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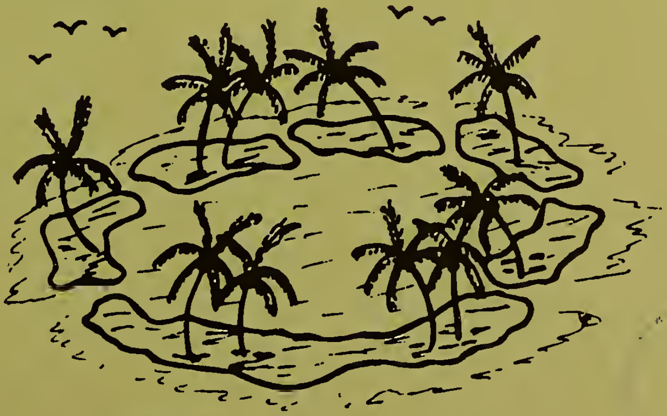

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ATOLL RESEARCH BULLETIN
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A MODEL FOR THE DEVELOPMENT OF TYPES OF ATOLLS AND VOLCANIC ISLANDS ON THE PACIFIC LITHOSPHERIC PLATE

BY

G.A.J. SCOTT AND G.M. ROTONDO

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A MODEL FOR THE DEVELOPMENT OF TYPES OF ATOLLS AND VOLCANIC ISLANDS ON THE PACIFIC LITHOSPHERIC PLATE

by G.A.J. Scott[1] and G.M. Rotondo[2]

ABSTRACT

A literature review on atoll origins and volcanic island development on the Pacific lithospheric plate is combined with bathymetric data on the Hawaiian, Marshall, Caroline, Tuamotu and Society island chains to produce a model which helps explain the development of all major Pacific plate island types. This model incorporates the concept that as new lithosphere is formed along the East Pacific Rise older crust moves north-west towards Asia, cools and causes ocean deepening. Some distance from the East Pacific Rise relatively fixed melting anomalies produce volcanic island chains. In warmer waters these islands develop fringing reefs which continue to grow to wave level as the islands are carried on the cooling plate into deeper water. Raised volcanic island forms can develop on arches produced by the isostatic subsidence of new magmatic outpourings close by. As volcanic islands with fringing reefs move into deeper water almost-atolls and finally true atolls develop. Partly raised and raised forms result if atolls rise over minor upwarps on the crust produced by, 1) asthenospheric bumps, 2) arch flexuring resulting from isostatic subsidence of nearby magmatic outpourings, 3) compression within the lithosphere alongside Pacific plate subduction zones. The model also helps explain certain types of drowned atolls and guyots.

INTRODUCTION

This paper attempts to develop one model to explain the origins of all major types of island found on the Pacific lithospheric plate (Fig. 1). Literally tens of thousands of seamounts are scattered over

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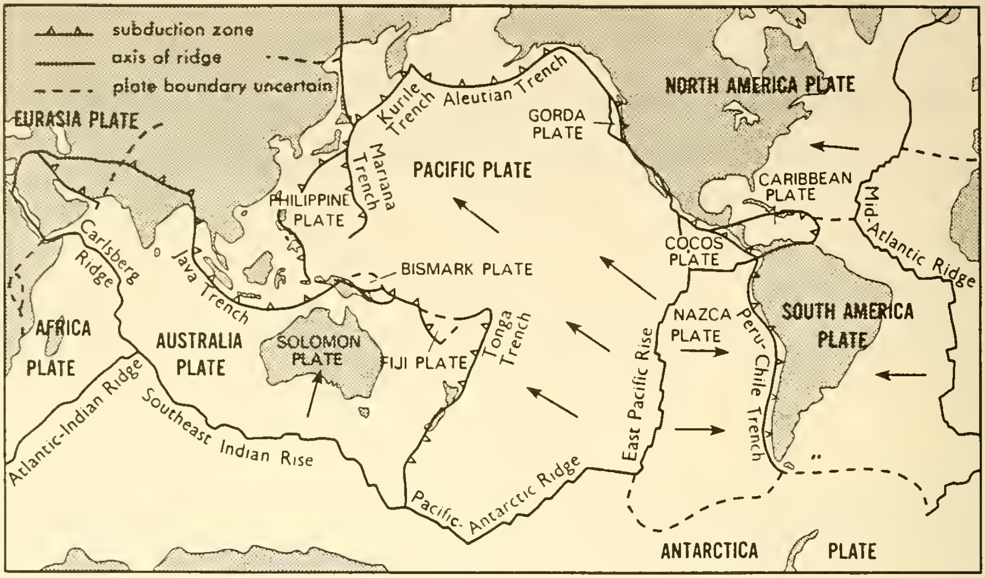

Figure 1. The Pacific lithospheric plate.

the surface of the Pacific plate but the majority of these igneous monoliths appear never to have reached the ocean surface and have therefore been preserved intact from alterations associated with subaerial weathering and erosion. Only occasionally do Pacific seamounts break the ocean surface forming islands. Some of these islands reflect characteristics of the submerged seamounts but take the form of tall volcanic peaks. More frequently they take the form of seamounts apparently truncated near sea level, capped by carbonate deposits, and variously described as atolls or reefs. Another striking feature of the Pacific plate is that islands of whatever type are normally only found in the somewhat shallower parts of the ocean near the East Pacific Rise, or where ocean temperatures normally remain above 22°C throughout the year.

Although fewer in number volcanic islands have received much more attention from geoscientists and geologists interested in origins and dynamics than their carbonate counterparts the atolls. It was only following WWII that the Pacific Science Board of the National Academy of Sciences organized a major program into atoll research and the text, *Atoll Environment and Ecology* by Harold Wiens (1962), represented a synthesis of this work. Perhaps partial blame for this lopsided research thrust was due to the seemingly explicable and visually more dynamic characteristics of volcanoes as compared to the confusion and disagreement surrounding the low, relatively featureless, atolls. Although back in 1842 Darwin proposed the simple yet elegant explanation that these atolls resulted from the slow submergence of volcanic islands his ideas were contested and went unproven until 1951 when drilling through the

Figure 2. Western Pacific Ocean showing the major island groups mentioned in the text. Profile transects along dashed lines are shown in Figures 7 and 10-13.

carbonate platform on Eniwetok in the Marshall Islands (Fig. 2) hit volcanic basement rock at depths exceeding 1,200 m (Ladd, 1973). Despite Darwin's early linkage of volcanoes to atolls it was not until the last few decades that researchers focused more critical attention on their interwoven histories. The last ten years in particular have seen a great increase in geoscientific research on Pacific plate atolls and their possible links to both the horizontal and vertical movements of seamounts. Because of the vast amount of information presently available on the Pacific plate it is now possible to produce an atoll development model much more complex than that inferred by Darwin's simple subsidence model. The following discussion of island types, literature review and island chain analyses is therefore an attempt to formalize major current ideas on Pacific plate island origins into one coherent dynamic working model.

PACIFIC PLATE ISLAND TYPES

In warm tropical waters capable of supporting reef environments no less than eleven distinct island types can be differentiated (Fig. 3). The classifications of Pacific island types by such researchers as Wiens (1962) and Leont'yev et al. (1975) are expanded here simply in preparation for the development of a model designed to explain why they differ. The precursor of all other island types on the Pacific plate is a volcanic island with no (or incomplete) fringing reef. All other types then depend on the development of a fringing reef and then some degree of subsidence or emergence or some combination of these two.

a) Volcanic island with no fringing reef. This island type usually takes the form of a young "high-island". During and particularly following the cessation of volcanic activity such cones are subjected to rapid subaerial weathering and erosion. Fringing reefs are absent or incomplete either because there has not yet been time for them to develop as is the case with Hawaii, or because they are located in poor reef growing waters such as with the Marquesas.

b) Volcanic island with fringing reef. Good reef growing conditions and time have permitted full or almost full development of a typical fringing reef such as that around Kusaie Island in the Carolines. If slow subsidence occurs the reef will remain at wave level due to upward growth, but will broaden. Volcanic activity may still occur intermittently and subaerial erosion and island dissection continue.

c) Raised volcanic island with fringing reef. Similar to type b above except that emergence has elevated the original reef above sea level and a new reef forms oceanward at wave level. Oahu in the Hawaiian Islands is such an example (McNutt and Menard, 1978). Subaerial erosion continues to lower maximum island elevation.

d) Almost-atoll. With this type the volcano is extinct and deeply eroded. Submergence has left one or more embayed basaltic islands and stacks in a lagoon surrounded by a barrier reef. Good examples of this type are Aitutaki in the Cook group and Truk in the Carolines.

e) Raised almost-atoll. If the almost-atoll undergoes uplift instead of subsidence then the central volcanic projections remain, the lagoon may drain and a new reef develops at wave level. An example of this is Atiu Island in the Cook group.

f) Atoll. If the almost-atoll continues to subside the fringing reef keeps growing to wave level while all traces of the original volcanic core disappear below sea level. Small low islets formed from coralline and algal rubble separate the reef from the shallow lagoon. Examples include Arutua in the Tuamotu group and Bikini in the Marshalls. As with Eniwetok, continued subsidence could lead to the development of a carbonate cap exceeding 1,200 m thick.

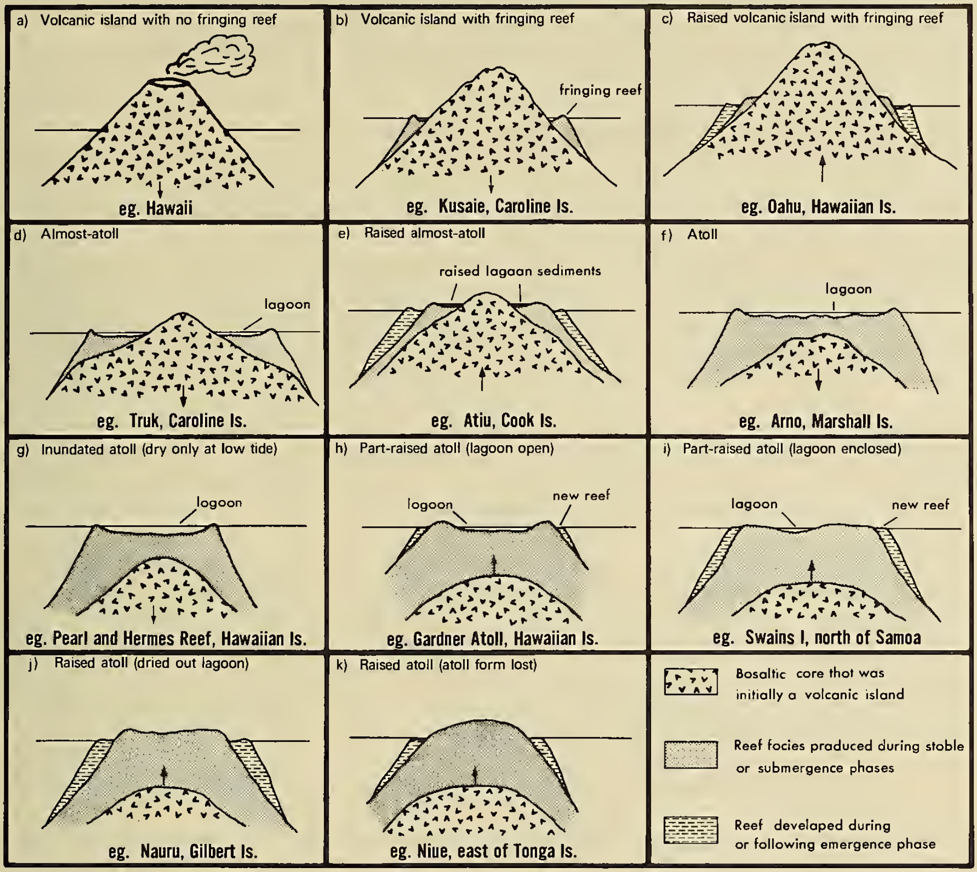

Figure 3. Island types on the Pacific lithospheric plate. Arrows indicate relative vertical motion. Modified from Wiens (1962) and Leont'yev et al. (1975).

g) Inundated atoll. In this type the annular reef sand bars only project above sea level at low tide. Examples of this include Pearl and Hermes reef in the Hawaiian Islands and Suvorov Atoll in the Cook group. Inundation of this typical atoll form may be due to, 1) deterioration of reef growing conditions followed by wave planation, 2) lack of time for the reef to regrow to wave level following subaerial erosion during Pleistocene low sea level stands and then rapid post glacial eustatic rise, or 3) a rate of subsidence too rapid for reef buildup to keep pace.

h) Part raised atoll with open lagoon. This type has the form of a regular atoll but has been raised only a few meters with the lagoon remaining tidal. An example of this is Gardner Atoll in the Hawaiian chain. Early reports that some of these raised reefs are due to 120,000 BP high sea level stands are not supported by more recent explanations (McNutt and Menard, 1979). Some atolls with higher than typical reef flats have also been attributed to this same high sea level stand, but recent reports again do not confirm this (Curray et al., 1970; Newell and Bloom, 1970).

i) Part raised atoll with enclosed lagoon. Here the atoll appears elevated sufficiently above sea level for the lagoon to be cut off and reduced in size. Elevation may exceed ten meters. Typical examples are Swain's Island north of Samoa and Vaitupu in the Ellice group.

j) Raised atoll with dried out lagoon. Here apparent uplift has been in the order of tens of meters. A karst type landscape described by the term "makatea" results, and small ponds may form in the lower depressions where the previous lagoon was located. Examples of this are Nauru Island in the Gilbert group and Makatea Island in the Tuamotus.

k) Raised-atoll with typical form lost. This atoll type has been sufficiently elevated long enough for all remnants of the typical atoll form to be lost. Irregular uplift may have left terraces. An example of this type is Niue Island east of Tonga.

It is recognized that many authors use other names or intermediate examples in their descriptions of island types and specific atolls. The eleven categories listed above serve only as indicators of important examples, and, as the model developed at the end of this paper shows, under ideal conditions they could be considered genetically related along a continuum. This continuum could also include foundered island types such as drowned atolls and guyots.

CLASSICAL VIEWS OF PACIFIC ISLAND ORIGINS

An explanation for the existence of volcanic islands on the Pacific lithospheric plate has never been considered a problem. It is clear they are the product of sub-oceanic and subaerial magmatic outpourings which have built igneous seamounts rising from the ocean floor at depths of 5,000 m or more to elevations above sea level sometimes exceeding 4,000 m. Why Pacific plate volcanoes develop at all has received considerable recent attention and some of the possibilities will be discussed in the next section. Origins for the many versions of atolls scattering the central and western Pacific have differed widely however, and they therefore constitute a more interesting topic for debate.

While Darwin was one of the first to propose a scientific explanation for the origins of atolls, he was certainly not the last. Since his 1842 edition of *"On the Structure and Distribution of Coral Reefs,"* Wharton (1897), Daly (1915), Davis (1928), Hoffmeister and Ladd (1944), Keunen (1947), MacNeil (1954), Menard (1969, 1973) and Purdy (1974) among others have all contributed ideas as to their origin and modification. Darwin's well known subsidence theory postulated that a subsiding volcanic island base was first surrounded by a fringing reef, then a barrier reef, and finally, as the volcanic rock disappeared below sea level, an atoll remained. Recent investigations into the structure and development of Bikini and Eniwetok Atolls basically support Darwin's premise that subsidence is the key factor. Drillings show that the coralline limestone caps on both these atolls exceeds 1,220 m (Ladd, 1973). It now seems clear that the life cycle of Bikini and Eniwetok was one of subsidence of volcanic mounds, reef building, emergence during the Miocene, and erosion and growth during the fluctuating sea level of the Pleistocene.

A major alternative to Darwin's ideas was Daly's "glacial-control theory". Rather than the island sinking, he envisaged that it was planated during a Pleistocene low sea-level stand and then, when the sea rose again, the reef grew to sea level giving rise to an atoll. While Davis (1928) considered Daly's theory as the only serious rival to Darwin's, he reasoned that if reefs were indeed killed during the glacial low sea level stands, then cliffed headlands ought to be commonplace along island shores inside present-day barrier reef lagoons. The headlands are in fact singularly absent in the warmer parts of the coral seas but become increasingly apparent towards the northern and southern limits of present-day coral growth. At best, Daly's theory was therefore only applicable to the marginal belt atolls (Purdy, 1974).

Hoffmeister and Ladd (1944) did not feel that barrier reefs and atolls were genetically related in the Darwinian sense. They considered that both simply developed through upward growth of corals at the edges of antecedent platforms. These platforms depended on a fortuitous combination of erosion, deposition, volcanic activity and tectonism. Keunen (1947), recognizing the possible relationships between the theories of Darwin and Daly, developed his own "glacially controlled subsidence theory". Unfortunately his theory is difficult to accept because he devised two mechanisms to account for the same thing. During the Tertiary he envisaged Darwinian subsidence, but during the Pleistocene a modified glacial control theory is required to give the same result through the upgrowth of reefs along the edges of truncated barrier reefs or atolls.

MacNeil (1954) did not agree with Keunen's idea that the Tertiary atoll was planed off during the Pleistocene and then regrew rapidly in the Holocene. He considered that subaerial limestone solution during the Pleistocene was the only logical explanation for the saucer shape of atolls, and that Holocene growth simply added a "veneer" of new carbonate to the karst landscape. This idea, fully developed by Purdy (1974) under the title "antecedent karst", ties together the essential premise of Darwinian subsidence and the significance of Pleistocene low sea level karst development. There is good evidence to support this antecedent karst theory (Bloom, 1974), and this theory accords most fully with our present knowledge of atoll morphology. Because of the significance of Pleistocene karst development on "emergent" island forms the topic is discussed more fully below.

Karst and Submerged Atolls

The "swinging sea level of the Pleistocene" has been a major factor in the morphology of modern reef complexes, although not in the sense that Daly intended by his glacial-control planation theory. Reefs in general were not in fact truncated at the glacial low sea level surface; rather rugged karst landscapes were produced on the emerged limestone terrains (Bloom, 1974). Evidence for this can be interpreted from drowned karst features that pass below sea level on the east Pacific continental shoreline, from the thickness of new post-glacial coral-algal deposits, from the present morphology of atolls, and by experimentation.

Emery et al. (1954) interpreted the closed depressions at 33 to 35 m below sea level in Bikini lagoon as sinks formed by groundwater circulation. Similar but more abundant depressions are developed to depths of 54 m in the eastern part of the lagoon of the almost-atoll, Truk. These were interpreted by Shepard (1970) as also being sinks on a glacial-age karst plain. Purdy (1974) presents a table summarizing the work of many other studies on antecedent solution unconformities on Holocene carbonate platforms, and there seems little doubt that present day atoll morphology closely reflects the karst landscape drowned by post-glacial eustatic rise.

Experimentation with acid on limestone blocks has also given impetus to the antecedent karst idea. Under a uniform acid shower the flat-top of an exposed limestone block develops into a rimmed basin that is such an excellent scale model of an atoll that MacNeil and Purdy regard the experiment as proof that glacial-age weathering is the primary control of present reef configuration (Purdy, 1974). The topography of the Mariana limestone on the northern plateau of Guam mirrors this experiment. Here the well-defined reef and lagoon facies of the limestone have been subaerially weathered to the point that the reef facies actually form a peripheral range of hills around a karst plateau that is underlain by lagoon facies. Likewise, Bourrouilh (1975, 1977) examined profiles through many atolls and comes to the same conclusion.

The significance of antecedent karst in the discussion of Pacific island types is two-fold. First, it is clear that the present atoll morphology is fundamentally karst induced, rather than growth induced. Second, it illustrates the point that certain atolls may have been subject to more rapid solution during Pleistocene low sea level periods and that the slow rate of growth following post-glacial eustatic rise has not yet allowed these drowned atolls to re-emerge as islands.

Drowned or submerged atolls are quite common. Tayama (1935) considered that of the 20 shoals or banks in the Western Carolines at least eleven are atolls drowned by tectonic subsidence. It is quite unlikely that tectonic subsidence is sufficiently rapid to cause their drowning, particularly as they are found under good coral growing conditions. Rather, regrowth following the production of antecedent karst has simply not been sufficiently rapid to raise these shoals to sea level again. However, this mechanism could trigger the demise of atolls in areas which, even with today's conditions, would be considered marginal reef growing areas. A probable example of this is the shoal located at 35°N, 172°E some 1,250 km northwest of Kure Atoll in the Hawaiian Chain at a depth of 60 m. It is also quite possible that truncation during some Pleistocene low sea stands did occur to the extent that with subsequent eustatic rise corals simply found themselves in water too deep in the euphotic zone to survive, and the shoal stopped growing. While this supposition tends to agree with the planation aspect of Daly's theory, the most unlikely form that would result would be an atoll.

THE TECTONIC POSSIBILITIES

An acceptance of Darwin's atoll origin model requires the acceptance of island subsidence. But is subsidence merely isostatic or are other more complex factors needed to account for the great vertical displacements required to alter volcanic island peaks into atolls with carbonate caps as thick as 1,200 m? With all island types in mind the question of emergence must also be addressed. Tectonic information needed to help answer these questions include; lithospheric plate movements, lithospheric cooling and compressions; melting anomalies (hot-spots) and volcanic activity; asthenospheric bumps, lithospheric loading and isostatic changes.

Lithospheric plate movements, lithospheric cooling and compressions

The earth's lithosphere is made up of seven major, and a number of minor, rigid lithospheric plates (Fig. 1). These plates are usually in motion relative to each other. Where plate margins separate asthenospheric magma upwells to form new lithosphere, and where plates collide the denser is normally subducted below the lighter (Fig. 4). Because of the inherent potential for fracturing along plate boundaries their distribution tends to coincide with seismic and volcanic activity. Volcanic activity, however, can also be associated with melting anomalies in the thin (75-100 km) oceanic crust. For a detailed explanation as to how mid-ocean ridges form please see Dillon (1974).

Evidence substantiating the fact that the Pacific Plate ages with distance from the spreading centre along the East Pacific Rise comes from a number of sources. McDougall (1971) has dated the volcanic (basaltic) islands of the Hawaiian Chain using the potassium-argon method and found that they increase in age towards the north-west. Each island in the Hawaiian-Emperor Chain is presumed to have been created over a stationary melting anomaly presently capped by the island of Hawaii (Wilson, 1963 a,b; Shaw and Jackson, 1973).

Very convincing evidence as to the older nature of the north-western portion of the Pacific Plate comes from the study of ocean sediments (Heezen et al., 1973). Sediments close to the East Pacific Rise are thin or non-existent, while with distance from the rise the sediment lens thickens. Sediments in contact with the Pacific Plate close to the Kurile subduction zone were actually deposited in equatorial waters during the Mesozoic (Upper Jurassic) at least 120 million year ago (Heezen & McGregor, 1973). Rates of platal movement have also been established. Le Pichon et al. (1973) estimate that the Pacific Plate is underthrusting the Aleutian Trench at 6.5 cm per year, while Heezen et al. (1973) indicate that the plate presently has a westward component of 8 cm per year and a northward component of 2 cm per year.

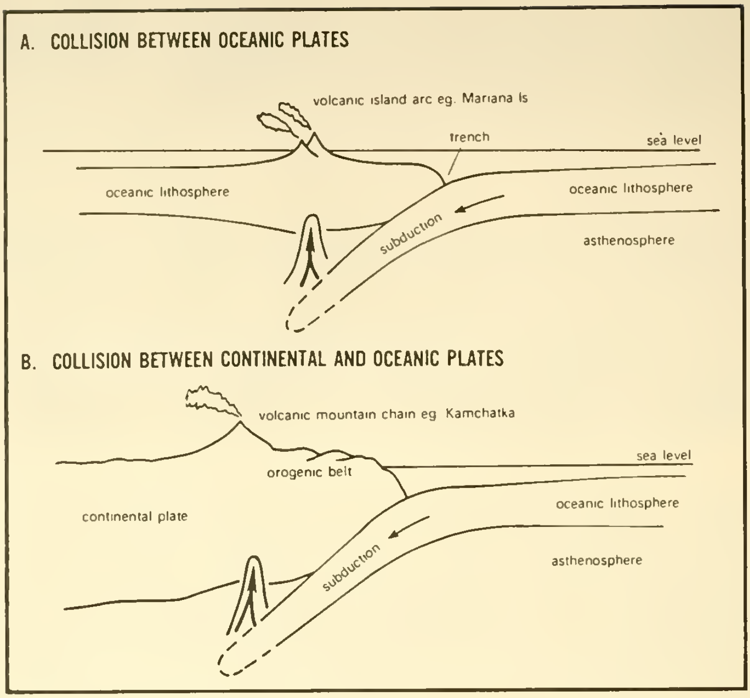

Figure 4. Typical subduction patterns in the western Pacific.

In the discussion of the relationship between plate tectonics and island type differences another important characteristic of ocean plates must be stressed. The upper surfaces of ocean plates are not in fact horizontal relative to sea level. As the hot newly-created lithospheric plate moves away from the accreting plate boundary along the East Pacific Rise it progressively cools and "contracts". Because this occurs at the same time as upper asthenosphere cools and "accretes" to the lower lithosphere surface, lithospheric thickening is the actual result. The overall effect of this cooling, however, is to cause the ocean to deepen with increasing distance from the East Pacific Rise and creates a sloping of the crustal plate. Le Pichon et al. (1973) calculate that at the East Pacific Rise average depth is 2780 m, while at 30 million years the Pacific Plate is at a depth of 4350 m, and at 75 million years at a depth of 5610 m. Clearly any volcanic islands or seamounts produced on the slopes of the East Pacific Rise or over a melting anomaly will be carried tangentially into deeper water. So regular is the rate of ocean deepening due to lithospheric cooling with distance from the East Pacific Rise that Sclater et al. (1971) indicate an impirical relationship between ridge elevation and age of the crust that can be used to date crust up to 40 my old to within 2 my.

There is no unanimity as to the time required for crustal cooling-ocean deepening to approach zero. Sclater and Francheteau (1970) infer that the effects of lithospheric cooling cease by the time the plate has moved 6,000 km (approximately 75 my), while Watts and Cochran (1974) indicate negligible cooling at 80 my. Le Pichon et al. (1973) suggest that cooling continues beyond 75 my but is greatly reduced in rate. That the ocean progressively deepens towards subduction zones is clear, however, and crustal cooling may well be the principal cause. Crustal cooling need not necessarily be regular or linear in all parts of the Pacific plate at the same time. This is because crustal reheating at asthenospheric bumps and fixed melting anomalies (Menard, 1973; Crough, 1978; Rotondo, 1980) can cause expansion and thinning of the plate above with a renewed cooling-ocean deepening pattern to the north-west (Fig. 5).

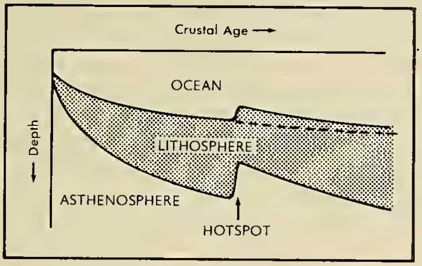

Figure 5. Inferred interaction of the lithosphere with a mid-plate hot-spot. From the ridge to the hot-spot the lithosphere thickens and subsides by cooling. At the hot-spot, extra heat drives the isotherms upwards, thins the lithosphere and causes uplift. Beyond the hot-spot, the lithosphere cools rapidly because it is thin and thus subsides as younger lithosphere at the same depth, rather than as normal lithosphere of the same age (dashed line). After Detrick and Crough (1978, Fig. 4).

It is obvious that if the Pacific plate is being forced north-west to be subducted below the edge of Asia there must be considerable compressional forces acting close to the subduction zone. Hanks (1971) reports strong horizontal compressional stresses seaward of the Kurile trench. Watts and Talwani (1974) call the positive gravity anomalies seaward of many trenches "outer gravity highs" and indicate that they correlate well with regional rises of up to a few hundred meters. Pacific plate margins showing slight upwarps before final subduction include areas along the Kurile, Bonin, Japan and Philippine trenches. The outer gravity highs seaward of the southern Bonin and Mariana trenches also correlate with regional topographic rises but they can be explained without inferring horizontal compressional stresses (Watts and Talwani, 1974). Topographic rises are not present along all subduction zones. In the discussion of island forms close to subduction zones the presence or absence of these topographic rises must be considered.

Melting anomalies and volcanic activity

All Pacific plate island types require an original volcanic base. It is easy to envisage magmatic outpouring forming volcanic islands close to spreading centres that then drift away from these ridges as the plate cools and moves into deeper water. But how do we account for volcanic islands such as Hawaii which are both young and distant from the East Pacific Rise? A number of explanations have been proposed to explain this phenomenon of mid-oceanic plate volcanic activity which is not directly attributible to spreading centres along mid-oceanic ridges. They include the 1) hot-spot theory, 2) gravitational anchors, 3) asthenospheric bumps, and 4) slip-strike motion theory. The term "hot-spot" is frequently used to describe the phenomenon of magma discharge that forms line island-seamount chains on oceanic plates. Because the term hot-spot is also often used in the more specific sense as a theory to explain the origin of these island-seamounts, the term "melting anomaly" (Shaw and Jackson, 1973) will frequently be used to encompass all theories on their origin. The "hot-spot" theory depends upon the principle of a thermal plume originating at a fixed spot beneath the surface of the oceanic plate in the asthenosphere (Wilson, 1963; Morgan, 1965, 1972a,b). Essentially a convection cell mechanism is operative. This in turn causes weakness in the 100 km thick lithesphere and outpourings of magma occur over the plume. Magma discharges from a series of closely spaced point source vents that coalesce into a single vent as eruptions progress in time (Jackson & Shaw, 1975). As the ocean plate moves across this fixed hot-spot a series of volcanic seamounts results. It is most likely, however, that volcanism is not as precise as this ideal description infers, nor is it necessary that magmatic outpourings be aligned perpendicular to the East Pacific Rise spreading centre (Moberly and Larson, 1975).

Shaw and Jackson (1973) proposed that volcanic activity at the south-eastern end of the Austral, Tuamotu and Hawaiian Chains is not the result of fortuitous location of thermal plumes but rather is a consequence of shear melting caused by plate motion. Once such melting begins a dense residuum is formed and sinks. This downwelling ultimately forms "gravitational anchors" that stabilize the anomalies and cause inflow of fresh parent materials into the source area for the basalts. Such gravitational anchors, they feel, provide a much more sensitive inertial guidance system for positioning of melting anomalies.

Menard (1973) noted the close relationship between asthenospheric bumps and the actively growing end of volcanic chains on the Pacific Plate. He concluded that melting anomalies are located on the "updraft" sides of positive gravity or depth anomalies and are being overridden by moving plates. It is quite possible that this "warping" of the lithospheric plate determines the location of the melting anomaly, which, according to Menard (1973) would be the result of a thermal plume. Because of the importance of asthenospheric bumps in epeirogenic uplift resulting in raised island forms they will be discussed more fully in the next section.

Handschumaker (1973) suggested that the Emperor Seamounts may have been formed as a result of extrusion induced by strike-slip motion. Jackson and Shaw (1975), however, found that there is no evidence that any significant intraplate finite strain has been imposed on the lithosphere in the region of linear chains, so this theory is considered unlikely to explain the linear seamount chain phenomenon.

Melting anomalies may therefore result from a number of possible mechanisms. The very fact that they do occur, however, produces the seamount-island chains on which atoll development depends. They also help account for the renewed crustal cooling-subsidence phase needed for atoll development (Fig. 5). It should be stressed that not all melting anomalies give rise to atolls, however. No atolls are found in waters where either cold or the simple absence of certain reef species prevent reef development as in the Marquesas, or where certain seamounts never reach the ocean surface. Kidd et al. (1973) indicated that there are as many as 150 terrestrial plumes giving rise to melting anomalies so oceanic seamounts are not the exception. While evidence indicates that melting anomalies are relatively stationary as in the Hawaiian Emperor Chain (Jackson et al., 1980), it is also possible that some are less fixed, particularly where they abut other continental plates and are subject to forces not directly attributable to their own lithospheric plate motion.

Asthenospheric bumps

Menard (1973) was perhaps the first to fully appreciate the relationship between the emergence of Pacific islands and broad low "bumps" on the ocean floor. Because he attributed these bumps to an asthenospheric surface which is not exactly level, he called them "asthenospheric bumps". In actuality they appear as low bumps up to several hundred metres in vertical elevation and 1,000-3,000 km in width on the surface of the ocean plate and are detected as positive gravity anomalies. As the plate moves over these asthenospheric bumps the general tendency for the lithosphere to deepen due to cooling (Le Pichon et al., 1973) is temporarily counteracted. Any islands or atolls on the upslope side begin to rise out of the water instead of subsiding in the expected way (Fig. 6). Ocean, Nauru and Marcus islands are good examples of the effects of asthenospheric bump uplift on islands (McNutt and Menard, 1978).

Asthenospheric bumps are located in many parts of the Pacific. Care must be taken in evaluating their overall significance however. While it is tempting to associate all seamounts and islands riding over one asthenospheric bump with one melting anomaly, it may be that peaks produced by another melting anomaly nearer the East Pacific Rise have simply advanced to this new bump-melting anomaly area (Rotondo et al., 1981). In this way the idealized sequence of atoll formation may appear confused as high islands from the nearby melting anomaly may be associated with atolls from another but distant melting anomaly.

Isostatic subsidence and lithospheric loading

Darwin's original atoll development model infers isostatic subsidence

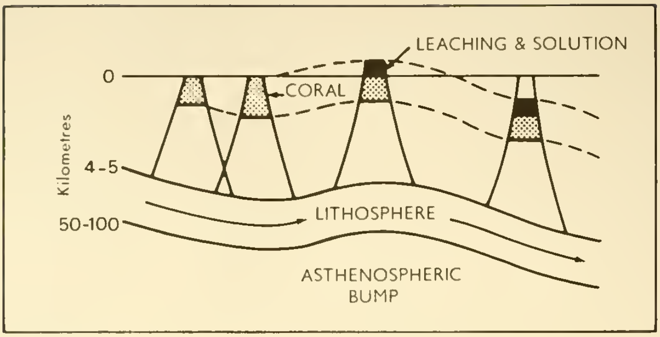

Figure 6. Idealized history of an atoll emerging-subsiding as it passes over an asthenospheric bump. After Menard (1973).

due to the islands own mass. Although some atolls have been subsiding for more than 50 ml years and have undergone subsidence exceeding 1,000 m it is very unlikely that isostasy alone could occur over such long periods of time. McNutt and Menard (1978) suggest that lithospheric loading by a new volcanic island produces a response over geologic time scales of 100,000 years or more, while Watts and Cochrane (1974) state that after only a few million years of loading isostatic adjustments approach zero and that the ocean plate then seems capable of supporting seamount chains for periods of tens of millions of years. Isostatic subsidence, for newly formed volcanic islands and submerged seamounts is very real, however, and immediately gives rise to a "moat-arch" development (McNutt and Menard, 1978, 1979; Jarrard and Turner, 1979).

Depression of the lithosphere by a new volcanic mass is variously described as crustal loading or lithospheric loading, and a crustal moat develops peripheral to the seamount. This moat may fill rapidly with sediments and not appear on bathymetric maps. Beyond the outer edge of the moat, flexuring develops an arch which experiences uplift in the order of tens of metres. If there are islands at various distances from this new loading mass those within the developing moat will experience gradual subsidence, while those on the developing arch will be slowly elevated. McNutt and Menard (1978) argue that the uplift of Atui, Mitiara, Mauke and Mangaia atolls in the Cook Islands result from lithospheric loading by three nearby volcanoes. Jarrard and Turner (1979), while agreeing with this conclusion, disagree as to the exact amount of resultant elevational change.

When magmatic outpourings cease above a melting anomaly and the volcanic island "drifts" away isostatic subsidence will soon cease. Likewise any island over which it had an influence would continue to move into deeper waters due to non-isostatic crustal cooling-ocean deepening. This picture can be confused in practice, however, if a new seamount again develops before other islands have had the opportunity to move beyond any new moat-arch development. Likewise, atolls drifting past a hot-spot seamount system not associated with its own igneous pedestal development could undergo subsidence or uplift depending on their proximity to the new crustal loading. McNutt and Menard (1978) consider this latter mechanism explains the emergence of some Tuamotu atolls following recent moat-arch development in the Tahiti area.

In our consideration of island types on the Pacific plate isostasy by itself seems of minor short term influence in causing volcanic islands to subside. Unless a volcanic island ceased growth at, or just above, sea level an atoll could hardly result from isostatic causes alone. Isostasy can clearly have a major influence on other island types, however, causing increased but modest subsidence rates for existing atolls within the new moat and emergence of atolls or volcanic islands on the arch. Beyond the arch little or no isostatic influences will be felt and Watts and Cochrane (1974) consider that the 400 m thick carbonate cap on Midway could not be due to this influence.

CASE STUDIES ON SPECIFIC ISLAND CHAINS

A number of island groups are examined to show how the various island types within them correspond to the tectonic, volcanic and reef growing conditions known to be operating on the Pacific plate. Three island groups in the North Pacific were examined using information from the literature and extracting bathymetric data from maps produced by the Scripps Institution of Oceanography (Chase et al., 1970). These island groups are the Hawaiian, Marshall-Gilbert and Caroline. The Tuamotu and Society Island groups in the southern hemisphere were also examined with bathymetric data coming from a bathymetric map of the Pacific produced by the Academy of Sciences (1964).

Hawaiian-Emperor Chain

This chain was selected because not only is it the most intensively researched group but because it is also the best example of a continuous line island group that runs from warm reef-promoting waters to cooler reef-inhibiting waters. The Hawaiian-Emperor chain lies entirely within the North Pacific and constitutes the Hawaiian Islands, the atolls and shoals of the Midway group, and the seamounts and guyots of the Milwaukee-Emperor chains (Fig. 7). This volcanic (basaltic) ridge runs from the Island of Hawaii, a total of 6,340 km to the Kamchatka Trench. Figure 7 depicts the peaks and corresponding ocean floor depths from a point south-east of Hawaii to the Kamchatka Peninsula. Data was taken from bathymetric maps prepared by Chase et al. (1970) which use 200 fathom depth intervals. In order to determine ocean floor depths and the heights of peaks with respect to sea level and the ocean floor, a line was plotted from a point south-east of Hawaii through the major peaks to the Kamchatka Trench (see Fig. 2 for profile route). Sampling points were placed at regular intervals along this line and data on the elevations and depths between the closest volcanic islands, atolls or submerged seamounts were recorded for each point. In all there were 132 points along the 6,700 km transect and using this data a profile of the more prominent peaks was produced (Fig. 7).

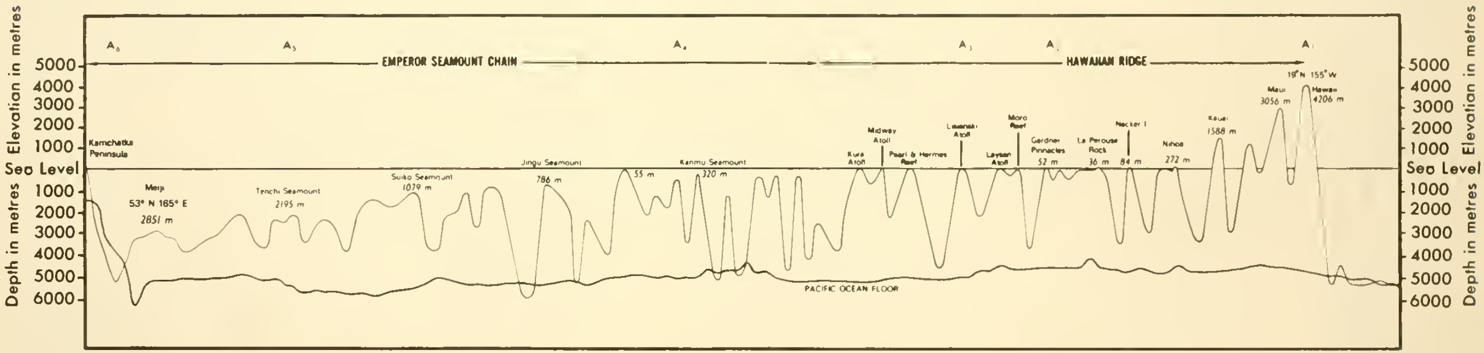

Figure 7. Profile of the Hawaiian-Emperor Chain (modified from Rotondo, 1975 Fig. 1.9). For profile route see Figure 2.

To obtain data on sea floor depths four lines were drawn parallel to the central ridge line at three and six centimetres to either side. Ocean depths were recorded exactly on these parallel lines at right angles to the 132 points on the central ridge line. The ocean floor profile in Figure 7 is the average of these four depths for each of the 132 profile positions. It should be noted, however, that this ocean floor curve is not coincident with the surface of the lithospheric plate. Since the Pacific plate was formed at the East Pacific Rise, thin layers of sediment as well as outpourings of magma associated with the Hawaiian melting anomaly have been superimposed on it to varying degrees. Despite the visible bumps that result from these magmatic ourpourings, the bumps are actually locked onto the plate as it moves into deeper water due to lithospheric cooling with age (Le Pichon et al., 1973). Minor asthenospheric bumps would be independent of these outpourings and could well cause the "bobbing" motion described by Menard (1973), but they could not be detected simply by examining bathymetric maps.

An examination of these profiles shows a number of interesting characteristics. Following the peak-curve from the Island of Hawaii north-west, it can be seen that the average high island elevation drops off rapidly due to the longer exposure to subaerial erosion (Fig. 7). There is no reason why these islands should appear to be reduced in elevation in a linear way because the original islands were never all at the same elevation to begin with (MacDonald and Abbott, 1970). The majority of these high islands, however, did exceed 1,000 m before cessation of volcanic activity, and heavy orographic precipitation combined with high temperatures and easily weathered besalts gives rise to rapid chemical weathering (Scott and Street, 1976). This subaerial erosion, together with coastal erosion, combine to rapidly reduce the elevation of islands, and this trend does appear in the profile.

The findings of Moore (1970) concerning isostatic readjustment of the Pacific Plate to the additional load of a new volcanic island must also be considered here because they indicate that isostatic subsidence is not as significant as originally suggested by the Darwinian subsidence model. According to Moore (1970) the absolute subsidence of the still-active Island of Hawaii is 4.4 mm per year. This agrees well with Apple and MacDonald (1966) who estimated that the west coast of Hawaii is subsiding at 3 mm per year. Moore also indicated that Maui (0.8-1.3 my, McDougall, 1964) is subsiding only 1.7 mm per year, Oahu (2.2-3.4 my) is stable, and Kauai (3.8-5.6 my) is actually rising. There is of course the real possibility that the Hawaiian chain in general will experience subsidence as it moves north-west because it will be descending the now cooling flank of a rise created over the Hawaiian hot-spot (Fig. 5). This cooling is similar to that near the mid-oceanic ridge and for the Hawaiian Islands would appear as in Figure 8. The true picture is somewhat confused near the hot-spot because of the current moat-arch development around Hawaii and the residual effects of Maui which must combine to give rise to the isostatic subsidence-emergence noted by Moore (1970) above. Oahu clearly does have a raised reef probably resulting from the arch produced by the combined masses of Maui and the earlier development of Hawaii. Now that Hawaii has become so massive

Oahu has stopped rising possibly because the Hawaii moat has now radiated outwards to bring Oahu into its flanks. The emergent island of Kauai continues to rise, however, as it may now have been fully overtaken by the Hawaii arch.

The most northerly islands in the Hawaiian chain with visible basaltic rock, Necker, La Perouse Rock and Gardner Pinnacles, are all reduced to less than 90 m above sea level. It is unlikely that all of this reduction results from subaerial and marine erosion alone. Each of these islands is surrounded by extensive flat reef-shoals and all indications are that they have undergone gradual submergence (Menard, 1973). Between Gardner Pinnacles and Kure Atoll, island and ocean floor subsidence is clearly indicated (Fig. 7). North of Kure only one seamount, between Jingu and Kaumu seamounts at 35°N, 172°E, is within 60 m of sea level. Apart from this peak, which must have been a Pleistocene island, there are no peaks north of Kure that could have been above sea level in recent times. This peak is no doubt a submerged atoll which experienced difficulties in producing reef growth sufficient to keep it at wave level as it continued to move into cooler waters. Karst formation on this eustatic low-sea level island during the Pleistocene would have encouraged this submergence relative to present sea level.

North of 35°N, 172°E, peaks deepen in a relatively linear fashion, and parallel deepening of the ocean bottom occurs. Close to the Kamchatka Trench, seamount elevations are variable, the ocean floor receives greater thicknesses of continental sediments and there appears to be minor buckling associated with bending of the Pacific Plate as subduction begins. This buckling effect is confirmed by Watts and Talwani (1974) but it will only have the effect of modestly raising deeply submerged seamounts close to the trench. Irregularities are to be expected, however, as most seamounts never reached sea level even when they were first formed, and at their present great depths it is difficult to differentiate between a seamount that never reached the ocean surface, and a guyot which may have been truncated at sea level and subsequently subsided. The term guyot must be treated with caution here because not all flat topped seamounts (i.e. guyots) are considered

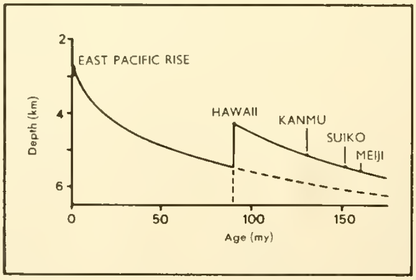

Figure 8. Subsidence after reheating at Hawaiian hot-spot. Hawaii depicted at the depth of normal 25 my lithosphere. Dashed line is expected subsidence without reheating. Modified from Crough (1978, Fig. 16).

to have been planated at sea level. Recent corings on Ojin, Nintoku, Yomei and Suiko seamounts in the Emperor Seamount Chain (Jackson et al., 1980) confirm that these guyots were in fact volcanic islands before subsidence allowed them to pick up carbonate caps. Borings on Suiko (Fig. 7) hit a "Paleocene shallow-water reef or bank assemblage of carbonate sand and sandy mud with algal nodules, from 52.5 to 163.5 meters. Basalt directly underlies the shallow-water limestone" (Jackson et al., 1980:11). Paleomagnetic measurements indicate that Suiko was formed at approximately 25°N latitude at a time when carbonate deposition (and possibly discontinuous reef formation) was occurring in water somewhat cooler than around the present-day Hawaii. The paucity of coral material on seamounts in the northern Emperor Chain is in marked contrast to seamounts at the bend of the Hawaiian-Emperor Chain (see A4 on Fig. 2) where corals are more abundant (Jackson et al., 1980). It appears then that a southward movement of the Hawaiian hot-spot into warmer waters accounts for the earlier development of bryozoan-algal caps (without coral) to the present day coral-algal caps. Figure 8 suggests that given time present day Hawaiian atolls will indeed become truly submerged atolls just as this appears to have already happened to Darwin Guyot in the Mid-Pacific Seamounts to the West (Ladd et al., 1974). This guyot has subsided to a depth of 690 fathoms but has preserved intact the atoll annular ring and ten-fathom deep lagoon.

