands of Raroia consists mainly of tightly cemented gravel of low porosity. The coarsest texture, dominantly of cobbles and boulders, is found along the seaward coast, particularly on the lee side of the atoll and along the windward shore of the lagoon. Some of the shore outcrops on the upwind side of the lagoon consist of fine-grained calcarenite, but even along this sheltered shore much of the beachrock consists of pebbled sandstone with fragments an inch or so in diameter.

The fragmental constituents of the rock are mainly broken and worn colonies of corals. An occasional disoriented reef block, however, is incorporated in or welded to the conglomerate. These blocks are composed of entire colonies of _Pocillopora elegans_ in parallel arrangement bound together by _Porolithon onkodes_.

On the leeward outer shore there are erosional remnants of one or more low, parallel ridges, old beachrock ridges along the seaward lee shore, composed of strata of fine-grained conglomerate dipping seaward at 15 degrees to 20 degrees. These ridges form low cuestas a few centimeters to about one meter high between shallow tide pools. The ridges originally extended seaward as much as 20 to 30 meters as shown by detached low ridges on the reef flat parallel to the shore, and nearly obliterated by erosion. These generally have been completely cut away by the waves on the windward shore.

Inclined beds of beachrock are quite rare along the lagoon shore. At most of the outcrops the rock is essentially unstratified and it is exposed in a low ledge with a vertical face which rises from low water level, or a few centimeters below, to as much as 25 centimeters above normal high water. Clearly the rock has been eroded to some extent and the normal lagoonward inclination of the strata of the original beach has been cut away by erosion.

The modern beaches and ramparts show no tendency for cementation, perhaps because they are frequently disturbed by storms. Small patches of blue-green algae on the sand beaches lightly bind together thin crusts of the sand, but these are not cemented by calcium carbonate. Moat areas behind the lagoon shore ridges and behind the seaward ramparts, particularly those of the windward side of the atoll, frequently are inundated by the sea. In many places these areas samples of foraminiferal sand

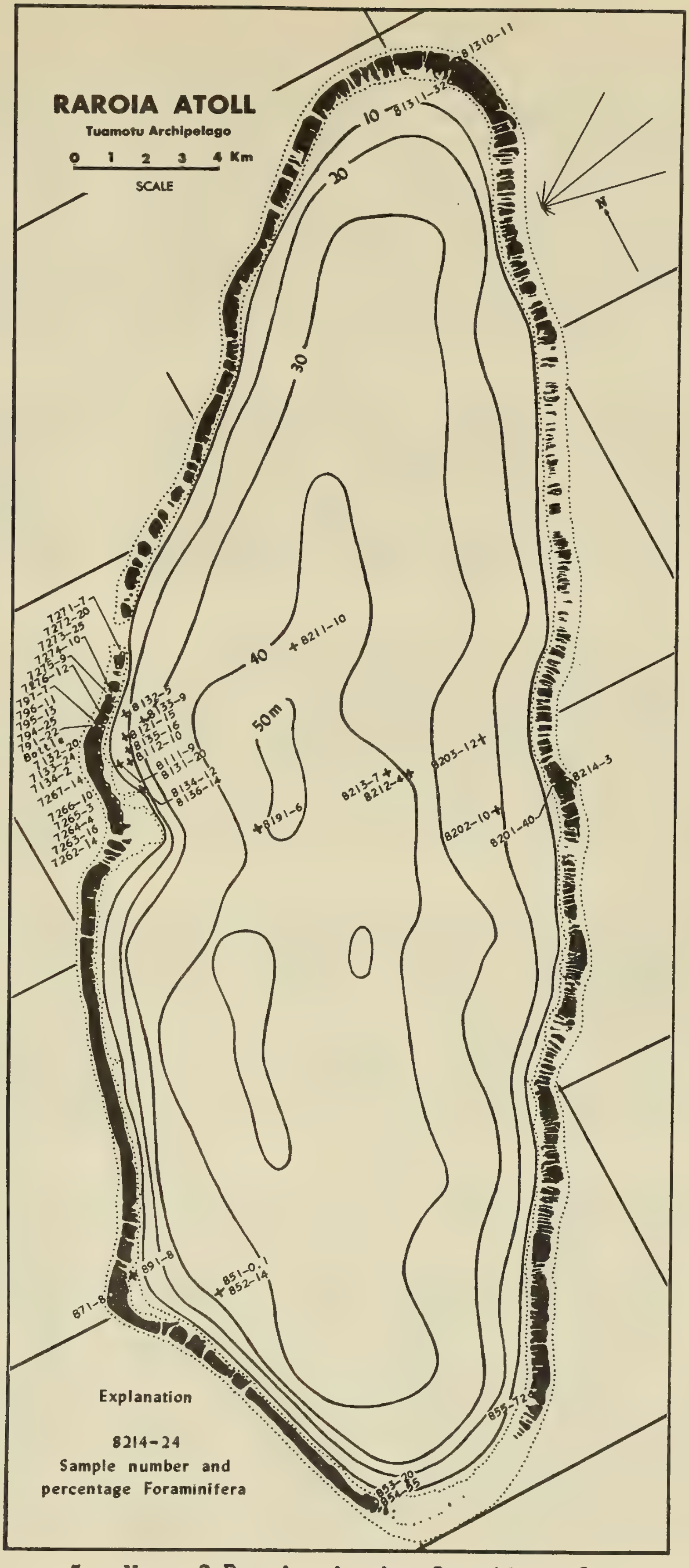
Table 1. Foraminifera from Raroia Atoll, Tuamotu Archipelago, French Oceania

