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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

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STUDY OF THE BIRDS OF THE STATE OF TEXAS

Part I

General Notes on the Birds of Texas

and Other Notes on the Birds of Texas

By J. P. H. Morrison

Part II, Notes on the Birds of Texas

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Part III

Notes on the Birds of Texas

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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 helicimid 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 rock-

snails 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 convictor 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 inter-spaces. 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 deprivations 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 ceratophthalma 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 brevipanus 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 Ngaru-maoa, 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 Röding, 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 tessellata 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 Coraliohila 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 coral-line algal (Goniolithon) growths and foram sand the same as the pavement, is the golden-mouthed rock-snail Drupa grossularia Rödning. 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 ransonii Pruvot-Fol recently described from Hikueru 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 erythroductyla 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 stel-laeformis 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 ascendancy, 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 Padolus 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.

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 senescens 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 granulorum, 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 granulorum 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 branches, 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 hippoboscoid 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 atypa atypa 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.