On the basis of the above analysis a schematic representation of what may well have happened to the Hawaiin-Emperor seamount chain over the last 70 my is presented (Fig. 9). While this figure clearly generalizes the actual profile given in Figure 7 it does exhibit a remarkable approximation to the known facts and tectonic possibilities. It should be noted that not only does Figure 9 account for many of the island types illustrated in Figure 3, but it indicates four distinct island-seamount zones or "phases". It should also be noted that but for the fact that many of the Emperor Seamounts were formed in poor reef-growing waters, submerged atolls would extend all the way to Kamchatka.

Marshall-Gilbert Chain

These islands differ quite markedly from the Hawaiian-Emperor chain. They are in fact much more scattered and do not represent a characteristic line island group. The chain also lacks almost-atolls and high volcanic islands at its south-eastern end. Likewise there is no clear indication that the chain continues north-west, as does the Emperor Chain, to be subducted into a trench.

Figure 10 is based on a composite profile of the scattered atolls, shoals and seamounts of the Marshalls, and therefore differs from the single profile-transect method used in Figure 7, for the Hawaiian chain (bathymetric data from Chase et al., 1970). Because of the difficulty in interpretation of seamounts north of the Marshalls it was difficult to decide exactly the path taken or to be taken, by the most northerly seamounts in the chain. As a result two profiles are drawn. Both begin on the equator (B1 on Fig. 10) and move north-northwest to Wake (B2 and B3). Then one continues in the same direction to B4 in the deep ocean north of the Mapmaker Seamounts. It is possible that the numerous

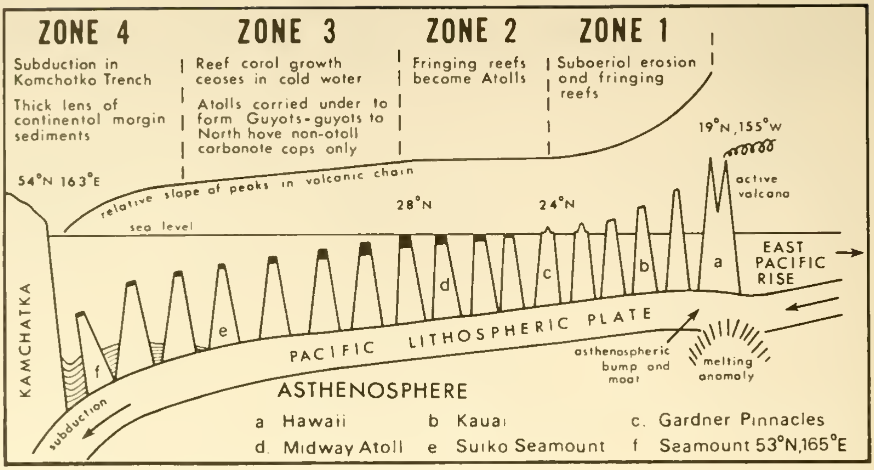

Figure 9. Schematic representation of the major physical factors influencing the Hawaiian-Emperor Seamount Chain (modified from Scott et al., 1976).

seamounts to the west and northwest may be part of the Marshall chain so another profile continues from B3 through Marcus Island to B5 at the Bonin Trench.

For both profiles the generalized ocean floor depth increases towards the northwest. The members of the Gilbert group shown on the profile are of a line island type, but appear to be separated from the Marshalls both visibly and bathymetrically. The numerous atolls of the Marshalls are scattered in two general lines running SSE to NNW and are associated with numerous seamounts (not shown in Fig. 10). North of Taongi Atoll none of the Marshall Seamounts appear to have reached sea level. From the bathymetric map Wake Atoll would appear to result from a different melting anomaly than that which produced the main Marshall cluster. Marcus Island and the shoal just beside the Bonin trench represent isolated peaks, but it is more likely they were previously shallow drowned atolls. Marcus is now rising over an asthenospheric bump and is now a raised atoll (McNutt and Menard, 1978). The shoal close to the Bonin trench may have been elevated close to sea level by the outer gravity high produced just before subduction.

In the case of the Marshalls, which must represent a senile volcanic chain produced by a long-inoperative hot-spot, the gradual movement into deep water combines with subaerial erosion to leave only atolls. Drillings on Bikini and Eniwetok (Ladd, 1973) at the northern end of the Marshall Chain hit basalt at depths exceeding 1,220 m, and shallow water fossils taken just above the basalt basement are about 55 my old. It is therefore quite probable that the parent volcanoes on which these atolls developed were formed just south of the equator in shallower water. They then collected these vast thicknesses of carbonate deposits on their slow

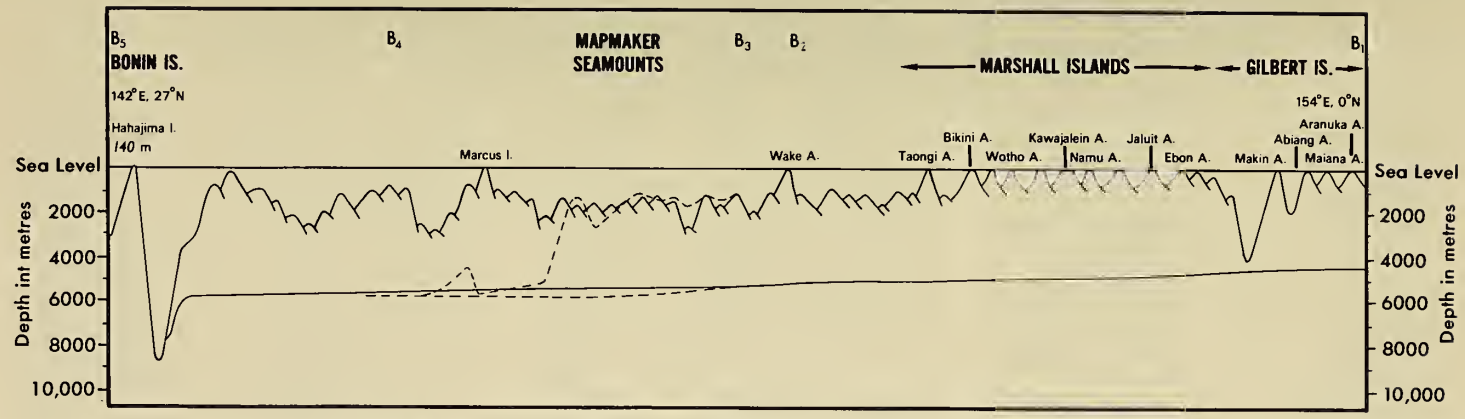

Figure 10. Profiles along the Marshall-Gilbert island chains.

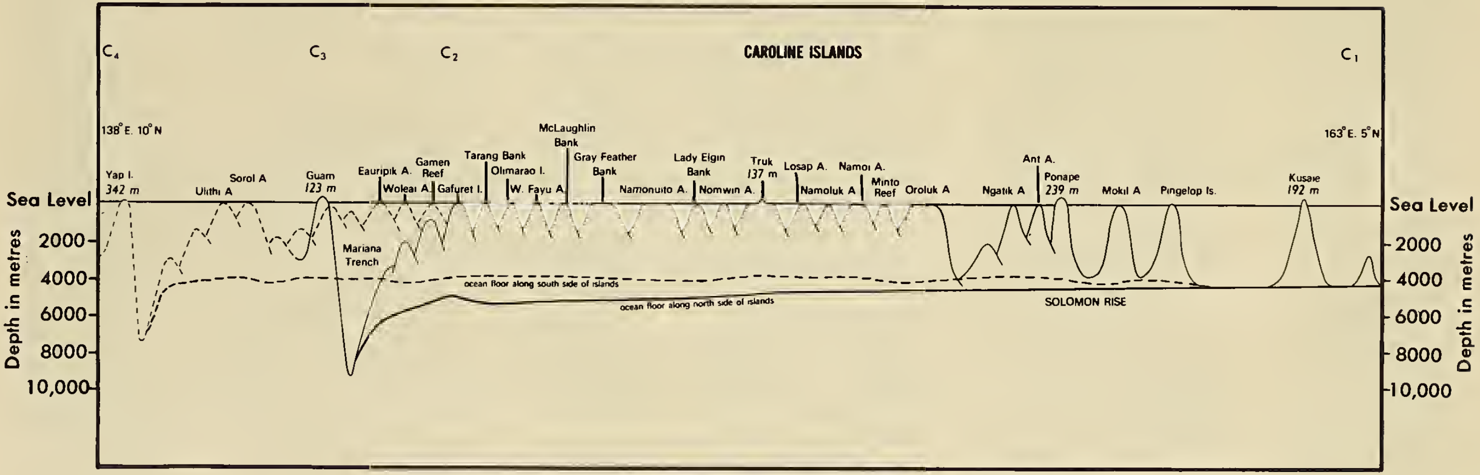

Figure 11. Profiles along the Caroline Island Chain.

journey northward. Such thicknesses are greatly in excess of those in the northern end of the Hawaiian Chain and reflect the truly equatorial location of their parent melting anomaly. In the Hawaiian Islands great thicknesses of carbonate are inhibited by a much shorter passage through reef-promoting waters between the time their basalt cores are reduced to sea level and the time atolls suffer demise north of 30°N in cooler waters.

Caroline Islands

The Carolines run west-northwest from Kusaie to the Mariana Trench (Fig. 11). Like the Hawaiian-Emperor Chain there are volcanic islands to the south-east and atolls to the west. Unlike the Hawaiian Chain, however, the almost-atoll form is also present, and the complete chain lies within warm tropical waters conducive to reef growth. The presence of almost-atolls as well as young volcanic islands and atolls make the Caroline Chain one of the more typical line island chains insofar as island form is concerned.

A composite profile based on data taken from bathymetric maps compiled by Chase et al. (1970) is shown in Figure 11. As is the case with the Marshall profile in Figure 10 the western end of the chain appears as a confused pattern on the bathymetric maps, thus this portion of the profile follows two separate paths (see Fig. 2 for profile routes). Figure 11 also shows two profiles for the ocean floor, one along the southern side of the chain and one along the northern. They are separated because it is considered that to average these depths would be misleading. This discrepancy may arise because the southern side of the atoll portion of the chain on the Pacific plate appears to be under considerable stress from the north-eastern advance of the Bismark portion of the Australia plate and the Eauripik-New Guinea Rise. Long east-west trenches just south of Woleai Atoll tend to support this conclusion. Thus, depths to the south of the chain are not considered to be reliable indicators of Pacific plate deepening as it approaches the Mariana Trench.

It is also possible that the melting anomaly which gave rise to these islands has been forced to migrate east as the Australia plate slowly moves north-east. This hypothesis might help explain the more east-west orientation of the Carolines that supposedly lies on a rigid lithospheric plate with a northwest movement and on which most line islands trend northwest. While deformation of the Pacific plate similar to that found by Rea (1970) north of the Hawaiian Ridge may account for some of this east-west trend it is unlikely to account for such a marked departure from the normal line-island trend.

Despite these problems the Caroline Islands reflect the classical Darwinian atoll formation sequence when superimposed on a plate moving into deeper waters. It differs from the Hawaiian-Emperor chain sequence, however, in that atolls do not appear to die off except where subduction causes rapid subsidence into the Mariana Trench. Some circumstantial evidence also suggests that as the Carolines move towards the west they enter deeper water. While there is no reason to assume that newly-formed islands have always been of the same size, the hypothesis presented here would require gradual reduction in area at sea level if they were moving into deeper water. Wiens (1962) indicated that the average dimensions of the 15 westernmost sea-level atolls is 12.2 x 5.6 km, while the average for those 17 to the east (in relatively shallower water) is 16.8 x 9.6 km.

Tuamotu and Society Islands

There is a total of 72 atolls in the Tuamotu Islands (Fig. 12). At the southeastern end of the chain is a near-atoll, Mangareva, an old volcano in a similar stage to Truk in the Carolines. Mangareva consists of a dozen small embayed islands and stacks in a lagoon surrounded by a well-developed barrier reef some 41 km in diameter. Pitcairn, a relatively young volcanic island, lies 450 km to the southeast of Mangareva. If Pitcairn was actually produced by the same melting anomaly responsible for the Tuamotu Archipelago proper, then the Tuamotu Chain cannot yet be considered a totally senile volcanic chain.

In the area of the Tuamotu Islands there is no doubt as to the actual deepening of the ocean floor as it moves northwest towards the equator. These islands are relatively close to the East Pacific Rise where lithospheric cooling causes most rapid increases in depth (Heezen et al., 1973), and as they move into successively more suitable reef growing conditions atoll development conditions are optimal. The large number and close spacing of the Tuamotu atolls is also indicative of their origin in shallower waters close to the East Pacific Rise. On average more of the newly formed seamounts would have reached sea level here simply because of the shallower water.

Because of their ideal position south of the equator it is probable that many of the larger atolls in the Tuamotu group will survive for many millions of years during their slow passage through warm equatorial waters. It is possible, however, that some of the smaller atolls will suffer demise even in equatorial waters because as island bases move into deeper water the top of their carbonate peaks will become so narrow that they will no longer support any island form whatsoever. Data for the Tuamoto Archipelago profile given in Figure 12, as well as for the Society Islands (Fig. 13), were extracted from Russian bathymetric maps of the Pacific (1:40,000,000) giving depths in 500 m intervals (Academy of Sciences, 1964). Although it does not show up well on a profile of this scale (Fig. 12) some of the atolls at the north-western end of the Tuamotus are raised. While there is some disagreement as to the absolute uplift involved there is general consensus that the uplift of Matahira, Tikehau, Makatea, Niau and Anoa is due to arch flexuring following recent crustal loading by Tahiti and Mahetia to the west-south-west in the Society Islands (McNutt and Menard, 1978, 1979; Jarrard and Turner, 1979).

The Society Islands (Fig. 13) appear more like the Hawaiian than the Tuamotu except that they do not continue as seamounts to the northwest as do the Hawaiian. The Society group are probably much younger than the major portion of the Tuamotus because of their short length and lack of subaerial erosion. They exhibit all the characteristics of a

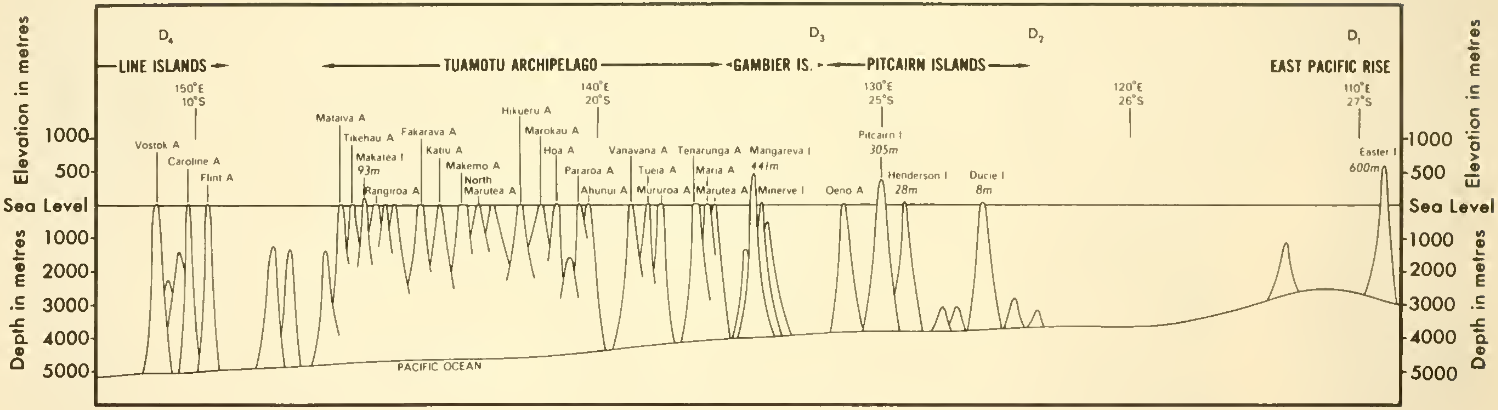

Figure 12. Profile from the East Pacific Rise through the Tuamotu Archipelago.

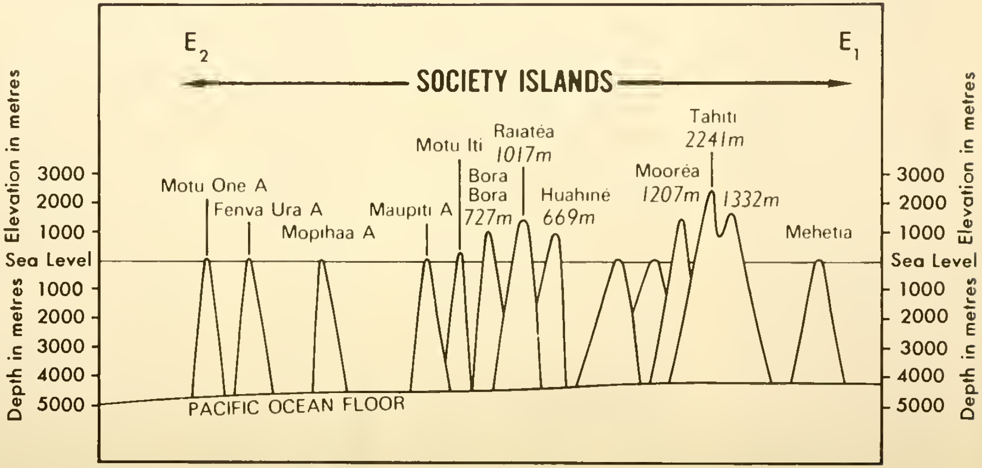

Figure 13. Profile through the Society Islands.

young island chain being subaerially eroded to sea level and being carried progressively into deepening water where their fringing reefs ultimately form atolls.

A MODEL FOR ISLAND-TYPE DEVELOPMENT

The following model is based on an acceptance of the idea that successive volcanic islands are formed over relatively stationary hot-spots on an oceanic lithospheric plate which is moving tangentially into deeper water. Important additional considerations include, the possible effects of asthenospheric bumps, moat-arch development due to lithospheric loading, uplift due to outer gravity highs close to subduction zones, an acceptance of the antecedent-karst influence on atoll form, and the realization that upward reef growth will slow, and ultimately stop, if it enters cool waters. Bearing these points in mind the eleven island types given in Figure 3 can now be illustrated in one dynamic working model (Fig. 14).

In Figure 14 new lithosphere is seen to accrete to the oceanic plate margin along the East Pacific Rise as the plates are forced apart by strong upwelling in the viscous asthenosphere below. With distance from this ridge the plate cools and ocean deepening is quite rapid. The seventeen volcanic island-atoll-submerged seamount positions north-west of the oceanic ridge shown in Figure 14 are described below. It should be stressed that probably no island chain actually possesses all of the eleven island-type possibilities at one time. It is very likely, however, that most types are found in major island chains during some stage of their history. This model is extended to show submerged seamounts which were former islands.

Position 1. The rigid oceanic plate overrides a hot-spot which injects magma through the lithosphere to form a young, active volcanic island. Isostatic subsidence creates a moat-arch flexuring of the crust. Fringing reefs have not yet had time to develop.

Position 2. Relatively inactive volcanic island undergoing some residual isostatic subsidence but sinking more rapidly due to the moat development caused by lithospheric loading at position one. By now a fringing reef has developed and elevation of volcanic peaks is being rapidly reduced by subaerial erosion. Any subsidence due to tangential movement caused by crustal cooling is minor.

Position 3. Volcanic island with complete fringing reef undergoing no vertical change. Isostatic changes due to its own mass no longer operate and any tangential movement-subsidence caused by crustal cooling or any residual moat effects from position two are counteracted by arch flexuring due to lithospheric loading at position one.

Position 4. Volcanic island undergoing uplift due to the arch flexuring created by crustal loading at position one. The fringing reef will be raised out of the water and a new reef develops seaward to wave level. Subaerial erosion continues and will affect both raised reef and basalt.

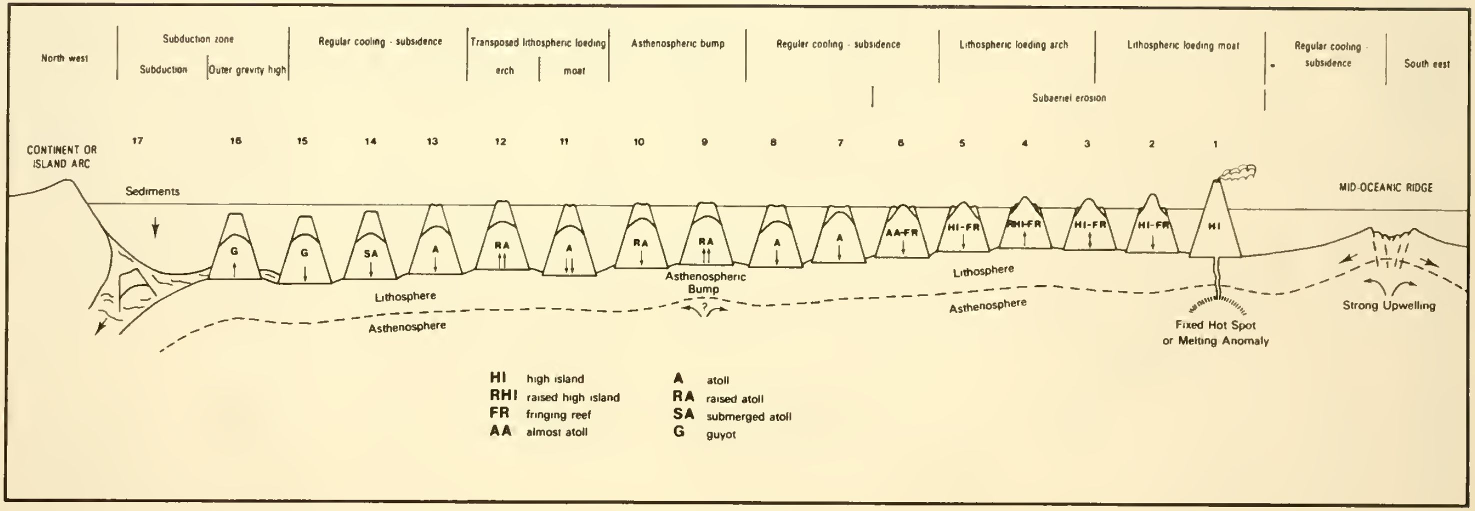

Figure 14. A model for island-type development on the Pacific lithosphere plate. For explanations of the seventeen positions indicated see text. Vertical arrows indicate relative rates of subsidence-emergence.

Position 5. Volcanic island undergoing subsidence due to crustal cooling-deepening and "lee-of-arch" deepening. Fringing reef grows upwards and begins to form a barrier reef as the volcanic island is reduced in both elevation and areal size.

Position 6. Almost-atoll stage. A few remnant volcanic pinnacles or islets remain in the centre of a large lagoon partly rimmed by low reef-rubble islands. Subsidence due to crustal cooling only. If an asthenospheric bump (see position 9) or a lithospheric loading arch (see position 12) develops here, we would get a raised almost-atoll.

Position 7. Crustal cooling-subsidence continues until no volcanic remnants can be seen. Reef keeps growing to wave level and a true atoll develops.

Position 8. Typical atoll developing a thick carbonate cap as crustal cooling-subsidence continues. If causes for vertical movement other than cooling-subsidence are not considered this form can be maintained and the carbonate cap continues to thicken until it reaches either a subduction zone or waters too cool for proper reef growth.

Position 9. Part-raised or raised atoll develops as an atoll rises up the south-east flanks of an asthenospheric bump. No magmatic outpourings occur. Degree of uplift determines which type of part-raised or raised atoll will develop.

Position 10. Raised atoll or part-raised atoll descending the north-west side of the asthenospheric bump undergoes rapid subsidence due to crustal cooling to form a regular atoll again. (No influence of the lithospheric-loading influencing position eleven is indicated here although arch flexuring might in fact occur.)

Position 11. Rapid subsidence due to the moat effect of new lithospheric loading offset from the line island chain by a short distance. Atoll form remains intact and carbonate cap thickens quickly. Submergence processes are essentially similar to those at position two. This could occur at any position along the chain where a new hot-spot breaks through or where the atoll in question moves alongside the hot-spot of another island chain e.g. the Tuamotu atolls passing Tahiti's hot-spot.

Position 12. Part-raised or raised atoll rising rapidly due to the arch effect generated by lithospheric loading near position eleven. Degree of uplift again influences raised atoll form.

Position 13. Typical atoll form returns as the island passes beyond the moat-arch effects of positions eleven and twelve. Here subsidence is attributable to tangential movement as the crust cools.

Position 14. An inundated or drowned atoll develops if the structure moves into water too cool to support algal-coral populations needed to maintain a sinking carbonate platform at sea level. Drowned forms could also result if rapid subsidence occurs as an atoll enters a subduction zone.

Position 15. Guyot stage results when the atoll is deeply submerged. Here submergence will be quite slow if only crustal cooling is operating. Guyots (or atolls) near a continental or island arc margin will receive thick sediment layers around their bases.

Position 16. Temporary uplift of guyot as it crosses the outer gravity high just before subduction. If this had occurred while the drowned-to-typical-atoll stages were present then a raised atoll form should develop.

Position 17. Guyot (or atoll if still in warm waters) will be subducted into the trench where it undergoes accretion-destruction.

CONCLUSION

It is concluded that island-types on the Pacific plate result primarily from the subsidence of volcanic islands due to the tangential motion of the lithospheric plate. An analysis of melting anomaly island groups such as the Hawaiian, Caroline, Marshall, Tuamotu and Society chains tends to confirm this conclusion, and such peculiarities as raised or drowned atolls can be explained if asthenospheric bumps, lithospheric loading, outer gravity highs and subaerial erosion during Pleistocene low sea level stands are considered. The almost complete absence of islands north of 28°N in the Pacific, other than those attributable to plate collisions, is considered to be due to the combined action of rapid subaerial erosion of basalts and this tangential component. These geomorphic and tectonic processes clearly encourage rapid subsidence of volcanic islands produced over melting anomalies, but if their reduction to sea level occurs during passage through warm tropical waters upward reef growth normally prevents their demise. Rapid subduction or movement into cooler waters eventually cuases upward reef growth to diminish and the atoll becomes submerged. Drowned atolls and guyots may result before final subduction.

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ECOLOGICAL PROBLEMS ASSOCIATED WITH DISRUPTION OF DUNE VEGETATION DYNAMICS BY CASUARINA EQUISETIFOLIA L. AT SAND ISLAND, MIDWAY ATOLL

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ECOLOGICAL PROBLEMS ASSOCIATED WITH DISRUPTION OF DUNE VEGETATION DYNAMICS BY CASUARINA EQUISETIFOLIA L. AT SAND ISLAND, MIDWAY ATOLL

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INTRODUCTION

Exotic plants and animals may be introduced in ecosystems because of desirable qualities or by accident. Many introductions have caused great harm because of unpleasant characteristics which are realized only after introduction. Ironwood *(Casuarina equisetifolia* L.) is one such species. Introduced for shade and ornamental purposes in subtropical and tropical areas, this adaptable and quick growing tree has caused ecological changes which may limit its future introduction. Ironwood can be a pioneer species that colonizes nutrient depauperate soils, especially nitrogen poor areas, because of its nitrogen fixing capability (Aldrich and Blake, 1932). Equally important is its ability to reproduce by several assexual modes in addition to sexual routes. These characteristics make this species a persistent management problem. This paper presents our observations of Ironwood ecology and this plant's relationships with native vegetation, seabirds, and man on Midway Atoll.

The Casuarinaceae is a distinctive family of trees and shrubs from dry or saline habitats of southeast Asia and the southwest Pacific. Ironwood branches have a characteristic weeping habit with peculiar jointed leaves in a whorled branching pattern. Male and female flowers are separate with the latter borne in dense spheroid heads near branch ends. Leaf size is reduced with photosynthetic tissues and stomatal openings found in stem interrib spaces, probably an adaptation to prevent dessication. Surprisingly, little ecological, life history, or manage-information is available on the Casuarinaceae.

THE STUDY AREA

Midway Atoll, located 2100km northwest of Honolulu, Hawaii, has been occupied by man since the early 1800's. Midway was a major link in the first trans-Pacific telegraphic cable system and has been a major U.S.

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naval facility since 1939. Two islands are found in the southeastern area of the enclosed atoll lagoon. Sand, the larger island (Figure 1) is 2.9km by 1.9km, with an area of 482 hectares. It has a maximum elevation of 13.1m. Eastern Island, 1.5km east of Sand is 320 hectares with an elevation of 10.4m. Before human settlement, Sand Island was a sandy expanse with a naturally depauperate vegetation. Shorelines and dunes were stabilized by the dune binding complex including *Scaevola taccada* and the prostrate herb, *Ipomoea indica*. Shifting sands were normal, especially in central areas of the islands. Since settlement, beach erosion on Sand Island has been an expensive problem which complicates maintenance of shorelines, buildings, docking facilities and other military structures. The climate is subtropical with an average annual precipitation of 101cm. Rainfall occurs an average 12 days a month; December through February are the wettest months; March is the driest. Northeastern trades prevail from March through October with stronger westerlies from November to February. Highest mean monthly temperatures approach 30° C. while May, June and November temperatures range from 21-27° C. (Woodward, 1972). Although no data are available on evapotranspiration rates, these are certainly highest during warmest and windiest periods.

In 1903, the telegraph company planted Ironwood in the northern windward areas of Sand Island. Ironwood now covers much of the unpaved surface of the island, where it often forms a thick canopy or tangle of saplings. Many other trees and shrubs have been introduced, but, by far, Ironwood dominates the island ecosystem. Some Ironwood individuals exceed a 25m height and 1m diameter at breast height (d.b.h.). Along the northeast shore, this tree forms a thick canopy and litter that may reduce understory vegetation. Ironwood selects against birds of open habitats and favors those species associated with forested areas.

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METHODS AND MATERIALS

Vegetation studies were conducted February 15-24, 1979 in Sand Island. Casual observations of Eastern Island vegetation were made during this same time. Beach vegetation dynamics were investigated along representative beach exposures on Sand Island. We measured intercepts for each plant species along 30, 2x25m transects that originated at the seaward foot of the foredune and went inland. Using this method, relative cover for each plant species was summarized over the north, west and south beach areas of the island. Ten transects were established in

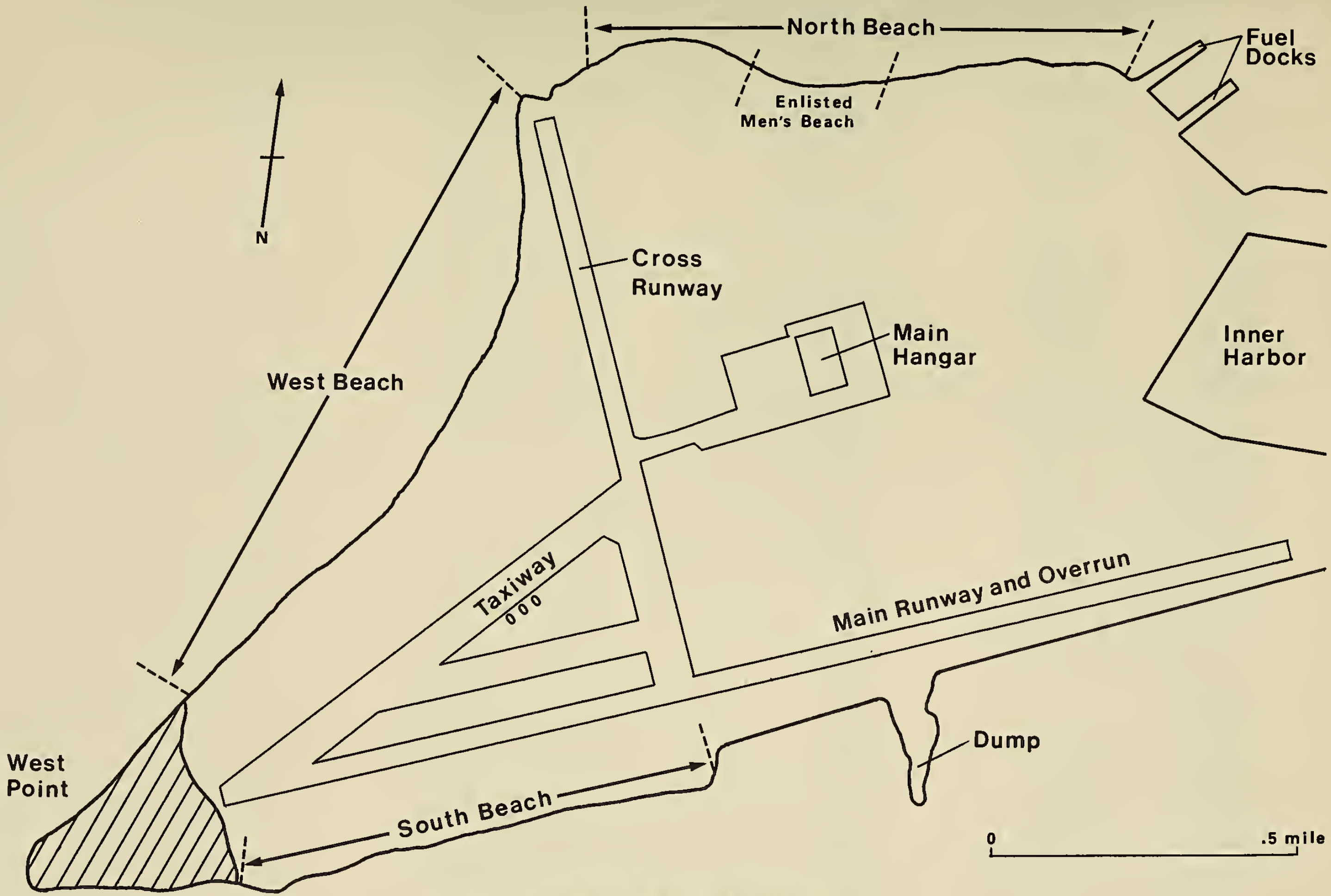


Fig. 1. Sand Island, Midway Atoll

each of these exposures. Fruit and seed productivity estimates were made for Ironwood. All newly fallen cones located in four $0.25m^2$ quadrats were used to estimate and measure fruit production. Seed production estimates were made by counting the number of pairs of woody bracts opened in the cones that had dropped seed.

A plant species list was generated for Sand Island (Appendix). Species of noteworthy status, those providing difficulty in identification, or of uncertain status, were collected and are maintained at the University of Illinois Herbarium, Urbana. Other species were listed as observed.

RESULTS

Ironwood has wind disseminated samaroid seeds approximating a measurement of 5mm x 2.5mm. Small Ironwoods (having a d.b.h. of 5cm or less and less than 2m in height) produced cones and seeds of identical size as larger older trees. Comparative germination and viability tests were not undertaken. However, Aldrich and Blake (1932) reported an average germination rate of 84% ($n \simeq 437$) for Ironwood seeds washed in mercuric chloride and water. They found seedling mortality to be "low". Over a 15 month period, their control plants attained a height of 40cm compared to test plants innoculated with extracts from root nodules on wild Ironwood which grew to 140cm heights.

Ironwood seedling densities along Sand Island runways suggest high germination and seedling success rates. Ironwood seedling density in one location exceeded 75 seedlings per square meter. Fruit production estimates averaged 30 cones/m^2 beneath the test trees (Table 1) and ranged from 21-38 cones. Seed production varied from 3,696 to 5,168 ($\bar{x}$=4,602) seeds per meter square. Total estimated seed production for the test trees ranged from 109,880 to 258,400 and averaged 184,000 seeds per tree which assumes a single seed crop per year.

TRANSECT RESULTS

Frequency distribution for vegetation as a function of distance from the foredune is plotted in Figures 2A-2F. Ironwood and *Scaevola* were the most frequently encountered species in all locations. *Scaevola* was encountered more frequently near the foredune and declined inland on the north and south beaches (Figures 2A and 2C). As *Scaevola* declined, Ironwood became more abundant; *Scaevola* was almost displaced by Ironwood in the first 25m inland from the foredune, especially in the north and west beach study areas. Data from the west beach (Figure 2B) suggest Ironwood invasion to be far more complete than along other beaches. Ironwood dominated *Scaevola* from the foredune inland to 18m where *Scaevola* became slightly more abundant, but only as a decadent understory element. *Scaevola* had a relatively uniform distribution inland from the foredune for 25m along the west beach. Most plants except *Tournefortia* occurred behind the foredunal *Scaevola*. There *Scaevola*

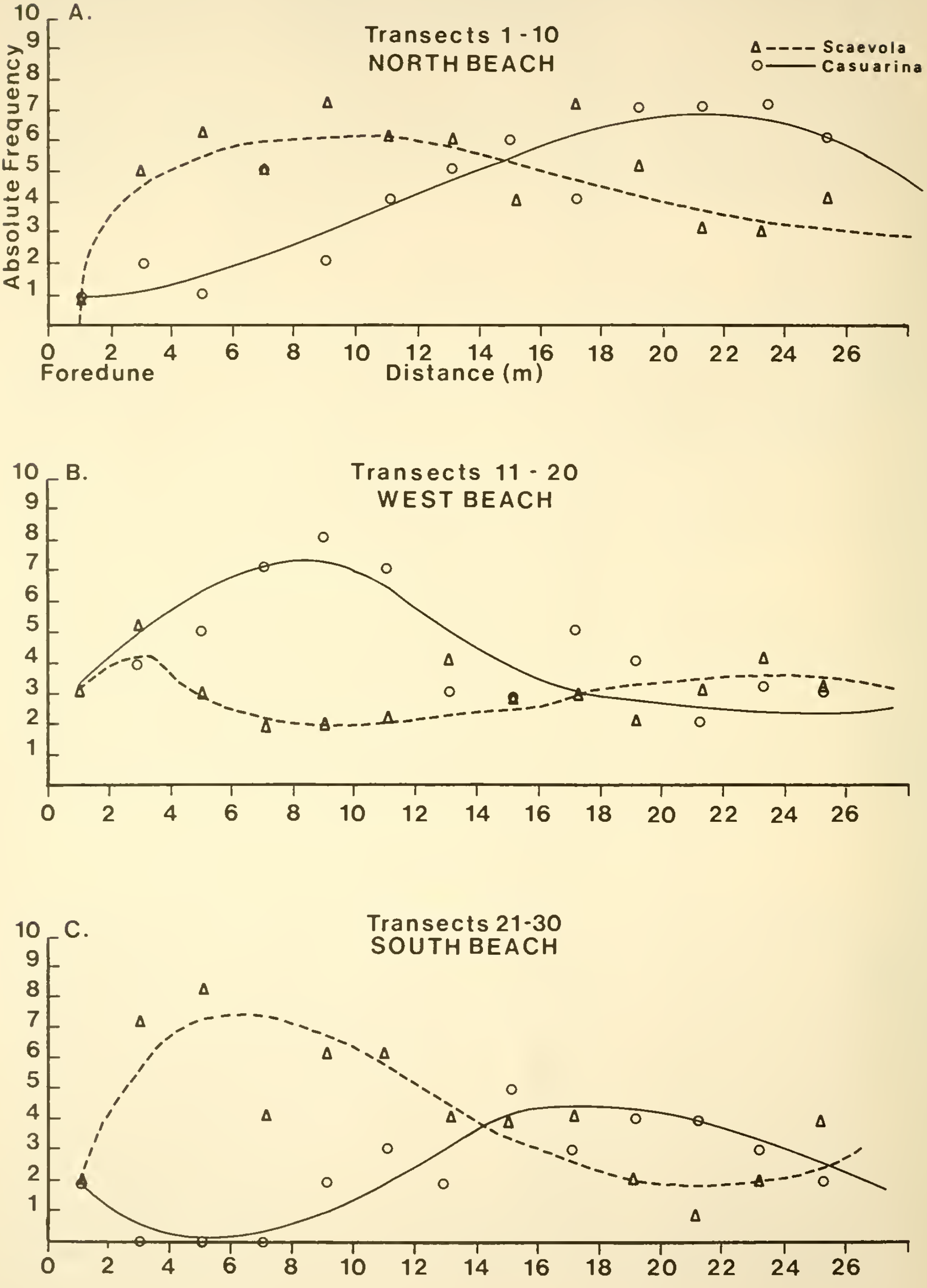
Table 1. Fruit & Seed Production for *Casuarina equisetifolia* on Sand Island, Midway Atoll.

Tree/Quadrat #	Tree Diameter (cm)	Number of Cones	$\bar{x}$ ± S.D.	Seed #	$\bar{x}$ ± S.D.	
A/1	85	9		36-60-28-29-32 34-46-30-31	36.2 ± 10.4	
A/2		11		34-46-42-43-34-38 25-32-34-35-37	36.4 ± 5.8	
A/3		9		28-25-26-28-22 31-35-28-38	29.0 ± 5.0	
			9.6 ± 1.2		34.0 ± 7.9	
B/1	42	5		36-30-48-33-56	40.6 ± 11.0	
B/2		5		49-48-48-52-36	46.6 ± 6.1	
B/3		6		36-56-54-36-56-33	45.2 ± 11.2	
			5.3 ± 0.6		44.2 ± 9.5	
$\bar{x}$ ± S.D.			7.5 ± 2.5		39.0 ± 6.5	
Fruit and Seed Productivity per $1m^2$:						Seeds/m^2
Tree A			38		136	5168.0
Tree B			21		176	3696.0
Mean			29.5		156	4602.0

Est. Ground Area:	Total Seeds:
$50m^2$	258,400
$30m^2$	109,880

$\bar{x}$ = 184,140

Figure 2.
Plant Frequency vs. Distance Inland from Foredune Origin:



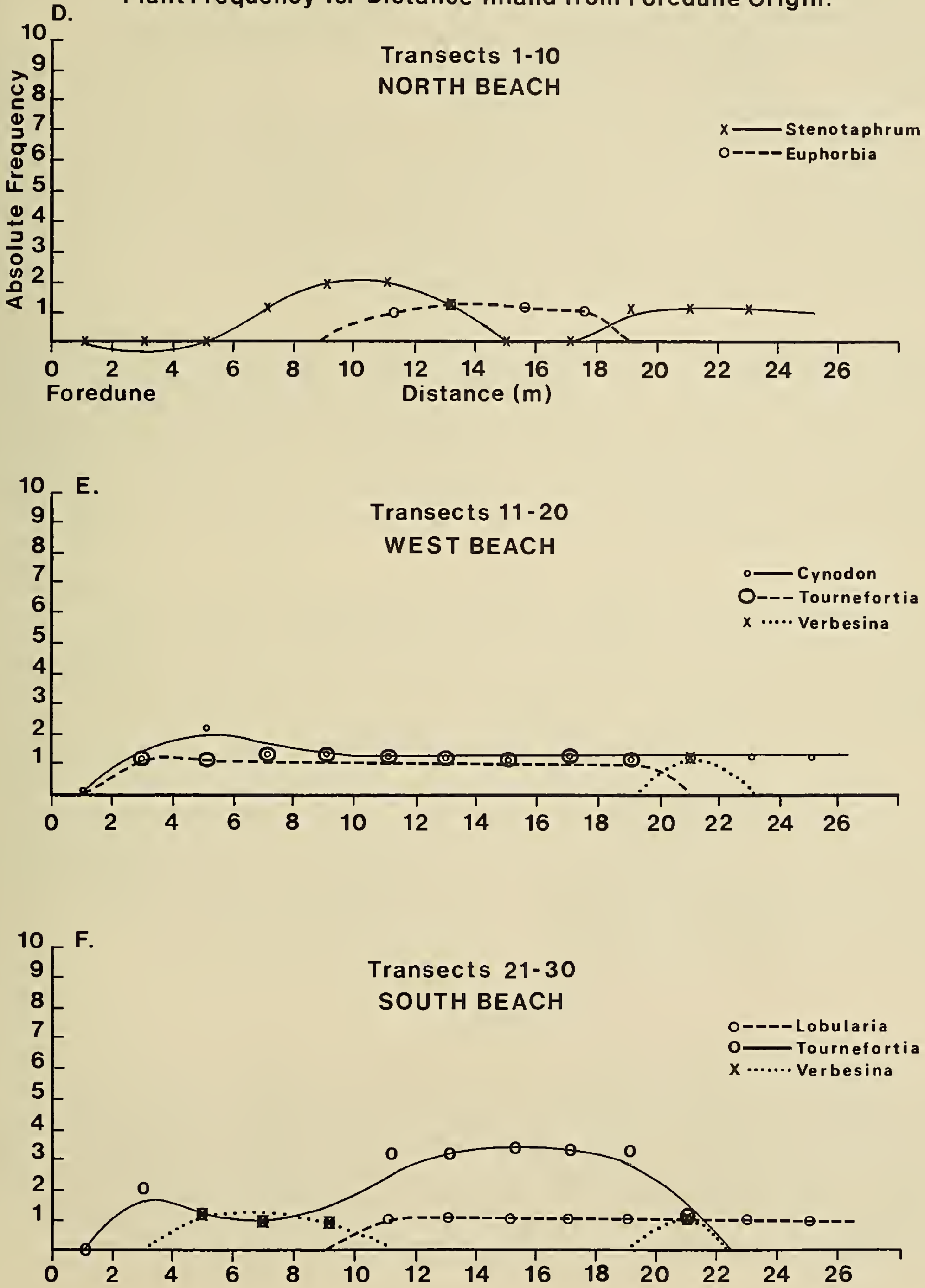
A. Transects 1 - 10 NORTH BEACH

B. Transects 11 - 20 WEST BEACH

C. Transects 21-30 SOUTH BEACH

Figure 2. (continued)

Plant Frequency vs. Distance Inland from Foredune Origin:



distribution trends hold in the north and south beaches as well, although Bermuda Grass *(Cynodon dactylon)* also occurred in the foredunal areas. Along the west and south beaches, *Tournefortia* occurred infrequently from the foredune to at least 20m inland. Along the west and north beaches *Scaevola* was reduced to an understory layer beneath a closed Ironwood canopy.