Legend

- Abundant a
- Common c
- Rare r
- Fragments f

Bathyal distribution and occurrence of lagoon Foraminifera (Dredge Samples, Ft.) — Occurrence of Foraminifera from the shore-sands (Beach Samples; + indicates seaward reef)

Recent Species	8-9-1 (10')	8-13-4 (40')	8-13-6 (40')	8-13-2 (48')	8-13-5 (60')	8-13-1 (66')	8-13-3 (70')	8-20-3 (70')	8-20-2 (80')	8-21-3 (85')	8-12-1 (90')	8-21-2 (90')	8-21-1 (110')	8-19-1 (150')	8-11-1 (?)	8-11-2 (?)	+7-9-1	+7-9-4	+7-9-5	+7-9-6	+7-9-7	7-13-2	7-13-3	7-13-4	+7-22-1	+7-23-1	7-26-2	7-26-3	7-26-4	7-26-5	7-26-6	7-26-7	7-27-1	7-27-2	7-27-3	7-27-4	7-27-5	7-27-6	8-5-1	8-5-2	8-5-3	8-5-4	8-5-5	+8-7-1	+8-13-10	8-13-11	8-20-1	+8-21-4
Acervulina inhaerens Schultze		c	c	c	c	c	c	c	c	c		c	a			c																																
Amphisorus hemprichi Ehrenberg	c	c				c	c		c						c			r	r	r		r			c		r												c	c						r		
Amphistegina lessoni d'Orbigny	a	r	r	r		r	r	r	r	r		r	r	r	a		a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a
Amphistegina madagascarensis d'Orbigny	a	a	a	a	a	a	a	a	a	a	a			r	a	a	c	c	c	c	r	r	r	c	c	c	r	c	c	c	c	c		c		c	a	c	c	c	c	r	c	r	c	c	c	c
Anomalina globorata Cushman			r						c																																							
Anomalina grosserugosa Gumbel (?)							r		c																																							
Anomalinella rostrata (H. B. Brady)			c	c	a	r	c	c	c	c	c	c	a	c	r	a							r	r																					r			
Archaias aduncus (Fichtel and Moll)	c	a	c	a	c	c	c	c			c	c	c	c	c																																	
Articulina antillarum Cushman													r	r																																		
Articulina sagra d'Orbigny			r		c	c	c			c				r		c																																
Articulina sulcata Reuss					c				c	c	r		r	r		c																																
Bolivina capitata Cushman		r					c						c	c		c																																
Bolivina compacta Sidebottom	r										c				r	c																																
Bolivina ligularis Schwager						c																																										
Bolivina punctata										c																																						
Bolivina rhomboidalis (Millet)	r				c	c		c			c	c		r		c																																
Bolivina striatula Cushman						r				r																																						
Bolivina subertheloti Cushman											r																																					
Bolivina tortuosa H. B. Brady	r	r			c					c	c			c	r	r																																
Bolivina vadescans Cushman											c			c																																		
Bolivina variabilis (Williamson)		r	c													c																																
Bolivina vilardeboana d'Orbigny	c		c											c	c	c																																
Bolivinella folia (Parker and Jones)	c		c		c	c	c		c	c	c	c		c		c																																
Bolivinella folia (Parker and Jones) var. ornata Cushman											r			r		r																																
Borelis melo (Fichtel and Moll)	r	r							r																																	r						
Buliminella milletti Cushman										r																																						
Cancris oblongus (Cushman)										c	c		r	r																																		
Cassidulina laevigata d'Orbigny														r																																		
Cibicides lobatulus (Walker and Jacob)							c					c		c	a																																	
Cibicides refulgens Montfort					c				c	c	c		c	c	r	c																																
Clavulina communis d'Orbigny						r									r																																	
Clavulina difformis H. B. Brady	r	r	r	c	c	c	c	a		c	c	c	c	r		a																																
Clavulina pacifica Cushman			r	c	c	c	c	a		a	c	c	c		a	a																		r		r												
Cornuspira involvens Reuss				r						r																																						
Cymbalopora bradyi Cushman	c	r		c			r	c	c			c	r	c		c																																
Cymbaloporetta squammosa (d'Orbigny)					r	c	c		c	c												c			c												r											
Cymbaloporella tabellaeformis (H. B. Brady)						c							c	r			r								c																							
Discorbis globularis d'Orbigny				c	r	c		c	c	c	c	c		c		c																																