Scaevola and Ironwood each accounted for nearly 33% of all species intercepted in the transects. Thus, over 60% of all the plant intercepts along the transects resulted from these species. The cover importance of *Scaevola* and bare ground dropped to 24% each, while Ironwood and Bermuda Grass values were highest in the west beach. Along the south beach, Ironwood was less abundant than *Scaevola* or bare ground and *Tournefortia* was nearly as important as Ironwood.

Most of the 123 plant species we encountered on Sand Island were exotics. Of these, few were found in the beach areas. Most occurred only where organic soils had been imported or developed near dwellings, or in the shade of larger *Casuarina* (Neff and DuMont, 1955; Lamoureux, 1961). Ironwood seedlings were present throughout, but only in association with *Scaevola* and *Tournefortia* when present in the foredunes. Seedlings were numerous behind the foredunes along the north beach, but were not found independent of these dune binding shrubs except in areas shaded during most of the day.

Black rat *(Rattus rattus)* damage to native shrubs was not quantified. However, we found severe damage to *Scaevola* especially inland of the foredune where larger Ironwood were present as canopy elements. Rat damage was found only on *Scaevola*. The rodents chewed succulent apical and lateral buds which reduced lateral and vertical growth potentials of *Scaevola*. In some places, particularly along the west beach, damage was so severe that we believe *Scaevola* is certain to be eliminated.

Along the vegetation surveys, Laysan Albatross nest densities (Table 2) varied from 8 to 89 nests per acre. Black-footed Albatross nested in the west and south beaches but no nests were located along the north beach transects. The Albatross species seldom nested together. Black-foots associated with openings between *Scaevola* clones; Laysans nested within thinned *Scaevola* clones under Ironwood canopies, or where Ironwood seedlings and saplings grew into a thick bush-like form.

DISCUSSION

The foredune begins 50-75m from the high tide along the north beach, which was actively building. This beach had dense rounded clones of *Scaevola* 0.5-1.8m in height, especially between the cross runway and the enlisted men's beach. Immediately behind the foredune were large Ironwood that shaded the foredune at various times of the day and season. Ironwood seedlings were scattered throughout the *Scaevola*. However, few seedlings were present under the larger Ironwood. Inland of the Ironwood were numerous cultivated plants, especially in yards of abandoned houses.

Table 2. Breeding bird nest densities for nests Encountered in 2x25m Vegetation Transects

	# of Nests by Species Encountered	
North Beach Transects 1-10	Black-footed Albatross	Laysan Albatross
1		1
2		1
3		1
4		1
5		2
6		1
7		2
8		
9		
10		2
Nesting density per 500m^2	0	11
Nesting density per acre		89
Nesting density per hectare	0	220
West Beach Transects 11-20		
11		1
12		
13		
14		
15		
16		4
17		
18	2	
19	2	
20	4	
Nesting density per 500m^2	8	5
Nesting density per acre	65	40
Nesting density per hectare	160	100
South Beach Transects 21-30		
21	1	
22	1	1
23		
24		
25		
26		
27		
28	1	
29	2	
30		
Nesting density per 500m^2	5	1
Nesting density per acre	40	8
Nesting density per hectare	100	20

These included the exotics Chinese Banyan *(Ficus microcarpa)*, Poinsettia *(Euphorbia cyathophora)*, and Bermuda Grass.

The west beach was severely eroded even though rip-rap had been previously installed for prevention. In winter, northwest storms subject this beach to erosive winds and waves that develop over the 9.6km (6m) distance to the fringing reef. The tide-line to foredune distance varied from 0-25m. Fallen Ironwood showed the original shore had been undermined and the beach zone lost. Based on comparisons with the north and south beaches (Figures 2A and 2C), 12-18m of beach and foredune have been removed by erosion along this beach. *Scaevola* is overtopped by Ironwood along this beach. Surviving *Scaevola* was in very poor condition with severe dieback and rat damage evident. Beneath high density Ironwood stands, herbaceous ground cover was absent. In some areas, *Scaevola* had recently died back and few stems survived. Most stems were leafless and assumed a shriveled-desiccated appearance. Young Crown-beard *(Verbesina enceloides)* plants invaded dead and dying *Scaevola* clones. We have no information on the persistence of this species under the Ironwood. Since Crown-beard did not occur in exposed foredunes, it may require ameliorated conditions associated with the larger Ironwoods to establish in the dunes.

The west point of Sand Island just west of the paved end of the main runway was dominated by large *Scaevola* that showed little rat damage. In this area, no Ironwood seedlings were found seaward of a few established Ironwood trees 5-10 years of age located 80m inland from the tide line.

Between the south beach and dump, *Scaevola* declined and was largely restricted to an undercut sand ridge with a relief of 3-5m from the level of Waldron Blvd. to the ocean. Erosion abatement structures, including wood and steel pilings, and cement breakwalls, have been utilized here. However, most were washed out. Present between the ridge and boulevard were Ironwood, sea grape *(Coccoloba uvifera)*, *Scaevola* and *Tournefortia*. Large *Tournefortia* shrubs up to 5m tall were present east of the naval facility buildings on the ridge. Ironwood seedlings grew in the *Scaevola*, especially with older Ironwood along the crest of the ridge. To the east, the ridge flattened; *Scaevola* and *Tournefortia* became less abundant. In this area, scattered Ironwoods were present in and around several dune blowouts. Dense colonies of Black-footed Albatross nested in these blowouts and associated sparsely vegetated areas. However, little nesting occurred on the beach below blowouts. Sweet Alyssum *(Lobularia maritima)* was the most common ground cover species in and around blowouts. This plant was especially lush where Albatross defecated, often growing in circular patterns around their nests. We found less rat damage on *Scaevola* here than along either the west or north beaches.

Beach vegetation dynamics on Sand Island result from interactions between native plants, rats, the complement of introduced species, and continuing disturbance by mankind. Native dune shrubs tolerate high sand temperatures, salt spray and prevailing windy conditions. They grow well under these conditions for there is little competition, and unlike most introductions, they are able to compensate for sand burial by differential growth and adaptive growth forms fitted to wind, sand scour and dessication stresses.

Adaptations include waxy, succulent and pubescent-reflective foliage. Aerodynamic spheroid to prostrate growth forms such as thick, hemispherical shape of the *Scaevola* and trailing *Ipomoea* are important adaptive features. Though adjusted to the environmental stresses of beaches and dunes, these plants seem to have a limited adaptive flexibility. Apparently, slight environmental changes can have serious impacts on these plants, probably due to their extreme specialization to a severe environment and relatively slow growth rates. Rat damage and Ironwood intrusion, singly or synergistically, stress *Scaevola,* the key native species. *Scaevola* is undoubtedly shade intolerant, growing best in exposed beach sites, with sparse *Tournefortia* or other shrubs. The establishment and growth of Ironwood in *Scaevola* clones may eliminate this plant and the entire dune-shrub complex.

Micro-habitat changes that occur with Ironwood establishment and growth among dune binding shrubs need investigation. Factors affecting *Scaevola* may include increased shading, relative humidity, and physical damage effects from branch and fruit fall from Ironwood, allelopathic effects and associated alterations to hydrology and nutrient availabilities may also occur. *Scaevola* germination and seedling establishment may be hampered by thick and usually dry *Casuarina* litter. When these factors are coupled with differential rat feeding pressures on *Scaevola* this becomes a rather complicated problem for controlled investigations.

Scaevola clones are aerodynamically suited to tolerate high winds, sand scour and evaporative stresses. Ironwood was growing only in *Scaevola* clones when in the beach areas which suggests that establishment is dependent on an altered micro-climate offered by *Scaevola* clones. Following establishment in a clone, Ironwood seedlings apparently send long tap roots to ground water sources and rapid growth occurs. Lighter red colored infrared tones on photos (Ludwig, *et. al.*, 1979) suggest these Ironwoods are less productive and more water stressed than Ironwoods occurring more inland. However, Ironwood's colonization in *Scaevola* occurs rapidly and is quickly followed by the establishment of other Ironwood seedlings. This invasion pattern may explain the even size (and possibly age) stands of Ironwood forming bands parallel to the beach, especially along the west beach.

It is plausible that *Scaevola, Ipomoea* and other native plants could be eliminated from Midway. With high seed set, apparent fast growth and invasion rates, Ironwood is a major threat to the remaining native plants of Midway. If Ironwood invades the beach zones, severe erosion is likely to occur. Ironwood lacks the growth form and physiology to effectively stabilize the beach areas. Severe erosion problems already occur on the east shore of Eastern Island. Erosion control methods and strategies deserve careful attention at Midway. Rip-rap apparently functions as short-term control of a long-term erosion problem. This method is less effective than natural vegetation erosion control, especially against aeolian sand movements. Native dune binding shrub management schemes, including means to control Ironwood would be especially helpful for long-term erosion control; control of these exotics may also cost less than structural alternatives such as pilings and rip-rap. A well thought-out control plan can also benefit nesting seabirds.

Changes in bird populations that occur with Ironwood establishment are important considerations. Although Fairy and Noddy Terns, and Laysan Albatross benefit from increased nesting habitat offered by Ironwood, species such as the Red-footed Booby, Frigate Bird, and Black-footed Albatross which use *Scaevola* and open areas for nesting seem certain to suffer habitat losses.

Comprehensive studies on the management and control of Ironwood should be initiated. Surprisingly, little information is available on managing this species. It is clear that certain areas on Midway are being damaged for continued Navy use and altered for other uses. The cross runway is being invaded rapidly by Ironwood. The runway aprons are almost completely invaded and root-heaving of the pavement by Ironwood will probably destroy the runway in the 1980's. Similar problems are far more advanced on the Eastern Island runways. Safe and effective control methods for Ironwood are not known. However, any chosen method should be amenable to continued human and seabird use. This will require holistic ecosystem management.

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APPENDIX

LIST OF PLANTS ON MIDWAY ATOLL, HAWAII
February 15-24, 1979

		OBSERVED	VOUCHERED
ACANTHACEAE			
Asystasia gangetica (L.) T. Anders.	Asystasia		X
Odontonema strictum (Nees) Kuntze			X
AGAVACEAE			
Agave sp.	Century Plant	X	
Cordyline sp.	Colored ti	X	
Dracaena sp.	Dracaena	X	
Sansevieria sp.	Bowstring hemp		X
AMARYLLIDACEAE			
Crinum asiaticum L.	Spider lily		X
ANACARDIACEAE			
Mangifera indica L.	Mango	X	
APOCYNACEAE			
Carissa macrocarpa (Eckl.) DC.	Natal plum	X	
Catharanthus roseus (L.) G. Don	Madagascar periwinkle	X	
Nerium oleander L.	Oleander		X
Plumeria sp.	Plumeria;frangipani	X	
Thevetia peruviana (Pers.) K. Schum	Yellow oleander	X	
ARACEAE			
Alocasia cucullata (Lour.) G. Don	Chinese taro	X	
Anthurium andraeanum Lind.	Anthurium	X	
Colocasia esculenta (L.) Schott	Taro	X	
Dieffenbachia sp.	Dumb cane	X	
Monstera deliciosa Liebm.	Monstera		
Rhaphidophora aurea (Sinden Andre)	Birdsey Pothos; Taro vine		X
Syngonium podophyllum Schott	(may be *S. angustatum)*		X
Xanthosoma sp.	Elephant ear; Ape	X	

		OBSERVED	VOUCHERED
ARALIACEAE			
Schefflera actinophylla (Endl.) Harms	Octopus tree	X	
ARAUCARIACHEAE			
Araucaria heterophylla (Salisb.) Franco	Norfolk Island pine	X	
BORAGINACEAE			
Tournefortia argentea L.f. *(Messerschmidia argentea* (L.f.) Johnst.)	Tree heloptrope	X	
CANNACEAE			
Canna indica L.	Canna	X	
CARICACEAE			
Carica papaya L.	Papaya	X	
CARYOPHYLLACEAE			
Cerastium vulgatum L.	Larger mouseear chickweek		X
Spergularia marina (L.) Griseb	Saltmarsh sand spurry		X
Stellaria media (L.) Cyrillo	Common chickweed		X
CASUARINACEAE			
Caruarina equisetifolia L.	Ironwood		X
CHENOPODIACEAE			
Chenopodium murale L.	Nettle-leaved goosefoot		X
COMBRETACEAE			
Terminalia catappa L.	Tropical almond	X	
COMMELINACEAE			
Commelina sp.	Day flower	X	
Rhoeo spathacea (Sw.) Stearn	Rhoeo	X	
Zebrina pendula Schnizl.	Wandering Jew	X	
COMPOSITAE			
Bidens alba L.			X
B. pilosa L.	Spanish needle	X	
Conyza bonariensis (L.) Cronq.	Horseweed		X
Gnaphalium sandwicensium Gaud.	'Ena 'ena		X
Pluchea nymphytifolia (Mill.) Gillis	Fleabane		X
Sonchus oleraceus L.	Sow thistle		X
Verbesina enceloides (Can.) Gray	Golden crown beard		X

		OBSERVED	VOUCHERED
CONVOLVULACEAE			
Ipomoea batatas (L.) Poir.	Sweet Potato	X	
I. indica (Burm.) Merr.	Morning glory		X
I. pes-caprae subsp. *brasiliensis* (L.) van Ooststr.	Beach morning glory		X
Ipomoea sp.	Morning glory	X	
CRASSULACEAE			
Kalanchoe pinnata (Lam.) Pers.	Air plant	X	
CRUCIFERAE			
Brassica nigra (L.) Koch	Black mustard	X	
Capsella bursa-pastoris (L.) Medik	Shephard's purse		X
Coronopus didymus (L.) J.E. Smith	Swinecress		X
Lepidium densiflorum Schrad.			X
Lobularia maritima (L.) Desv.	Sweet alyssum		X
CUPRESSACEAE			
Cupressus sp.	Cypress	X	
CYCADACEAE			
Cycas circinalis L.	Cycad		X
CYPERACEAE			
Cyperus alternifolius L.	Umbrella plant		X
C. papyrus L.	Papyrus	X	
C. rotundus L.	Nut grass	X	
Fimbristylis pycnocephala Hbd.			X
EUPHORBIACEAE			
Euphorbia cyathophora		X	
GERANIACEAE			
Pelargonium sp.	Geranium		X
GOODENIACEAE			
Scaevola taccada (Gaertn.) Roxb. *(S. frutescens* auct. nom. (Mille.) Krause)	Naupaka		X
GRAMINEAE			
Bromus catharticus Vahl			X
Cenchrus echinatus L. *(C. hillebrandianus* Hitchc.)	Sand bur		X
Chloris inflata Link	Swollen finger grass		X
Cynodon dactylon (L.) Pers.	Bermuda grass		X

		OBSERVED	VOUCHERED
GRAMINEAE			
Digitaria sanguinalis (L.) Scop. var. *ciliaris* (Retz.) Parl.	Crab grass	X	
Eleusine indica (L.) Gaertn.	Goose grass		X
Eragrostis tenella (L.) Beauv.	Love grass		X
E. variabilis (Gaud.)	Emoloa		X
Lepturus repens (Forster) R. Br.	var. *subulatus* Fosb.	X	
Poa annua L.	Annual blue grass		X
Tricholaena rosea Nees	Natal redtop		X
Setaria verticillata (L.) Beauv.	Bristly foxtail grass		X
Sporobolus africanus Poir.) Robyns et Tournay	African Dropseed		X
Stenotaphrum secundatum (Walt.) O. Ktze.	Buffalo grass		X
LABIATAE			
Coleus scutellarioides (L.) Benth.	Coleus	X	
LILIACEAE			
Aloe sp.	Aloe	X	
Asparagus setaceus (Kunth) Jessop	Asparagus fern	X	
MORACEAE			
Ficus benghalensis L.	Banyan	X	
F. elastica Hornem.	Rubber plant	X	
F. microcarpa L.f.	Chinese banyan		X
MALVACEAE			
Abutilon grandifolium (Willd.) Sweet	Hairy abutilon		X
Hibiscus sp.	Hibiscus		X
Malva parviflora L.	Little mallow		X
Malvastrum coromandelianum (L.) Garcke	False Mallow		X
Malvaviscus arboreus Cav.	Turks cap		X
NYCTAGINACEAE			
Boerhavia repens L.	Alena		X
Bougainvillea sp.	Bougainvillea		X
ORCHIDACEAE			
Unidentified orchids			X
Vanda sp.			X

		OBSERVED	VOUCHERED
OXALIDACEAE			
Oxalis corniculata L.	Lady's sorrel		X
O. martinana Zucc.	Pink wood sorrel		X
PALMAE			
Cocos nucifera L.	Coconut	X	
Phoenix sp.	Date Palm	X	
Pritchardia sp.	Fan Palm	X	
Roystonea sp.	Cabbage and royal	X	
PANDANACEAE			
Pandanus sp.	Screwpine; Hala	X	
PLANTAGINACEAE			
Plantago lanceolata L.	Narrow leaved plantain		X
P. major L.	Broad leaved plantain		X
POLYGONACEAE			
Coccoloba uvifera L.	Sea grape		X
POLYPODIACEAE			
Microsorium scolopendria (Burm.) Copel.	Laua'e		X
Nephrolepis hirsutula (Forst.) Presl.	Sword fern		X
PORTULACACEAE			
Portulaca oleracea L.	Purslane		X
PRIMULACEAE			
Anagallis arvensis L.	Scarlet pimpernel		X
ROSACEAE			
Rosa sp.	Rose	X	
RUBIACEAE			
Gardenia sp.	Gardenia	X	
RUTACEAE			
Citrus sp.	Citrus	X	
Murraya paniculata (L.) Jack	Mock orange	X	
SOLANACEAE			
Capsicum annuum L.	Red papper		X
Solanum nigrum L.	Nightshade		X
UMBELLIFERAE			
Apium tenuifolium (Moench) Hegi	Fir-leaved celery		X

		OBSERVED	VOUCHERED
URTICACEAE			
Pilea microphylla (L.) Liebm.	Artillery plant; Rockweed	X	
VERBENACEAE			
Lantana camara L.	Lantana		X
Vitex trifolia L.	Polinalina		X
ZINGIBERACEAE			
Alpinia zerumbet (Pers.) Burtt & R.M. Sm. *(A. speciosa* K. Schum.)	Shell ginger	X	
Hedychium gardnerianum Lindl.	Kahili ginger	X	
ZYGOPHYLLACEAE			
Tribulus cistoides L.	Puncture vine	X	
OUT OF ALPHABETICAL ORDER:			
LEGUMINOSAE			
Albizzia lebbeck (L.) Benth.	Woman's tongue	X	
Crotalaria incana L.	Fuzzy rattle-pod		X
Delonix regia (Bojer) Raf.	Royal poinciana	X	
Desmanthus virgatus (L.) Willd.	Slender mimosa		X
Erythrina variegata var. *orientalis* (L.) Merr	Tiger's claw		X
Leucaena leucocephala (Lam.) deWit	Koa haole		X
Medicago lupulina L.	Hop clover		X
Samanea saman (Jacq.) Merr.	Monkeypod	X	
	SUBTOTALS:	54	69
	TOTAL:	123	

ATOLL RESEARCH BULLETIN

No. 262

THE FLORA AND VEGETATION OF SWAINS ISLAND

BY

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THE FLORA AND VEGETATION OF SWAINS ISLAND

by W.A. Whistler[1]

INTRODUCTION

Swains Island is an isolated atoll lying about 270 km north of Samoa. Although geographically and floristically a part of the Tokelau Islands 160 km to the northwest, it belongs politically to the Territory of American Samoa. The island lies at a latitude of 11°03' S and a longitude of 171°03' W. It has an area of 210 ha and a maximum elevation of less than 6 m (Fig. 1).

The island is a ring-shaped atoll with a large, completely enclosed, brackish water lagoon in the center (Fig. 2). In prehistoric times the lagoon was connected to the sea, but it is now completely landlocked. It is shallow, but in spots reaches a maximum depth of 15 m. The water of the lagoon is not potable, but is used for bathing and washing clothes. Drinking water is obtained from a well, and from water catchment. The rainfall on Swains Island is probably about 250 cm/year, since the Tokelau Islands to the northwest have an average annual rainfall of over 250 cm (Parham, 1971).

Although the lagoon is nearly devoid of fish life, it is rich in algae; one particular blue-green alga species (or mixture of species) forms conspicuous, irregular chunks which make the shallow lagoon water appear like a thick vegetable soup (Fig. 3). Buried deposits of a white bivalve shell are found in the lagoon, but this mollusc species apparently disappeared after the lagoon became landlocked. The pretty shells are used by the Swains islanders to make unique leis.

Landing on Swains Island is made on the west side at Taulaga, the only village on the island. Besides a small number of thatched, Samoan-style huts ("fale"), Taulaga has a small white church and a large, barn-like copra shed. Leading from the copra shed to the nearby beach are old railway tracks which were once used to transport copra from the shed to the beach for transfer to cargo vessels. Nearby is a large cleared area that may one day be made into an airport runway to link Swains Island by air to Tutuila, the main island of American Samoa. At the present time supplies are brought in by boat from Tutuila several times a year.

East of Taulaga, one third of the way around Swains along the jeep road that circles the palm-covered island, is Etena (=Eden), the former residence of the Jennings family, the owners of the island. The imposing colonial-style house now stands abandoned in a state of disre-

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pair. Nearby are several well-kept graves, a final resting place for some of the original settlers of the island.

The Swains islanders are a mixture of Tokelauans and Samoans, mostly the former, with a bit of American and Portuguese heritage as well. At the time of the author's visit, the population was less than fifty. The language usually spoken is Tokelauan, but most of the islanders are also conversant in Samoan and some in English as well. The original Tokelauan name of the island is "Olosega", but this name is no longer used. The name has led to some confusion, since there is another island with the same name in the nearby Manu'a Islands of American Samoa.

The original inhabitants of Swains Island were Tokelauan, but when it was "discovered" by the Western world, it was uninhabited. Its discovery is erroneously attributed to Quiros in 1606, but the island discovered by this Spanish explorer is apparently Manihiki in the Northern Cooks. The credit for the discovery goes to an American whaling captain named W.C. Swain in or around 1839. It was visited by the U.S.S. Peacock of the United States Exploring Expedition in 1840. Later, title to the island was obtained by Eli Jennings, an American living on Upolu (now a part of Western Samoa). With his Samoan wife, Malia, and his family, he settled on the island in 1856, and the ownership of the island has remained in the Jennings family ever since. The current head of the family is Wallace Jennings who resides on the island.

BOTANICAL HISTORY

The first botanical information about Swains Island was gathered by the U.S. Exploring Expedition during the aforementioned visit of the U.S.S. Peacock in 1840. Although plant specimens were collected, they, along with specimens from the Tokelau Islands, were subsequently lost. Pickering (1876) stated, "Lists of plants growing up on them were communicated to me by Mr. Rich; after the loss of his specimens by shipwreck." Pickering's list of Swains Island plants included twelve species--*Hedyotis romanzoffiensis* ("*Petesia*"), *Guettarda speciosa*, *Cordia subcordata*, *Messerschmidia argentea*, *Boerhavia tetrandra*, *Procris pedunculata*, *Pandanus tectorius*, *Cocos nucifera*, *Christella dentata* ("*Aspidium*"), *Asplenium nidus*, *Microsorium scolopendria* ("*Polypodium*"), and *Psilotum* sp.

The next collector to visit Swains was apparently J. Lister in 1891. No listing of his collections were published, but they are deposited at Kew and Cambridge University. One of his specimens--*Hedyotis romanzoffiensis*--was cited by Fosberg in his revision of the genus (1943). Other unpublished collections were made between 1929 and 1939 by P. Diefenderfer, E. Bryan, and L. Schultz. Diefenderfer, an anthropologist working for the Department of Education of American Samoa, collected about 14 species during trips to Swains in 1929 and 1930, but no field notes are known to exist. Bryan collected on Swains during visits in 1935 and 1938. Approximately 82 specimens were collected (nos. 912-55, 1345-74, and some unnumbered ones), the data for which is found in field books stored at the Bishop Museum in Honolulu. The specimens of Diefenderfer and Bryan are also deposited at the Bishop Museum. Schultz, an ichthyologist, visited Swains in 1939 and made a small collection of about 10 specimens, and these are deposited at the Smithsonian Institution.

In 1966-67 R.B. Clapp, an ornithologist, visited Swains a number of times and recorded the bird life of the island (Clapp, 1968). Although he did not directly discuss the vegetation or flora of the island, he did mention the presence of Cocos, Pisonia, Pandanus, Messerschmidia, and Scaevola. He apparently did not collect any plant specimens.

In 1971 B. Parham published a study of the vegetation of the nearby Tokelau Islands, based on his own work and the work of others. It includes a checklist of the flora of Nukuono from specimens collected by K. Wodzicki in 1966-68. The flora of the Tokelau Islands is very similar to that of Swains, but based on Parham's checklist of the flora of the largest of the three atolls, it may be smaller than that of Swains. Parham's paper included the Tokelauan names for the plants; these names were very useful when questioning the Swains islanders about their island's plants.

The first and only comprehensive collection of the flora of Swains was made by the author from the 18th to the 21st of May 1976. The four day visit was part of an inventory of the flora and fauna being carried out for the USFWS (1978), and this report, which is as yet unpublished, contains much biological information about Swains. Up until that time, only 56 species of vascular plants had been collected or recorded from Swains, but now this number is 95. Only three of the previously reported species were not found during the author's visit--Solanum nigrum, Hedyotis romanzoffiensis, and Annona muricata. Approximately 88 specimens were collected during this visit (nos. W 3352A to W 3439), and these will be deposited at the Smithsonian Institution and the Bishop Museum.

THE VEGETATION

The vegetation of Swains Island is greatly disturbed and nearly the whole island is covered with coconut palms. It is doubtful if any of the original forest vegetation remains. Due to the short duration of the author's visit, no quantitative work could be done. However, based on the observations made, the vegetation of Swains can be divided as follows:

- Native vegetation
    - Sand strand
    - Littoral shrubland

    - Littoral forest
    - Coastal marsh

- Disturbed vegetation

    - Coconut plantation
    - Village land

Each of these types of vegetation is discussed below.

Sand strand

The sand strand or "Pes-caprae" formation as it is often called, consists of a small band of herbaceous plants on the seaward margin of the littoral forest (Fig. 4). This vegetation type is poorly developed on Swains, particularly because the most characteristic plant--*Ipomoea pes-caprae*--is absent. Another characteristic plant of the sand strand--*Vigna marina*--is apparently only a recent introduction and was found in only one small patch at Taulaga.

The dominant species of the sand strand of Swains Island are *Lepturus repens*, *Fimbristylis cymosa*, *Boerhavia tetrandra*, and *Triumfetta procumbens*. The first two are common in scattered clumps on the exposed sandy shore above the hightide mark, while the latter two are in less exposed areas.

Littoral shrubland

The littoral shrubland is the shrub-dominated vegetation on the seaward margin of the littoral forest. In Samoa, this vegetation is dominated by *Scaevola taccada*, *Wedelia biflora*, *Ficus scabra*, and *Clerodendrum inerme* (Whistler, 1980), but only the first of these species is found on Swains.

In addition to the shrubland on the edge of the littoral forest, northeast of Etena there is a large inland area of this vegetation dominated by *Scaevola taccada* (Fig. 5). The reason for this patch of shrubland in the midst of the coconut groves was not determined, but it probably resulted from some disturbance by the islanders.

Other less common plants found in the littoral shrubland are *Pemphis acidula*, *Messerschmidia argentea*, *Ipomoea macrantha*, *Cassytha filiformis*, and *Achyranthes velutina*.

Littoral forest

Originally, most of the island was covered by littoral forest. That which remains today is found along the shores and in scattered patches in the coconut plantation (Figs. 6 and 7). Probably all of the existing littoral forest is secondary and has developed when parts of the coconut plantation were neglected and coconut palms were gradually replaced by littoral forest species.

The dominant littoral tree on Swains is *Hernandia sonora*, and there are some small patches of nearly pure *Hernandia* forest away from the immediate coast. The forest floor in these patches is very open, with only scattered *Bryophyllum pinnatum*, *Asplenium nidus*, and *Microsorium scolopendria* on the ground (Fig. 8). Other common littoral forest trees are *Pisonia grandis*, *Neisosperma oppositifolia*, *Pandanus tectorius*, *Guettarda speciosa*, and *Messerschmidia argentea*. The latter species is limited to sunny areas, mostly on the forest margins.

Less common are *Hibiscus tiliaceus*, *Cordia subcordata*, *Calophyllum inophyllum*, and *Barringtonia asiatica*. The latter species may have been more common in the past, but only two individuals were seen during the visit. Wallace Jennings reported that he had others cut down because he doesn't like this tree, perhaps because of its potential use as a fish poison. Epiphytes in the littoral forest are few, consisting only of *Procris pedunculata*, *Vittaria rigida*, *Psilotum nudum*, and *Psilotum complanatum*.

Coastal marsh

The herbaceous vegetation growing along the margins of the lagoon can be classed as a coastal marsh. Where disturbed, the vegetation is dominated by *Ludwigia octivalvis*, *Cyperus javanicus*, and *Paspalum distichum*.

On the north shore of the lagoon there is a small peninsula extending out into the water (Fig. 2). It is covered by undisturbed coastal marsh vegetation dominated by *Eleocharis geniculata* and *Paspalum distichum*, with some scattered *Pemphis acidula* in higher, drier areas. This is the first record of this species of *Eleocharis* in Samoa or Tokelau. A specimen of this rush collected by E. Graeffe in 1870 was listed as being collected in "Samoa", but this is probably a mistaken locality, and it may have been collected in Fiji instead.

Similar coastal marsh vegetation in Samoa is dominated by *Eleocharis dulcis*, *Cyclosorus interruptus*, and *Acrostichum aureum*, but none of these species is found on Swains.

Coconut plantation

Most of Swains Island is covered with coconut plantation (Fig. 9). The plantation is in a state of neglect, since copra is no longer exported. Patches of littoral forest species are scattered throughout the coconut palms, and it is apparent that if left undisturbed, most of the palms would be eliminated by other more aggressive littoral forest species.

Underneath the coconut palms is a thick, almost impenetrable growth of young coconut palms and the "bird's-nest fern", *Asplenium nidus*, which exclude nearly all other species from becoming established.

Village land

The village land consists of areas cleared for houses, roads, and for crops other than coconut. These disturbed areas are dominated by introduced weedy species. The large grassy village green ("malae") at Taulaga (Fig. 10) and grassy areas at Etena are dominated by grasses, sedges, and other herbaceous weeds. The dominant weedy species are *Euphorbia hirta*, *Phyllanthus amarus*, *Sida rhombifolia*, *Portulaca oleracea*, *Boerhavia tetrandra*, *Spermacoce assurgens*, *Physalis angulata*, *Stachytarpheta urticaefolia*, *Cyperus kyllingia*, *Cyperus rotundus*, *Fimbristylis dichotoma*, *Cenchrus echinatus*, *Chrysopogon aciculatus*, *Axonopus compressus*, *Cynodon dactylon*, *Eleusine indica*, *Eragrostis tenella*, *Lepturus repens*, and *Paspalum conjugatum*. In wet areas, *Ludwigia octovalvis* is the dominant weedy species.

The crops grown for food on Swains Island are *Musa paradisiaca*, *Ipomoea batatas*, *Carica papaya*, *Pandanus tectorius* (a cultivar), *Mangifera indica*, *Citrus aurantium*, *Citrus medica*, and *Artocarpus altilis*. These grow around houses and on the edges of the village. West of Taulaga, there is a swampy area where the large aroid *Cyrtosperma chamissonis* is grown. *Alocasia macrorrhiza* and *Colocasia esculenta* are also grown, but to a lesser extent.

In addition to the crop plants, some ornamentals are grown, but except for some remnants at Etena, these are mostly in the vicinity of houses at Taulaga.

THE FLORA

The following is an annotated checklist of the vascular flora of Swains Island. The species are listed in alphabetical order by family under Pteridophyta, Dicotyledonae, and Monocotyledonae. Following the species name is the collection number of the author which is always preceded by a "W", while those of the other collectors are preceded by their names. The native names for the species, which are usually the same as in Samoa or the Tokelau Islands, are also given.

Pteridophyta

ASPLENIACEAE

Asplenium nidus L.

> "Laumea", which is the Tokelauan name. In Samoa it is called "laugapāpā." The bird's-nest fern is very common as an epiphyte or growing on the ground in the forest. The young stems are cooked and eaten. W 3397, Bryan 919.

DAVALLIACEAE

Nephrolepis hirsutula (Forst.f.)Presl

A very common fern of the forest and particularly in sunny disturbed places. Parham lists the Tokelauan name as "laumailekimoa." W 3399, Bryan 940, 941, 942, and 1352.

POLYPODIACEAE

Christella dentata (Forssk.)Brownsey & Jermy in Brit.

A large ground fern common in disturbed places. This was previously referred to as Dryopteris nymphalis (Forst.f.)Copeland. W 3398, Bryan 943.

Microsorium scolopendria (Burm.f.)Copeland

"Laumaile", which is the Tokelauan name. In Samoa it is called "Lau autā." A common epiphyte or ground fern of the forest. It is also known as Polypodium scolopendria Burm. f. and Phymatodes scolopendria(Burm.f.)Ching. W 3401, Bryan 913, 914, 915, 939, 1353, & 1359.

PSILOTACEAE

Psilotum complanatum Sw.

An epiphyte growing on the trunks of coconut palms. W 3433, Bryan 1367.

Psilotum nudum (L.) Beauv.

"Moegaotekimoa" (bed of the rat), according to Mr. Jennings. Parham lists the Tokelauan name as "faleotekimoa" (house of the rat). An epiphyte occasional on forest trees and coconut palms. W 3359, Bryan 1366.

VITTARIACEAE

Vittaria rigida Kaulf. var. samoensis (Luerrs.)C.Chr.

A small unbranched epiphytic fern, occasional on forest trees. W 3425 and W 3396.

Angiospermae

DICOTYLEDONAE

ACANTHACEAE

Hemigraphis alternata (Burm.f.) T. Anders.

"Suipi." Not seen, but reported by a reliable islander to be growing there. A purple-leafed prostrate herb occasionally cultivated in Samoa.

AMARANTHACEAE

Achyranthes velutina H. & A.

No name was given, but this is called "tamatama" in Tokelau (a closely related species, Achyranthes aspera, is called "lau tamatama" in Samoa). It was found in only one locality, on the coast north of Taulaga. It was not previously recorded from American Samoa. W 3420.

ANACARDIACEAE

Mangifera indica L.

"Mago." The mango was not seen, but it was reported by a reliable islander to be growing in at least one locality.

ANNONACEAE

Annona muricata L.

"Sasalapa", according to Bryan. This is the same as the Samoan name for the soursop. It is cultivated, or at least it was when Bryan visited the island. Bryan 916.

APOCYNACEAE

Catharanthus roseus (L.)G. Don

A garden escape found around houses and grave sites. W 3374.

Neisosperma oppositifolia (Lam.)Fosb. & Sachet

"Pulu fao." A small to medium-sized tree occasional in the forest. In Samoa the name is "fao", and "pulu" refers to the milky sap of the tree. This species has not previously been recorded from American Samoa. W 3424.

Plumeria rubra L.

"Pua." The frangipani tree is commonly cultivated around houses. Both the red variety (var. rubra) and the white one (var. acuminata) were seen, but only the later was collected. W 3388

ARALIACEAE

Polyscias guilfoylei (Bull.)L.H.Bailey

"Tagitagi." A cultivated shrub found at Etena. It is a common hedge plant in Samoa. W 3391.

BORAGINACEAE

Cordia subcordata Lam.

"Tauanave." A large tree scattered over the island. In Tokelau it is called "kanava." On Swains Island the wood is called "taiuli" and is excellent for posts and carvings, since it is strong and durable. W 3406, Bryan 920.

Messerschmidia argentea (L.f.)Johnst.

"Tausuni." The common "tree heliotrope" is known as "tauhunu" in the Tokelau Islands, and is common along the shore and in sunny disturbed areas. It is also commonly known as Tournefortia argentea L.f., but is probably most correctly called Argusia argentea (L.f.) Heine. W 3392.

CARICACEAE

Carica papaya L.

"Esi." The papaya is commonly cultivated and sometimes grows wild. Two varieties occur on the island--one called simply "esi" and the other "esi loa." The male flowered tree is called "esi tane." Seen, but not collected.

COMPOSITAE

Adenostemma lanceolatum Miq.

A weed with white flowers, found in wet, shady places. The same or a similar species is found as a trailside weed in mountain forests of Samoa. W 3357, Bryan 931.

Synedrella nodiflora (L.)Gaertn.

A yellow-flowered weed common in disturbed places. W 3437.

Vernonia cinerea (L.)Less.

A lavender-flowered weed occasional in disturbed places. W 3380, Schultz 11, Bryan 931A and 1371.

CONVOLVULACEAE

Ipomoea batatas (L.) Lam.

"'Umala." The sweet potato is occasionally cultivated on the island. W 3418.

Ipomoea macrantha R. & S.

"Fue itulā." A white flowered morning-glory vine common in the littoral forest. The word "itulā" means hour, perhaps referring to the short time while the flower is open in the morning before wilting. The name has not previously been recorded from the Tokelau Islands or Samoa, so it is probably just a local name. W 3393, Bryan 1374.

CRUCIFERAE

Nasturtium sarmentosum (Forst.f.)Schultz

A small weed of shady disturbed places such as in dirt roads and trails. W 3378.

CRASSULACEAE

Bryophyllum pinnatum (Lam.)Kurz

"Pagi." A common weed of disturbed places and naturalized in the forest. Children call this plant "mimiti"(to suck), which refers to their method of obtaining a sweet juice from the flower. It is also known as Kalanchoe pinnata (Lam.)Pers. W 3410, Bryan 928 and 1360 , Diefenderfer 9, 15, and s.n.

EUPHORBIACEAE

Codiaeum variegatum (L.)Bl.

The croton is a common hedge plant in Samoa. At least two varieties are found on Swains. W 3384 and 3430, Bryan 937 and 1357.

Euphorbia hirta L.

This spurge is common in disturbed gravel and grassy areas around houses. W 3366, Bryan 1373.

Euphorbia prostrata Ait.

A small, prostrate weed found in the village in gravel and on rock walls. W 3413.

Phyllanthus amarus Sch. & Thon.

A common weed of disturbed places. Elsewhere incorrectly referred to as Phyllanthus niruri L. W 3402, Bryan 1372, Schultz 12.

GOODENIACEAE

Scaevola taccada (Gaertn.)Roxb.

"To'ito'i." This shrub is common on the coast and in sunny disturbed places inland. The name in Tokelau is "gahu." "To'ito'i" is used on Swains, but this term apparently more correctly refers to the pith of the stems. W 3389, Schultz 13, Diefenderfer s.n.

GUTTIFERAE

Calophyllum inophyllum L.

"Fetau." This widespread Pacific tree is found scattered in the forest, often reaching a very large size. In Tokelau it is called "hetau." W 3407, Bryan 917 and 1354, and Schultz 5.

HERNANDIACEAE

Hernandia sonora L.

"Pu'a." This is the second most common tree on Swains Island (second to *Cocos*). It is called "puka" or "pukavaka" in the Tokelau Islands. W 3395, Bryan 926 and 1368, Diefenderfer s.n.

LABIATAE

Coleus scutellarioides (L.)Benth.

"Fāteine." *Coleus* is a cultivated shrub with showy leaves. The Samoan name is "patiale", and since *Coleus* is not reported from Tokelau, "fāteine" may be a local name. W 3385, Bryan 936.

Ocimum sanctum L.

"Militini." The basil is a garden escape that is occasionally found around dwellings, particularly at Etena. It is used to scent coconut oil. W 3372, Bryan 1356.

LAURACEAE

Cassytha filiformis L.

"Fetai." This is a leafless parasitic vine common growing on shrubs and small trees in disturbed areas and in coastal vegetation. W 3367, Bryan 921 and 1345, Schultz 16.

LECYTHIDACEAE

Barringtonia asiatica (L.)Kurz

"Futu." A common coastal tree of the Pacific, but only two mature trees were found during the visit. They may have previously been more common, but Mr. Jennings reported he has had them cut down. The Tokelauan name is "hutu". W 3423.

LEGUMINOSAE

Adenanthera pavonina L.

"Lopā." A tree cultivated for its edible seeds. Occasional in village areas and along roads. W 3386.

Delonix regia (Bojer)Raf.

"Elefane." The poinsiana tree is found cultivated in several places on the island. The name appears to be a local one. W 3383, Bryan 922 and 1358.

Vigna marina (Burm.)Merr.

A coastal vine widespread in the Pacific, but seen in only one small patch near Taulaga. Mr. Jennings reported it was a very recent arrival. W 3426.

LYTHRACEAE

Pemphis acidula J.R.& G.Forst.

"Gagie." A shrub growing on the shore and along the lagoon. It is reported to be the hardest wood on Swains Island, and is used to attach the canoe outrigger. It has not been previously reported from American Samoa, and is rare in Western Samoa. W 3354, Diefenderfer s.n.

MALVACEAE

Hibiscus rosa-sinensis L.

"'Aute." A cultivated shrub with showy red flowers, not seen, but reported by a reliable islander to be growing on the island.

Hibiscus tiliaceus L.

"Fau." The beach hibiscus is scattered in disturbed areas on the island. The Tokelauan name is "hau." W 3405, Bryan 933 and 1359.

Sida rhombifolia L.

"Mautofu." A shrub with salmon-colored flowers,common as a weed in disturbed areas. W 3365, Bryan 930 and 1370, Schultz 9.

MORACEAE

Artocarpus altilis (Park.)Fosb.

"'Ulu." Several varieties of breadfruit are cultivated on Swains, and some of the trees are over 50' high. Varietal names include "māfala", 'ulu Elise", and "puou", all of which are also known in Samoa. W 3434.

Ficus tinctoria Forst.f.

"Mati." Not seen but reported by the islanders to be present. The small orange fruits are eaten. This small tree is also found in Samoa and the Tokelau Islands, and in both places it is also called "mati."

NYCTAGINACEAE

Boerhavia tetrandra J.R.& G.Forst.

"Nuna." A pink-flowered prostrate herb growing in disturbed places on the island. It is a widespread littoral species in the Pacific. W 3382.

Mirabilis jalapa L.

A shrub with white flowers, cultivated near Taulaga. W 3422.

Pisonia grandis R.Br.

"Pu'avai." A tree with sticky fruits, found in scattered patches in the coconut-dominated secondary forest. The leaves are used to feed pigs and the wood is used for posts. The Tokelauan name is "pukavai" or "pukakakai." W 3409.

ONAGRACEAE

Ludwigia octovalvis (Jacq.)Raven

An erect yellow-flowered herb, common as a weed in wet places. W 3415, Bryan 927, Diefenderfer 10.

POLYGALACEAE

Polygala paniculata L.

A weed with tiny white flowers and an aromatic root, uncommon growing in disturbed places. Only a single individual was seen. W 3358.

PORTULACACEAE

Portulaca oleracea L.

"Tamole." A prostrate, succulent, yellow-flowered herb growing as a weed in sunny disturbed places. W 3371.

RUBIACEAE

Gardenia taitensis DC.

"Tiale tiale." A white flowered shrub or small tree cultivated around houses. Although this is native to the region, it was probably introduced to Swains. W 3435, Bryan 1355, Diefenderfer s.n.

Guettarda speciosa L.

"Puapua." A medium to large littoral forest tree with white flowers, common in the forest. W 3394, Bryan 924 and 935.

Hedyotis romanzoffiensis (Cham.& Schlecht.)Fosb.

"Kautokiaveka", the Tokelauan name for it. This small shrub was first reported from the island by the U.S.Exploring Expedition and was later collected there by Lister in 1891. However, it was not seen during the most recent visit. One knowledgeable islander said he has not seen the plant growing on the island, but only its fruits which have washed up on the beach. Perhaps, then, it no longer occurs on Swains, but a more detailed search would be needed to verify this.

Morinda citrifolia L.

"Nonu." A small tree growing in the forest and in disturbed places. This is probably an aboriginal introduction, since in Polynesia it is known for its uses as a medicine, in preparing dyes, and as an emergency food in times of famine. W 3419, Diefenderfer 8.

Spermacoce assurgens R.& P.

A small white-flowered weed common in disturbed places. It has also been commonly known as Borreria laevis (Lam.)Griseb. W 3376, Bryan s.n.

RUTACEAE

Citrus aurantium L.

"Moli." A cultivated species of orange tree found at Taulaga. W 3431.

Citrus medica L.

"Tipolo." The cultivated citron with a thick, rough peel, growing at Etena. Seen, but not collected.

SOLANACEAE

Capsicum frutescens L.

"Polo." The cultivated red pepper, growing at Taulaga. W 3421, Diefenderfer s.n.

Physalis angulata L.

"Vivao." A common weedy herb with whitish flowers. It has a small edible fruit. W 3439.

Solanum uporo Dun.

"Polo." Not seen, but said by an islander to be growing in the forest. A specimen collected by Schultz was verified by F.R.Fosberg to belong to this species. Parham, however, records *Solanum viride* R.Br. from Tokelau, but this is possibly a mistaken identification. Schultz 8. This species was misidentified in the USFWS inventory.

TILIACEAE

Triumfetta procumbens Forst.f.

"Totolo." A woody, prostrate, creeping shrub with yellow flowers, common on beaches and sometimes in disturbed sunny places inland. W 3403, Bryan 934, Diefenderfer s.n., Schultz 15.

URTICACEAE

Laportea ruderalis (Forst.f.)Chew

A weed of shady disturbed places. It does not occur in Samoa, but a related species, *Laportea interrupta* L., does. W 3377, Bryan s.n.

Pipturus argenteus (Forst.f.)Wedd.

"Fau vine" or "vine." A silvery-leafed tree with white succulent fruit, occasional in disturbed places. In Samoa it is called "fau sogā" and in Tokelau it is "hau sogā." The bast fiber is used to make fishing lines, nets, and lashings. One islander reported that the trees occurring in Tokelau have a sweet-tasting fruit unlike those in Samoa. W 3404, Bryan 918 and 1369.

Procris pedunculata (Forst.f.)Wedd.

"Matavao." An epiphytic herb with red edible fruit. The Tokelau name is "gahevao", while in Samoa it is usually called "fua lole", so the name is probably a local one. W 3355, Bryan 932.

VERBENACEAE

Stachytarpheta urticaefolia Sims

"Mautofu." A shrub with purplish-flowers, common in sunny disturbed places. W 3364.

MONOCOTYLEDONAE

AMARYLLIDACEAE

Crinum asiaticum L.

"Lautalotalo." A large, white-flowered lily cultivated around houses. W 3387, Bryan 929 and 1365.

Zephyranthes rosea (Spreng.)Lindl.

"Lili." Bryan records the name "suisana", but both of these names appear to be local. A pink-flowered garden escape growing in grassy areas around houses. W 3375, Bryan 955 and 1363.

ARACEAE

Alocasia macrorrhiza (L.)Schott

"Ta'amu." A large aroid occasionally cultivated on Swains. Seen, but not collected.

Colocasia esculenta (L.)Schott

"Talo." Taro is cultivated in swampy areas. The variety on Swains is called "talo Niue" which is the common one in Samoa. Bryan 1364, Diefenderfer s.n.

Cyrtosperma chamissonis (Schott)Merr.

"Pula'a." A large aroid commonly cultivated in swampy areas. In Tokelau it is called "pulaka." Seen, but not collected.

COMMELINACEAE

Commelina diffusa Burm.f.

A blue-flowered herb common as a weed in wet places such as in the taro and Cyrtosperma patches. W 3428, Diefenderfer 11.

CYPERACEAE

Cyperus brevifolius (Rottb.)Hassk.

A small sedge with green bracts, common as a weed in grassy village areas. W 3414.

Cyperus compressus L.

A low weedy sedge occasional in disturbed areas. W 3412.

Cyperus javanicus Houtt.

A coarse sedge growing in wet places along the edge of the lagoon. This is a widespread littoral species which is called "selesele" in Samoa. W 3416.

Cyperus kyllingia Endl.

"Mutia." A white-bracted sedge growing as a weed in grassy areas. W 3368, Bryan 951.

Cyperus rotundus L.

"Mumuta." This nut grass is a weed of disturbed and grassy areas. Its tubers are used to scent coconut oil. W 3429.

Eleocharis geniculata (L.)R.& S.

A low, clumped sedge growing in marshy areas along the edge of the lagoon, mostly on a peninsula on the northeast corner. It was reportedly collected in Samoa by Graeffe in 1871, but since it is otherwise unknown from Samoa or the Tokelau Islands, this may be in error. It does, however, occur in Fiji. W 3352A.

Fimbristylis cymosa R.Br.

"Tuisē." An indigenous sedge common in sunny littoral areas and also as a weed in open village areas. W 3360 and W 3417, Bryan 952, 954, and 1350, Diefenderfer s.n., Schultz 16.

Fimbristylis dichotoma (L.)Vahl

An erect weedy sedge common in open village areas. W 3361, Bryan 953.

GRAMINEAE

Axonopus compressus (Sw.)Beauv.

A prostrate grass common in open village areas. W 3412

Cenchrus echinatus L.

"Vao tuitui." The sand burr is a common weed of sandy and grassy village areas. W 3370, Bryan 945 and s.n.

Chrysopogon aciculatus (Retz.)Trin.

A clump-forming weedy grass of open village areas. W 3369.

Cynodon dactylon L.

An occasional weedy grass of open village areas and disturbed places. W 3436, Bryan 946.

Digitaria ciliaris (Retz.)Coel.

A small grass with digitate racemes, occasional in disturbed areas. W 3438.

Eleusine indica (L.)Gaertn.

A coarse grass with digitate racemes, common in disturbed areas. It is called "ta'ata'a" in Samoa. W 3362, Bryan 949 and 1362.

Eragrostis tenella (L.)Beauv. ex R.& S.

A small delicate grass occasional in open village areas. W 3363, Bryan 950 and 1361.

Lepturus repens (Forst.f.)R.Br.

A clump-forming grass with an unbranched inflorescence that breaks up into one-seeded segments, common on coastal sands and also as a weed in disturbed places. W 3379 and 3390, Bryan 944 and 948.

Paspalum conjugatum Berg.

"Vaolima." A weedy grass with a t-shaped inflorescence, common in disturbed places. W 3381, Bryan 947.

Paspalum distichum L. (usually known as *P. vaginatum* Sw.)

A clump-forming grass growing in large patches in marshy areas along the edge of the lagoon. W 3353A, Bryan 938.

Saccharum officinarum L.

"Tolo." Sugar cane was reported to be cultivated, at least until recently, but it was not seen during the visit.

MUSACEAE

Musa paradisiaca L.

Two varieties of banana are growing on Swains Island, but no specimens were collected during the visit. Diefenderfer 18.

PALMAE

Cocos nucifera L.

"Niu." A number of varieties of coconut are grown on Swains Island, including one which in the young stage has an edible husk. Seen, but not collected.

PANDANACEAE

Pandanus tectorius Park.

"Falavao." Wild screwpine is common in secondary forest and the neglected coconut plantation, as well as along the seashore. W 3408, Bryan 912 and 1346, Schultz 10.

Pandanus tectorius Park. var. ---?

"Falakai" or "fala Elise.". This cultivated screwpine is grown for its edible fruit. The bases of the phlanges are chewed uncooked. W 3432.

TACCACEAE

Tacca leontopetaloides (L.)O.K.

"Masoā." The Polynesian arrowroot is cultivated and is somewhat naturalized. In the Tokelau Islands it is called "mahoā." W 3373, Bryan 923, 1323, and 1351, Diefenderfer s.n.

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The visit by the author was made during the USFWS inventory of the wildlife and wildlife habitats of the Islands of American Samoa, conducted by Environment Consultants, Inc. (contract. no. 11-16-0001-5782FA of the Interior Department). For further details of the study of the biota of Swains Island, see this report (1978, mimeograph copy).

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Ed. note. -- A collection of plants was made on Swains Island and Manihiki some years back and sent to the Smithsonian Institution by Mr. Wm. S. Blankley, but no data were received with the specimens nor supplied later.

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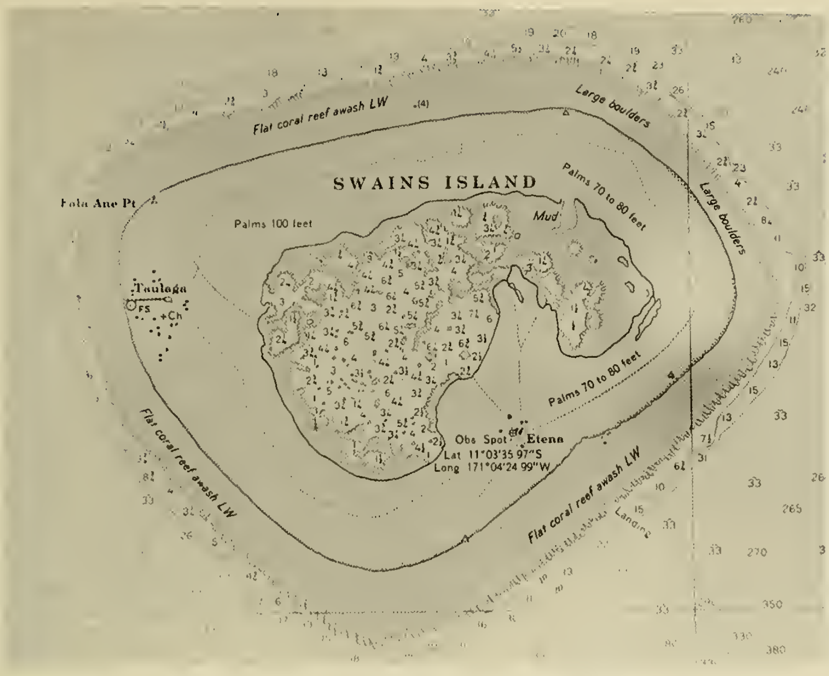

Figure 1. DMAHC nautical chart of Swains Island.

Figure 2. The central, brackish water lagoon of Swains Island.

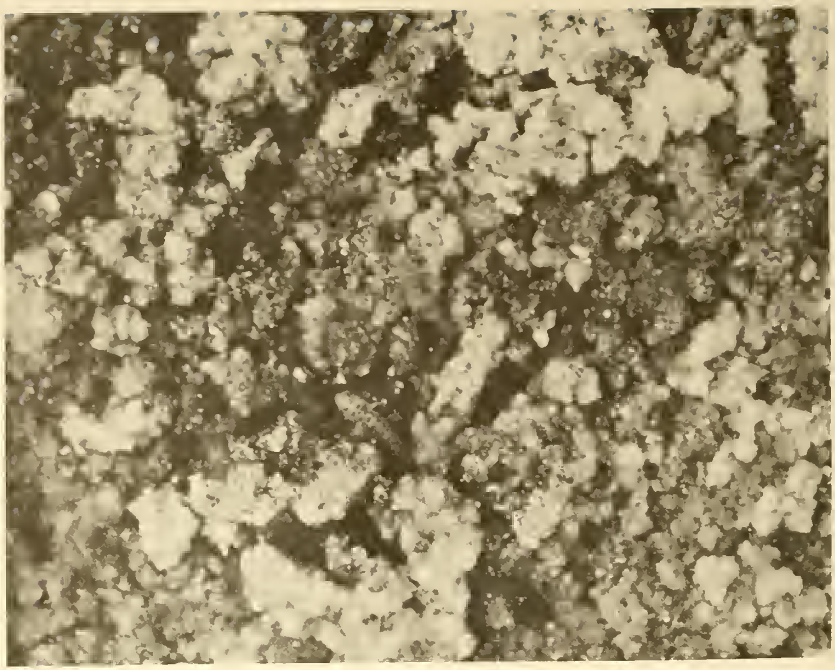

Figure 3. Large, irregular chunks of algae floating in shallow water of the lagoon of Swains Island.

Figure 4. Sparse sand strand vegetation near Taulaga.

Figure 5. Scaevola-dominated shrubland near Etena.

Figure 6. Littoral forest on the south shore of Swains Island.

Figure 7. Forest on Swains Island dominated by <u>Pandanus tectorius</u>.

Figure 8. Open forest floor in littoral forest dominated by <u>Hernandia sonora</u>.

Figure 9. Coconut palms on the lagoon shore of Swains Island.

Figure 10. The grassy village green at Taulaga, with railroad tracks leading up to the copra shed.

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SHELF MARGIN REEF MORPHOLOGY: A CLUE TO MAJOR OFF-SHELF SEDIMENT TRANSPORT ROUTES, GRAND CAYMAN ISLAND, WEST INDIES

BY

HARRY H. ROBERTS

ISSUED BY
THE SMITHSONIAN INSTITUTION
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SHELF MARGIN REEF MORPHOLOGY: A CLUE TO MAJOR OFF-SHELF SEDIMENT TRANSPORT ROUTES, GRAND CAYMAN ISLAND, WEST INDIES

Harry H. Roberts [1]

Abstract

Side-scan sonar, high-resolution seismic, and echo-sounder data, coupled with the results of other reef-related studies on Grand Cayman Island, show that abundant sediments have accumulated on the deep fore-reef shelf. The most important accumulation sites are on the downdrift northwest and southwest flanks of the island, where gradients from high to low energy are maximized.

Shelf-margin reef morphology along the lee or western side changes from a continuous sill-like structure that impounds sediment along most of this sector to a discontinuous reef along the southwestern flank. Isolated reef buttresses, separated by wide sediment-floored channels, characterize this area, where abundant sediments are stored on the lower forereef shelf. The wide channels between reef buttresses provide avenues through which sediments produced in shallow-water environments can be transported to deep off-shelf sites of deposition. Echo-sounder traces off the shelf at the southwestern corner of the island display characteristics suggesting depositional slopes. Shelf-margin reef morphology strongly indicates that off-shelf sediment transport is occurring along the southwestern flank of the island. Side-scan sonar data were extremely valuable for rapidly evaluating the morphological variability of reefs on the forereef shelf.

Introduction

Recent studies of physical processes interacting with island reef systems in trade-wind settings suggest that around-the-island gradients in both wave energy and current energy favor transport and accumulation of sediment along the lee coast and adjacent shelf (Roberts et al., 1975; Murray et al., 1977; Davies, 1977; Roberts, in press). Both observations and theory show that zones of intense currents (jets or rips) and zones of weak currents (stagnation zones) are systematically distributed around the shores of islands and that prisms of shelf sediment accumulate in response to the deceleration of high-speed currents (Murray et al., 1977). Within quasi-unidirectional wind and wave systems, major low energy or sheltered zones around islands generally correspond to regions where nearshore current fields display minimal velocities. In the northeast trade-wind setting of the Caribbean, these low-energy zones occur on the western sectors of islands.

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Carbonate research conducted on the reefs and sediments of Grand Cayman (West Indies), a trade-wind island that fits the above observations concerning energy distribution (Fig. 1), indicates that sediments have accumulated in abundance on the deep forereef shelf along the western (lee) side of the island (Rigby and Roberts, 1976; Roberts, 1977). Although shallow fringing reefs, which are abundant sediment sources, are not evident along the leeward coast, flourishing mid-shelf and shelf-margin reefs are present. Higher energy shelves, compared to low-energy shelves of Grand Cayman, tend to support more coral cover and less open areas of sediment accumulation in both shallow and deep environments (Roberts, 1974). Sediments produced by both physical and biological degradation of the reef framework in these higher energy shelf areas appear to be largely trapped in the reef matrix and thereby diverted from primary routes of off-shelf sediment transport. Meaney (1973), Moore et al. (1976), Land and Moore (1977), Ginsburg and James (1973), and Hanna and Moore (1979) have studied various aspects of shelf to basin sedimentation, including sediment budgets, facies relationships, and stratigraphic history of off-shelf deposits. The study reported in this paper provides additional data from side-scan sonar, subbottom, and echo-sounder surveys (Fig. 1) concerning identification of optimal sites for shelf-to-basin sediment transport associated with a low-relief Caribbean island.

Objectives of this investigation were twofold. Firstly, from previous geological and physical process studies of Grand Cayman, the location of important sediment sinks and general areas of maximum sediment input to the shelf were identified. It then became important to determine if these areas of accumulation are also sites of significant sediment transport and if reef morphology is linked to this process. Secondly, the usefulness of side-scan sonar for reef-related studies was tested.

Instrumentation

Three instruments were used in conjunction with accurate location control. These instruments included a side-scan sonar system, a 3.5-kHz subbottom profiler, and a linear chart recording fathometer. All instruments were deployed on an 11-metre boat, which served as a research vessel. Instrumentation was operated simultaneously, and event marks indicating position fixes were automatically recorded on all records at 1-minute intervals. The position fix numbers and distances from known points were recorded on paper tape as a permanent record. Each instrument is discussed below, with more emphasis being given to side-scan sonar because of its usefulness in this study and its recent importance to marine geology in general.

Side-Scan Sonar

The first operable side-looking sonars were made by the British in the early 1960s. Side-scan did not become a valuable instrument for marine surveys until the late 1960s. In the 1970s it has become increasingly important as standard instrumentation in marine survey work. For the marine geoscientist, the development of side-scan sonar must be considered a major technological milestone. Through the use of this instrumentation, which is now readily accessible, it is possible to map sea-floor surface features with complete coverage, a task very similar to mapping from aerial photography. Previously, our understanding of sea-floor morphology was derived primarily from profile data such as is generated by a precision depth recorder. Between survey lines extrapolations must be made, whereas adjacent side-scan sonar lines may be spaced so that records overlap for continuous sea-floor coverage. Recent development of systems that digitally acquire side-scan data and play it back in an undistorted analog form is yet another major improvement in this valuable instrumentation. In an undistorted format spatial distributions of bottom features, textures, and shapes can be easily assessed in a quantitative way, much like mapping and form analyses using air photos.

The area of sea floor covered is a swath, commonly to 1,000 metres (500 metres on each side of the source), rather than a line, as is the case with profiling techniques. Objects on the sea floor reflect the acoustic energy, which is received by the towed sonar source. Returned signals are then amplified and printed as various tones on either wet or dry paper. Precise measurements of distances between the vessel and a reflector, as well as shapes, heights, and other relationships, are not possible with conventional side-scan without corrections (Flemming, 1976). The new digital system offers a method for obtaining distortion-free images and therefore the possibility of easily employing this instrumentation for precise topographic mapping (Prior et al., 1979).

A conventional side-scan sonar system consists of three basic units: (1) a transducer (or "fish"), which is the underwater transmitting unit, (2) a steel-reinforced cable, which is used for towing the fish and transmitting signals to the third component, (3) the recorder.

For optimum results from a side-scan sonar survey, precise navigational control is needed, and track lines should be arranged so that adjacent records overlap on one channel. Without accurate navigational control, both conventional and the new digital side-scans are of limited use as instruments for collecting quantifiable data from the sea floor.

For research in coral reef environments side-scan sonar may be used to collect data on reef shape, orientation, and general configuration which may then be compared to physical expressions of the environment such as wave direction and wave power. Density changes on the side-scan sonograph may also represent well-defined facies changes, e.g., muds to sands. This method is invaluable for the study of shelf reefs that are too deep to be recorded by aerial photography. Other uses in carbonate environments include the determination of sediment transport routes and sediment sinks in deep shelf areas where other methods of observation may be difficult and time consuming.

The Klein side-scan system used in this study was coupled to the 3.5-kHz subbottom profiler, and records from both sensors were printed on a single wet-paper recorder, which has three channels. The side-scan has a frequency of 100 kHz with lookout ranges from 25 to 600 metres. We found the 100-metre range to be optimal for the Grand Cayman study.

Subbottom Profiler

The subbottom profiler is designed so that it fits on the nose of the side-scan sonar fish (Fig. 2). This unit operates at a frequency of 3.5 kHz and is designed to produce details of reflection events in the upper 100-200 feet of the stratigraphic column, depending on the type of sedimentary material. Unfortunately, the acoustic energy is transmitted at relatively low power. In reef and reef-associated areas, the sea floor is generally very hard, which causes much of the acoustic energy to be reflected without penetrating the bottom. Only a few of our records contained useful subbottom information. These records, however, provided additional data concerning sediment thickness on the forereef shelf.

Fathometer Depth Recorder

A Raytheon Model DE-731 depth recorder was used in conjunction with other instrumentation. This particular instrument was selected for use because of its linear chart, versatile depth ranges, and portability. Although both the side-scan sonar and the 3.5-kHz subbottom profiler records a bottom trace, the fathometer is a much more accurate and convenient method of generating a bathymetric profile. The fathometer was run on all survey lines during this study.

Our unit is equipped with a narrow-beam transducer, which gives the best resolution of the sea floor. However, in rough seas this transducer does not function well. The system will record in both feet and fathoms (0-410 feet or fathoms is the depth recording range). The operating frequency is 41 kHz, and the sounding rate is 270 pulses per minute in FEET mode and 45 pulses per minute in FATHOMS mode.

Survey Position Fixing Instrumentation

A Decca Del Norte electronic range-range locating system which employs advanced microwave and digital techniques was used for survey control. This system has a "line of sight" capability, with maximum ranges in the order of 80 km when both remotes and the master receiving antenna are elevated. Distance is obtained by measuring the round-trip travel time of signals transmitted between the master and the remote. Then, 10 or 100 path lengths, selected by digital filtering, are averaged to determine each distance displayed. Ranges are obtained in a matter of milliseconds. Positions can be resolved with this equipment to an accuracy of 1-3 metres. The instrumentation is very lightweight, easy to install, and reliable under a full range of field conditions. The system used in this study consisted of two remote stations (land based), a master receiving station (boat based), and a printer. All units are powered by two 12-volt car batteries. The remotes are deployed at known survey control points along the coast (Fig. 3). These stations are interrogated by the master unit on the boat, and the distance in metres from each remote to the master antenna on the boat is printed out on paper tape, along with position fix number and time. A 1-minute rate for these position checks was used in the Grand Cayman study. As position fixes are taken every 1 minute, an event mark is simultaneously triggered on the side-scan sonar, subbottom, and bathymetric records.

Shelf Morphology

The shelf surrounding Grand Cayman is narrow, ranging in width from approximately 0.5 km to 2.0 km. Geomorphically, the most distinctive features of any given shelf profile are two persistent submarine terraces which can be traced around the entire island (Fig. 4). Although differential reef growth and other generally slower forms of shelf accretion account for a moderate degree of variability in terrace topography, the seaward break in slope of the shallow terrace generally occurs at a depth of 8-10 metres. The base of this shallow terrace averages 15 metres where the deep terrace is encountered. Except for the seaward margin, most of the shallow terrace is a hardground surface with very little, if any, sediment cover. It is sparsely colonized by reef-building organisms, and is commonly dissected by shallow grooves (Fig. 5). On the lee side, however, localized areas of sediment accumulation are associated with adjacent hardgrounds. Spurs and grooves are not characteristic of the shallow terrace of the central lee shelf (Fig. 6).

The seaward margin of the shallow shelf break in slope supports a prolific growth of coral superimposed on a distinct spur and groove structure. Well-defined ridges or spurs of living coral are prograding seaward and building toward the surface. The linear depressions in the shallow terrace surface are sometimes discontinuous and therefore do not always extend to the seaward margin of the terrace. Most well-defined grooves either reach the lower terrace or intersect other grooves until the network extends across the upper shelf. It is clear, however, that whether these grooves terminate upslope in actively growing fringing reefs, as is generally the case, or in a limestone sea cliff, common on lee side, they function as pathways for sediment transport to the lower shelf.

Spur and groove structure is also typical of the deep shelf terrace. However, the landward portion of this terrace is frequently an area of sediment accumulation (Fig. 7). Extremely coarse carbonate material (cobble- to coarse-sand-sized sediment) is concentrated at the base of coral-covered spurs of the shallow terrace. Particle size generally decreases to a bimodal sediment of coarse sand-sized constituents in a silt- to clay-sized matrix near the shelf margin. Spurs of living coral that extend landward from the actively growing shelf edge reef tend to break the continuity of the lower shelf sediment belt. Considerable variability is displayed in sediment plain characteristics, in terms of both geometry and sediment properties. High-energy sectors of the shelf tend to have coarse sediment plains that are highly segmented by spur growth. Contrasting low energy shelves tend to have broader unbroken areas of sediment accumulation. Most of these sites occur on the lee (western) side of the island, where sediments can be quite fine grained in localized areas. Depending on relationship to dominant wave direction, spurs that extend into the sediment plain may not be oriented normal to the shelf edge. Roberts (1974) has shown that differences in orientation between spurs and grooves on the shallow and deep terraces are related to progressive changes in direction of dominant waves as they intersect the shelf and refract across it.

A thriving reef community is present at the seaward edge of the deep shelf terrace where an abrupt break in slope separates the shelf from deeper off-shelf environments. Morphologically, the shelf margin reef can vary from an unbroken ridge, through regularly spaced massive coral buttresses separated by narrow sediment-floored grooves, to irregularly spaced and widely separated coral buttresses. The degree to which the deep reef morphology is exaggerated or amplified appears to depend greatly on the wave energy conditions under which it developed (Roberts, 1974). Along high-energy sectors of the shelf, massive and regularly spaced living coral buttresses protrude into deep water (Fig. 8). These huge coral spurs occasionally coalesce, forming a wide variety of tunnel and cavern structures. The massive buttresses generally have a steep to overhanging seaward profile, with as much as 20-30 metres of relief. Low-energy shelf-margin reefs support thriving coral communities (Fig. 9) but display less exaggerated buttress formation and less steep offshelf profiles. Morphological elements of the reef at these depths have coalesced to form a semicontinuous ridge at the shelf edge which has grown to a height of 3-5 metres above the adjacent deep terrace sediment plain. Inasmuch as this linear topographic feature is infrequently dissected by narrow grooves, it essentially forms a sill that causes sediment to be impounded behind it.

Sediment Transport Routes and Variability of Deep Reef Morphology

Previous research on Grand Cayman (Roberts, 1974; Roberts et al., 1975; Murray et al., 1977) has demonstrated that strong westerly directed currents exist along both the northern and the southern flanks of the island (Fig. 1). At Grand Cayman's southwestern extremity, where much of the research reported in this paper was concentrated, the combined effects of shoaling waves, tidal currents, and westward-flowing backreef lagoon currents from South Sound (Fig. 1) result in the transport of sedimentary particles to the lee shelf, where they accumulate.

As discussed in a recent paper by Roberts (in press), continuous reefs separating shallow backreef lagoons from the open shelf can be abundant sources of sediment to deeper shelf and off-shelf environments. Reefs of this description function as continuous sources of sedimentary particles, first to backreef environments and subsequently to deeper depositional settings outside the lagoon. Coarse sediment bodies tend to accumulate behind the reef as a result of wave overwash processes and at the adjacent backreef shoreline by swash action. Strong currents develop in the downdrift ends of these systems, transporting sediment outside the confines of the lagoon. Such flow is driven by both wind stress on the lagoon and constant input of water to the backreef by breaking waves that generate strong shore-normal surge currents at the reef crest (Roberts and Suhayda, 1977; Suhayda and Roberts, 1977). These processes provide the driving forces for creating a significant flow out of the lagoon. The combined result is to export reef-derived and lagoonal sediment to the adjacent forereef shelf. Although mean conditions produce flows sufficient to move sand-sized sediments, storm events create proportionately higher velocities and thereby become important sediment transport events.

Even though the movement of sediment to deep shelf environments is reasonably well understood, processes responsible for transporting sediments off the shelf to deeper depositional sites have not been studied in detail. Investigations of off-shelf sediment transport by Meaney (1973), Moore et al. (1976), Land and Moore (1977), Ginsburg and James (1973), and Hanna and Moore (1979), among others, have focused primarily on the products of the transport process. They demonstrate that sediments generated in shallow reef and reef-associated environments are moved off the shelf and into deepwater sedimentary environments. The conditions responsible for displacing sedimentary particles from a shelf domain to a basinal environment are not well understood. Most recently, Hine and Newmann (1977), Hine et al. (in press), and Mullins et al. (in press) have shown, from research on the margins of the Bahama Bank, that large volumes of shallow-water sediments have engulfed Holocene shelf-margin reefs and now reside on the deep flanks of the Bahamian platform. They have attributed much of this off-bank transport to storm-related processes. Islands such as Grand Cayman are somewhat more limited in areas available for sediment generation as compared to vast shallow-water platforms such as the Bahama Banks. There are, however, favored sites where sediment accumulation around islands is focused by the physical dynamics of the island system (Murray et al., 1977; Roberts, in press).

Side-scan sonar data indicate that the morphology of Grand Cayman's shelf-margin reefs provides important clues to interpreting the location of significant off-shelf sediment transport routes. On the lee or western shelf, where sediments collect more abundantly than on higher energy flanks of the island, there are long sections of shelf-margin reef which have coalesced to form a relatively coherent ridge. Sediments are impounded in the lee of this structure and can be transported over the shelf edge only through narrow grooves (Fig. 10).

Grooves are active transport routes (Meaney, 1973) especially on high-energy flanks of the island, where they are kept open by tidal exchange at the shelf edge and wave-related forces (Roberts et al., 1975, 1977). However, only limited amounts of sediment can be fluxed through these narrow passageways to deeper sedimentary environments. Higher energy shelves seem to maintain the integrity of a basic spur and groove structure (Fig. 6), and sill-like structures do not generally develop. The southwestern extremity of Grand Cayman is a site where maximum energy gradients favor sediment deposition. Figures 11 and 12 illustrate the large area of sediment deposition on the deep shelf, as well as the discontinuous nature of the adjacent shelf-margin reef. Rather than a coalescence of reef elements to form a sill at the shelf edge, which is typical of the Grand Cayman lee side, along the downdrift southwestern flank of the island the shelf-margin reef breaks into irregularly spaced reef masses or buttresses separated by wide channels. These wide channels provide free access for shelf sediments to deeper off-shelf environments. Such shelf-margin reef morphology has probably developed in response to a constant input of sediment to this accumulation site since sea level rose above the level of the shelf edge (approximately 20-24 metres). Assuming that Grand Cayman has been subject to the same general unidirectional wind and wave system since sea level was at the level of the shelf edge, the island's southwestern flank has been a favored site of sediment deposition. An abundant supply of sediments has probably inundated once-living shelf-edge reefs and produced a mobile sediment substrate that restricts coral attachment and growth. Apparently only the highest topographic points have been able to perpetuate themselves by continued reef growth.

Figure 13 summarizes the general sediment sinks and transport routes associated with the southwestern flank of Grand Cayman Island. Shallow-water accumulation zones are found in the sheltered areas of the backreef lagoon. Over-the-reef currents, modulated by the tide and wind stress, drive lagoonal water from east to west. Strong axial currents capable of transporting sand-sized particles to the adjacent shelf develop at the downwind end of the system. Significant shelf sediment accumulation takes place only on the deep shelf terrace. Our 3.5-kHz subbottom profiles show that these deposits are at least 5 metres thick. High-resolution seismic data, showing more penetration from neighboring Caribbean islands with similar shelf morphology, suggest that these deposits may be up to 20 metres thick. Recent studies from the shelf and shelf margin of Little Bahama Bank (Hine et al., in press) illustrate Holocene sediment thicknesses in this range at preferred sites.

Shelf-margin reef morphology suggests that along high-energy flanks of the island sediments move off the shelf through narrow, well-defined groove systems. In contrast, the lee shelf-margin reef has fused to essentially prohibit off-shelf transport of significant volumes of sediment. Very narrow (1-3 metres), irregularly spaced grooves offer a few minor pathways through which sediments may be carried off the shelf (Fig. 10). Only at the northwest and southwest extremities of the island where energy gradients are maximized do sediments accumulate in such abundance that reef growth on the shelf edge is affected. At these locations the shelf-margin reef becomes discontinuous (Fig. 12). Large breaks in this sill-like structure are interpreted as major routes for the movement of shallow-water sediments to deep sedimentary environments. Echo-sounder profiles of the southwestern island margin tend to support the depositional nature of this site over steeper higher energy flanks of the island (Fig. 14). Additional high-resolution seismic work, coupled with a coring program, needs to be accomplished in order to verify the extent of off-shelf deposits and to calculate a budget for sedimentation during Holocene times at this preferred site.

Conclusions

Side-scan sonar, high-resolution seismic, and echo-sounder data, coupled with results from previous studies on Grand Cayman, have led to the following conclusions linking shelf-margin reef morphology and off-shelf sediment transport:

1. Sediments accumulate in abundance on the down-drift southwestern flank of Grand Cayman, where gradients in wave and current energy are maximized. An abundant source of sediments to the southwestern shelf is associated with the east to west flushing of South Sound, which is forced primarily by strong reef overwash caused by breaking waves.

2. Shelf-margin reef morphology along the island's southwestern flank changes from a continuous sill-like structure which impounds sediments to a discontinuous reef characterized by isolated reef buttresses. Wide avenues exist between reef buttresses through which sediments produced in shallow-water environments can be transported to deep sites of deposition off the shelf. Echo sounder profiles of windward to leeward island margins suggest that the island's southwestern flank is a zone of deposition, as evidenced by less steep "depositional" slopes and slump-like topography.

3. Side-scan sonar data proved to be particularly useful in this study for determining details of shelf and shelf margin reef morphology. This method of acquiring morphological details of bottom features is rapid and quantitative, and allows the geomorphic variability of large areas of sea floor to be compared without making direct underwater observations.

Acknowledgements

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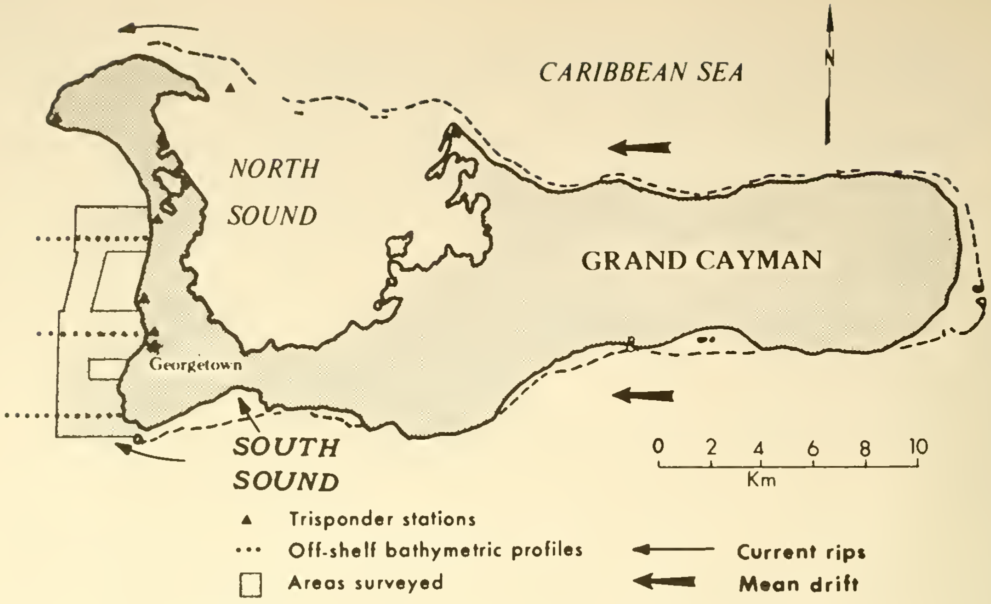

Figure 1. Location map of Grand Cayman Island showing the survey areas.

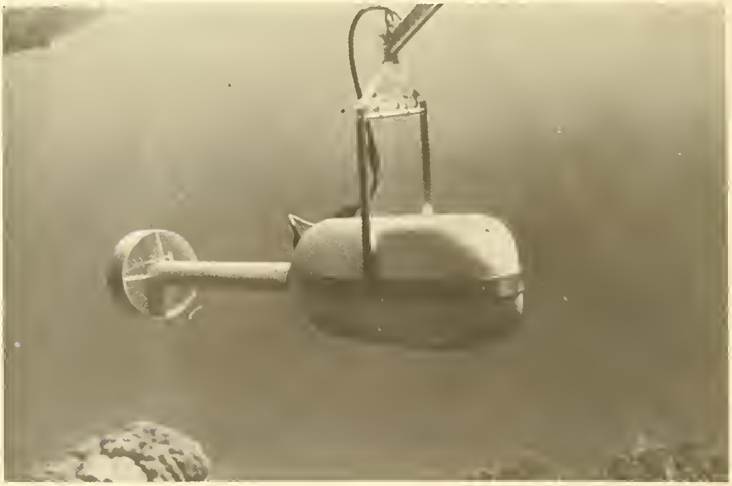

Figure 2. The Klein side-scan sonar fish plus 3.5-KHz subbottom profiler used in this study.

Figure 3. Trisponder shore location being installed in preparation for an offshore survey.

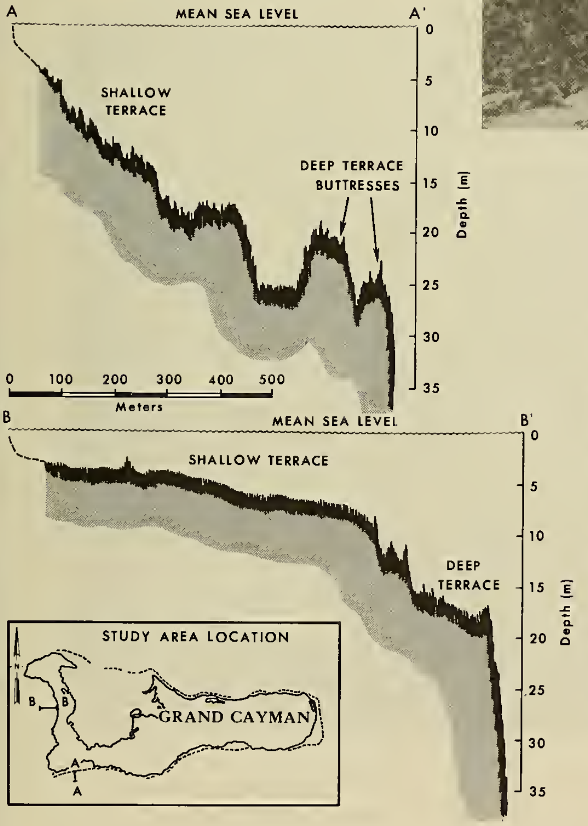

Figure 4. Echo-sounder traces across Grand Cayman's narrow southern forereef shelf (profile A-A') and somewhat wider western shelf (profile B-B'). Shallow and deep terraces are characteristic of each profile. Large coral buttresses with intervening grooves are common along high-energy flanks of the island (A-A'). A rather continuous shelf margin reef is the norm on the lee or western side of the island (B-B').

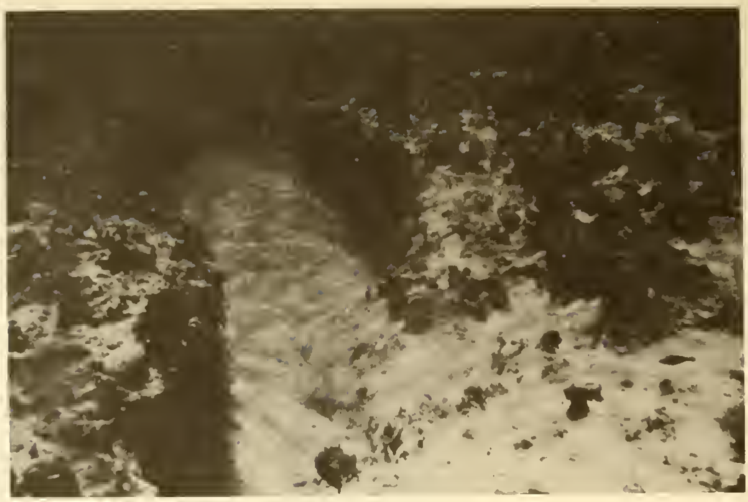

Figure 5. Surface of shallow terrace (depth ~3 metres). Note the lack of sediment cover, sparse colonization of reef-building organisms, and shallow groove.

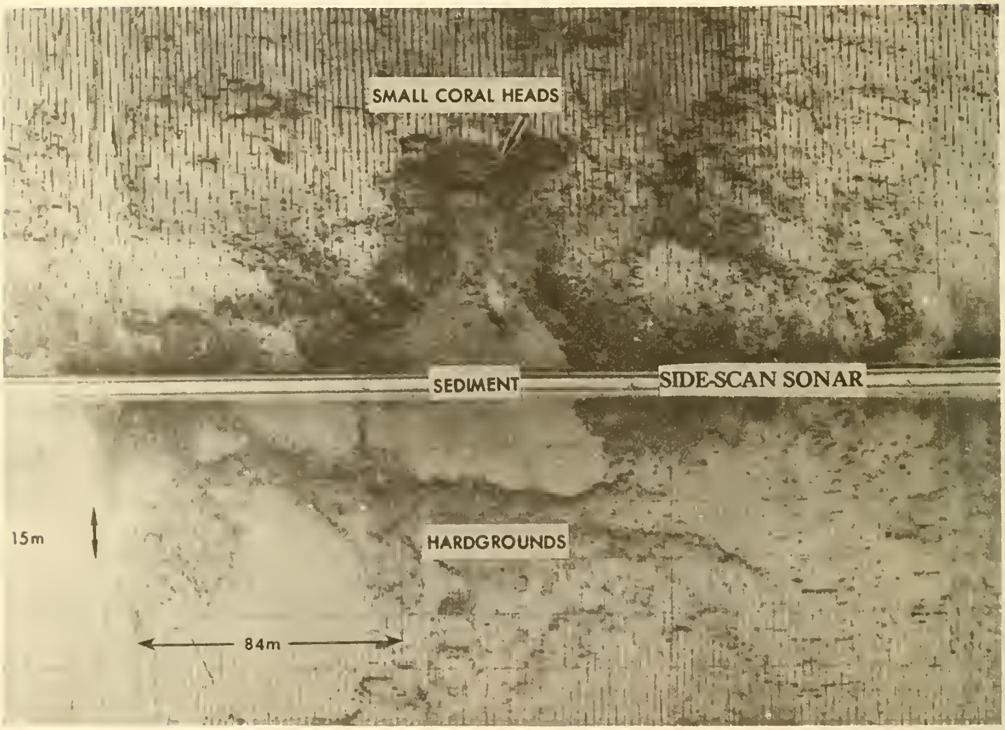

Figure 6. Side-scan sonograph of the shallow shelf terrace on the lee side of the island. Note the lack of spur and groove structure, isolated areas of sediment accumulation, and hardgrounds. Water depth is 5-7 m.

Figure 7. Deep shelf terrace sediment plain that is dissected in this locality by a linear spur constructed by a thriving reef community. Note the rippled sediment. These structures are oscillation ripples from recent storm waves (water depth 24 metres).

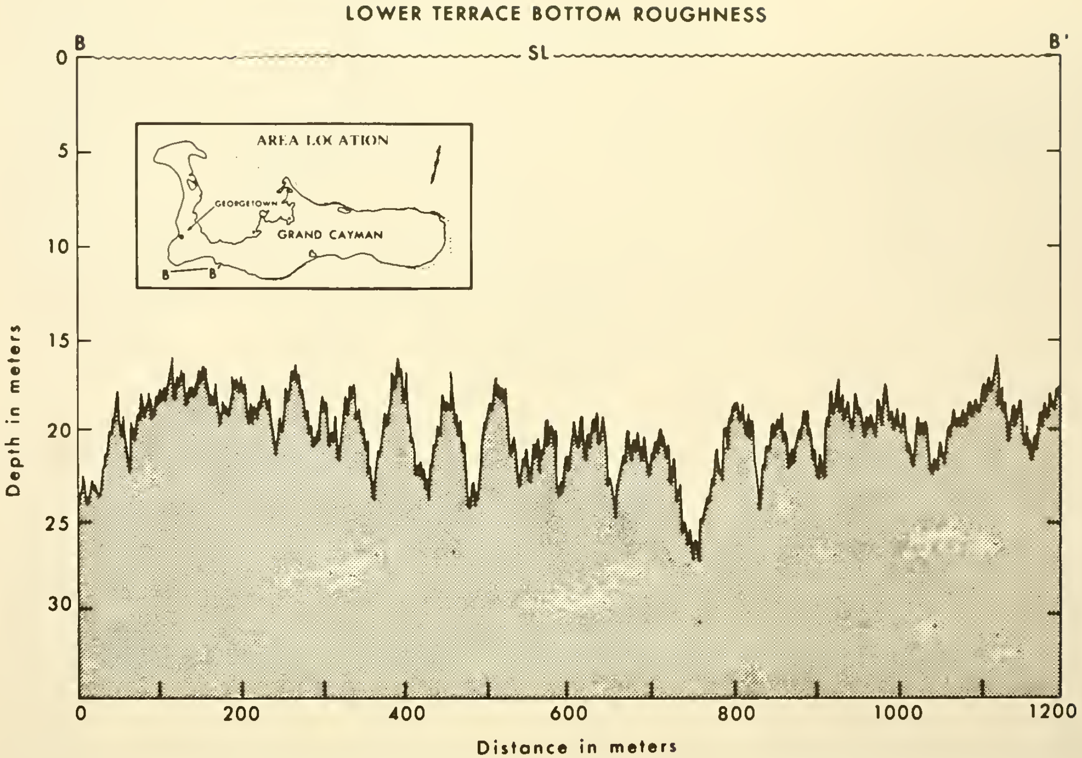

Figure 8. Echo-sounder trace along the shelf edge of a high-energy sector of the shelf showing the regularly spaced coral buttresses separated by narrow sediment-floored grooves.

Figure 9. Diverse coral community typical of the shelf-margin reef (water depth 22 m).

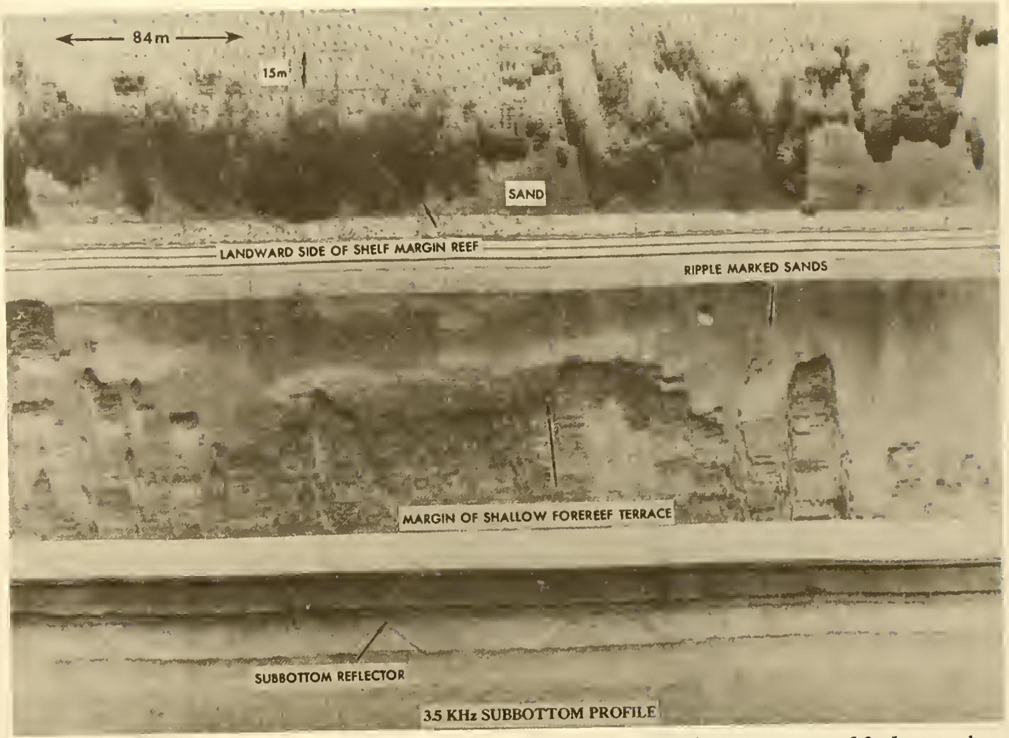

Figure 10. Side-scan sonograph and subbottom profile run parallel to the rather continuous shelf-margin reef (water depth ~22 metres) along the western part of the island. Note the well-developed spurs and grooves and extension of the shelf-margin coral spurs across the adjacent sediment plain. This configuration of extended spurs and a compartmentalized sediment plain is typical of higher energy shelves around the island. The shelf edge is represented by the area of "no return" at the top of the figure.