Discorbis subertheloti Cushman	c		c					r	r			r		c	c							r										r																
Discorbis vilardeboana (d'Orbigny)								r																																								
Eponides punctulatus (d'Orbigny)									c				r	r																																		
Eponides repandus (Fichtel and Moll)	r				r				r	r	r	r	r	r																																		r
Elphidium jenseni Cushman				c	c	c	c	c	c		c	c		c								r																										
Elphidium macellum (Fichtel and Moll)	c	c		a	a	a	c	c	a	c	c	c	c	a		c																																
Elphidium macellum (Fichtel and Moll) var. limbatum (Chapman)										c				r																		r								r								
Fisherina pellucida Millet	r	r		c	c	c	r						r		r																																	
Globigerina bulloides d'Orbigny	r	r		r			r	r			r		r	r																																		
Globorotalia canariensis (d'Orbigny)				r	r		r	r	r		r	r	r	r		r																																
Gypsina globulus (Reuss)		r				c		c	c					r		c				r																								c	c			
Gypsina vesicularis (Parker and Jones)			r						c	c		r			c																																	
Heterostegina curva Moebius	c		r		c		r		c		c		c			c																																
Heterostegina depressa d'Orbigny			c	c	c	c	r	c	c	c	c	r	r		r	c	r					r	r													r								r				
Heterostegina suborbicularis d'Orbigny			r				r	r	c	r						c																				r												
Hauerina bradyi Cushman	c				c			c			c		r	c		c																																
Hauerina fragilissima (H. B. Brady)	c				c	c	r			r	r			c	c	c																																
Hauerina ornatissima (Karrer)		c	c	c		c	c	c		c	c	c		c	c	c																																
Lagena spiralis H. B. Brady														r																																		
~~Loxostomum limbatum (H. B. Brady)~~		c			c						c		c	c																																		
Loxostomum limbatum (H. B. Brady) var. costulatum (Cushman)		r					c			c						c																																
Loxostomum mayori Cushman				r												c																																
Marginopora vertebralis Blainville	c	r	r			r		f	f	f					c	r	a	a	a	a	c	c	a	c	c	a	a	c	r	r	c	a	r	r		c	c	r	a	c	a	a		c	c	a	c	c
Massilina sp.																																																
Massilina alveoliniformis Millet														r																																		
Massilina crenata (Karrer)	r									r				r																																		
Massilina inequalis Cushman									r																																							
Massilina planata Cushman												r		r																																		
Miniacina miniacea (Pallas)			f	f			f		f									f	f	f			f		f		f			f		f	f	f		f	f	f			f	f	f	f	f	f	f	
Monalysidium sollasi Chapman										r																																						
Monalysidium politum Chapman	c	c			c		c		c		c	c	c	r																																		
Nubeculina divaricata (H. B. Brady) var. advena Cushman					r		c	r	c	c	c																																					
Nonion grateloupi (d'Orbigny)		r	r			c		r				r		r	r	r																																
Parrina bradyi (Millet)																r																																
Peneroplis pertusus (Forskal)	c	c					c				c																																					
Planorbulina larvata (Parker and Jones)	c	c	c	c	c	c	c		c	c		c	c	c																																		
Pyrgo denticulata (H. B. Brady)		c		c		r		c		c	c		c	c	r	c																																
Quinqueloculina anguina Terquem	c				c	r	r	c		c			r	r	c																																	
Quinqueloculina bidentata d'Orbigny		c	c			a	c			a	c				c	c																																
Quinqueloculina berthelotina d'Orbigny					c									r		c																																
Quinqueloculina costata d'Orbigny	c	c	c	c		c	c		c	c	c	c		c	c																																	
Quinqueloculina crassa d'Orbigny															r																																	
Quinqueloculina linnaena (d'Orbigny)		c	c												r																																	
Quinqueloculina parkeri (H. B. Brady)				r	c	c	c	c	c	c	c	c	c	c		c															r																	