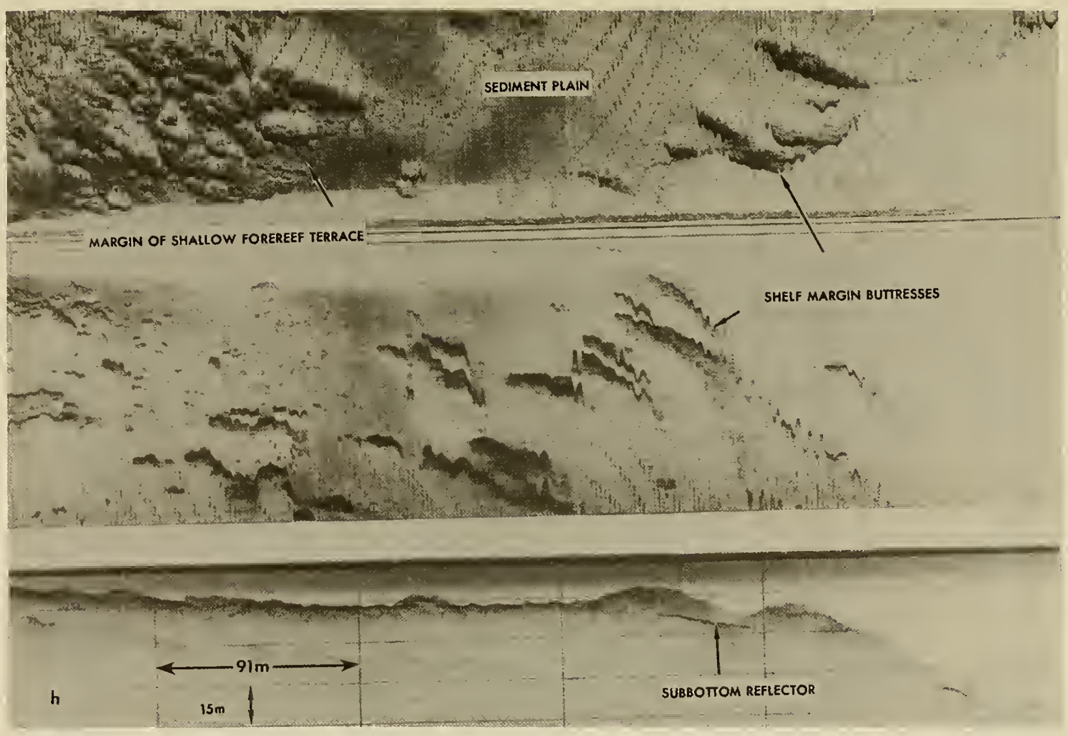

Figure 11. Side-scan sonograph and subbottom profile run across the shelf near the sediment-rich area of the island's southwestern flank. Much of this sediment was generated from shallow reefs acting as the seaward boundary for South Sound. Back-reef lagoon currents carry this material to the west, where it eventually reaches the lower shelf. Note the widely spaced and well-defined coral spurs or buttresses at the shelf edge.

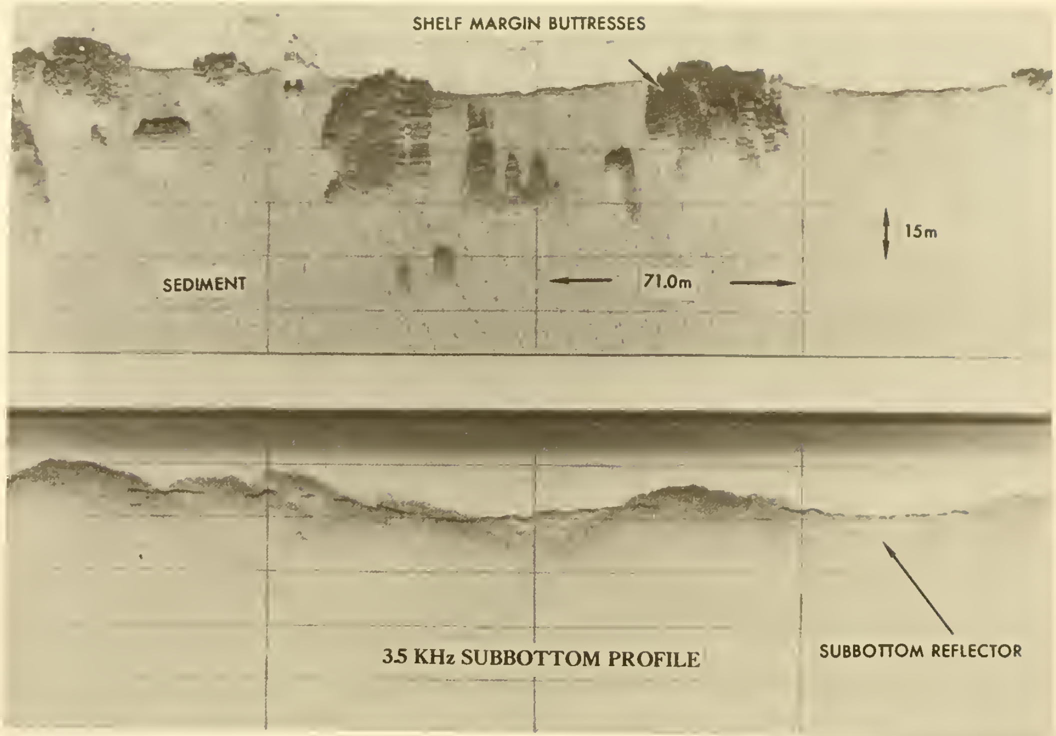

Figure 12. Side-scan sonograph (only one channel) and subbottom profile of the shelf margin opposite Southwest Point, where shelf sedimentation rates are relatively high. The shelf margin in this area consists of a few localized coral buttresses separated by wide paths for off-shelf sediment transport, clearly delineated. The side-scan sonar channel omitted was facing deep water and therefore no images were recorded.

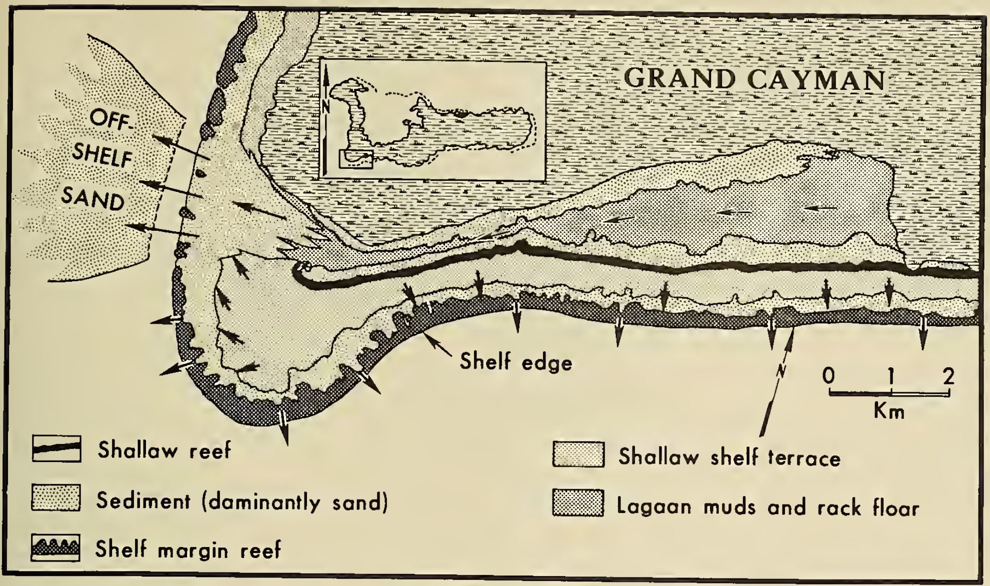

Figure 13. Sediment sinks and transport routes associated with the south western flank of Grand Cayman Island (South Sound and adjacent shelf areas). Arrows indicate sediment transport directions.

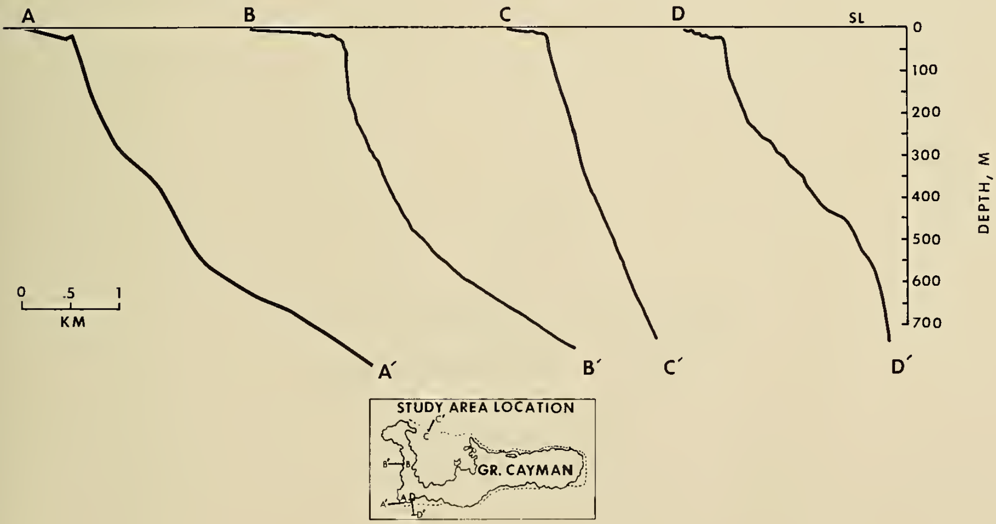

Figure 14. Echo-sounder profiles showing the variability in shelf and shelf-margin slope morphology around the western end of the island. Note the less steep and more "depositional" configuration to the lee side profiles.

ATOLL RESEARCH BULLETIN
No. 264

AN ANNOTATED CHECK LIST OF THE CORALS OF AMERICAN SAMOA

BY

AUSTIN E. LAMBERTS

ISSUED BY

THE SMITHSONIAN INSTITUTION
WASHINGTON, D.C., U.S.A.

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AN ANNOTATED CHECK LIST OF THE CORALS OF AMERICAN SAMOA

by Austin E. Lamberts*

SUMMARY

Reef coral collections from American Samoa are in the National Museum of Natural History, Smithsonian Institution, Washington, D.C., and in the Hessisches Landesmuseum, Darmstadt, W. Germany. The author has a collection of 790 coral specimens for a total of 1547 items known to be from American Samoa.

A total of 177 species (including 3 species of non-scleractinian corals) belonging to 48 genera and subgenera (including the genera _Millepora_ and _Heliopora_) known to date are listed with data as of frequency of occurrence and habitat.

INTRODUCTION

The territory of American Samoa comprises the six eastern islands of the Samoan archipelago. It is located in the tropical central south Pacific (14°S latitude, 170°W longitude) about 2300 nautical miles (4420 km) southwest of Hawaii and 80 miles (130 km) southeast of Western Samoa. Five of the islands are volcanic in origin and are aligned along the crest of a discontinuous submarine ridge which extends over 300 miles (480 km) and tends roughly northwest by southeast. My collecting was done on the five major inhabited islands of American Samoa which are the largest, Tutuila, Aunu´u (a small island located 1 mi (1.6 km) off the southeast coast of Tutuila), Ofu, Olesega, and Ta´u. The latter three islands are collectively referred to as the Manu´a group and lie about 66 miles (106 km) east of Tutuila. An uninhabited coral atoll, Rose Island is located 100 mi (161 km) east of Tutuila. One other island, Swains Atoll, is considered part of the Samoan group but is geographically a part of the Tokelau Island group and is not included in this study.

The first scientist to reach the Samoan (Navigator) Islands was probably Dr. Charles Pickering, a physician naturalist who explored Rose Atoll when ships of the United States Exploring Expedition under Capt. Wilkes met

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there in October 1839. Specimens he collected were added to those of James D. Dana who visited Tutuila for only four hours and made no coral collection in Samoa. In 1918 Dr. Alfred Mayor headed an expedition to American Samoa under the auspices of the Carnegie Institution of Washington. During three visits he collected 354 coral specimens which were donated to the National Museum of Natural History (NMNH), Smithsonian Institution and were described by Hoffmeister in 1925. In 1941 the NMNH received a collection of 380 corals from Mrs. Thompson. They were acquired while her husband served wih the U.S. Navy. These specimens were accompanied with no data although it was indicated that all were collected about Tutuila. In 1967 Dr. D.K. Hofman obtained 23 coral specimens from Tutuila. These are now at the Hessisches Landesmuseum in Darmstadt, W. Germany and were reported by Pillai and Scheer in 1973. This study incorporates these data with material I gathered in American Samoa.

MATERIAL AND METHODS

My collections of 690 specimens were made during four trips to Samoa between 1973-79. Specimens were taken from reef flats but mostly from deeper waters using mask and snorkel. Friends participated when SCUBA was used. All specimens were numbered at time of collection and data was recorded in a permanent record. Many photographs were taken of live specimens. All were cleaned, dried and transported to my home in Michigan for further study. They will eventually be placed in the collections of the Bernice P. Bishop Museum, Honolulu, Hawaii.

A typical coral reef as herein described may start in shallow inshore waters or a lagoon which might be 2 m deep, ascends to a shallow fore-reef, then to a reef crest usually out of water at low tide, a surge zone with spur and groove formation on windward (SW, Samoa), a sharp reef front dropping 5 - 10 m to a reef terrace and gradually descending to deep water. Most of the reefs have passes (Samoan:ava) of variable width and depth. The maximum width of reefs in American Samoa is about 500 m and most are much narrower. Taema Bank is a drowned barrier reef some three miles off the entrance of Pago Pago harbor. Also mentioned is the Airport lagoon which was dredged in stages from 1942 to 1973 during construction of Pago Pago International Airport complex. This lagoon lies between the runway and the Nu´uuli fore-reef. The dredgings contained some recent fossil coral (Goniopora, Acrhelia) species not found live in Samoa along with mollusc shells of the genus Cypraea with nacre virtually unblemished.

Corals are listed systematically by genera and alphabetically by species. Relative abundances are listed as: *abundant* when they are readily found in large numbers on most reef complexes; the 41 species listed as *common* are found on most reefs; the 45 species termed *sporadic* may be common but are noted in my own collection data a few times; those listed as *rare* were found only once or twice. In such instances the collection location is given with place names of Samoan villages which fronted the reef. Depths at which specimens were found are listed in meters. The Aua line mentioned is that of Mayor´s study in 1918.

This paper lists all corals by specific names given in the literature as coming from American Samoa. Studer´s (1901) specimens probably did not come from there and have not been included. Specific names which have been changed are listed within brackets with their synonyms. Behind each entry (H) appears if it was described by Hoffmeister (1925) and P&S if it was described by Pillai and Scheer (1973).

ANNOTATED LIST

Class	ANTHOZOA	
Subclass	HEXACORALLIA	Haeckel, 1896
Order	SCLERACTINIA	Bourne, 1900
Suborder	ASTROCOENIINA	Vaughan & Wells, 1943
Family	ASTROCOENIIDAE	Koby, 1890
Subfamily	ASTROCOENIINAE	Yabe & Sugiyama, 1935
Genus	STYLOCOENIELLA	Yabe & Sugiyama, 1935

Stylocoeniella armata (Ehrenberg, 1834).
Sporadic, lagoons, under rocks or coral growth, (1-2m)

Family	THAMNASTERIIDAE	Vaughan & Wells, 1943
Genus	PSAMMOCORA	Dana, 1846

Psammocora contigua (Esper, 1795) (H)
Abundance, Inner reef flats, lagoons (0-3m)
Psammocora folium Umbgrove, 1947
Rare, Reef face; Fagasa (3m)
Psammocora nierstraszi van der Horst, 1921
Rare, Reef flats (0-1m)
[*Psammocora samoensis* Hoffmeister, 1925] (H)
Synonym *P. nierstraszi*
Psammocora superficialis Gardiner, 1898
Locally common. Reef edge, reef slopes (0-3m)

Psammocora contigua var. tutuilensis Hoffmeister 1925 (H)
Rare, Reef flats (1-2m)

Family POCILLOPORIDAE Gray, 1842

Genus STYLOPHORA Schweigger, 1819

Stylophora mordax Dana, 1846
Sporadic, Passes, reef fronts & terraces (3-10m)

Genus SERIATOPORA Lamarck, 1816

Seriatopora hystrix var. gracilis Dana, 1846
Rare, Masefau & Fagatele Bays (2-5m)

Genus POCILLOPORA Lamarck, 1816

Pocillopora ankeli Scheer, 1975
Rare, Fagasa reef front (3m)
Pocillopora brevicornis Lamarck, 1816 (H)
Common, Back reefs (1-2m)
Pocillopora cf. bulbosa Ehrenberg, 1834
Sporadic, Lagoons (1-3m)
Pocillopora damicornis (Linnaeus, 1758) (H & P&S)
Abundant, Inshore lagoons, reef flats (0-5m)
Pocillopora danae Verrill, 1864
Rare, Masefau Bay (1m)
Pocillopora eydouxi Edwards & Haime, 1816 (H)
Common, Reef fronts, surge zones (1-5m)
Pocillopora cf. setchelli Hoffmeister, 1929
Rare, Reef flat near surge zone (0-1m)
Pocillopora verrucosa (Ellis & Solander, 1786)
Abundant, Reef flats, lagoons, reef fronts (1-10m)
Pocillopora woodjonesi Vaughan, 1918
Common, one area in Masefau Bay only (2-3m)

Family ACROPORIDAE Verrill, 1902

Genus ACROPORA Oken, 1815

Acropora abratanoides (Lamarck, 1816)
Rare, Fagasa (2m)
Acropora africana (Brook, 1893) (H)
Rose Atoll, Dr. Mayor.
Acropora aculeus Dana, 1846)
Sporadic, Reef slopes, Bays (1-3m)
Acropora arbuscula (Dana, 1846)
Locally common, Fagaʹitua pass (2-3m)
Acropora aspera (Dana, 1846)
Abundant, Lagoons, back reefs (0-3m)
Acropora brueggemanni (Studer, 1878)
Rare, Reef slope, Aua line (3m)

Acropora cerealis (Dana, 1846)
Common, Back reefs, grooves in reef crest (0-2m)

Acropora clathrata (Brook, 1893)
Rare, Taema Bank (25m)

Acropora corymbosa (Lamarck, 1816) (H, P&S)
Sporadic, Masefau (1-3m)

Acropora crateriformis (Gardiner, 1899) (H)
Locally common, reef flats, passes (1-3m)

Acropora cuspidata (Dana, 1846)
Rare, Faga´itua, Masefau passes (1-2m)

[*Acropora symbicyathus* (Brook, 1893)] (H)
Synonym *A. nasuta*

Acropora cytherea (Dana, 1846)
Sporadic, Reef face, Bays (2-20m)

Acropora delicatula (Brook, 1893)
Rare, Fagasa ((2m)

Acropora diversa (Brook, 1893)
Locally common, Aunu´u, Olesega (0-2m)

[*Acropora fructicosa* (Brook, 1893)] (H)
Synonym *A. humilis*

Acropora exigua (Dana, 1846) (H)
Sporadic, Lagoons, usually with *A. formosa*
(2-5m)

Acropora formosa (Dana, 1846) (H)
Abundant, Huge thickets; lagoons (0-20)

[*Acropora hebes* (Dana, 1846] (H)
Synonym *A. aspera*

Acropora humilis (Dana, 1846)
Abundant, Reef crests, surge zones, passes (0-2)

Acropora horrida (Dana, 1846)
Rare, Ofu lagoon (1m)

Acropora hyacinthus (Dana, 1846) (H, P&S)
Abundant, All reef fronts, passes (1-20m)

Acropora intermedia (Brook, 1893)
Locally common, Passes, lagoons (2-5m)

Acropora latistella (Brook, 1893)
Common, Reef crests (1-3m)

[*Acropora leptocyathus* (Brook, 1893)] (H)
Synonym *A. humilis*

Acropora longicyathus (Edwards & Haime, 1860)
Rare, Faga´itua pass (3m)

Acropora massawensis (von Marenzellar, 1906) (H)
Rare, Aua line, Dr. Mayor. Taema Bank (0-25m)

Acropora millepora (Dana, 1846)
Rare, Nu´uuli reef crest (0-1)

Acropora granulosa (Edwards & Haime, 1860)
Rare, Masefau (20m)

Acropora nana (Studer, 1878)
Common, Back reefs, grooves (102m)

Acropora nasuta (Dana, 1846)
Common, Reef crest, reef slopes, Bays (1-3m)

Acropora nobilis (Dana, 1846) (H)
Sporadic, passes, lagoons (3-5m)

Acropora pagoensis Hoffmeister, 1925 (H)

Rare, Dredged, Taema Bank, Dr. Mayor

Acropora palmerae Wells, 1954
Sporadic, Reef crest, surge zones (0-1m)

Acropora palifera (Lamarck, 1816) (H)
Sporadic, Reef fronts in bays (1-3m)

Acropora paniculata (Verrill, 1902)
Rare, Faga'itua pass (1-2m)

Acropora pinguis Wells, 1950
Rare, Fagamalo and Fagatele Bays (1-2m)

[*Acropora prolixa* (Verrill, 1866] (H)
Synonym *A. longicyathus*

Acropora pulchra (Brook, 1893) (H)
Common locally, Inner reef flat (1-2m)

[*Acropora quelchi* (Brook, 1893)] (H)
Synonym *A. cerealis*

Acropora rambleri (Bassett-Smith, 1890)
Rare, Masefau (20m)

Acropora robusta (Dana, 1846)
Sporadic, Reef slopes, grooves (1-5m)

Acropora rotumana (Gardiner, 1899) (H, P&S)
Common, Reef edge, surge zones (0-2m)

[*Acropora samoensis* (Brook, 1893)] (H)
Synonym *A. humilis*

Acropora schmitti Wells, 1950
Rare, Reef slope, Aua line (3m)

Acropora splendida Nemenzo, 1967
Rare, Airport lagoon, Aasu Bay (2-3m)

Acropora squarrosa (Ehrenberg, 1834)
Rare, Taema Bank (20m)

Acropora surculosa (Dana, 1846)
Sporadic, Reef slope (2-5m)

Acropora spicifera (Dana, 1846)
Sporadic, Passes, bays (1-3m)

[*Acropora syringodes* (Brook, 1893)] (H)
Synonym *A. nana* (?)

Acropora teres (Verrill, 1866) (H, P&S)
Rare, Reef flat (1-3m)

[*Acropora tutuilensis*, Hoffmeister, 1925] (H)
Synonym *A. clathrata*, *A. rotumana*

Acropora valida (Dana, 1846) (H)
Sporadic, Lagoons (1-2m)

[*Acropora vanderhorsti*, Hoffmeister 1925] (H)
Synonym *A. intermedia*

Acropora variabilis (Klunzinger, 1879)
Locally common, Lagoons, Olesega, Ofu

Acropora sp. 1
Sporadic. Passes, Colonies of heavy stalks with blunt tops, brilliant blue in situ (1-2m)

Genus ASTREOPORA de Blainville 1830

Astreopora cucullata Lamberts, 1980
Sporadic, Faga'itua pass Pago Pago Bay (2-4m)

Astreopora listeri Bernard, 1896

Rare, Reef flats (0-1m)

Astreopora myriophthalma (Lamarck, 1816)
Sporadic, Reef flats, lagoons, bays (0-3m)

[*Astreopora profunda* Verrill 1875] (H, P&S)
Synonym *A. myriophthalma* (usually when free rolling)

Astreopora scabra Lamberts, 1982
Sporadic, Reef flats, lagoons (0-3m)

Genus MONTIPORA de Blainville 1830

Montipora berryi Hoffmeister 1925 (H)
Sporadic, Lagoons, reef flats (1-4m)

Montipora bilamina Bernard 1897
Rare, Airport lagoon (3m)

Montipora caliculata (Dana, 1846)
Sporadic, passes, back reefs (1-3m)

Montipora composita Crossland 1952
Sporadic, Reef face in bays, passes (1-3m)

Montipora elschneri Vaughan 1918 (H)
Sporadic, Reef flats (0-1m)

Montipora foveolata (Dana, 1846)
Rare, Faga´itua pass (0-1m)

Montipora marshallensis Wells, 1954
Rare, Faga´itua pass (1-3m)

Montipora ehrenbergii Verrill, 1875
Common, Lagoons, back reefs (0.5-2m)

Montipora cf. *pulcherrima* Bernard, 1897
Rare, Faga´itua fore reef (1-2m)

Montipora acutata Bernard, 1897
Rare, Masefau (30m)

Montipora socialis Bernard, 1897
Sporadic, Reef face (0-2m)

Montipora spumosa (Lamarck, 1816) (H)
Sporadic, Reef flats (0-2m)

Montipora trabeculata Bernard, 1897 (H)
Sporadic, Ta´u, Olesega reef flats (1-3m)

Montipora tuberculosa (Lamarck, 1816) (H)
Common, Reef flats, lagoons (0-2m)

[*Montipora vaughani* Hoffmeister 1925] (H)
Synonym *M. socialis*

Montipora venosa (Ehrenberg, 1834) (H)
Common, lagoons, back reefs (0-3m)

Montipora verrilli Vaughan, 1970 (H)
Common, Reef flats, fore reefs (0-3m)

Suborder FUNGIINA Verrill 1865
Superfamily AGARICIICAE Gray 1847
Family AGARICIIDAE Gray 1847

Genus PAVONA Lamarck 1801

Pavona clavus Dana, 1846
Sporadic, Reef slopes, passes (3-10m)

Pavona decussata Dana, 1846 (H)
Common, Lagoons, back reefs (1-3m)

Pavona divaricata Lamarck, 1846 (H)
Common, Reef flats, back reefs, passes (0-3m)

Pavona duerdeni Vaughan, 1907
Rare, Taema Bank (30m)

Pavona fondifera Lamarck, 1816 (H)
Abundant, Reef flats (0-1m)

Pavona cf. *gigantea* Verrill, 1869
Rare, Taema Bank (30m)

Pavona maldivensis (Gardiner, 1905)
Rare, Masefau (2m)
Previously listed as *P. (pseudocolumnastrea) pollicata* Wells, 1954

Pavona varians Verrill, 1864
Common, Lagoons, reef edges, Taema Bank (2-30m)

Genus GARDINEROSERIS Scheer, 1975

Gardineroseris planulata (Dana, 1846)
Sporadic, Reef crests, surge zones (0-1m)

Genus LEPTOSERIS Edwards & Haime 1849

Leptoseris gardineri van der Horst, 1921 (H)
Dredged, Dr. Mayor, Pago Pago Harbor (25-50m)

Leptoseris scabra Vaughan, 1907 (H)
Dredged, Dr. Mayor, Pago Pago Harbor (15-30m)

Genus PACHYSERIS Edwards & Haime 1849

Pachyseris carinata Brueggemann 1879 (H)
Rare, Masefau (2m)

Pachyseris levicollis (Dana, 1846) (H)
Dredged, Dr. Mayor, Pago Pago Harbor; Airport dredgings.

Pachyseris speciosa (Dana, 1846) (H)
Dredged, Dr. Mayor, Pago Pago Harbor (15-30m)
Locally common, Masefau (30m)

Genus COSCINARAEA Edwards & Haime 1848

Coscinaraea columna (Dana, 1846) (H)
Sporadic, Reef fronts, terraces (1-20m)

Superfamily FUNGIICAE Dana 1846

Family FUNGIIDAE Dana 1846

Genus FUNGIA Lamarck 1801

Fungia concinna Verrill, 1864 (P&S)
Rare, Airport lagoon (1m)

Fungia echinata (Pallas, 1766)
Sporadic, Masefau (30m)

Fungia fungites (Linnaeus, 1758) (H)
Common, Reef terraces, Bays (2-5m)

Fungia granulosa Klunzinger 1869
Rare, Pago Pago Bay (30m)

Fungia patelliformis Boschma, 1923 (H)
Dredged, Dr. Mayor, Pago Pago Harbor (25-30m)

Fungia paumotensis Stutchbury, 1833 (H)
Rare, Airport lagoon (1m)

Fungia repanda Dana, 1846
Locally common, Masefau (3-5m)

Fungia scutaria Lamarck, 1816
Rare, Masefau reef (2m)

Genus HERPOLITHA Escholtz 1826

Herpolitha limax (Houttyn, 1772)
Locally common, Masefau (30m)

Herpolitha crassa Dana, 1846
Rare, Afono Bay (15m)

Genus LITHACTINIA Lesson 1831

Lithactinia novaehiberniae Lesson 1831
Thompson collection, no data

Superfamily PORITICAE Gray 1842

Family PORITIDAE Gray 1842

Genus GONIOPORA de Blainville 1830

Goniopora parvastella Ortman, 1888
Sporadic, Faga´itua Pass (3m)

Goniopora samoa I Bernard, 1903
Locally common, Airport dredgings

Goniopora sp. 1 cf. *somaliensis* Vaughan, 1907
Rare, Reef slopes, Aua line (2m)

Goniopora sp. 2 cf. *gracilis* (Bassett-Smith, 1890)
Rare, Utelei, Olesega (1-2m)

Goniopora sp. 3 cf. *traceyi* Wells, 1954
Rare, Olesega (1-2m)

Genus PORITES Link 1807

Porites andrewsi Vaughan, 1918 (H, P&S)
Abundant, Reef flats, back reefs (0-2m)

Porites latistella Quelch 1886
Locally common, Airport lagoon (0-2m)

Porites matthaii Wells, 1954
Sporadic, Reef flats, back reefs (0-1m)

Porites pukoensis Vaughan, 1907 (H)
Rare, Aua line (3m)

Porites lobata Dana, 1846 (H, P&S)
Sporadic, Back reefs, lagoons (0-5m)

Porites lutea Edwards & Haimes, 1851 (H, P&S)

Abundant, All collecting sites (0-30m)
Porites lutea var. haddoni Vaughan, 1918 (H)
Common, Reef flats, lagoons (0-5m)
Porites murrayensis Vaughan, 1918 (H)
Rare, Faga´itua lagoon (1m)
Porites queenslandi septima Bernard, 1905
Rare, Taema Bank (30m)
Porites lichen Dana, 1846
Sporadic, Surf zones, passes, Taema Bank (0-30m)

Genus PORITES (SYNARAEA) Verrill 1864

Synaraea horizontalata Hoffmeister, 1925 (H)
Sporadic, Masefau, Pago Pago Bay (10-30m)
Synaraea faustino Hoffmeister, 1925 (H)
Dredged by Dr. Mayor (7-12m)
Synaraea undulata Klunzinger, 1879 (H)
Abundant, Reef flats, passes, lagoons (0-5m)

Genus ALVEOPORA de Blainville 1830

Alveopora allingi Hoffmeister, 1925 (H)
Dredged, Dr. Mayor, Pago pago Harbor (25-35m)
Alveopora verrilliana Dana, 1872 (H)
Sporadic, Reef flats, lagoons, back reefs (0.5-5m)
Alveopora viridis (Quoy & Gaimard, 1827)
Rare, Fagasa, Utelei (bright green) (1-2m)

Suborder FAVIINA Vaughan & Wells 1943
Superfamily FAVIICAE Gregory 1900
Family FAVIIDAE Gregory 1900
Subfamily FAVIINAE Gregory 1900

Genus FAVIA Oken 1815

Favia favus (Forskaal, 1775) (H)
Sporadic, Reef flats (0-3m)
Favia laxa (Klunzinger, 1879)
Rare, Fagasa (15m)
Favia pallida (Dana, 1846) (H, P&S)
Sporadic, Reef flats, reef terraces (0-5m)
Favia rotumana (Gardiner, 1899) (H)
Common, Passes, bays (1-10m)
Favia speciosa (Dana, 1846)
Rare, Faleosoa (on Ta´u) (0.5m)
Favia stelligera (Dana, 1846) (H)
Sporadic, Reef flats, reef terrces (0-10m)

Genus FAVITES Link 1807

Favites abdita (Ellis & Solander, 1786) (H)
Common, Reef flats (0-3m)
Favites halicora (Ehrenberg, 1834) (H)
Common, Reef flats, Taema Bank (0-30m)

Favites chinensis Verrill, 1866
Rare, Masefau, Faga'itua reef flat (1m)
Favites russelli Wells, 1954
Rare, Taema Bank (30m)

Genus GONIASTREA Edwards & Haime 1848

Goniastrea edwardsi Chevalier 1971
Rare, Breaker's Point reef flat (0.5m)
Goniastrea favulus (Dana, 1846)
Sporadic, Faga'itua pass (0-2m)
Goniastrea palauensis Yabe & Sugiyama 1934
Rare, Taema Bank (30m)
Goniastrea pectinata (Ehrenberg, 1834) (H)
Rare, Poloa, Fagamalo (1-2m)
Goniastrea retiformis (Lamarck, 1816) (H)
Sporadic, Reef flats, passes (0-3m)

Genus PLAYTGYRUS Ehrenberg 1834

[*Platygyrus daedalea* (Ellis & Solander, 1786)]
Name pre-occupied by a Forskaal species,
Synonym *P. rustica*
[*Meandra esperi* (Edwards & Haime, 1857)]
Synonym *P. rustica*
Platygyrus lamellina Ehrenberg, 1834 (H)
Rare, Masefau, Taema Bank (1-20m)
Platygyrus rustica (Dana, 1846)
Common, Reef flats, lagoons (0-5m)

Genus LEPTORIA Edwards & Haime 1848

Leptoria phrygia (Ellis & Solander, 1786) (H, P&S)
Common, Reef flats to Taema Bank (0-30m)
[*Leptoria tenuis* (Dana, 1846)] (H)
Synonym *L. phrygia*

Genus OULOPHYLLIA Edwards & Haime 1848

Oulophyllia crispa (Lamarck, 1816)
Rare, Masefau (25m)

Genus HYDNOPHORA Fisher de Waldheim 1807

Hydnophora exesa (Pallas, 1766)
Sporadic, Passes, bays, Taema Bank (2-30m)
Hydnophora microconos (Lamarck, 1816) (H, P&S)
Common, Reef flats to Taema Bank (0-30m)

Subfamily MONTASTREINAE Vaughan & Wells 1943

Genus MONTASTREA de Blainville 1830

Montastrea curta (Dana, 1846)

Common, Lagoons, reef flats, fore-reefs (0-5m)
[*Orbicella curta* Dana, 1846]
Synonym *M. curta*

Genus PLESIASTREA Edwards & Haime 1848

Plesiastrea versipora (Lamarck, 1816) (P&S)
Rare, Falesao (1m)

Genus DIPLOASTREA Matthai 1914

Diploastrea heliopora (Lamarck, 1816) (P&S)
Sporadic, Reef slopes, Bay terraces (0.5-10m)

Genus LEPTASTREA Edwards & Haime 1848

Leptastrea purpurea (Dana, 1846) (H)
Abundant, Inshore waters, reef flats (0-1m)
Leptastrea bottae Milne-Edwards & Haime 1848
Rare, Fagamalo (1m)

Genus CYPHASTREA Edwards & Haime 1848

Cyphastrea chalcidicum (Forskaal, 1775)
Rare, Taema Bank (30m)
Cyphastrea cf. *gardineri* Matthai, 1914
Sporadic, Inshore waters, lagoons (0-1m)
Cyphastrea microphthalma (Lamarck, 1816) (H)
Rare, Dredged by Dr. Mayor (35m)

Genus ECHINOPORA Lamarck 1816

Echinopora lamellosa (Esper, 1795)
Locally common, Faga´itua pass, Masefau (3-5m)

Family OCULINIDAE Gray 1847

Subfamily GALAXINAE Vaughan & Wells 1943

Genus GALAXEA Oken 1815

Galaxea clavus (Dana, 1846)
Sporadic, Reef terraces, Leone, Fagatele Bays (3-5m)
Galaxea fascicularis (Linnaeus, 1758) (H, P&S)
Common, Reef flats, terraces (0-25m)

Genus ACRHELIA Edwards & Haime 1849

Acrhelia horrescens (Dana, 1846)
Rare, Airport dredgings

Family MUSSIDAE Ortman 1890

Genus ACANTHASTREA Edwards & Haime 1848

Acanthastrea echinata (Dana, 1846)
Rare, Poloa (1m)

Genus LOBOPHYLLIA de Blainville 1830

[Lobophyllia corymbosa (Forskaal, 1775)]
Reported by Pillai & Scheer. No data. (P&S)
Lobophyllia costata (Dana, 1846)
Common, Passes, reef slopes, terraces (2-5m)
[Mussa sinuosa (Lamarck, 1816)] (H)
Synonym L. costata

Genus SYMPHYLLIA Edwards & Haime 1848

Symphyllia nobilis (Dana, 1846) (H)
Rare, Matu´u, Fagatele Bay (0-4m)

Family MERULINIDAE Verrill 1866

Genus MERULINA Ehrenberg 1834

Merulina ampliata (Ellis & Solander, 1786) (H)
Rare, Fagatele Bay (3m)

Family PECTINIIDAE Vaughan & Wells 1943

Genus ECHINOPHYLLIA Klunzinger 1879

Echinophyllia aspera (Ellis & Solander, 1786)
Rare, Utelei (30m)

Genus OXYPORA Saville-Kent 1871

Oxypora lacera (Verrill, 1864)
Rare, Masefau (3m)

Suborder CARYOPHYLLIINA Vaughan & Wells 1943
Superfamily CARYOPHYLLIICAE Gray 1847
Family CARYOPHYLLIIDAE Gray 1847
Subfamily EUSMILIINAE Edwards & Haime 1857

Genus EUPHYLLIA Dana 1846

Euphyllia glabrescens (Chamisso & Eysenhardt, 1821) (H)
Sporadic, Masefau, Avatele passage (3m)

Genus PLEROGYRA Edwards & Haime 1848

Plerogyra simplex Rehberg, 1892
Rare, Utelei reef front (1m)

Suborder DENDROPHYLLIIDA Gray 1847
Family DENDROPHYLLIIDAE Gray 1847

Genus TUBASTREA Lesson 1831

Tubastrea coccinea Lesson, 1831
Rare, Aua reef slope, Faga´itua pass (1-3m)
[*Dendrophyllia diaphana* Dana, 1846] (H)
Synonym *Tubastrea aurea* = *T. coccinea*

Genus TURBINARIA Oken 1815

Turbinaria frondens Dana, 1846
Sporadic, Leone terrace, Masefau terrace (2-6m)
Turbinaria peltata (Esper, 1794)
Rare, Massefau (30m)

Subclass OCTOCORALLIA Haeckel 1896
Order COENOTHECALIA Bourne 1895
Family HELIOPORIDAE Moseley 1876

Genus HELIOPORA de Blainville 1834

Heliopora coerulea (Pallas, 1766)
Common, Reefs of Ta´u, Ofu, and Olesega only (0-2m)

Class HYDROZOA Huxley 1856
Order MILLEPORINA Hickson 1901
Family MILLEPORIDAE Fleming 1828

Genus MILLEPORA Linnaeus 1758

Millepora platyphylla Hemprich & Ehrenberg, 1834
Common, Reef flats, reef fronts (0-3m)
Millepora tenera Boschma 1949
Locally common, Ofu back reefs (1-2m)
[*Millepora alcicornis* Linnaeus, 1758] (H)
Synonym Probably *M. tenera*
[*Millepora truncata* Dana, 1846] (H)
Synonym *M. platyphylla*

CONCLUSIONS

This check list is neither exhaustive nor final. No attempt was made to collect on every reef and most reef terraces remain relatively unexplored. In all, 174 species of scleractinian corals are presented. These represent 48 genera and subgenera. Also listed are 3 species, one a *Heliopora* and two of *Millepora*; though not scleractinian, they certainly are reef formers. In all there are 199 nominal listings of which I considered 22 invalid.

Because a coral species was reported from Samoa does not mean that it can be readily collected there. Frequently a coral listed as rare was the only specimen of that kind seen in many hours of searching and may have been the only relict or new colony of its type in the Islands. The number of species found increases with the time spent searching, the astuteness of the collector, his purpose in collecting and where he happens to collect. I was primarily looking for certain genera and must certainly have overlooked species of other genera which were not my main concern.

I accept responsibility for all identifications listed. Coral taxonomy as based on skeletal differences is an imprecise science and an ongoing search for adjunctive methods to aid in classification is in progress. As long as this state continues, many species determinations must necessarily be considered tentative and this entire study can only be regarded as one in a series.

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ATOLL RESEARCH BULLETIN
No. 265

SOME MARINE BENTHIC ALGAE FROM CHRISTMAS ISLAND, LINE ISLANDS

BY

WILLIAM J. GILBERT

ISSUED BY
THE SMITHSONIAN INSTITUTION
WASHINGTON, D. C., U.S.A.

SEPTEMBER 1983

SOME MARINE BENTHIC ALGAE FROM CHRISTMAS ISLAND, LINE ISLANDS

by William J. Gilbert*

Published records of marine algae from the Line Islands are restricted to Palmyra, Fanning, and Christmas Islands. Howe and Lyon (1916), Dawson, Aleem and Halstead (1955), Dawson (1959) and Taylor (1966b) have all listed algae from Palmyra I. More recently a series of papers treat the benthic marine algae of Fanning I. (DeWreede and Doty, 1970; Tsuda, Russell, and Doty, 1973; and Tsuda, 1973.) Only occasional reference to the marine algae of Christmas I. can be found. Taylor (1966a, 1966n) cites _Turbinaria ornata_ (Turner) J. Ag. and _Caulerpa cupressoides_ (West) C. Ag., v. _mammilosa_ (Mont.) W.-van Bosse. Tsuda (1968) reported the presence of _Ulva fasciata_ Delile and _Halimeda lacunalis_ Taylor is mentioned from Christmas I. in the paper by DeWreede and Doty (1970). There is mention, also, of a few benthic algae from Cochrane Reef in a paper by Helfrich, et al. (1968). Voucher specimens are cited for Christmas I. species only by Taylor.

The algae reported below are from two sources: 1) collections made by the author between June 19 and 23, 1963, who accompanied a group led by Philip Helfrich that was working on ciguatera fish poisoning (Helfrich, et al., (1968) at Christmas Island and 2) some miscellaneous collections provided through the kindness of Dr. Maxwell S. Doty, University of Hawaii.

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SPECIES LISTING

Except where otherwise noted, collection numbers are those of Gilbert´s 1963 collections.

DIVISION CYANOPHYTA

Lyngbya majuscula (Dillw.) Harvey ex Gomont
63025, common on reef flat, Commissioner´s Reef, London, 20 VI 1963.

DIVISION CHLOROPHYTA

Acetabularia mobii Solms-Laubach
63008, on corals, Cochrane Reef, Londom, 19 VI 1963.

Boodlea composita (Harvey) Brand
Doty 20050, N.E. Point of Christmas Island, 3 VI 62.

Bryopsis pennata Lam.
63009, on coral, Cochrane Reef, London, 19 VI 63.

Caulerpa racemosa (Forsskal) J. Ag.
63028, in holes of coral along surge channels, Commissioner´s Reef, London, 20 VI 1963.

Caulerpa racemosa (Forsskal) J.Ag. var. *exigua* (W.-van Bosse)
Eubank 63046 and 63047, Commissioner´s Reef, London, 22 VI 1963. This material was in the drift in large, tightly packed, matted clumps.

Caulerpa racemosa (Forsskal) J.Ag. var. *peltata* (Lam.) Eubank
63013, Cochrane Reef, London, 19 VI 1963.

Caulerpa serrulata (Forsskal) J. Ag. emend Børg.
63048, in drift, Commissioner´s Reef, London, 22 VI 1963; CRL 2807.3, on shore, west side of lagoon above London, 24 XI 1964; Doty 26700, East London, 26 IV 1977, coll. Sapayani Adjak.

Caulerpa urvilliana Mont.
63019, on reef, main USA Camp, 20 VI, 1963; 63051, abundant on reef flat near Poland Village, 23 VI 1963; Doty 18981, seaward reef flats off "L" site, 16 V 1962, coll. R.F. Palumbo; Doty 18982, N.E. Point of Christmas Island, 3 VI 1962; CRL 2802.1, west reef, 1/2 mile north of London, in shallows but covered at low tide, 23 XI 1964; Doty 20014.

Caulerpa webbiana Mont.
CRL 2782.5, north reef near airport, from exposed reef rocks subject to wave battering, 23 XI 1964.

Cladophora spp.

Doty 20026, 16 V 1962, coll. R.F. Palumbo. The material consists of a mixture of two species.

Cladophoropsis _sundanensis_ Reinbold

63057, on vertical walls of small tide pools, reef flat, Bay of Wrecks, 23 VI 1963.

Codium sp.