Quinqueloculina polygona d'Orbigny		r	r							c	c			r																																		
Quinqueloculina samoaensis Cushman	c	c	c			c	c		a	c	c	a	a	a																																		
Quinqueloculina seminulum (Linne)	c				c	c	c	c	c	c	c	c		c	c	c																																
Quinqueloculina sulcata d'Orbigny	a	c	c	a	a	a	c	c		c	c	c	c	c	c	c						r			c									r			r											
Quinqueloculina striata d'Orbigny	r																																															
Quinqueloculina tropicalis Cushman			c	c	c	c	c			c	c			r		c																																
Quinqueloculina transversicata H. B. Brady														r	r																																	
Quinqueloculina undosa Karrer						r																																										
Quinqueloculina sp.	c	c				c	r				c			c		c																																
Rotalia sp.										r																																	r					
Reussella spinulosa (Reuss)	c	c	c		c	c	c	c	c	c		c	c	c	c	c																																
Schlumbergerina alveoliniformis (H. B. Brady)			c	c	c	r	r		r		c	r	r	c	c	c																				r												
Siphogenerina raphana (Parker and Jones)		r	r	c	c	c	c		c	c	c	c		c	c	c																																
Siphonina tubulosa Cushman						r	r		r	r	r	r																																				
Sorites marginalis (Lamarck)	c	c	c	a	c	a	a	c	c	c	c	c	c		c	c	c	c	c	c	c	c	r	c	c	c	c	c	r	c	c	c		c		c	c		c	r	c	a			c		c	c
Spirillina inequalis H. B. Brady				r																																										r		
Spirillina limbata H. B. Brady			r						r					r																																		
Spirillina spingera Chapman				r																		r									r																	
Spirillina subbertheloti Cushman									r																																							
Spirillina vivipara Ehrenberg							r																		r																							
Spirolina arietinus (Batsch)	c	c	c	c	c	c	c	c	c	c	c	c			c	c																																
Spirolina acicularis (Batsch)	c	r		c	c	c	c		c		c	c	r	c	r	c																																
Spiroloculina antillarum d'Orbigny	a	c	c		c	c	c	c	c	c	c	a			a							r					r	r						r														
Spiroloculina antillarum d'Orbigny var. angulata Cushman		c						c	c			c				c																																
Spiroloculina grateloupi d'Orbigny										r			r																																			
Spiroloculina mayori Cushman				r		c	c	r	r	c	c	c	r	r		r																																
Spiroloculina planissima (Lamarck)				r	r				r			r										r																										
Spiroloculina sp.								r		r																																						
Textularia agglutinans d'Orbigny		r		c	c	c	c	c	c	c	c	c		c	r	c																																
Textularia candeiana d'Orbigny		r	r	c	c	a	a	a	a	a	a	a	a	a	r	c																																
Textularia conica d'Orbigny		r		r			r		c	r	r	c		r	r	c																																
Textularia corrugata Heron - Allen and Earland				r		r																																										
Textularia sp.										r		r																																				
Tretomphalus bulloides (d'Orbigny)	c	c	r	r		r		r		c			a	c	c	f						c															r											
Tretomphalus milletti Heron - Allen and Earland											r	r	r																																			
Triloculina austriaca d'Orbigny			r	c	r		c		c							c																																
Triloculina circularis Borneman									r				r	r														r		r																		
Triloculina irregularis (d'Orbigny)			c	c		c	c	c		r			c	a	c																																	
Triloculina labiosa d'Orbigny								c		c		r																																				
Triloculina oblonga (Montagu)										r				r																																		
Triloculina oceanica Cushman					r																																											
Triloculina tricarinata d'Orbigny	c	c	c		c		c			c		c	c	c	c																																	
Triloculina trigonula (Lamarck)						c		c					c			c																																
Tubinella funalis (H. B. Brady)	c	c						c	c					r		r												r																				
Virgulina pauciloculata (H. B. Brady)													r	r		r																																