CRL 2781.1, north reef, found in drift, 23 XI 1964. The material is very close to _C._ _edule_ Silva, the thallus consisting of cylindrical anastamosing branches, 2-3 mm diam., more or less matted and prostrate, with utricles simple, not forming secondary utricles, and well within the size range of _C._ _edule_. There was no evidence of gametangia.

Derbesia _minima_ W.-van Bosse

63016, attached to iron plates of scow, London, 20 VI 1963; 63026, Commissioner´s Reef, London, 20 VI 1963.

Dictyosphaeria _setchellii_ Børg.

63002, in drift, main U.S.A. Camp, 19 VI 1963; 63052, on reef, near Poland Village 23 VI 1963; 63058, on reef flat, Bay of Wrecks, 23 VI 1963; Doty 18970.

Enteromorpha _lingulata_ J. Ag.

63022, attached to corals, Commissioner´s Reef, London, 20 VI 1963; 63050, in small tide pool near the Royal Navy Dock, London, 22 VI 1963.

Enteromorpha _clathrata_ (Roth) Greville

63010, on coral, Cochrane Reef, London, 19 VI 1963.

Halimeda _fragilis_ Taylor

63004, in drift, main U.S.A. Camp, 19 VI 1963; 63053, on reef flat, Poland Village 23 VI 1963; Doty 18977, N.E. Point of Christmas Island, 3 VI 1962; Doty 18989, `16 V 1962, coll. Ralph F. Palumbo.

Halimeda _gracilis_ Harvey ex J. Ag.

63001, in drift, main U.S.A. Camp, 1963; 63012, Cochrane Reef London, 19 VI 1963.

Halimeda lacunalis Taylor

63006, in drift, main U.S.A. Camp, 19 VI 1963, 63020, on reef, main U.S.A. Camp, 20 VI 1963.

Valonia fastigiata Harvey

63021, in drift, Commissioner's Reef, London, 20 VI 1963; CRL 2782.1, forming mats over exposed reef rocks, subject to wave battering, north reef near airport, 23 XI 1964; Doty 20010.

Ulva fasciata Delile

63018, attached to iron plates of scow, London, 20 VI 1963; Doty 26702, Southeast Point, 7 V 1977, coll. Sapayani Adjak; Doty 28411, in lagoon, E. of London, 16 IV 1977, coll. Sapayani Adjak; CRL 2803, beach reef, 1/2 mile north of London, 23 XI 1964.

PHAEOPHYTA

Dictyota friabilis Setchell

63014, on coral, Cochrane Reef, London, 19 VI 1963.

Ectocarpus indicus Sonder

63024, Commissioner's Reef. London, 20 VI 1963.

Lobophora variegata (Lam.) Womersley

63011, on coral, Cochrane Reef, London, 19 VI 1963; 63022, attached to corals, Commissioner's Reef, London, 20 VI 1963.

Turbinaria ornata (Turner) J. Ag.

63023A, forming dense growth on reef flat, main U.S.A.Camp, 20 VI 1963.

RHODOPHYTA

Acanthophora spicifera J. Ag.

Doty 28409, lagoon, E. of London, 16 IV 1977, coll. Sapayani Adjak.

Acrochaetium gracile Børg.

63049, epiphytic on Turbinaria, Cochrane Reef, 22 VI 1963.

Ceramium sp.

64027, scraped from iron plates of scow, London, 20 VI 1963.

Pterocladia capillacea (Gmelin) Bornet

63056, Reef flat near Poland Village, 23 VI 1963.

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ATOLL RESEARCH BULLETIN
No. 266

AN ACCOUNT OF THE VEGETATION OF KAVARATTI ISLAND, LACCADIVES

BY

P. Sivadas, B. Narayanan and K. Sivaprasad

Issued by

THE SMITHSONIAN INSTITUTION
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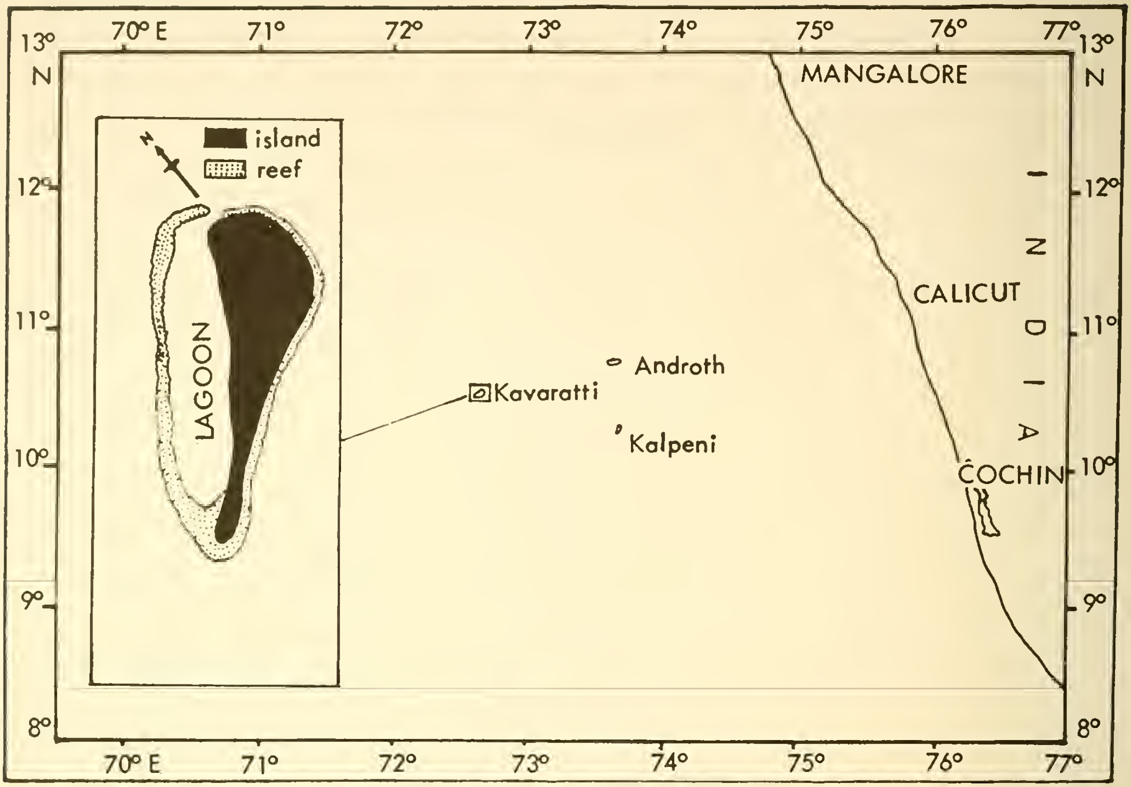

Figure 1. Location map of Kavaratti Island in relation to Indian coast line.

AN ACCOUNT OF THE VEGETATION OF KAVARATTI ISLAND, LACCADIVES

By P. Sivadas[1], B. Narayanan[1] and K. Sivaprasad[2]

The Laccadive archipelago, consisting of about 20 islands and separated from the Indian peninsula by about a 290 kilometre stretch of sea, offers a unique ground to study the insular flora. A few attempts have been made to describe the flora of these islands in general (Gardiner, 1906; Prain, 1890-94). However, the occurrence and distribution of the plant species and the ecological variations exhibited by them, if any, have hitherto not been studied in these islands. As a prelude to such a comparison, the distribution of the plants of individual islands is being studied. A short account of the climatic conditions and soil chemistry of Kavaratti Island is mentioned before describing its flora.

Kavaratti, Headquarters of the Union Territory of Lakshadweep (Laccadives), lies on a NE-SW axis at 10°33´N latitude and 72°36´E longitude (Fig. 1). The length of the island is 5.82 km and the maximum width is 1.53 km, the toal area is 3.63 sq. km. The island has an extensive lagoon on the western side which is separated from the sea by a coral reef.

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CLIMATE

Kavaratti has a humid tropical climate. The annual minimum temperature varies from 22.6° to 27°C while the annual maximum temperature varies from 29.3° to 32.6° C. December-January are the coolest months while April-May are the hottest. The island has the benefit of both SW and NE monsoons. The SW monsoon is much more severe, characterized by heavy gales and winds. The NE monsoon is milder. The total number of rainy days varies from 65 to 85. The average monthly rainfall for the years 1970 to 1975 varies from 130 to 190 mm.

SOIL

The soil is formed by the dead, disintegrated and weathered skeletons of corals. It is estimated to contain 95% calcium carbonate in the form of aragonite. The pH of the soil varies from 8 to 8.4. Percentage of organic carbon is 1 to 1.4. Available phosphorus is present at the rate of 98.8 kg/Ha and available potash at the rate of 65 kg/Ha. The nitrification of the soil is affected by the alkalinity to a considerable extent. The soil is of an open character and possesses good drainage and aeration.

VEGETATION

During the present study, emphasis was given to determining the plant species represented in the island. The plants are taxonomically arranged according to the Bentham and Hooker system. For the convenience of collection and recording, the whole island is arbitrarily divided into four zones, and the distributions of some of the plants have been shown in Figs. 2 and 3.

Kavaratti has a good vegetation cover. The northern portion of the island is inhabited and plants like *Musa paradisiaca*, *Colocasia esculenta*, *Carica papaya*, *Amaranthus* sp., etc., are cultivated here. *Moringa oleifera*, *Artocarpus altilis* and *Terminalia catappa* are seen growing wild in zones 1 and 2. The southern end of the island has a shrub jungle consisting of plants like *Scaevola sericea*, *Premna obtusifolia*, *Calophyllum inophyllum*, *Pandanus odoratissimus*, *Morinda citrifolia*, etc. Trees like *Casuarina equisetifolia*, *Zizyphus mauritiana* and

Thespesia populnea are distributed throughout zones 1, 2 and 3. *Tournefortia argentea* and *Pemphis acidula* are seen on the western side of the island in zones 3 and 4. *Ficus bengalensis* does not seem to adhere to any specific pattern of distribution and is seen at random in the island.

The ground vegetation consists of plants like *Spinifex littoreus*, *Argemone mexican*, *Ipomoea pes-caprae*, *Aerva lanata*, *Alysicarpus monilifer*, *Evolvulus alsinoides*, *Commelina bengalensis*, etc. Distribution of *Spinifex littoreus* is restricted to certain areas in zones 1, 3 and 4. Zones 1 and 4 have an extensive coverage of herbs like *Kyllinga monocephala* and *Setari italic*. *Blumea membranace* is seen distributed in zones 3 and 4. There is an extensive growth of *Stachytarpheta indic* in zones 2 and 3 especially in front of the Secretariat buildings. *Lantana camara* and *Bougainvillea spectabilis* are two plants occurring throughout the island. The Gandhi Centenary Park has a number of recently introduced garden plants like *Codiaeum variegatum*, *Ipomoea quamoclit*, *Hibiscus rosa-sinensis*, *Cosmos sulphureus*, *Nerium indicum*, *Pedilanthus tithymaloides*, etc.

The Lakshadweep administration is maintaining an agricultural farm where a number of common vegetables like *Hibiscus esculentus*, *Solanum melongena*, *Capsicum minimum*, *Trichosanthes cucumerina*, *Cucumis sativus*, etc. are grown. *Eucalyptus* sp. is now grown in this farm as a trial.

It appears that an attempt was made to cultivate *Oryza sativa* in this island long ago. The information collected from the islanders corroborates well the evidence of soil removed from certain areas in the island to make paddy fields. The soil thus removed was dumped on other portions of the island, thus making artificial sand dunes. However, paddy cultivation here appears to have been unsuccessful. This may be because of the high alkalinity of the soil and the unavailability of sufficient fresh water for irrigation.

Cocos nucifera is the main plantation crop. Two varieties are grown; the common tall variety and the endemic micro-variety. The micro-variety is small and is under 5′ or 6′ in height. The yield is very high though the size of the fruit is comparatively small. The ′Copra′ obtained from these coconuts contains a high level of oil when compared to the ordinary variety. Some of the islanders are cultivating *Piper nigrum* and *Manihot esculenta* in their private lands. *Piper betle* and *Areca catechu* are the two other common plants grown by the islanders.

There is a sea grass bed consisting of *Thalassia hemprichii* and *Syringodium isoetifolium* on the bottom of the lagoon, growing from about low water neap tide and continuing out to a distance of about 100 m. In certain parts it extends even farther than 100 m forming smaller patches in the lagoon. Usually a huge bulk of dead *Thalassia hemprichii* is washed ashore and it is possible that it also contributes greatly to the particulate organic carbon of the lagoon.

A total of one hundred and seventeen terrestrial plants have been collected from the 3.629 sq. km island alone. Forty-eight families of angiosperms are represented here. However, this investigation has not revealed any endemic forms.

New plants are being introduced constantly and the human influence is quite visible. Plants like *Alysicarpus monilifer*, *Crotalaria fysonii*, *Codiaeum variegatum*, *Ipomoea quamoclit* seem to have been introduced since they are not recorded by Gardiner (1906). Following is the complete list of plants collected from Karawatti Island:

	PAPAVERACEAE
Argemone mexicana L.	H 001*, Z1, Z2.
	CAPPARIDACEAE
Cleome viscosa L.	IS, Z1, Z2.
	PORTULACACEAE
Portulaca oleracea L.	IS, Z1, Z2, Z3, Z4.
	GUTTIFERAE
Calophyllum inophyllum L.	IS, Z1, Z2, Z3, Z4.
	MALVACEAE
Abutilon indicum (L.) Sweet	H 002, Z2, C3.
Gossypium barbadense L.	IS, Z1, Z2, Z3.

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* H - Herbarium kept in Regional Centre, NIO. (No standard symbol available).

IS - Identified on sight.

Z - Zone.

\# - Names followed by # have been substituted by the editors to correspond to recent changes or in some cases for consistency with what seems the best current usage. Hence they are not the responsibility of the author and his advisors. It is with some hesitation that we publish the numerous sight records that are not supported by specimens. F.R.F., ed.

Hibiscus rosa-sinensis L.	IS, Z2.
Hibiscus esculentus L.	IS, Z2, Z3.
Thespesia populnea (L.) Sol. ex Correa	H 003, Z1, Z2, Z3.
TILIACEAE	
Corchorus trilocularis L.	H 004, Z2, Z4.
Corchorus capsularis L.	IS, Z3, Z4.
RUTACEAE	
Citrus grandis (L.) Osbeck #	IS, Z1.
Citrus medica L.	IS, Z1.
MELIACEAE	
Azadirachta indica A. Juss.	H 005, Z1, Z2, Z3.
RHAMNACEAE	
Zizyphus mauritiana Lamk.	H 006, Z1, Z2.
Zizyphus sp.	H 007, Z1, Z2.
VITACEAE	
Leea sp.	H 008, Z2.
SAPINDACEAE	
Dodonaea viscosa L.	IS, Z3, Z4.
Cardiospermum halicacabum L.	IS, Z2, Z3, Z4.
LEGUMINOSAE	
Alysicarpus monilifer DC.	H 009, Z1, Z2, Z4.
Crotalaria fysonii Dunn.	IS, Z1, Z2, Z3.
Crotalaria verrucosa L.	H 010, Z2.
Crotalaria retusa L.	H 012, Z2.
Cassia occidentalis L.	IS, Z2, Z3.
Cassia tora L.	IS, Z2, Z3.
Cassia sp.	H 013, Z2, Z3.
Clitoria ternatea L.	IS, Z1, Z2.
Desmodium gangeticum (L.)DC.	IS, Z1, Z2, Z3.
Indigofera tinctoria L.	H 014, Z2, Z3.
Phaseolus sp.	H 015, Z2, Z3.
Tephrosia sp.	H 016, Z2, Z3.
COMBRETACEAE	
Terminalia catappa L.	H 017, Z1, Z3.
MYRTACEAE	
Psidium guajava L.	IS, Z2.
LYTHRACEAE	
Pemphis acidula Forst.	IS, Z3, Z4.
CARICACEAE	
Carica papaya L.	IS, Z1, Z2, Z3.
CUCURBITACEAE	
Trichosanthes cucumerina L.	H 018, Z1, Z2, Z3.
Cucumis sativus L.	IZ, Z1, Z2.
Coccinia grandis (L.) Voight	H 019, Z1, Z2, Z3.

RUBIACEAE

Morinda citrifolia L.	IS, Z3.
Hedyotis umbellata (L.) Lamk.	H 020, Z2, Z4.

COMPOSITAE

Blumea membranacea DC	H 021, Z3, Z4.
Cosmos sulphureus Cav.	H 022, Z2.
Spilanthes calva DC.	H 023, Z2, Z3, Z4.
Veronia cinerea (L.) Less.	H 024, Z2, Z3, Z4.
Tridax procumbens L.	H 025, Z2,Z3, Z4.
Zinnia sp.	H 026, Z2.

GOODENIACEAE

Scaevola sericea Vahl #	H 027, Z4.

SAPOTACEAE

Chrysophyllum cainito L.	IS, Z2.
Manilkara zapota (L.) P.V. Royen #	IS, Z2.

APOCYNACEAE

Neisosperma oppositifolia (Lamrk.) Fosberg & Sachet #	H 028, Z2.
Parsonsia alboflavescens (Dennst.) Mabberly	H 029, Z2, Z3.
Nerium oleander var. *indicum* (Mill.) Deg. #	H 030, Z2, Z3.

ASCLEPIADACEAE

Calotropis gigantea R. Br.	IS, Z1, Z2.

BORAGINACEAE

Tournefortia argentea L.f.	H 031, Z3, Z4.

CONVOLVULACEAE

Ipomoea pes-caprae (L.) Sweet	IS, Z2, Z3, Z4.
Ipomoea macrantha R. & S. #	H 032, Z3, Z4.
Evolvulvus alsinoides L.	H 033, Z1, Z2, Z4.
Ipomoea quamoclit L.	H 034, Z2.
Cuscuta reflexa Roxb.	IS, Z3.

SOLANACEAE

Capsicum minimum Roxb.	IS, Z2.
Capsicum frutescens L.	IS, Z2.
Datura stramonium L.	H 035, Z2, Z3.
Solanum lycopersicum L. #	IS, Z2.
Solanum melongena L.	IS, Z2.

BIGNONIACEAE

Tecoma stans (L.) H.B. & K.	H 036, Z2, Z3.

ACANTHACEAE

Andrographis sp.	H 037, Z1,Z2, Z3,Z4.
Justicia procumbens L.	IS, Z1, Z2, Z3, Z4.

VERBENACEAE

Clerodendrum inerme (L.) Gaertn.	H 038, Z2.
Lantana camara L.	IS,Z1, Z2, Z3, Z4.
Premna obtusifolia R. Br.	H 039, Z3.
Stachytarpheta indica Vahl	H 040, Z2, Z3.
Lippia nodiflora (L.) Rich.	H 041, Z2, Z4.

LABIATAE

Ocimum sanctum L.	IS, Z2.
Anisomeles indica O. Ktze.	H 042, Z1, Z2, Z3.

NYCTAGINACEAE

Boerhavia diffusa L.	H 043, Z1, Z3,Z3.
Bougainvillea spectabilis Willd.?	IS, Z2, Z3.

AMARANTHACEAE

Achyranthes aspera L.	H 044, Z1, Z2, Z3.
Amaranthus gangeticus L.	IS
Amaranthus spinosus L.	IS
Amaranthus caudatus L.	IS
Amaranthus viridis L.	IS
Aerva lanata (L.) Juss.	H 045, Z1, Z2, Z3,Z4.
Celosia argentea L.	IS,Z2, Z3.

PIPERACEAE

Piper nigrum L.	IS, Z1, Z2.
Piper betle L.	IS, Z1, Z2.

EUPHORBIACEAE

Acalypha indica L.	H 046, Z2, Z3.
Codiaeum variegatum L.	H 047, Z2.
Ricinus communis L.	H 048, Z1.
Pedilanthus tithymaloides (L.) Poit.	H 049, Z2, Z3.
Emblica officinalis Gaertn.	H 050, Z2.
Manihot esculenta Crantz	IS, Z1.
Euphorbia tirucalli L.	IS, Z3.
Euphorbia rosea Retz	IS, Z2, Z3, Z4.
Euphorbia thymifolia L.	IS, Z2, Z3, Z4.
Euphorbia hirta L.	IS, Z1, Z2, Z3, Z4.

MORACEAE

Artocarpus altilis (Park.) Fosberg	IS, Z1, Z2.
Ficus religiosa L.	IS, Z1, Z2, Z3, Z4.
Ficus bengalensis L.	IS, Z1, Z2, Z3.

URTICACEAE

Pouzolzia zeylanica(L.)Benn.	H 051, Z1, Z2, Z4.

CASUARINACEAE

Casuarina equisetifolia L.	H 052, Z1, Z2, Z3.

CANNACEAE

Canna indica L.	IS, Z3.

MUSACEAE

Musa paradisiaca L.	IS, Z1, Z2, Z3.

	AMARYLLIDACEAE
Agave sp.	IS, Z2, Z3.
	DIOSCOREACEAE
Dioscorea alata L.	IS, Z1, Z2, Z3.
	LILIACEAE
Gloriosa superba L.	H 053, Z2, Z3.
Rhoeo spathacea (Sw.) Stearn	IS, Z2, Z3.
Asparagus racemosus Willd.	IS, Z3.
	COMMELINACEAE
Commelina benghalensis L.	H 054, Z1, Z2, Z3,Z4.
	ARECACEAE
Areca catechul L.	IS, Z1.
Cocos nucifera L.	IS, Z2, Z2, Z3, Z4.
	PANDANACEAE
Pandanus odoratissimus L.f.	IS, Z4.
	ARACEAE
Alocasia macrorrhiza (L.) Schott	IS, Z1, Z2.
Colocasia esculenta (L.) Schott	IS, Z1, Z2.
	CYPERACEAE
Cyperus kyllingia Endl. #	IS, Z1, Z2, Z3, Z4.
	GRAMINEAE
Spiniflex littoreus Merr.	IS, Z1, Z3, Z4.
Saccharum officinarum L.	IS, Z2.
Setaria italica Beauv.	IS, Z1, Z2, Z3, Z4.

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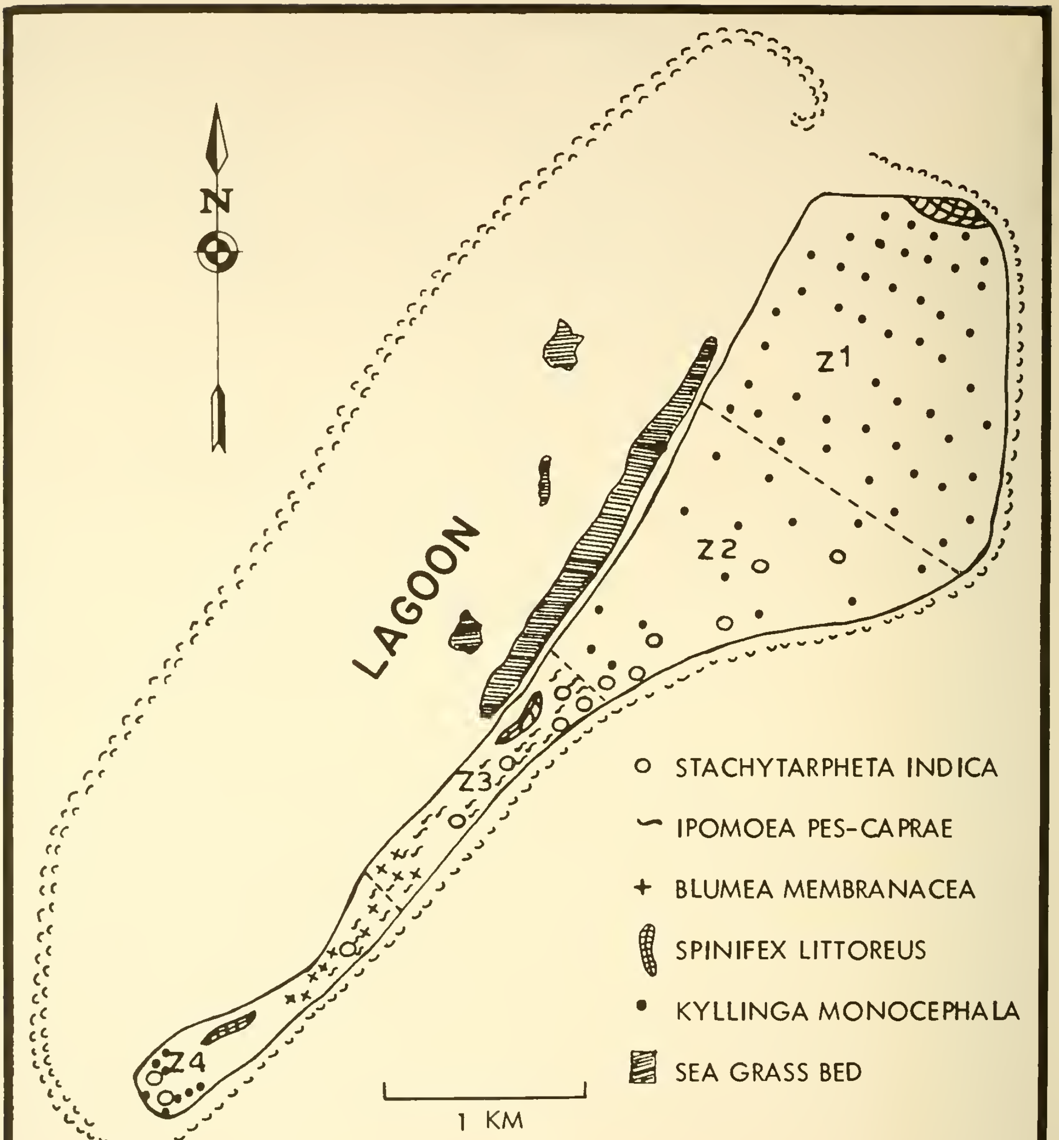

Figure 2. Kavaratti Island. Diagrammatic representation of the distribution of some terrestrial plants.

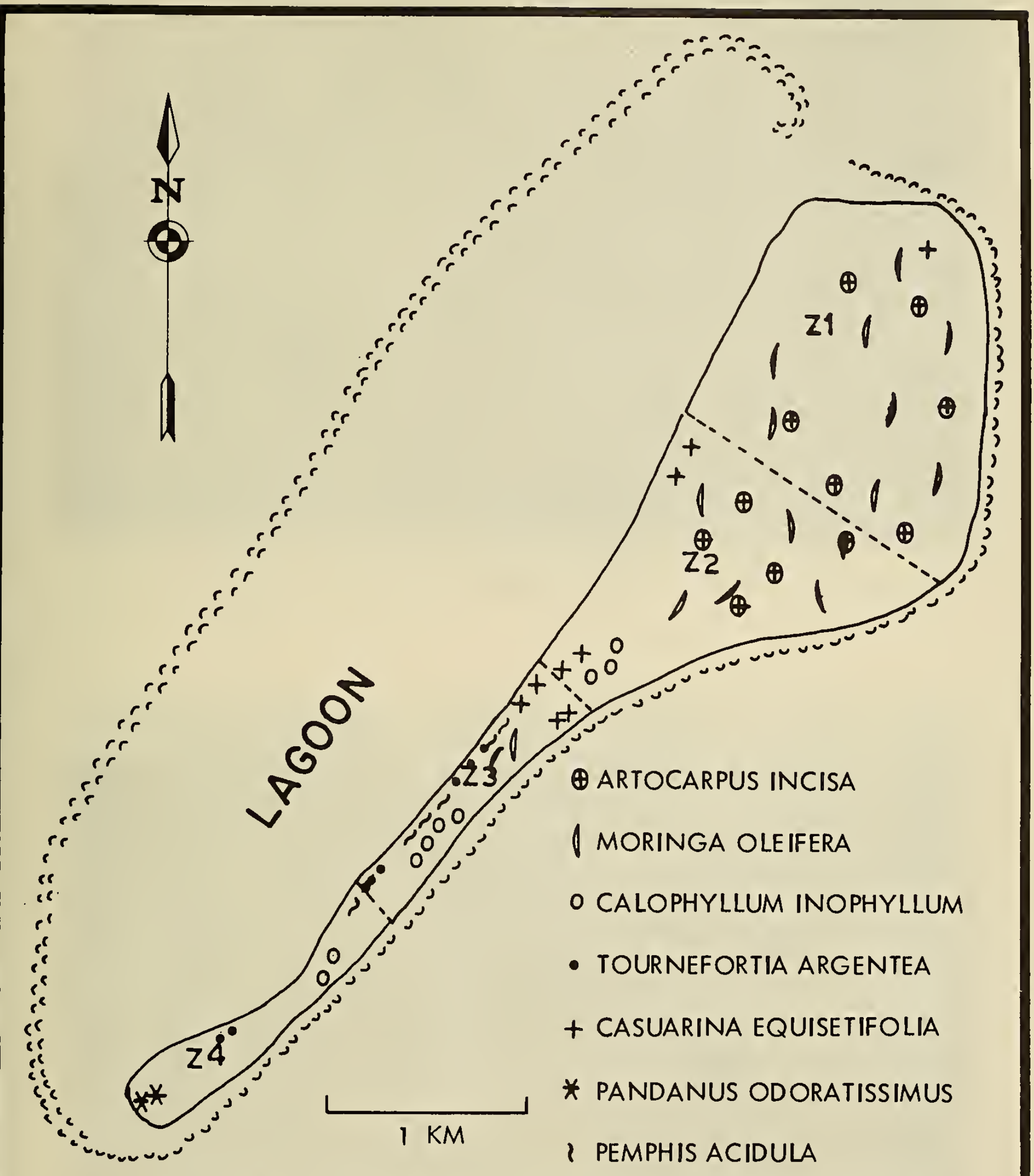

Figure 3. Kavaratti Island. Diagrammatic representation of the distribution of some terrestrial plants.

Plate 1. Extensive bed of *Thalassia* on the intertidal area

Plate 2. Huge bulk of dead *Thalassia* washed ashore

Plate 3. Spinifex littoreus close-up view

Plate 4. Pemphis acidula on the lagoon side of the beach

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AVIFAUNA OF THE SOUTHWEST ISLANDS OF PALAU

BY

JOHN ENGBRING

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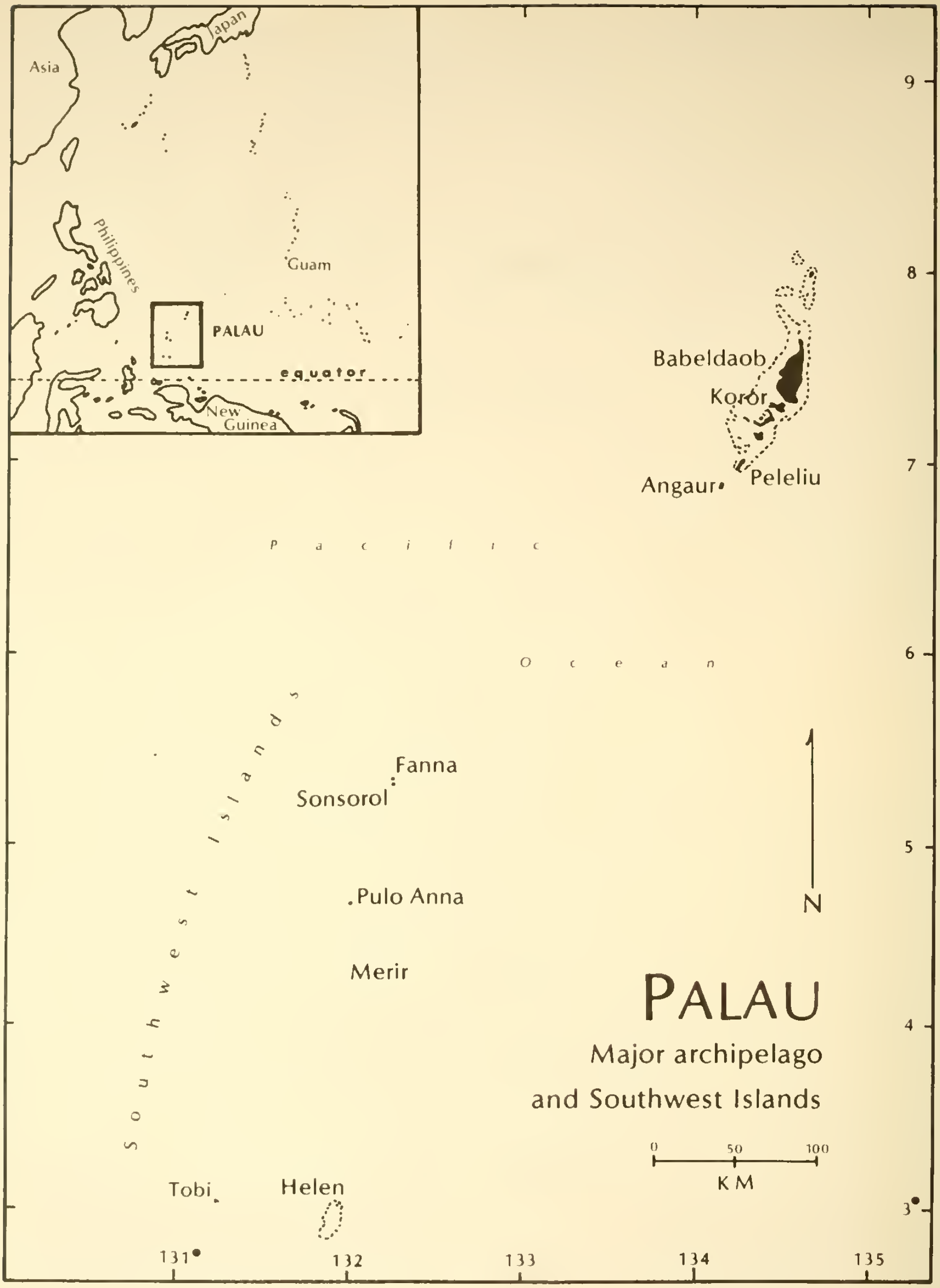

Figure 1. Major islands of Palau, including the six Southwest Islands.

AVIFAUNA OF THE SOUTHWEST ISLANDS OF PALAU

by John Engbring[1]

INTRODUCTION

The Palau Archipelago (7° 20' N, 134° 30' E) lies at the westernmost edge of the Pacific, just north of the equator and nearly equidistant from New Guinea to the south, the Philippines to the west, and Guam to the northeast (Figure 1). As a part of Micronesia, Palau became a United States Trust Territory following World War II. The government is now in a transitional state, and is shifting from a trust to independent status.

The Southwest Islands of Palau are composed of six tiny islands, each less than 2 km^2, extending 600 km southwest of the capital, Koror. The islands are Sonsorol and Fanna (the Sonsorol Islands), Pulo Anna, Merir, Tobi, and Helen. Other place names for the islands, and areas, are listed in Bryan (1971). Tobi and Helen, the southernmost of the group, lie only 400 km north of western New Guinea. All of the islands are of low elevation, with a substrate of coralline rubble interspersed with sandy areas. Most of the islands harbor minor deposits of phosphate, much of which was removed before World War II during the Japanese administration (Hutchinson 1950). The islands support relatively verdant forests, with coconut (Cocos nucifera) being the dominant species on most. Other trees include Artocarpus spp., Ficus spp., Calophyllum inophyllum, Barringtonia asiatica, Pandanus sp., Tournefortia argentea, Scaevola taccada, Neisosperma oppositifolia, and Eugenia javanica. Other than Helen, which has a large encircling outer reef and an inner lagoon, the islands are surrounded by fringing reefs that generally extend 200-600 m from land before dropping off steeply into ocean depths. These fringing reefs form rocky flats that are exposed at low tides.

Politically, the islands are part of Palau, but the residents are culturally distinct and speak a separate language. Historically, all the islands except Helen have been inhabited by Micronesians related to those of other outer islands in the Western Carolines (Eilers 1935, 1936). Though densely populated at one time, only a few families reside

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there today. The economy remains at a subsistence level, with copra the nearly sole source of income; other minor trade items include coconut syrup, shells, and handicrafts. On Helen, sea cucumbers are also collected, dried, and exported for consumption in the Orient. Contact with the outside world is made every 3-4 months by ship from Koror. This "field trip ship" stops for 1-2 days at each island, purchases copra, delivers staples, and fulfills other needs of the residents.

The avifauna of the Southwest Islands is undescribed, although large seabird colonies are present on Fanna and Helen. From Helen, Owen (1977a) recorded the Great Frigatebird (Fregata minor) and Lesser Frigatebird (Fregata ariel) and Yamashina (1940) recorded the Sooty Tern (Sterna Fuscata) and Crested Tern (Thalasseus bergii). Two unpublished reports, a checklist (Owen 1977b) and a field guide (Engbring 1981), give distribution and relative abundance of Southwest Island seabirds. Outside of these references little else is available on the birds of the region.

METHODS

The following report is based on two trips I made to the islands while working in Palau as a Smithsonian-Peace Corps Volunteer. One trip was in the fall from 9-20 November 1977, and one was in the spring from 18-26 May 1979 ("spring" and "fall" in this report refer to seasons of the Northern Hemisphere). During each of these trips the ship generally spent 1-2 days at each island, and I spent several hours per day on shore making general observations. Seabirds were also frequently recorded from the ship as it waited a few hundred meters from the outer edge of the reef. I spent a total of 6 daylight hours on Fanna, 14 on Sonsorol, 15 on Pulo Anna, 8 on Merir, 26 on Tobi, and 19 on Helen. Offshore (within sight of land) I spent 6 daylight hours at Fanna, 22 at Sonsorol, 8 at Pulo Anna, 6 at Merir, 16 at Tobi, and 10 at Helen. At Helen I stayed one night on shore, when I was able to observe the large number of birds returning to roost at dusk. Whenever possible, I questioned the local residents regarding avifauna.

Additional information was contributed by Warren King, Dennis Puleston, and Thomas Ritchie, who spent 18 and 19 October 1979 on Helen and Merir while traveling on the M.S. Lindblad Explorer; by Greg Bright, who visited the region from 24 November to 2 December 1978; and by Robert Owen, who spent 30 years in Palau and visited the Southwest Islands on several occasions.

THE ISLANDS

Sonsorol Islands; 5° 20' N, 132° 13' E

Because of their proximity, two islands are included in this group, Sonsorol (136 ha), which has about 25 residents, and Fanna (54 ha), an uninhabited island located 2 km north of Sonsorol. Residents of Sonsorol regard Fanna as a reserve, but make occasional foraging expeditions by dugout canoe to Fanna for fish, coconut crabs, and birds. Both islands are covered by a forest of tall trees with a relatively well-formed canopy and a moderately dense understory. Several huge, stately Ficus and Artocarpus grow on Fanna.

Fanna harbors spectacular seabird colonies. The Black Noddy (Anous minutus) and Red-footed Booby (Sula sula) nest in immense numbers. Although less plentiful, White Terns (Gygis alba) are also abundant. In Palau, Fanna is the only known nesting site for Great Frigatebirds, and possibly Lesser Frigatebirds as well. Also resident are the Brown Noddy (Anous stolidus), and a few Brown Boobies (Sula leucogaster). Only four seabirds are known to reside on Sonsorol, none in profuse numbers. In order of abundance these are the Brown Noddy, the White Tern, the Black Noddy, and the White-tailed Tropicbird (Phaethon lepturus). Fruit bats (Pteropus sp.) are conspicuous arboreal denizens on both Sonsorol and Fanna, but are not seen on the other Southwest Islands.

Pulo Anna; 4° 40' N, 131° 58' E

Pulo Anna (50 ha) is covered by large trees, with a relatively open understory. A shallow, open, brackish swamp, approximately 200 by 200 m, is located in the center of the island. The swamp is littered with decaying logs, remnants of mangrove trees that were cleared by U.S. military forces after World War II during a mosquito control program. Water level fluctuates with the tides, though there is no above-ground connection with the ocean. Approximately 20 or fewer people live on the island.

Resident seabirds include an abundance of Brown Noddies and White Terns, and lesser numbers of White-tailed Tropicbirds and Black Noddies. Great Frigatebirds commonly soar above the island, but are not known to nest on Pulo Anna. Migratory shorebirds regularly use the swamp, which provides an excellent resting and feeding area despite its limited size.

Merir; 4° 19' N, 132° 19' E

Merir (90 ha) is moderately elongated, just over 2 km from the northern to southern tip. A typhoon in the mid-1960's destroyed much of the vegetation, and a thick growth of medium-sized trees has since grown. Numerous large, dead trees still extend above the post-typhoon canopy. A shallow, heavily overgrown swamp is present on the southern, interior portion of the island, but because it is overgrown by shrubs, few shorebirds utilize it. Merir is riddled with mosquitos, and this, along with the dense understory, makes the interior generally inhospitable. In recent years only one family of fewer than ten people has resided on the island.

Brown Noddies are the most abundant species on the island, with lesser numbers of White Terns and White-tailed Tropicbirds. King *et al*. (1980) recorded Black Noddies in moderate numbers in 1979. Frigatebirds, mostly Great but a few Lesser, regularly soar above and roost on the island, but are not known to nest.

Tobi; 3° 01' N, 131° 11' E

With about 70 people, Tobi (60 ha) is the most heavily populated of all the Southwest Islands. Much of the triangular island is covered with tall coconut groves that are relatively well manicured and have open understories. A shallow, centrally located swamp, which is partly planted with taro (*Colocasia esculenta*), is largely the result of pre-war phosphate mining by the Japanese. The small amount of open water provides good but limited habitat for migratory shorebirds. Scattered throughout the swamp area are large earthen mounds, also the result of mining activities. The limited amount of native forest on the island contains several massive specimens of *Ficus* and *Calophyllum*.

Seabird densities on Tobi are similar to those on Pulo Anna, with healthy populations of Brown Noddies and White Terns, and many fewer White-tailed Tropicbirds and Black Noddies. Great Frigatebirds are commonly seen soaring overhead.

Helen; 2° 59' N, 131° 49' E

Unlike the other Southwest Islands, Helen is an atoll and consists of a large reef that encircles an open lagoon (100 km^2). The only dry land, which is at the northern tip of the reef, is low and small (approximately 25 ha), and is mostly sand. At low tide, conspicuous sand spits extend to the north and south of the crescent shaped island. Though the island was historically uninhabited, residents of Tobi, nearly 75 km away, made occasional forays to Helen. When this study was made, fewer than ten people lived on Helen, but the population varies depending on the number of "visitors" from Tobi or other Southwest Islands. The vegetation consists almost exclusively of large coconut trees, medium-sized *Tournefortia* trees, and a few sparse clumps of grass.

Impressive numbers of seabirds reside on Helen, and seabird density is greater here than on any other Southwest Island. The superb quality of Helen as a nesting site is probably due to its isolation, its beaches which are protected from large waves by the outer reef, and its lagoon which supplies an abundant food supply. There are sizable colonies of Crested Terns, Black Noddies, Sooty Terns, and Red-footed Boobies, and moderate numbers of Brown Boobies and Black-naped Terns (*Sterna sumatrana*). White Terns recently began nesting on Helen in small numbers. Both Great and Lesser Frigatebirds commonly soar near the island and roost in the tall coconut trees. Neither species is thought to nest regularly on Helen, but a male Lesser Frigatebird was recorded on a nest in 1969 (Owen 1977).

AVIFAUNA

Forty-seven species of birds have been recorded from the Southwest Islands (Table 1), of which 14 are resident and 33 are migrant or vagrant. Four additional genera have been recorded that are not identified to species (Table 1). Out of the 14 resident species, 11 are seabirds and three are land birds. The 11 species of resident seabirds represent four families: Phaethontidae (one species), Sulidae (two species), Fregatidae (two species), and Laridae (six species). Conspicuously absent is the family Procellariidae. Most nonresidents are migratory shorebirds. Several recent new bird records for Palau (Engbring and Owen 1981, King et al. 1980) were nonresidents recorded from the Southwest Islands. These are the Red-tailed Tropicbird, Masked Booby, Chinese Goshawk, Bush Hen, Brown Shrike, and Lanceolated Warbler.

Nonresident Birds

Though a number of vagrant and migratory species have been recorded from the Southwest Islands (Table 1), the list is no doubt incomplete. Any of the migratory species already recorded from the Palau Archipelago (Engbring 1981, Owen 1977c) are likely to occur in the Southwest Islands as well. The majority of migrants are shorebirds from the Eastern Eurasian Region that are moving south during the boreal winter; a few are birds from New Guinea or Australia that are traveling north during the austral winter; and a small number are probably east-west migrants from Southeast Asia, the Philippines, or Indonesia (Baker 1951). The most common shorebirds (5-20 regularly seen at any one time on each island during migration) include Lesser Golden Plover, Ruddy Turnstone, Whimbrel, and Gray-tailed Tattler. Important habitat types utilized by shorebirds include the small inland swamps on Pulo Anna and Tobi, reef flats, and sandy beaches.

Unidentified Species

A number of birds were observed that were not positively identified:

Shearwater - Puffinus sp.: One all dark shearwater was seen about 80 km north of Sonsorol on 26 May 1979. Its size and color matched that of the dark phase of the Wedge-tailed Shearwater, Puffinus pacificus, but there are several all dark shearwaters in the Pacific with which the bird could have been confused. This was the only Procellarid that I saw in 18 days at sea.

Tattler - Heteroscelus sp.: Tattlers were regularly observed on most of the islands. On the basis of call, I identified Gray-tailed Tattlers on Merir and Tobi. King et al. (1980) identified Gray-tailed Tattlers on Helen and Merir. Unidentified Tattlers could possibly be the Wandering Tattler, Heteroscelus incanus, a migrant in Palau which is less common than the Gray-tailed Tattler.

Table 1. Distribution and status of Southwest Island birds. Common and scientific names follow the American Ornithologists' Union (1982) check-list whenever possible. Other names are from Owen (1977c) and King *et al*. (1975).

Status Symbols

R - Resident; nests within the Southwest Islands and is generally present year-round. Different classes of resident birds are indicated with lower case letters as follows:

b - Breeding species on the island; nests, eggs, or young recorded.

p - Probable nester on the island, but nests, eggs, or young not recorded.

t - Transient; recorded near (generally within sight of) land, but is not thought to nest on the island. May or may not roost on the island.

M - Migrant; migratory species not resident in the Southwest Islands.

V - Vagrant; accidental occurrence of a normally non-migratory species.

Abundance Symbols

S - Single individual recorded on one or more occasions.

U - Uncommon; 2-10 birds recorded on at least one visit.

C - Common; 11-50 birds recorded on at least one visit.

N - Numerous; 50-1,000 birds recorded on at least one visit.

A - Abundant; over 1,000 birds recorded on at least one visit.

Island Symbols

FA - Fanna.

SO - Sonsorol.

PU - Pulo Anna.

ME - Merir.

TO - Tobi.

HE - Helen.

Table 1, continued

Species		Island					
		FA	SO	PU	ME	TO	HE
Shearwater genus (M)	*Puffinus* sp.		S				
White-tailed Tropicbird (R)	*Phaethon lepturus*		Up	Up	Up	Up	
Red-tailed Tropicbird (M)	*Phaethon rubricauda*		S		S*		
Masked Booby (V)	*Sula dactylatra*						S
Brown Booby (R)	*Sula leucogaster*	Sp	St		St		Nb
Red-footed Booby (R)	*Sula sula*	Ab	Nt		St*	Ut	Ab
Great Frigatebird (R)	*Fregata minor*	Nb	Nt	Ct	Nt	Ct	Nt
Lesser Frigatebird (R)	*Fregata ariel*				Ct*		Cp
Cattle Egret (M)	*Bubulcus ibis*		S	U	S	S	
Pacific Reef Heron (R)	*Egretta sacra*	Up	Up	Sp	Up	Up	Cp
Little Egret (M)	*Egretta garzetta*[1]					U	
Plumed Egret (M)	*Egretta intermedia*					S	
Chinese Goshawk (M)	*Accipiter soloensis*				S*		
Red Junglefowl (R)	*Gallus gallus*		Ub	Ub	Ub	Cb	
Bush Hen (V)	*Amaurornis olivaceus*			S			
Black-bellied Plover (M)	*Pluvialis squatarola*				S	S	
Lesser Golden Plover (M)	*Pluvialis dominica*	U	U	C	U	C	C
Mongolian Plover (M)	*Charadrius mongolus*[2]			U	U	U	S
Little Ringed Plover (M)	*Charadrius dubius*				U*		S*
Oriental Plover (M)	*Charadrius veredus*[3]				S*		U*
Common Greenshank (M)	*Tringa nebularia*					U	
Wood Sandpiper (M)	*Tringa glareola*			S		S	
Gray-tailed Tattler (M)	*Heteroscelus brevipes*				U	C	U

Table 1, continued

Species		Island					
		FA	SO	PU	ME	TO	HE
Tattler genus (M)	*Heteroscelus* sp.		U	S	U	C	U
Common Sandpiper (M)	*Actitis hypoleucos*	S		S	U	U	S*
Little Curlew (M)	*Numenius minutus*					S	
Whimbrel (M)	*Numenius phaeopus*		U	U	U*	C	S*
Black-tailed Godwit (M)	*Limosa limosa*			S			
Bar-tailed Godwit (M)	*Limosa lapponica*				U*		U
Ruddy Turnstone (M)	*Arenaria interpres*			S	C	C	C
Rufous-necked Stint (M)	*Calidris ruficollis*[4]						S
Stint genus (M)	*Calidris* sp.			S			S
Curlew Sandpiper (M)	*Calidris ferruginea*						S
Snipe genus (M)	*Gallinago* sp.					U	S*
Common Tern (M)	*Sterna hirundo*					S	
Black-naped Tern (R)	*Sterna sumatrana*						Nb
Sooty Tern (R)	*Sterna fuscata*						Ab
Little Tern (M)	*Sterna albifrons*			U			
Crested Tern (R)	*Thalasseus bergii*			Ut	Ct	Ut	Ab
Brown Noddy (R)	*Anous stolidus*	Cp	Ab	Nb	Ab	Ab	
Black Noddy (R)	*Anous minutus*	Ab	Nb	Cb	Cp*	Cp	Ab
White Tern (R)	*Gygis alba*	Ab	Ab	Nb	Cp	Np	Cb
Nicobar Pigeon (V)	*Caloenas nicobarica*						S
Oriental Cuckoo (M)	*Cuculus saturatus*						S*
Cuckoo genus (M)	*Cuculus* sp.					S	
Hawk-Owl genus (M)	*Ninox* sp.						S

Table 1, continued

Species		Island FA	 SO	 PU	 ME	 TO	 HE
Collared Kingfisher (R)	*Halcyon chloris*	Sp	Up	Sp	Up	Up	Up
Bee-eater genus (M)	*Merops* sp.					U	
Dollar bird (M)	*Eurystomus orientalis*			U			
Barn Swallow (M)	*Hirundo rustica*		C	C	U	C	U
Yellow Wagtail (M)	*Motacilla flava*		U	S	U	U	U*
Brown Shrike (M)	*Lanius cristatus*					U	
Lanceolated Warbler (M)	*Locustella lanceolata*						S*
Gray-streaked Flycatcher (M)	*Muscicapa griseisticta*					S	S

[1] It is not certain whether the Little Egret can be separated from the Snowy Egret (*E. thula*), which has not been recorded from Palau. I saw two white egrets wading on reef flats along the shore at Tobi on 15 November 1977. Both were alike, with narrow plumes on the nape, black beaks, orange-yellow lores, black legs (with a greenish tinge), and greenish-yellow toes.

[2] The Mongolian Plover is similar to the Greater Sand Plover (*C. leschenaultii*). Prior to my visit to the Southwest Islands I regularly observed both species in Koror, Palau, and considered the two separable on the basis of size, leg length, and leg color, among other field traits.

[3] Some consider this as two species, *C. veredus* and *C. asiaticus*.

[4] The Rufous-necked Stint is similar to two other small Calidrids, the Little Stint (*C. minuta*) and the Semipalmated Sandpiper (*C. pusilla*), and would be difficult to separate from them in winter plumage. The individual I observed on Helen on 22 May 1979 was entering breeding plumage, and had an even wash of reddish color on the breast and neck. I used this trait to separate it from the other two species, neither of which have been recorded from Palau.

* Recorded by King *et al*. (1980).

Snipe - Gallinago sp.: I flushed three snipe on Tobi on 14 November 1977, and King et al. (1980) observed one on Helen on 18 October 1979. None of these individuals were identified to species, though it is likely that one or more were Swinhoe Snipe, Gallinago megala, the only species of snipe collected from Palau.

Stint - Calidris sp.: I observed two stints in winter plumage, one on Helen on 13 November 1977, and one on Tobi on 17 November 1977. These appeared to be and most likely were Rufous-necked Stints, Calidris ruficollis. However, they could not be safely separated from the winter plumage Little Stint, Calidris minuta, or Semipalmated Sandpiper, Calidris pusilla, neither of which has been recorded from Palau.

Hawk-owl - Ninox sp.: An unidentified, small brown owl was first reported from Helen on 28 November 1978 (Bright 1978). On 18 October 1979, another owl was observed that was identified as the Brown Hawk-Owl, Ninox scutulata (King et al. 1980). The owl was most likely the Brown Hawk-Owl, as it is a widespread species in Southeast Asia that migrates to the Philippines. However, there are several other Ninox spp. that reside on nearby islands with which the Brown Hawk-owl could conceivably be confused.

Cuckoo - Cuculus sp.: I observed one cuckoo on Tobi which was either the Oriental Cuckoo, Cuculus saturatus, or the Common Cuckoo, Cuculus canoris.

Bee-eater - Merops sp.: I observed a flock of eight bee-eaters on Tobi on 21 May 1979. Tentatively these have been identified as the Rainbowbird, Merops ornatus, an Australian species. All the birds were in immature plumage, however, and further comparison of the Australian species and two Philippine bee-eaters should be made.

In addition to the above unidentified birds, Bright (1978) observed an all black bird with a long tail on Tobi on 29 November 1978. The individual was at least 36 cm long, and had dark legs, but a lighter bill. It perched in a small tree near the edge of the swamp. The bird was probably a male Common Koel, Eudynamys scolopacea.

Resident Land Birds

Pacific Reef Heron - Egretta sacra. The reef heron is resident on all of the Southwest Islands, and is conspicuous as it feeds on reef flats at low tide. The population on each island probably numbers no more than 15-20 individuals. No nests have been recorded. Based on its widespread insular distribution one can assume that the reef heron is a capable overseas wanderer, but no patterns of movement are evident in the Southwest Islands. On Helen, records indicate a variation in population size; one bird was recorded in September 1969 (Owen, field notes), eight birds in November 1977 (this study), three birds in May 1979 (this study), and eleven birds in October 1979 (King et al. 1980).

This population fluctuation could be due to ingress/egress, reproduction, or simply counts of varying completeness. It is unlikely that reef herons are overlooked on Helen, but birds may be roosting on derelict ships on the surrounding reef, and thus missed during a count. White and dark phase birds are represented in about equal proportions on all the islands.

Red Junglefowl - Gallus gallus. Domestic junglefowl are regularly heard and seen on Sonsorol, Pulo Anna, Merir, and Tobi. The species is commonly raised by residents, and is likely to be found on any of the Southwest Islands, particularly near villages. The species was probably introduced by early island settlers. A few birds are probably feral, but this is difficult to determine. Early reports indicate that the junglefowl was valued more for its feathers, which were used for fishing lures, than for its flesh (Johannes 1981).

Collared Kingfisher - Halcyon chloris. A few, evenly dispersed individuals or pairs can be located on any of the Southwest Islands. The population is estimated at 20 or fewer on each island. I assume the species is resident, but found no nests. On Helen, only one or two birds have been recorded at any time, and these are possibly vagrants from other Southwest Islands, New Guinea, or Indonesia.

Resident Seabirds

Estimates of the size of nesting colonies are summarized in Table 2, and species accounts are as follows:

White-tailed Tropicbird - Phaethon lepturus. Although nowhere abundant, individuals and small groups can be found commonly on all of the Southwest Islands but Helen. Population size is estimated at under 50 individuals at any one time on each of the islands of occurrence. The tropicbird's absence from Helen can probably be explained by the limited amount of forest, which serves as nesting habitat. Though I recorded no birds from Fanna, the species is probably resident here. Birds were found in equal numbers in spring and fall, indicating negligible variation in nesting season and no definite migratory pattern. Though no nests have been recorded, the species presumably nests in the Southwest Islands. Elsewhere in Micronesia, the tropicbird has been found to nest throughout the year (Brandt 1962), as is probably the case in the Southwest Islands.

Red-footed Booby - Sula sula. The Red-footed Booby is abundant on the two islands on which it nests, Fanna and Helen, and sightings are possible near any of the other Southwest Islands. Boobies generally spend the day foraging over the open ocean, and population estimates are best made in early morning or at dusk as the birds leave or return to land. On Helen, it was possible to spend two evenings on the island and estimate numbers as the birds returned to roost. On Fanna, the population estimate is derived from a count of active nests. The total adult population (flying birds) is around 5,000 on Fanna and 2,500 on

Table 2. Population estimates for resident seabird colonies in the Southwest Islands

	Fanna	Sonsorol	Pulo Anna	Merir	Tobi	Helen
White-tailed Tropicbird		20-50	30-50	25-50	25-50	
Red-footed Booby	5,000					2-3,000
Brown Booby	10-25					500-1,000
Great Frigatebird	400-500					
Lesser Frigatebird	?					?
Black-naped Tern						200-500
Sooty Tern						80,000
Crested Tern						5-7,000
Brown Noddy	50-100	1-3,000	300-700	2-3,000	1,000	
Black Noddy	20,000	100-200	50-100	100-300	50-100	3-4,000
White Tern	3-5,000	1-2,000	200-500	1-2,000	500-1,000	20-50

Helen. Nearly all birds (over 90%) are of the white rather than dark color phase.

The Red-footed Booby is a colonial nester, and constructs nests of leaves, grass and twigs. On Fanna, the booby nests high in trees along the perimeter of the island, and to lesser extent in the interior. Favorite nest trees are Tournefortia and Artocarpus. Residents of Sonsorol state that the booby roosts so profusely at times that nest trees are injured, and indeed, several trees were conspicuously defoliated in May 1979. There were at least ten distinct sites in May 1979, each with nearly 100 active nests. Thus, there were about 1,000 active nests on the island. Young were at all stages of development. On Fanna, peak nesting activity occurs during spring months, and there is little or no nesting in the fall. A nesting cycle was apparently beginning in November 1977, when adult birds were on the ground picking up twigs and sitting on nests up in trees. However, I could see no young or eggs from below.

On Helen, the colony is smaller, but density is greater. Birds nest in the relatively low Tournefortia trees, and on rare occasions in the much taller coconut trees (both Tournefortia and coconut trees are utilized for roosting). About 265 downy young, along with a few nearly fledged birds, were counted in May 1979. In October 1979, 91 young at all stages of development were counted (King et al. 1980), and in November 1977, 25 young were found (this study). The pattern indicates nesting throughout the year, with a probable peak in spring months.

Brown Booby - Sula leucogaster. The Brown Booby is known to nest only on Helen and, in very limited numbers, on Fanna. On Helen, the colony numbers from 500 to 1,000, but on Fanna, fewer than 25 are present. The species can probably be sighted near or possibly roosting on any of the other Southwest Islands.

On Helen, pairs nest in shallow lined scrapes in the sand, often just above the high tide line. Concentrations of nesting birds are located under Tournefortia trees on the northern and southern portions of the island. A few young are raised throughout the year, but the peak nesting season is in spring months. In November 1977, I counted 10 downy young and saw no incubating adults. Likewise, there was only minor nesting activity in November 1978, when only one nest was found (Bright 1978) and in October 1979, when 11 active nests were located (King et al. 1980). In May 1979, the peak of the presumed nesting season, I counted 60 downy young of all sizes, along with at least 20 incubating adults. Large numbers of birds returned at dusk to roost on the Island.

Residents of Sonsorol informed me of a small colony of fewer than 25 birds that recently began nesting on Fanna. Although I visited Fanna in both fall and spring and observed Brown Boobies in the area, I discovered no nests. This new colony may succeed provided it is not unduly disturbed by humans, and provided the relatively exposed beaches prove suitable as nesting sites. It is possible that only Helen, whose beaches are protected by an outer reef, is capable of sustaining a stable colony of nesting Brown Boobies.

Great Frigatebird - *Fregata minor*, and Lesser Frigatebird - *Fregata ariel*. Frigatebirds occur uncommonly but widely on the oceans around Palau, and can characteristically be seen soaring above any of the Southwest Islands. Great Frigatebirds roost on all of the Southwest Islands. Lesser Frigatebirds have been recorded from Merir and Helen, but no doubt frequent the other Southwest Islands as well. Discussion of these two species is combined partly because of the incomplete information regarding relative numbers of each species. Out of 400 frigatebirds at Fanna in May 1979, I identified nearly 150 individuals, all of which were Great Frigatebirds. Only a few individuals, all Great, were identified at Pulo Anna, Merir, and Tobi. Thus, the great majority of frigatebirds on these islands appears to be Great Frigatebirds. At Helen, I found approximately equal numbers of the two species in May 1979, as did King *et al*. (1980) in October 1979. In May 1969, however, Owen (1977a) found 25 to 30 Great and over 100 Lesser Frigatebirds on Helen.

Although Great Frigatebirds roost on all the Southwest Islands, only Fanna is reported to have a nesting colony. Residents informed me that the birds nest high in the trees in the spring of the year. In May 1979 when about 400 frigatebirds were present, I observed birds entering tall trees during the day, but I could locate no nests. Occasional sporadic nesting may occur on other Southwest Islands as well. Residents have reported nesting on Merir, and in May 1969, Owen (1977a) recorded one male Lesser Frigatebird on a nest at Helen Island.

The following number of frigatebirds was recorded during several trips to the region:

	May 1969 (Owen 1977)	Nov. 1977 (this report)	Nov. 1978 (Bright 1978)	May 1979 (this report)	Oct. 1979 (King *et al*. 1980)
Fanna		over 100		400	
Pulo Anna		60		15	
Merir		34	over 150	10	moderate numbers
Tobi		26		1	
Helen	over 130	300		25	moderate numbers

The largest concentrations are found throughout the year on Fanna and Helen. The number of birds on each island varies, suggesting that birds travel from one island to another. The data also indicate that birds concentrate to nest at Fanna during the spring months. Frigatebirds are highly mobile, and much of the population may originate from or move to areas outside Palau. For example, Lesser Frigatebirds that nest on the Line Islands have been recorded in the vicinity of the Southwest Islands and beyond, a distance of over 6,000 km (Sibley and Clapp 1967).

Black-naped Tern - Sterna sumatrana. This species occurs only on Helen, where the population is 200-500 birds. It roosts and nests on shipwrecks on the surrounding reef. In May 1979, the species was conspicuous, and small groups could be seen foraging above the lagoon or circling near shipwrecks. Only a few were seen near the island itself, either resting on sand spits at low tide or circling overhead. On this same trip I visited an abandoned ship east of the island, where about 50 terns perched on and circled the ship. One chick and about 20 eggs were found on the deck. Sabino Zacharias, a resident of the island, informed me that greater numbers of birds resided at the other three shipwrecks on the reef. The nesting season appears to be in spring months only. Despite the relative abundance of Black-naped Terns in May 1979 and the apparently well established nesting population, there are no records of sightings during the fall. The disappearance of the population outside the breeding season is puzzling, since they are relatively sedentary elsewhere in the Palau Archipelago.

Sooty Tern - Sterna fuscata. Helen harbors the only colony of Sooty Terns in the Southwest Islands. This highly pelagic species returns to land only to nest, and, depending on the reproductive cycle, numbers fluctuate from a few hundred to tens of thousands on Helen. Despite the occasional abundance of birds at Helen, sightings of Sooty Terns near the other Southwest Islands are rare. During my two trips through the region, I heard and saw Sooty Terns only at Helen.

At Helen, eggs are located in shallow scrapes on the ground, usually within the interior of the island well above the high tide line. The major nesting colony is located in the central and eastern portion of the island, which is a relatively open area interspersed with small grass clumps. This colony extends to well within the interior of the island during a peak nesting season. Another small colony, possibly a distinct population, is located on the beach on the southwest side of the island. Birds appear to avoid nesting under the trees. The nesting of Sooty Terns on Helen appears to follow no distinct annual cycle. On several trips, the following estimated numbers of nests and young were recorded:

Nov. 1977 (this report)	Nov. 1978 (Bright 1978)	May 1979 (this report)	Oct. 1979 (King *et al*. 1980)
five nests and 15 nearly grown young	500 nests	10 nearly grown young	37,876 eggs and small chicks and 3,000 nearly grown young
150 to 200 adults	no estimate of adults	50 adults	82,000 adults
(east side)	(southwest side)	(southwest side)	(east side)

From this limited data, it appears that the only concentration of nesting birds during this 2-year period was in the fall of 1979. This is in contrast to the normal spring breeding peak for most seabirds of the region. Elsewhere in Micronesia, the species seems to have several different nesting seasons, but these are poorly described (Brandt 1962).

Crested Tern - *Thalassius bergii*. The Crested Tern nests only at Helen, where it can regularly be observed in large numbers resting on sand spits or foraging within or near the lagoon. During the nesting season, the adult population is estimated at around 7,000. Uncommon visits are made to other Southwest Islands as well, and I recorded small groups near Pulo Anna, Merir, and Tobi.

The Crested Tern exhibits a distinct nesting season, with peak activity in spring and little or no nesting activity during the remainder of the year. The following numbers illustrate the pattern:

Nov. 1977 (this report)	Nov. 1978 (Bright 1978)	May 1979 (this report)	Oct. 1979 (King *et al*. 1980)
12 chicks	No chicks	No chicks	10 small chicks
No eggs	No eggs	3,250 eggs incubated	20 eggs being incubated
2-3,000 adults	Adults not estimated	7,000 adults	440 adults

In May 1979, the birds were at or near the height of their breeding cycle. The colony was located on the northern tip of the island on a level, open, sandy area just above the high tide line. Single eggs were deposited directly on the sand with no nest being made. By pacing, I estimated the size of the colony at 425 m^2, there being about 240 eggs in every 25 m^2 or about 4,080 total eggs. It appeared that nearly a fifth of these eggs were abandoned, and I thus estimated a total of 3,250 active nests. According to King *et al.* (1980) this is probably the largest nesting colony of Crested Terns in Micronesia. A small amount of nesting occurs outside the spring breeding season. In October 1979 King *et al.* (1980) noted a small colony (about 20 eggs) on the eastern side of the island between the Sooty Tern colony and the beach.

Although the Crested Tern is fairly sedentary in Palau and large numbers can generally be found roosting and feeding at Helen throughout the year, they apparently wander from Helen Island outside of the nesting season. King *et al.* (1980) observed only 440 roosting adults in October 1979, a marked decrease from the 7,000 or more that were present in spring of the same year. During their absence from Helen, the birds possibly disperse to the northern coast of New Guinea.

Brown Noddy - *Anous stolidus*. The Brown Noddy is widespread, and can be found on all the Southwest Islands except Helen. On Sonsorol, Pulo Anna, and Tobi, Brown Noddies reside at approximately the same densities. On each of these islands, I estimate the nesting population to number in the high hundreds or low thousands. At Merir, the population is slightly larger, and on Fanna, it is smaller, at least during spring months. The small size of the population on Fanna may be due in part to interspecies competition for nesting sites with Black Noddies, which nest in profusion on Fanna in spring. The Brown Noddy breeds moderately throughout the year, with a decided peak during spring months. Nests are placed in trees, frequently in the crown of a coconut or pandanus. The bird is relatively solitary in its nesting habits, and generally only one nest is placed in a tree.

Certain populations of Brown Noddies apparently indulge in seasonal migrations in the Southwest Islands, though in the main Palau Archipelago, numbers are similar throughout the year. In November 1977, I recorded no Brown Noddies from Pulo Anna or Tobi, yet in May 1979, the species was nesting in abundance on both islands. On Merir and Sonsorol, however, birds were present in both fall and spring. Possibly the Pulo Anna and Tobi birds migrate to Sonsorol or Merir during the fall, but they may also journey to regions outside of the Southwest Islands. It was suggested by a resident of Tobi that the complete absence of noddies in November 1977 was the result of overharvesting the birds with a gun, rather than a natural phenomenon.

Black Noddy - *Anous minutus*. A colonial and abundant nester on Fanna and Helen, the species occurs in much lesser numbers on the other Southwest Islands. Peak nesting occurs in spring on Fanna, but on

Helen nesting activity continues throughout the year. At Fanna in November 1977, the species was abundant, but I found no nests. In May 1979, the colony was nesting profusely around the perimeter of the island up to 100 m inland. Nests, placed in branch crotches, were constructed of twigs, leaves, and other debris, and were heavily caked with excrement. They were placed at all levels in medium-sized trees. Counts at ten random points within the colony revealed an average of 64 active nests within a 20 m radius of each point. I estimated the total area of the colony at nearly 20 ha, and the total number of active nests at 10,000. At any time during the day a dense cloud of several hundred to several thousand birds could be seen foraging within sight of the island.

In contrast to Fanna, the colony on Helen did not exhibit such marked seasonality in nesting. On all trips that I or other visitors have made to the island, a large number of birds was nesting regardless of the season. On Helen, the Black Noddy nests nearly exclusively in the low *Tournefortia* trees. In November 1977, I estimated 1,700 active nests at all stages of development, from eggs to fully fledged young. In May 1979, I recorded about 1,000 nests. King *et al*. (1980) in October 1979, recorded roughly 1,200 nests.

Outside of Fanna and Helen, there are no large colonies of Black Noddies in the Southwest Islands. In November 1979, I saw none at Pulo Anna, Merir, or Tobi. In May 1979, a very few were present at Sonsorol, Pulo Anna, and Tobi, but in all cases they were vastly outnumbered by Brown Noddies. King *et al*. (1980) observed moderate numbers on Merir in October 1979, but they were outnumbered by Brown Noddies 20 or 30 to one. Presumably a few birds nest on other Southwest Islands, although it remains to be documented. From the limited information I have from the Southwest Islands, I detected no major movement patterns.

Wherever Black Noddies are abundant there were no or few Brown Noddies, and superficially it appears that some form of interspecific competition exists. However, I feel that more is involved than mutual exclusion due to competition for food, nest sites, or other habitat parameters. A possible partial explanation is the influence of man on the two species of noddies. The Black Noddy may be susceptible to disruption by humans, as they are abundant on the traditionally uninhabited islands of Fanna and Helen. The Brown Noddy, however, may be more tolerant of human disruption, and has persisted on islands inhabited by man.

White Tern - *Gygis alba*. The White Tern is common to abundant on all the Southwest Islands except Helen, where a recently established colony of under 50 birds resides. The largest concentration is on Fanna, where several thousand birds nest. Lesser numbers, in the hundreds or low thousands, are found in the forests of Sonsorol, Pulo Anna, Merir, and Tobi.

Unlike most other seabirds, the White Tern is not strongly averse to humans, and frequently resides within or near villages. Individuals or pairs forage far out over the ocean, and are usually not seen feeding near land. Birds do not return nightly to roost, as individuals and small groups can occasionally be seen or heard flying over water after dark. Birds roost and nest in trees, usually high in large spreading trees such as *Ficus*, *Calophyllum*, or *Artocarpus*. When over land, birds are raucous and conspicuous, especially during morning hours.

The White Tern nests throughout the year in Micronesia (Baker 1951), and presumably does so within the Southwest Islands as well. Though the tern is not a highly colonial nester, several pairs usually occupy the larger, more desirable trees. A peak in nesting activity may occur in spring. On Fanna, Pulo Anna, and Tobi in May 1979, numerous birds repeatedly landed and lingered in the foliage of the upper canopy, and were noisy and active as if defending territories. Birds were evenly distributed throughout the forest except on Fanna, where the colony of White Terns did not overlap with the dense and extensive colony of Black Noddies. Though I could not locate eggs or young, a few individuals perched on branches and appeared to be incubating. A nesting cycle had apparently begun or was just beginning. In November 1977, White Terns on these islands were decidedly less active. Though a peak in nesting may occur in spring, nesting activity has been recorded in other months as well. In November 1977 on Sonsorol, I noted White Terns carrying small fish, possibly for feeding young. In October 1979, an incubating bird was observed on Helen (King *et al*. 1980).

The small colony of White Terns on Helen became established in 1978. In November 1977, no White Terns nested or roosted on Helen. A year later, Bright (1978) found at least 20 terns on the island, and nesting was reported by residents. The colony has remained on the island at least through the fall of 1979, as I found birds in May 1979, and King *et al*. (1980) found a few in October of the same year.

CONCLUSION

Though perhaps depauperate from a worldwide perspective, species diversity of seabirds in the Southwest Islands is comparable to other Micronesian island groups: there are eleven resident seabirds in the Southwest Islands, about nine in Yap, ten in the Marianas, nine in Truk, ten in Ponape, sixteen in the Marshalls, and ten in the Gilberts (Fisher 1950, Baker 1951, Brandt 1962, Amerson 1969, pers. observ.). The Marshall Islands group has a species diversity noticeably greater than the other island groups. The Marshalls, however, cover a relatively vast area on the northeastern edge of Micronesia, where components of the Hawaiian avifaunal community are represented. The seabirds of the Southwest Islands are almost exclusively tree-nesters, suggesting that humans or other predators have excluded certain ground-nesting species. Micronesia, on the other hand, might simply not provide the nesting habitat or food required for many seabirds. The Southwest Islands are heavily vegetated, a condition that certain ground nesting species avoid, and waters may be infertile, a likely case for offshore tropical waters where there are no major upwellings (King 1967).

Seabirds of the Southwest Islands presently survive under relatively undisturbed conditions, though in the past there might have been considerable human pressure on the resource. Introduced predators appear to be a minor problem, as I saw no rats, cats, or dogs while on the islands. Rats are almost certainly present, as they are on most Pacific islands, but they are apparently not abundant. Pigs were raised on Sonsorol and Tobi, but those that I saw were penned or tethered. The only actual predation I witnessed was on Fanna, where a land crab was eating a Black Noddy downy young. A locally catastrophic event occurred on Helen in May 1979, when a gravid green sea turtle (Chelonia mydas) wandered through the Crested Tern colony, destroying a swath of eggs nearly a meter wide.

Seabirds are well adapted to such natural disturbances, but most of man's activities are more destructive. It is perhaps no coincidence that the two largest concentrations of seabirds occur on Fanna and Helen, islands that have both been historically uninhabited or otherwise protected from excessive human intrusion. It is probable that only a few birds could exist on islands that sustained high human populations. On Tobi in the 1800's, 3-400 Micronesians resided in a continual state of near famine (Holden 1836) and any bird that lingered on the island was no doubt quickly consumed. From 1832-1834, Holden (1836) was a castaway on Tobi, and states that "during our stay there, scarcely a solitary sea-fowl was known to have alighted on the island." Many of the Southwest Islanders now reside in the capital of Koror, and the pressure of large human populations has somewhat diminished. Threats from outside harvesting still remain. Korean fishermen recently devastated seabird colonies in the Southwest Islands (Johannes 1981). In May 1979, two Taiwanese vessels were apprehended for illegal harvesting of birds, fish, and turtles. A Taiwanese vessel was in Helen Lagoon when the Lindblad Explorer visited Helen in 1979 (W. King, pers. comm.). Pillaging by outside boats is a common occurrence.

With greater public awareness and more education, Palauans are expressing increasing concern for their unique natural resources. On past trips to the Southwest Islands, eggs and birds have been occasionally taken by field trip members. These incursions are more the result of unbounded curiosity than any real subsistence needs; an educational lecture would do much to minimize disturbances. Disruption of colonies is particularly damaging during nesting, when incubating adults are easily frightened off their nests and eggs and young are lost. Because of their high densities, birds on Helen are especially susceptible to such losses. On Helen, a warden has been designated to assist in the protection of seabird colonies; positive actions such as these will assure the continued existence of Palau's seabird colonies.

Acknowledgments

I would like to first thank Robert P. Owen, who initiated this project and supported it throughout its duration. Warren King's timely contribution of his, Dennis Puleston's, and Thomas Ritchie's observations is much appreciated. Greg Bright helpfully offered his observations of the islands. Storrs Olson and John Farrand, Jr., kindly aided in the handling of specimens. Helpful comments on the manuscript were contributed by Dr. Cameron Kepler, Kay Kepler, Roger Clapp, and Warren King. Dr. Derral Herbst contributed much of the botanical information. Funding for the field work was supplied in part by the National Audubon Society through the efforts of C. John Ralph and George Peyton, Jr. A number of Palauans cheerfully offered information and assistance, and I would especially like to thank Sabino Zacharias, Marianos Carlos, and Antonio Andres.

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ATOLL RESEARCH BULLETIN
No. 268

RECENT HISTORY OF A FRINGING REEF, BAHIA SALINA DEL SUR, VIEQUES ISLAND, PUERTO RICO

BY

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ISSUED BY
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WASHINGTON, D. C., U.S.A.

SEPTEMBER 1983

RECENT HISTORY OF A FRINGING REEF, BAHIA SALINA DEL SUR, VIEQUES ISLAND, PUERTO RICO

by

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Introduction

The effect of U. S. Navy training activities on the shallow-water reefs at the eastern end of Vieques Island, Puerto Rico, was investigated during a 1978 ecological survey that included the drilling of three short core holes into an *Acropora palmata* (Lamarck) reef off the east coast of Bahia Salina del Sur (Figure 1). Radiocarbon dates of five core samples yield new information on the accumulation rates of *A. palmata* reef sections and provide further evidence that framework communities of many sea-level reefs are migrating leeward over loose, back-reef sediments.

General Setting

Bahia Salina del Sur is a small, crescent-shaped embayment (approximately 1 km wide and 1 km long) on the south coast of Vieques Island and close to its eastern end (Figure 1). The *Thalassia* seagrass and sand and rubble floor in this area do not exceed a depth of 7m (Raymond, 1978). Shallow reefs fringe the promontories on the eastern, western, and northern shores of the bay, and two extensive sand beaches border its northeastern and northwestern corners.

The fringing reef off the west side of the bay consists of a well-developed *Acropora palmata* community. Small coral heads grow beneath the open framework of *A. palmata*, which extends to a depth of 5m, where a halo of sand separates the reef from adjacent broad beds of *Thalassia*. This halo of sand may be related to the feeding activity of fish and sea urchins (Ogden and Zieman 1977).

Banks and mounds of *Porites porites* (Pallas)--which resemble the near-shore banks of *Porites* off the west coast of Barbados (Macintyre 1968) and off the southeast coast of St. Croix (Adey 1975)-- have developed around two distinct promontories on the north coast of Bahia Salina del Sur. Small scattered stands of *Acropora palmata* occur in association with these *Porites* buildups. During the May, 1978 survey it was observed that naval bombardment had destroyed the eastern end of this near-shore community. During a subsequent survey following Hurricane David, Raymond and Dodge (1980) found that storm waves had

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almost completely destroyed the entire north-shore *Porites* community, along with most of the *A. palmata* on the south coast of Vieques.

The reef cored during this study (designated S-5 reef in Antonius and Weiner's 1978 survey) juts out obliquely from about the center of the eastern shore of Bahia Salina del Sur and is protected in part by a large promontory that forms the eastern entrance to the bay and by the fringing reef adjacent to this promontory, which consists of *Montastrea*, *Siderastrea*, and *Diploria* coral heads. Additional protection is afforded by the *A. palmata* reef surrounding Roca Alcatraz, an island 1 km south of S-5 reef (figure 1). S-5 reef has the characteristic zonation of shallow-water Caribbean reefs dominated by *Acropora palmata* in the reef crest and shallow fore reef (Figures 2, 3D,E,F) (see, for example, Dahl et al. 1974; Adey 1975). At a depth of 4 m, the *A. palmata* community gives way to a mixed coral-head community that includes *Montastrea annularis* (Ellis and Solander), *Diploria strigosa* (Dana), and *Siderastrea siderea* (Ellis and Solander). Small scattered colonies of both *Acropora cervicornis* (Lamarck) and *Acropora prolifera* (Lamarck) were found in the shallow fore reef during the 1978 survey, but subsequently were almost entirely removed by storm surge associated with Hurricane David (Raymond and Dodge 1980). The seaward slope of S-5 reef levels off at a depth of 8 m, where it grades into the sediment floor of the bay (Figure 2). The back reef shoreward of the reef crest is composed of large colonies of *Montastrea annularis* on rubble and pavement, which grade into sand and rubble; only a few colonies of *M. annularis* occur at the inner limit of the drill-site transect (Figures 2, 3A,B,C).

Its faunal zonation indicates that S-5 reef has developed under moderate wave-energy conditions (Geister 1977). The algal ridges or *Palythoa-Millepora* reef-crest communities characteristic of high wave-energy reefs are absent here, as are *Acropora cervicornis* or *Porites porites* communities in low wave-energy reefs. Wave agitation does appear to be strong enough to prevent any significant accumulation of the fragile *Acropora cervicornis* either in the deeper fore-reef slope or in the protected back-reef sand flats.

Core Descriptions

Three core holes were drilled at 50-m intervals along a transect crossing S-5 reef and adjacent to the eastern coast of Bahia Salina del Sur (Figure 1)--two into the reef crest in a water depth of about 0.5 m and one into the shallow fore-reef slope in a water depth of 2 m below mean sea level (Figure 2).

Core hole 1, drilled in four intervals into the reef crest to a depth of 6.4 m, yielded the following material:

1. *0-.61 m.*--This interval consisted of fresh sections of *Acropora palmata* with a comparable amount of fragments bored and encrusted by *Homotrema rubrum*, coralline algae, and serpulids.

2. .61-1.83m.--This section was made up of fresh and bored sections of *Acropora palmata* and *Diploria strigosa*, along with some encrusted (by *Homotrema rubrum* and coralline algae) rubble consisting of *A. palmata*, *Diploria* sp., and *Porites porites*.

3. 1.83-3.35--Sections of *A. palmata* and *Diploria clivosa* were found throughout and cave-in rubble at the top of this interval.

4. 3.35-6.40 m.--Only cave-in rubble was collected from this interval. On-site observations indicated that the drill had dropped through a section of sand at this point.

Core hole 2 consists of one core interval drilled to a depth of 1.83 m below the surface of the reef. Except for a 6-cm core of bored and encrusted *Diploria strigosa*, the material here was mainly *A. palmata* bored to various degrees by sponges, molluscs, and worms and encrusted by *Homotrema rubrum*, coralline algae, and serpulids.

Core hole 3, drilled to a depth of 4.88 m below the surface of the reef, consists of three core intervals:

1. 0-1.83 m.--This interval is characterized by extensive submarine lithification, so that core sections are predominently agglomerate limestone. These cores, which are identical to those described from the shallow fore reef off Galeta Point, Panama (Macintyre 1977), consist of extensively bored and cemented agglomerations of crustose coralline algae, *Millepora* sp., *Porites* sp., and *Acropora palmata*. The multicyclic boring and submarine lithification have in some places destroyed much of the original skeletal framework, which has been replaced by magnesium calcite cement. Other material collected from this interval consists of bored, infilled, and cemented *A. palmata* and other coral debris.

2. 1.83-3.35 m.--Core sections contained mainly *Acropora palmata*, both fresh corals and samples bored by sponges, worms, and molluscs. Extensive cave-in material was present at the top of this interval.

3. 3.35-4.88 m.--Extensive cave-in rubble occurred in this interval. Two cores of bored *Acropora palmata* were also collected here.

Radiocarbon Dates

Five radiocarbon dates were obtained from fresh samples of *Acropora palmata*, which had been collected from the base of core intervals so as to reduce the error in estimating the depths of recovery for the dated samples. Even so, it is not known whether the last material to be cored is in place at the base of the core interval, since a core barrel can punch through a section of the reef and carry a sample below its real depth of recovery. The lack of any significant difference in the two dates from core hole 3, the poor recovery in the last core interval, and the drill-worn condition of the lower sample dated suggest that this core sample was carried below its true depth of recovery. Radiocarbon dates and the accumulation rates for the intervening reef sections are given in Table 1.

TABLE 1

RADIOCARBON DATES AND ACCUMULATION RATES, BAHIA SALINA DEL SUR REEF

Sample	Core Depth Interval (m)	Estimated Depth of Recovery below Reef Surface (m)	Interval of Reef Section Dated (m)	Radio-carbon Date	Accumulation Rate (m/1000 yrs)
Hole 1:					
Core 1	0-.61	.61	0-0.61	190±90	3.21
Core 1	0-.61	.61	.61-1.83	190±90	0.62
Core 2	.61-1.83	1.83		2155±80	
Hole 2:					
Core 1	0-1.83	1.83	0-1.83	860±90	2.13
Hole 3:					
Core 2	1.83-3.35	3.35	0-3.35	2020±70	1.66
Core 2	1.88-3.35	3.35	3.35-4.88	2020±70	*
Core 3	3.35-4.88	4.88		2020±70	

*Estimates invalidated owing to poor recovery in this core interval.

Summary and Conclusions

Excluding the lowest section of core hole 3 (where the estimates were discounted as invalid) we calculated that the Acropora palmata framework of S-5 reef has an average accumulation rate of about 2m/1000 years, which is lower than the average of 3.9m/1000 years reported for the A. palmata facies of the fringing reef off Galeta Point, Panama (Macintyre and Glynn 1976). This difference can be attributed to the changing rates of sea-level rise in the late stages of the Holocene transgression. Sea-level curves established for several areas in the Atlantic and Pacific oceans show a distinct decrease in the rate of sea-level rise, from 3,000 to 4,000 years B.P. (Macintyre and Glynn 1976). As pointed out in the study of Galeta Reef, accumulation rates there decreased considerably about this period of time because changing sea levels reduced the availability of vertical space for reef development. Wherever A. palmata communities have experienced rapid changes in sea level, however--for example, at the shelf edge off Florida 7,000 to 9,500 years ago (Lighty et al. 1978)--the mean accumulation rates have been estimated at 6.6 m/1000 years, the maximum rate reported being 10.7 m/1000 years.

The dates from the Vieques cores suggest that shallow-water Acropora palmata framework that is less than 2,000 years old can be expected to have accumulation rates around 2m/1000 years. In addition, the penetration of more than 3 m of sand at the base of core hole 1 lends support to Shinn's (1980) observation that some shallow-water A. palmata framework may accrete leeward over back-reef sands "by corals establishing themselves on storm-derived rubble periodically transported onto the leeward side of the reef flat" (p. 651). Observations of S-5 reef before and after Hurricane David indicate that both dead and living A. palmata, along with coral head debris, migrated several meters over the back-reef sands in this area. Furthermore, the extensive and multicyclic cementation present at the top of the shallow fore-reef core hole 3 is a characteristic associated with slowly accumulating reef facies (Macintyre, 1977).

This combination of relatively little present-day reef growth in the shallow fore reef and leeward migration of the reef flat indicates that S-5 reef is in a mature stage of reef development, extending laterally into the Bahia Salina del Sur.

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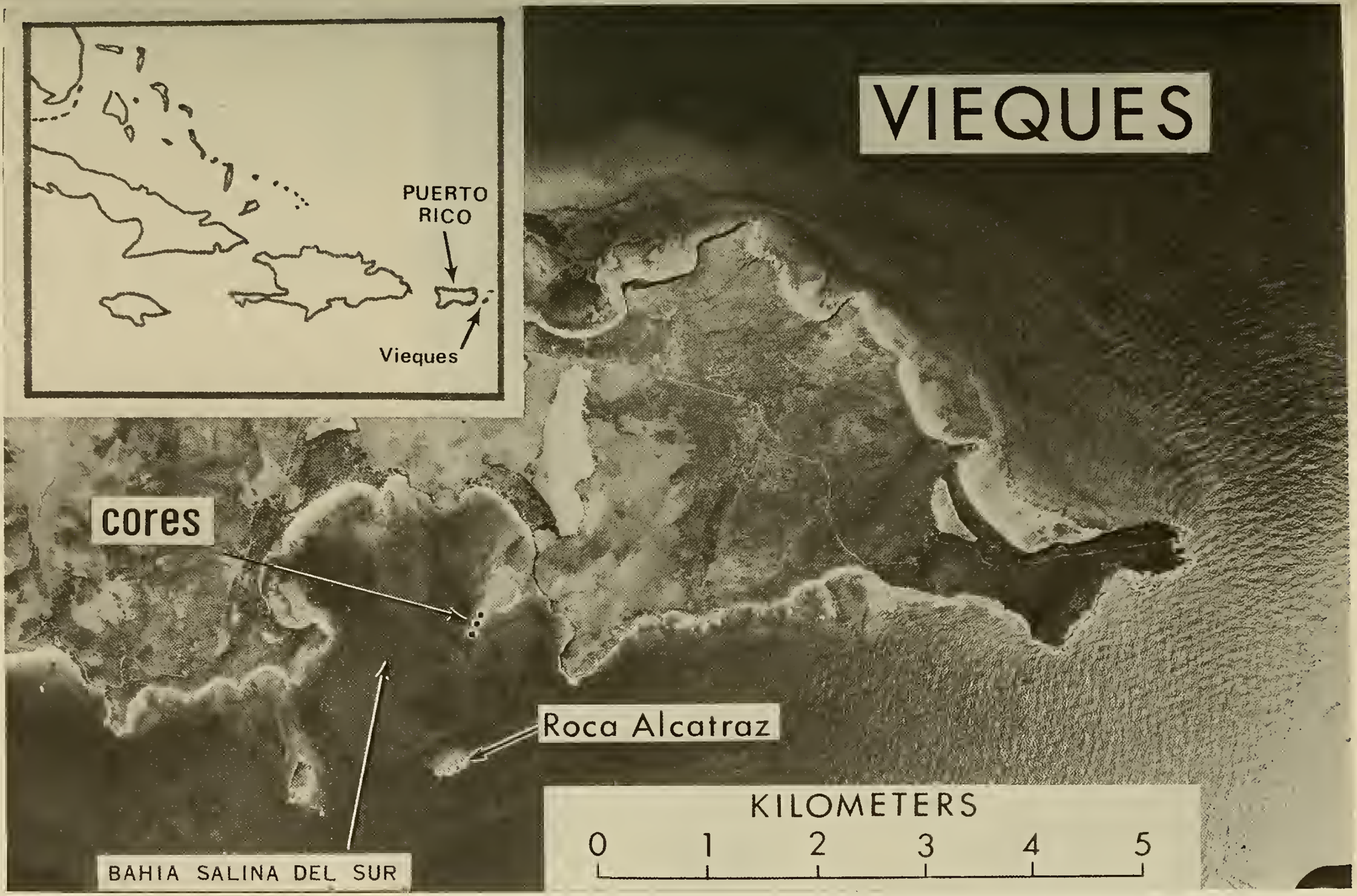


Figure 1. Index map showing location of Vieques Island, Bahia Salina del Sur, the distribution of fringing reefs in this bay, and the location of the three core holes drilled in this study.