5. Map of Raroia showing location of samples of foraminiferal sand

are actually below the level of high water. Wherever a surface inlet is lacking, sea water seeps through and beneath the gravel rampart at high water stage. These places are swampy and are underlain by organic muck and sand. Moats with surface access to the sea at high water levels commonly are free of muck and have a firm floor of gravel and sand. It is particularly in these areas that cementation of the sediments by calcium carbonate is taking place. Here blue-green algae extend several millimeters into the sediments and into the coral fragments. Beneath the gray stain of the surface is a thin green layer colored, probably, by chlorophyll. The pebbles and sand are here and there bound together by filaments into a firm friable fabric several centimeters thick. The sediments immediately below the algal crust are lightly cemented for a few millimeters, below which the rock is firmly cemented.

Without experimental data it is difficult to judge the function, if any, of the blue-green algae in cementation of the sediments. Certainly the binding action of the algae is of significance in anchoring the sediments until they can become cemented, a process which on Raroia evidently requires much more time than elapses between storms (Cloud, 1952, p. 29). It is also possible that the algae dissolve calcium carbonate at surfaces of contact. If so, this dissolved calcium carbonate might be available for cementation immediately below the surface.

I agree with K. O. Emery (personal communication) that sea water, which is saturated with calcium carbonate, is probably the most important source of the cementing agent. There is little evidence that meteoric water plays a significant role here. Normal sea water floods these moats twice daily, and for hours at a time the areas are exposed to the air with consequent concentration of salts held in the sediments. It is highly probable that lime is precipitated under these conditions and that part of it is incorporated as cement in the sediments.

There are two other situations in which lithification of sediments apparently is taking place. The test pits and water wells on Garumaoa Islet contain friable sandstone below about the highest level of the fluctuating water table. The water ranges from brackish to fresh and presumably is saturated with calcium carbonate most of the time. Rain water, percolating down through the loose sediments carries dissolved lime to the water table where it is concentrated. There is no indication of large scale upward migration of calcium carbonate by capillarity to form caliche. Evaporation rates probably are not high under existing mild climatic conditions.

The third condition is encountered on the seaward reef flat, particularly on the windward side of the atoll at the edge of the conglomerate platform, where coral blocks and reef blocks are occasionally welded loosely to the reef flat by means of blue-green algae. Algal blackened coral slabs, mainly Acropora conigera, imbricating toward the sea, form continuous patches of rubble in the intertidal zone. Fresh fractures reveal a green layer of living algae beneath the blackened surface film. At first examination it seems that the conglomerate platform of the windward shore is being extended by deposition at the shore of coral rubble. However, closer examination indicates that the rock platform is generally retreating. The algal cementation is not permanent under existing conditions. An earlier margin of the platform is identifiable by the erosion remnants and can be mapped well out on the reef flat. Apparently reef blocks are temporarily and loosely attached at the shore to be later stripped away during storms.

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