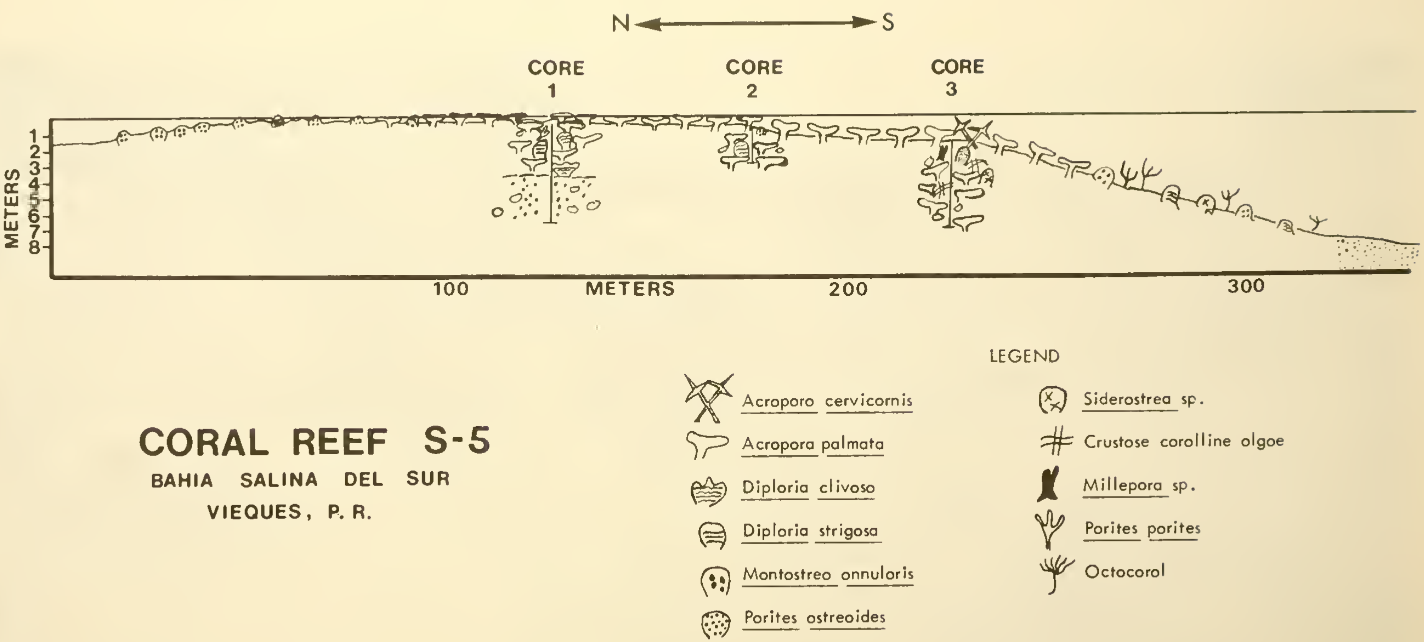
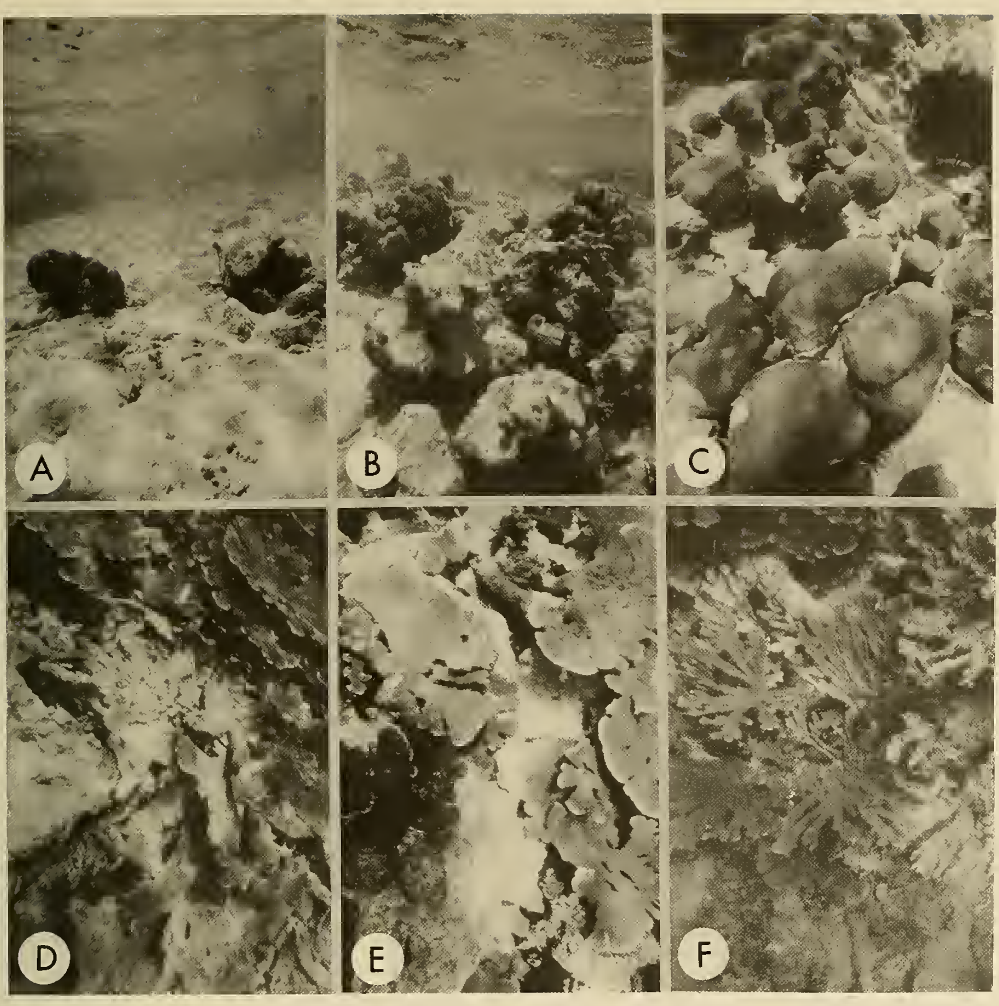


Figure 2. Schematic cross-section of S-5 reef along the core-hole transect, showing dominant reef components on the surface and those recovered from the core holes.



<u>Figure 3</u>. Bottom photographs of S-5 reef taken along transect shown in Figure 2. <u>A</u>. Isolated colonies of <u>Montastrea annularis</u> on sand and rubble bottom, at 5 m along transect. <u>B</u>. and <u>C</u>. Back-reef <u>M. annularis</u> colonies at 30 and 50 m, respectively. <u>D</u>, <u>E</u>, and <u>F</u>. <u>A. palmata</u> community on the reef crest in the vicinity of core hole 1 and 2, and on the shallow fore-reef, near core hole 3.

ATOLL RESEARCH BULLETIN

No. 269

THE INVERTEBRATES OF GALETA REEF (CARIBBEAN PANAMA): A SPECIES LIST AND BIBLIOGRAPHY

BY

JOHN CUBIT AND SUELYNN WILLIAMS

ISSUED BY
THE SMITHSONIAN INSTITUTION
WASHINGTON, D. C., U.S.A.

SEPTEMBER 1983

CONTENTS

THE INVERTEBRATES OF GALETA REEF (CARIBBEAN PANAMA)
A SPECIES LIST AND BIBLIOGRAPHY

by John Cubit[1] and Suelynn Williams[2]

ABSTRACT

The fringing coral reef at Galeta Point, on the Caribbean Coast of Panama, has been under intensive study for approximately ten years. The combined studies of the reef represent approximately 5,000 person hours of field sampling and have documented the presence of approximately 775 species of invertebrates. A list of these species is presented here together with annotations to all known sources of information pertaining to the occurrence of these species on Galeta Reef. For most species these records are the southernmost in the Caribbean Sea.

INTRODUCTION

The following is an inventory of the invertebrates that have been found on Galeta Reef, Panama, together with all known sources of information pertaining to the occurrence of these species on the reef. At present such data are lacking for Caribbean reefs, but are needed to formulate rational policies of resource management and to serve as baseline information for measuring natural and man-caused changes of the environment (FAO, 1969). This need was recently reiterated by the United Nations Environment Program (UNEP, 1981). We have compiled this list from published papers, unpublished reports, personal communications, our own observations, and the set of specimens in the reference collection of the Galeta Point Marine Laboratory. This listing has been restricted only to those invertebrates studied on, or

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collected from, Galeta Reef itself; it does not include species reported from nearby areas or the general Caribbean coast of Panama.

Galeta Reef has been under intensive investigation for approximately ten years. Most of the reef studies have been monitoring surveys designed to determine the species composition of the reef and to document temporal changes in the distribution and abundance of the biota of the reef.

This reef was established as a biological reserve in the late 1960s. Intensive monitoring of the reef biota was started by Charles Birkeland and others in 1970, beginning with a three-year program

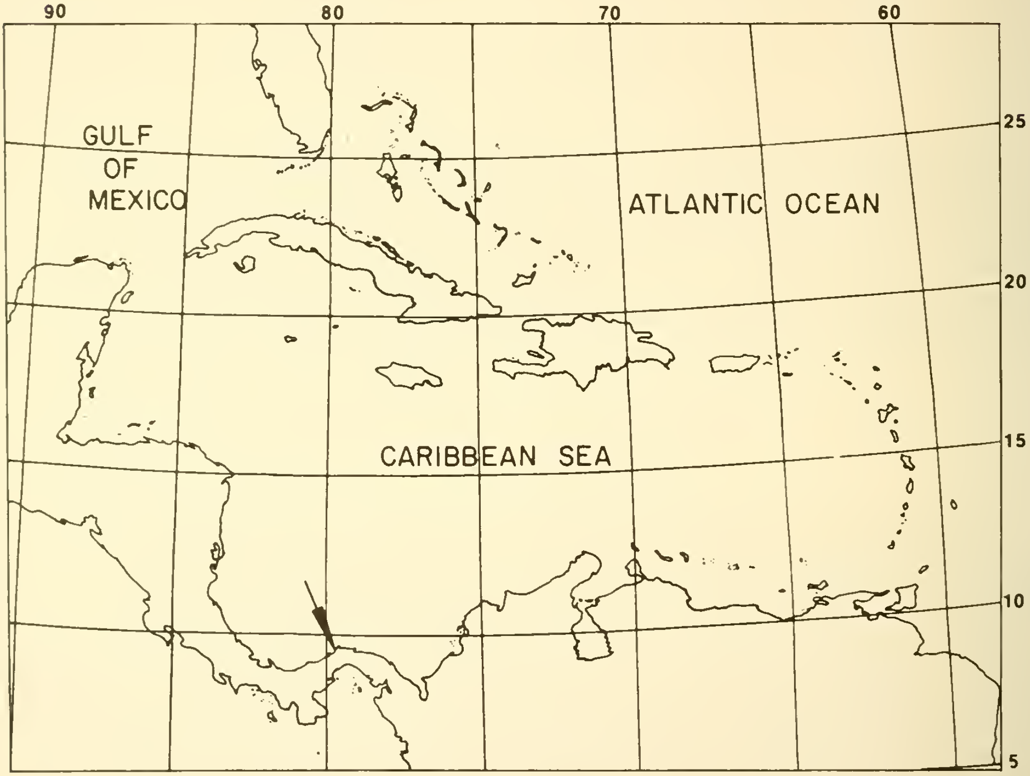

Figure 1. Map of Caribbean Sea showing the location of Galeta Point (9°24'18"N, 79°51'48.5"W) (marked by an arrow at lower left).

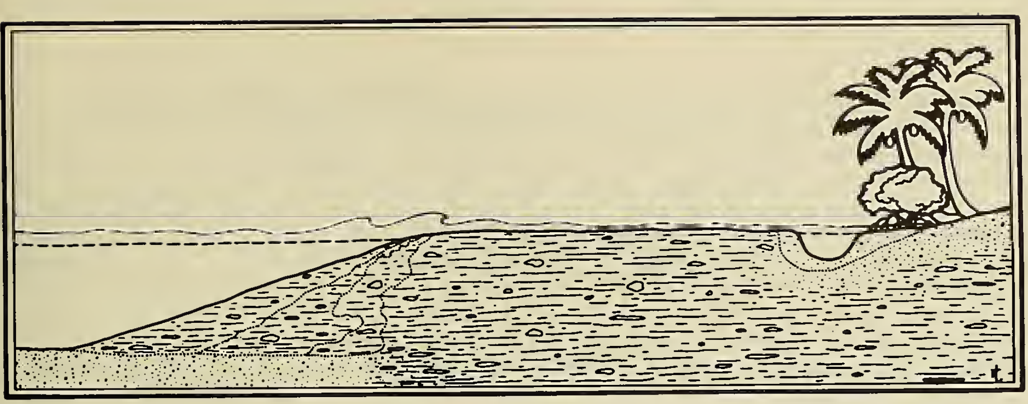

Figure 2. Schematic cross section of the reef at Galeta Point. The reef platform (10 to 300 m wide) is in shallow water (less than 40 cm deep), and is occasionally exposed above the level of the tide (shown as a dashed line). The seaward edge of the reef has various profiles (shown in the figure as the solid and dotted lines) which terminate at 3 to 10 m depth at a base of sand or coral rubble. The reef platform encloses a lagoon and channels and is backed on the landward side by mangroves and sand beaches.

supported by the U.S. Environmental Protection Agency (see Birkeland et al., 1976). Subsequently the monitoring was expanded to include physical factors in a set of projects supported by the Smithsonian Institution Environmental Sciences Program. In addition, the reef has been studied by a number of visiting investigators. Overall, the information in this inventory has been derived from the efforts of approximately 50 people who have conducted a variety of studies, of variable duration, during the period of 1969 to 1980. In all, we estimate that this represents approximately 5,000 person-hours of sampling effort of reef invertebrates. The presence of approximately 775 species of macroinvertebrates has been documented in these investigations of the reef. In these studies certain taxonomic and ecological groups have received more attention than others. For instance, the gastropods, polychetes, and certain groups of decapods have been more thoroughly collected, while the sponges, ascidians, bryozoans, and smaller crustaceans have not. There is also more information regarding those invertebrates that are major occupiers of primary substratum on the shallow reef platform than for those species that are mobile or occur on the subtidal reef slope and sand bottom.

Description of the Reef

The Galeta Reef is in the southwestern Caribbean Sea (9°24'18"N, 79°51'48.5"W). The Galeta Point Marine Laboratory, situated directly on the reef platform, is the southernmost marine laboratory in the Caribbean (see map, Fig. 1). The reef is near the western end of a system of fringing reefs that stretch for approximately 250 km along the Caribbean coast of Panama. The majority of these reefs are now at their post-climax stage, having passed through their period of most active coral growth more than 2,000 years ago. The general structure of this type of reef is of a broad platform, bordered on the landward side by mangroves, and often enclosing a lagoon. On the seaward side, the platform slopes into 3 to 10 m of water before reaching a sand bottom (Macintyre and Glynn, 1976; Fig. 2). The surface of the reef platform is at the lower level of the intertidal zone. The range of the tides on this coast is only about 30 cm, so the reef platform is never deeply under water. Wave action tends to maintain water over the reef even during the lowest low tides; however, during calm weather the reef platform may be exposed above water level for long periods of the day, subjecting the biota of the platform to extremes of desiccation, solar radiation, high temperatures, rainfall, and predation by shorebirds. There are approximately 30-40 such instances of reef exposure each year, varying in duration from 1 to 14 hours.

Other than the extreme low tides, the reef is subject to relatively little disturbance. Galeta Point is south of the Caribbean "hurricane belt" (the area traversed by hurricanes and tropical storms) (Neumann et al., 1978), and is thus protected from this source of periodic disruption to which most other Caribbean reefs are exposed. Salinity and seawater temperature have been monitored on this reef for approximately seven years: there is no evidence that the subtidal biota are ever exposed to extremes of any of these factors. Mean seawater temperature is approximately 29°C with the range of variation confined to plus or minus a few degrees (except during the extreme low tides previously mentioned, when temperatures in shallow pools of standing water on the reef platform may reach 35°C to 40°C). Salinities average approximately 33 ppt, also with little variation (except for those organisms above water level which may be exposed to heavy rains).

Most of the hard substrata of the reef platform are covered with algae, primarily the two red algae *Acanthophora spicifera* (Vahl) Borgesen and *Laurencia papillosa* (Forsskal) Greville. The seagrass *Thalassia testudinum* Koenig and Sims occupies much of the area of loose sediment. The biota of the subtidal reef slope consists of various species of foliose and crustose coralline algae, some fleshy algae, and live corals. Most of the species in this inventory were collected from the reef platform.

Explanation of Listings

All entries on this list are followed by notations which refer to the following: (1) published information regarding the occurrence of the species on Galeta Reef, (2) to whom to attribute the determination of the species, and (3) the presence of voucher specimens in the Galeta laboratory reference collection. Because of the large number of entries, we have had to abbreviate these notations. The meanings of the abbreviations are listed at the end of the inventory and follow this form:

1. Multiple capital letters are the initials of those persons who have made the species determinations of the specimens collected from Galeta Reef.

2. The single capitals B, D, F, and G refer to appendices in Birkeland et al. (1976), the single most comprehensive survey of Galeta Reef.

3. E73-E76 refer to reports of the Environmental Sciences Program for the years numbered.

4. Lower case letters denote references listed under Literature Cited.

5. + signifies voucher specimens of the species are present in the reference collection at the Galeta Point Marine Laboratory.

To aid users of this list and to avoid compounding errors, we have noted any variations in nomenclature and spelling among the sources. We refer the user to the sources in the annotations for the authors of the species.

Abbreviations Used

SPECIES DETERMINATIONS

AR	Amada A. Reimer
BM	B. Macurda
CAC	C. A. Child
CB	Charles Birkeland
CC	C. Cutress
DLM	David L. Meyer
DLW	Diana L. Werder
DS	Diane Stoecker
EK	Eugene Kaplan
GLH	Gordon L. Hendler
HD	Hugh Dingle

IT	Ina Tumlin
JC	John Cubit
JD	Judith Dudley
JH	Janet Haig
JR	Joseph Rosewater
JRY	Joyce Redemske Young
JS	James Stames
JSG	John S. Garth
JW	J. Wells
JWP	J. W. Porter
KBM	Kaniaulono B. Meyer
KS	Ken Sebens
KR	Klaus Ruetzler
LGA	Lawrence G. Abele
PAA	Peter A. Abrams
PG	Peter W. Glynn
RB	R. Bullock
RLC	Roy L. Caldwell
RHG	Robert H. Gore
RHM	R. H. Millar
RM	Raymond B. Manning
RO	Randy Olson
RS	Rick Steger
SS	Stephen Shuster
SW	Suelynn Williams
VB	Victoria Batista

LITERATURE REFERENCES

B, D, F, G = appendices B, D, F, and G in Birkeland et al., 1976.

E73, E74, E75, E76 = reports of the Environmental Sciences Program of the Smithsonian Institution (Environmental Monitoring and Baseline Data from the Isthmus of Panama - 1973, 1974, 1975, 1976, respectively).

a = Fauchald (1977)
b = Birkeland (1974)
c = Bertsch (1975a)
d = Reimer (1975)
e = Gore and Abele(1976)
f = Macintyre and Glynn (1976)
g = Sebens (1977)
h = Meyer (1977)
i = Sebens (1976)
j = Bertsch (1975b)
k = Hendler (1977)
m = Abrams (1976)
n = Koehl (1977)
o = Yee and Chang (1978)
p = Lawrence (1976)
q = Sebens (1982)

r = Sebens and DeRiemer (1977)
s = Gore (1977)
t = Porter (1972)
u = Gore and Abele (1973)
v = Olson (1979)
w = Birkeland et al. (1976)
x = Vasquez-Montoya (1979)
y = Batista (1980)
z = Abele (1972)
aa = Powell (1971)
bb = Smith (1973)
cc = Meyer (1973)
dd = Brattegard (1974)
ee = Lasker (1979)
ff = Lehman and Porter (1973)
gg = Spivey (1976)
hh = Henry and McLaughlin (1975)
ii = Jackson (1973)
jj = Rützler and Sterrer (1970)
kk = Child (1979)
ll = Southward (1975)
mm = Caldwell (1981)

OTHER

+ signifies this species is currently represented in the reference collection of the Galeta Point Marine Laboratory.

PORIFERA

Anthosigmella varians	E73, E74, E75, E76, v, q
Craniella sp.	E73, E74, E75, E76
Geodia sp.	F
Niphates erecta	KR, y
Placospongia sp.	E75
Sigmadocia caerulea	KR, y
Sigmadocia sp.	KR, y
Spongia sp.	KR, y
Tedania ignis	KR, y

COELENTERATA

(by Order)

HYDROIDA

Millepora alcicornis	t
Millepora complanata	B, E73, E74, E76, f, q, v, t, jj
Millepora moniliformis	t
Millepora spp.	v
Stylaster rosaceus	DLM, +
Unidentified sp.	y

CERIANTHARIA

Ceriantheopsis americanus	y
Cerianthus sp.	B, +

ACTINIARIA

Aiptasia tagetes	B, q, y, +
Anthopleura krebsi	B, F, +
Anthopleura sp.	B, E73, +
Bartholomea annulata	r, y
Bunodeopsis antilliensis	r
Bunodeopsis globulifera	KS, ? in y
Condylactis gigantea	i, r, bb
Epiphellia n. sp.	B, q, +
Lebrunia coralligens	r
Lebrunia danae	r
Phyllactis flosculifera	q, *P. floculifera* [sic] in CC, B, E73, E74, E75, E76, +
Phymanthus crucifer	CC, B, E73, E74, E76, q, r, +
Phymanthus sp.	E75
Stoichactis helianthus	CC, i, r
Telmatactis americana	B, +
Telmatactis roseni	B, +
Telmatactis vernonia	r

CORALLIMORPHARIA	
Paradiscosoma neglecta	r
Rhodactis sancti-thomae	r
Ricordea florida	r, v, *Recordia* in CC, JRY, +
ZOANTHIDEA	
Isaurus duchassaingi	AR, B, E73, E76, q, +
Isaurus tuberculatus	q
Palythoa caribaeorum	B, E73, E74, E76, g, n, q, v, +
Palythoa gigantea	E74
Palythoa sp.	E75, E76
Palythoa spp.	v
Palythoa sociatus	y
Palythoa variabilis	B, E74, d, g, n, q, y, +
Palythoa (= *Protopalythoa*) *grandis*	q
Parazoanthus parasiticus	q
Parazonathus swiftii	q
Zoanthus pulchellus	AR, +
Zoanthus sociatus	AR, B, F, E73, E74, E75, E76, g, d, q, y, +
Zoanthus solanderi	AR, B, E73, E74, E75, E76, + *Z. solandri* *[sic]* in g, q
Zonathus sp.	E76
RHIZOSTOMAE	
Cassiopea ?*xamachana*	JC
SCLERACTINIA (by family)	
Astrocoeniidae	
Stephanocoenia michelinii	JW, f, *Stephanocoencia* *[sic]* in t, +
Pocilloporidae	
Madracis decatis	JW, t, +
Acroporidae	
Acropora palmata	t, v
Acropora cervicornis	t

Agariciidae

Agaricia agaricites	JWO, B, E73, E74, E76, f, v, +
Agaricia agaricites forma *agaricites*	t
Agaricia agaricites forma *danae*	t
Agaricia agaricites forma *crassa*	t
Agaricia agaricites forma *purpurea*	t
Agaricia agaricites forma *humilis*	t
Agaricia tenuifolia	t
Agaricia spp.	v
Helioseris cucullata	t

Siderastreidae

Siderastrea siderea	DLM, B, f, q, t, v, y, +
Siderastrea radians	B, E73, E74, f, t, y, jj

Poritidae

Porites astreoides	JW, B, E73, E74, E76, f, t, v, y, + *P. astroides* in E75, jj
Porites branneri	JWP, t, +
Porites divaricata	t
Porites furcata	B, E73, E74, E76, f, t, jj
Porites porites	t, y
Porites sp.	E76

Faviidae

Colpophyllia amaranthus	t
Colpophyllia breviserialis	t
Colpophyllia natans	JW, t, +
Diplora clivosa	t, q, v
Diploria strigosa	t
Favia fragum	DLM, B, E73,E74,E76, f, t, y, +
Manacina areolata	JWP, t, +
Montastrea annularis	JW, f, t, +
Montastrea cavernosa	JW, t, +, ee, ff

Rhizangiidae	
Astrangia solitaria	B, t
Meandrinidae	
Dichocoenia cf. *stellaris*	JWP, +
Dichocoenia stokesii	B, f, t *D. stokesia* in E76
Meandrina meandrites	t
Meandrina meandrites var. *meandrites*	JW, +
Mussidae	
Isophyllia multiflora	t
Isophyllia sinuosa	PG, f, t, +
Mussa angulosa	JWP, t, +
Mycetophyllia lamarckana	JW, t, +
Mycetophyllia sp. B	t
Caryophyllidae	
Eusmilia fastigiata	t
Dendrophylliidae	
Tubastraea aurea	t
GORGONACEA	
Erythropodium caribaeorum	B, E73, E74, E76, q
Gorgonia flabellum	f
Gorgonia spp.	v
Gorgonia ventalina	b

PLATYHELMINTHES

Class: Turbellaria	
Unident. species	y

SIPUNCULA

Aspidosiphon broki	B, +
Aspidosiphon speculator	x
Aspidosiphon spinoscutatus	x
Aspidosiphon spp. (7 species)	B
Dendrostomum sp.	B
Golfingia rimicola	x
Golfingia spp. (4 species)	B, F
Lithacrosiphon spp. (5 species)	B
Lithacrosiphon sp. 3	F
Paraspidosiphon fisheri	B, F, +
Paraspidosiphon speciosus	? in B
Paraspidosiphon spinoso-scutatus	B, F, +
Paraspidosiphon steenstrupi	B, F, +
Paraspidosiphon spp. (7 species)	B
Paraspidosiphon sp. 4	F
Phascolosoma antillarum	B, F, +
Phascolosoma perlucens	B, F, +
Phascolosoma varians	B, +
Phascolosoma spp. (7 species)	B
Phascolosoma spp. 3, 4	F
Themiste spp. (3 species)	B
Unident. species	y

ANNELIDA

(by family)

Ampharetidae	
Isolda bipinnata	a
Isolda pulchella	x
Melinna n. sp.	B

Amphinomidae

Amphinomid sp. 1	B, F, +
Amphinomid sp. 2	B, +
Eurythoe complanata	B, F, a, q, +
Hermodice carunculata	B, a, q, y
Linopherus canariensis	a (family Phyllodocidae in B)
Unident. species	y

Aphroditidae

Aphrodita diplops	a
Aphrodita n. sp.	B

Arabellidae

Arabella mutans	B, F, a, x, y, +
Arabella sp. indet.	a

Ariciidae (listed thus by Vasquez-Montoya, 1979)

Naineris laevigata	x
Naineris mutila	x
Naineris setosa	x
Scoloplos armiger	x

Chrysopetalidae (Palmyridae in B)

Bhawania goodei	B, a, +
Bhawania riveti	+

Cirratulidae

Cauleriella hamata	x
Cauleriella sp. indet.	B, a
Chaetozone sp. indet.	B, a, y
Cirratulus cirratus	? in a, *C. cirratulus* in B
Cirriformia luxuriosa	B, + (specimen in collection from Pacific)
Cirriformia punctata	B, a, +

Dodecaceria concharum	B, E74, a
Tharyx sp. indet.	B, a
Dorvilleidae	
Dorvillea rubrovittatus	a, *D. rubrovittata* in B
Driloneresis nuda	x
Schistomeringos longicornis	a, x
Eunicidae (Leodicidae in F)	
Eunice afra	B, F, a, +
Eunice antennata aedificatrix	B, a, +
Eunice aphroditois	B, F, a, +
Eunice (Nicidion) cariboea	a, +, *E. caribaea* [sic] in B, F
Eunice filamentosa	B, a, +
Eunice vittatopsis	x
Eunice websteri	B, a, +
Eunice sp. indet.	B, a
Lysidice ninetta	x
Lysidice sp.	y
Marphysa amadae	a
Marphysa depressa	x
Marphysa n. sp.	B
Marphysa sp. indet.	a
Nematonereis unicornis	a, x
Palola siciliensis	B, a, +
Palola sp. indet.	B, a
Flabelligeridae (Chloraemidae in B)	
Pherusa capulata	x
Pherusa inflata	B, a, +
Piromis americana	+ (no identifier on voucher specimen)
Glyceridae	
Glycera abranchiata	x

Glycera oxycephala	B, F, a
Glycera tesselata	B, a
Glycera sp.	B
Goniadidae	
Goniada acicula	B, a
Hesionidae	
Hesione picta	B, a
Ophiodromus obscurus	B, a
Lumbrineridae	
Lumbrineris inflata	a, *Lumbrinereis* in B
Lumbrineris sp. aff. *latreilli*	y
Lumbrineris tetraura	x, y
Lysaretidae	
Lysaretid sp.	B, a
Oenone fulgida	B, a (in family Arabellidae in B)
Maldanidae	
Axiothella rubrocincta	x
Nereidae	
Ceratonereis mirabilis	B, a, +
Neanthes galetae	a, x
Neanthes n. sp. 1	B
Neanthes sp. indet.	B, a
Nematonereis sp.	y
Nereis callaona	B, F, a, +
Nereis panamensis	a
Nereis n. sp. A	B
Nereis riisei	a, *riseii* [sic] in B, x
Nereis sp.	y
Nereidae sp. indet.	a

Perinereis elenacasoi	B, F, +
Perinereis anderssoni	a, x, y
Perinereis sp. indet. A	B
Perinereis sp. indet. B	B
Platynereis dumerilii	B, F, a, x, +
Platynereis sp. indet.	B, a
Pseudonereis gallapagenesis	B, F, +
Onuphidae	
Onuphis nebulosa	x
Onuphis vermillionensis	B, a, x (in family Eunacidae in B)
Onuphis sp.	B (in family Eunacidae in B)
Opheliidae	
Armandia bioculata	x
Oweniidae	
Owenia collaris	B, a
Paraonidae	
Aricidea suecica	x
Phyllodocidae	
Anaitides erythrophyllus	a, *erythrophylla* [*sic*] in B
Anaitides sp. cf. *lamellifera*	x
Eulalia myriacyclum	B, F, a, +
Sige orientalis	B, ? in a
Poecilochaetidae	
Poecilochaetus johnsoni	x
Polynoidae	
Halosydna leucohyba	B, a, +
Halosydna sp. 1	B, +

Harmothoe sp. indet.	B, a
Harmothoe hirsuta	x
Lepidonotus humilis	B, a, +
Lepidonotus neophilus	+
Lepidasthenia varius	a
Sabellariidae	
Phragmatopoma sp. indet.	B, a
Sabellaria alcocki	B, + (specimen in collection from Pacific)
Sabellaria floridensis	B, a, +
Sabellidae	
Chone sp.	B, a
Demonax leucaspis	? in a
Demonax sp.	B
Hypsicomus torquatus	+, B, F
Hypsicomus phaeotenia	a
Megalomma sp.	y
Megalomma sp. aff. *pigmentum*	x
Megalomma roulei	x
Megalomma vesiculosum	a, *Megaloma* [sic] in B
Pseudopotamilla reniformis	B, a
Sabella melanostigma	B, a, +
Sabella sp. 17	B
Sabella sp. 18	B
Sabella sp.	y
Sabellidae sp. indet.	a
Sabellastarte magnifica	JC
Serpulidae	
Serpulid sp. 1	F
Serpulid sp. 2	F
Spirobranchus giganteus	JC
Spirorbis sp.	F, y

Sigalionidae	
Psammolyce spinosa	B, a, +
Sthenelais verruculosa	x
Spionidae	
Boccardia polybranchia	x
Malacoceros indicus	x
Nerinides cantabra	x
Prionospio cirrifera	x
Prionospio heterobranchia texana	B, a
Pseudopolydora antennata	x
Syllidae	
Autolytus anoplos	a
Autolytus n. sp.	B
Autolytus cf. *magnus*	B, F, +
Haplosyllis spongicola	B, a, +
Langerhansia cornuta	B, B, a, +
Langerhansia mexicana	B, a
Odontosyllis sp.	B
Opisthosyllis brunnea	B, F, a, +
Pionosyllis sp. indet.	a
Syllidae, unident. fragments	a
Syllis longissima	x
Trypanosyllis taeniaformis	x, y
Typosyllis aciculata	B, a, + (specimen in collection from Pacific)
Typosyllis fuscosuturata	a
Typosyllis sp. A	B
Typosyllis prolifera	B, ? in a
Typosyllis variegata	B, a, +
Terebellidae	
Eupolymnia nebulosa	B, F, a, +

Euthelepus pascua	a
Loimia medusa	B, F, a
Pista fasciata	B, a, +
Polycirrus sp.	B, a, x
Polycirrus sp. aff. *haematodes*	x
Streblosoma crassibranchia	B, a, +
Terebellidae sp. indet.	a
Thelepus setosus	B, a

Trichobranchidae

Trebellides stroemi	x

ARTHROPODA

CRUSTACEA: COPEPODA (by order)

CALANOIDA

Unident. species	y

CRUSTACEA: ISOPODA (by family)

Anthuridae

Accalathura sp.?	SS

Idoteidae

Cleantis planicauda	x

Cirolanidae

Cirolana parva	SS
Excirolana mayana	x

Excorallanidae

Alcinora sp.	y
Excorallana tricornis	SS

Ligiidae	
Ligia sp.	y
Limnoriidae	
Limnoria sp.	y
Sphaeromatidae	
Paracerceis caudata	SS
Stenetriidae	
Stenetrium serratum	SS

CRUSTACEA: AMPHIPODA (by family)

Gammaridae	
Elasmopus sp.	y

CRUSTACEA: DECAPODA: REPTANTIA (by family)

Porcellanidae	
Clastotoechus nodosus	B, JH, e
Megalobrachium poeyi	B, JH, e, +
Megalobrachium roseum	B, JH, e, +
Megalobrachium soriatum	B, JH, e, +
Neopisosoma angustifrons	e, s, +
Pachycheles chacei	B, JH, e, +
Pachycheles cristobalensis	B, JH, e, +
Pachycheles serratus	B, JH, JS, LGA, e, +
Pachycheles susanae	B, e, u, +
Petrolisthes armatus	B, JH, e, +
Petrolisthes galathinus	B, JH, JS, e, +
Petrolisthes jugosus	B, JH, e, +
Grapsidae	
Aratus pisonii	EK, y

Goniopsis cruentata	RHG, y
Grapsus grapsus	RHG, +
Pachygrapsus gracilis	y
Pachygrapsus marmoratus	B
Pachygrapsus transversus	B, JSG, +
Percnon gibbesi	RHG
Plagusia depressa	RHG, JPS, +
Sesarma cinereum	y
Sesarma curacaoense	y
Portunidae	
Callinectes sp.	JC
Majidae	
Acanthonyx petiverii	JSG, + *petriverii* [sic] in B
Epialtus sp.	B
= *E.* ?*longirostris*	JSG
Macrocoeloma subparallelum	B, JSG
Microphrys bicornutus	B, F, JSG, E74, E75, E76, x, y, +
Mithrax acuticornis	B, JSG
Mithrax coryphe	B, JSG, +
Mithrax commensalis	JRS, JS
Mithrax sculptus?	EK
Mithrax spinossimus	B
Mithrax sp.	B, JSG
Mithrax verrucosus	JRS, JS
Pitho aculeata	B, JSG, +
Stenorhynchus seticornis	JC
Thoe puella	B, JSG
Xanthidae	
Carpilius corallinus	JC
Cataleptodius floridanus	RHG, *Leptodium* in B, JSG, LGA, +
Domecia acanthophora	B, JSG
Eriphia gonagra	B, JSG

Leptodius floridanus	x
Micropanope sp.	B, JSG
Panopeus bermudensis	B, JSG, LGA
Panopeus harttii	RHG, +
Panopeus herbstii	JSG, x, y, +
Panopeus sp.	B, JSG
Panopeus sp. aff. *occidentalis*	x
Paraliomera dispar	B, JSG, LGA, +
Pilumnus dasypodus	B, JSG, +
Pilumnus holosericus	B, JSG, LGA, +
Pilumnus lacteus	B
Pilumnus reticulatus	B, JSG, +
Pilumnus sayi?	RHG, +
Pilumnus sp.	B, JSG
Platyactaea setigera	RHG, *Actaea* in B, JSG, +
Platypodia spectabilis	B, JSG, LGA, RHG, +
Xantho denticulatus	RHG, *Xanthodius* in B, JSG, +
Calappidae	
Calappa sp.	JC
Gecarcinidae	
Cardisoma guanhumi	RHG
Dromiidae	
Dromidia sp.	JC
Ocypodidae	
Ocypode quadrata	y
Uca burgersi	RHG, +
Uca sp.	y, jj
Palinuridae	
Panulirus argus	JC
Panulirus guttatus	JC

Scyllaridae	
Scyllarus sp.	JC
Parthenopidae	
Heterocrypta macrobranchia?	B, RHG
Leucosiidae	
Uhlias limbatus	B, JSG
Paguridae	
Paguristes cadenati	JC
Paguristes grayi	PAA, m, +
Paguristes cf *tortugae*	PAA, m, +
Pagurus bonairensis	PAA, m, +
Pagurus brevidactylus	PAA, m, +
Coenobitidae	
Coenobita clypeatus	PAA, m, +
Diogeniidae	
Calcinus tibicen	PAA, JH, m, +
Clibanarius antillensis	PAA, m, +
Clibanarius sp.	y
Clibanarius tricolor	PAA, m, +
Dardanus venosus	PAA, m, +
Dardanus sp.	o
Petrochirus diogenes	RHG, *P. bahamensis* in PAA, m, +
Petrochirus sp.	o
Pinnotheridae	
Pinnotheres maculatus	JSG
Pinnixa ?*faxoni*	JSG
Hapalocarcinidae	
Pseudocryptochirus	RHG

CRUSTACEA: DECAPODA: NATANTIA (by family)

Alpheidae

Alpheus armillatus	B, F, x
Alpheus armatus	JC
Alpheus bahamensis	B
Alpheus cristulifrons	B
Alpheus floridanus	x
Alpheus formosus	B
Alpheus normanni	B
Alpheus nuttingi	B
Alpheus paracrinitus	B
Alpheus peasei	B
Alpheus ridleyi	B
Alpheus schmitti	B
Alpheus simus	B
Alpheus sp.	B, F, y
Alpheus viridari	F, x
Automate rectifrons	B
Metalpheus rostratipes	B
Salmoneus ortmanni	B
Synalpheus anasimus	B
Synalpheus brevidactylus	RHG
Synalpheus fritzmuelleri	B
Synalpheus herricki	B
Synalpheus minus	
Synalpheus pandionis	B
Synalpheus sp.	B
Synalpheus tenuispina	B
Synalpheus townsendi	B
Thunor rathbunae	B

Callianassidae

Callichirus acanthochinus	x

Gnathophyllidae	
Gnathophyllum americanum	B
Hippolytidae	
Hippolyte curacaoensis	B
Lysmata intermedia	B
Thor manningi	B, x
Palaemonidae	
Periclimenes americanus	B
Stenopus hispidus	y
Stenopus scutellatus	JC
Penaeidae	
Penaeus duorarum	x
Penaeus sp.	mm
Sicyonia parri	B
Trachypenaeus similis	B
Processidae	
Ambidexter symmetricus	B, B, x, z
Processa bermudensis	B
Processa fimbriata	B
Processa sp. aff. *hemphilli*	x

CRUSTACEA: STOMATOPODA

Gonodactylus austrinus	RM, B, y, +
Gonodactylus bredini	RM, B, y, +
Gonodactylus oerstedii	RM, B, y, +
Gonodactylus spinulosus	HD and RS, +
Meiosquilla lebouri	RLC and RS
Pseudosquilla ciliata	RM, x, y, +
Nannosquilla sp.	x

CRUSTACEA: MYSIDACEA

Siriella chierchiae	dd
Bowmaniella bracescui	dd
Bowmaniella sewelli	dd
Amathimysis cherados	dd
Amathimysis gibba	dd
Brasilomysis castroi	dd
Cubanomysis jimenezi	dd
Mysidopsis brattstroemi	dd
Mysidopsis velifera	dd
Mysidopsis arenosa sp. nov.	dd
Mysidium columbiae	dd
Mysidium gracile	dd
Mysidium integrum	dd

CRUSTACEA: CIRRIPEDIA

Balanus sp.	jj
Balanus trigonus	gg
Balanus venustus	hh
Chthamalus angustitergum	ll
Chthamalus bisinuatus	ll
Chthamalus rhizophorae	ll
Chthamalus sp.	y
Newmanella radiata	gg
Tetraclita stalactifera	ll

PYCNOGONIDA

Achelia sawayai	B, kk, +
Anoplodactylus allotrius	kk
Anoplodactylus batangensis	*batangense* in B, kk
Anoplodactylus evelinae	B, kk, + (specimen in collection from Pacific)

Anoplodactylus galetensis	kk
Anoplodactylus insigniformis	kk
Anoplodactylus jonesi	kk
Anoplodactylus monotrema	kk
Anoplodactylus multiclavus	kk
Anoplodactylus pectinus	kk
Anoplodactylus spp.	B, kk
Anoplodactylus stri	kk
Anoplodactylus trispinosus	kk
Anoplodactylus viridintestinalis	kk
Ammothella appendiculata	B, kk, +
Ammothella exornata	kk, +
Ammothella marcusi	kk
Ammothella rugulosa	kk
Ammothella spp.	B
Ammothella spinifera	kk
Ascorhynchus castellioides	B, kk, +
Ascorhynchus latipes	B, kk, +
Callipallene emaciata	kk
Callipallene sp.	B
Endeis spinosa	kk
Eurycyde gorda	kk
Eurycyde raphiaster	B, kk, +
Eurycyde sp.	B
Nymphon floridanum	CAC, kk, +
Nymphopsis duodorsospinosa	B, kk, + (specimen in collection from Pacific)
Pallenopsis schmitti	kk
Pigrogromitus timsanus	B, kk, +
Rhynchothorax architectus	kk
Rhynchothorax sp.	B
Tanystylum birkelandi	kk
Tanystylum geminum	kk
Tanystylum isthmiacum difficile	kk
Tanystylum sp.	B, kk

MOLLUSCA

SCAPHOPODA

Dentalium gouldi	KBM, +
Dentalium antillarum	x

POLYPLACOPHORA

Acanthochitona hemphilli	B
Acanthochitona interfissa	B
Acanthochitona pygmaea	B
Acanthochitona spiculosus	B
Acanthochitona unident. sp.	y
Acanthopleura granulata	B
Calloplax janeirensis	B
Chiton viridis	B
Choneplax lata	B
Ischnochiton papillosus	B
Ischnochiton pectinatus	B
Ischnochiton purpurascens	B
Lepidochitona liozonis	B

GASTROPODA: PROSOBRANCHIA

Acmaea antillarum	B
Acmaea pustulata	B, f
Alvania aberrans	CB, +
Anachis catenata	CB, B, +
Anachis crassilabris	F
Anachis obesa	JR, CB, +
Antillophos sp. 1	CB, +
Architectonica nobilis	KBM, +
Arene cruentata	CB, B, +
Arene tricarinata	B

Astraea caelata	DLW, B, +
Astraea phoebia	KBM, IT, B, +
Bailya intricata	B, F
Bailya parva	KBM, +
Balcis intermedia	B
Balcis sp. 1	B
Batillaria minima	KBM, D, F, f, y, +
Bittium varium	B
Bursa cubaniana	B
Bursa granularis	KBM, +
Caecum sp.	y
Calliostoma jujubinum	KBM, +
Cantharus auritulus	F
Cantharus tinctus	B
Cerithiopsis emersoni	F
Cerithium eburneum	KBM, B, f, x, +
Cerithium litteratum	KBM, B, JR, f, x, y, + [cf. *C litteratum* (Young) by CB in +]
Cerithium variabile	B, D
Charonia variegata	B, o, +
Cheilea equestris	B, *Cheila* [sic] in B
Cittarium pica	B
Columbella mercatoria	KBM, +
Conus daucus	o
Conus mus	B
Coralliophila abbreviata	KBM, +
Coralliophila aberrans	CB, +
Coralliophila caribaea	B
Crassispira fuscescens	KBM, +
Crassispira leucocyma	CB, +
Crassispira nigrescens	JR
Crassispira tampaensis	x
Crepidula plana	B
Crucibulum auricula	KBM, f, +
Cyclostremiscus beaui	B

Cymatium muricinum	KBM, +
Cymatium nicobaricum	KBM, B, +
Cymatium pileare	KBM, B, o, +
Cyphoma gibbosum	KBM, b, +
Cypraea cinerea	KBM, +
Cypraea zebra	KBM, B, o, +
Cypraecassis testiculus	KBM, B, E76, k, o, +
Daphnella lymneiformis	CB, B, +
Diodora cayenensis	CB, B, +
Diodora dysoni	CB, B, JR, +
Diodora cf. *minuta*	KBM, B, JR, +
Diodora variegata	B
Drillia albinodata	RS
Drillia sp. 1	CB, JR, +
Drupa nodulosa	B, D, *Morula nodulosa* KBM, +
Emarginula phrixodes	B
Emarginula pumila	B
Engina turbinella	CB, +
Epitonium candeanum	B
Epitonium lamellosum	B
Epitonium occidentale	B
Epitonium sp. 1	B
Fasciolaria tulipa	KBM, B, o, x, +
Fissurella angusta	B
Fissurella barbadensis	B
Heliacus bisulcatus	B
Heliacus cylindricus	B
Heliacus infundibuliformis	B, *infunibuliformis* [sic] in F
Hemitoma octoradiata	JR, DLW, +
Hemitoma sp.	B
Hipponix antiquatus	CB, B, f, +
Hipponix subrufus	B
Hyalina albolineata	B
Hyalina avena	KBM, B, F, x, +
Hyalina tenuilabra	B

Janthina janthina	KBM, +
Latirus carniferus	RB, KBM, JR, +, *carnifera* [sic] in B
Latirus distinctus	y
Latirus infundibulum	o
Leucozonia nassa	RB, +
Leucozonia ocellata	KBM, B, +
Littorina angulifera	KBM, y, +
Littorina angustior	JC, (KBM, + as *L. lineata*)
Littorina lineolata	B, D
Littorina meleagris	D
Littorina nebulosa	KBM, y, +
Littorina tessellata	KBM, +
Littorina ziczac	KBM, D, +
Lucapina suffusa	KBM, +
Mangelia fusca	B, +
Marginella gracilis	x
Melongena melongena	KBM, x, +
Melongenidae sp.	o
Mitra nodulosa	KBM, +
Mitra sp.	B
Modulus modulus	KBM, B, f, +
Morula nodulosa	see *Drupa nodulosa*
Morum oniscus	KBM, o, +
Murex dilectus	KBM, +
Murex pomum	KBM, KBM, o, +
Murex recurvirostris rubidus	KBM, G, GLH, +
cf. *Murex woodringi*	KBM, +
Nassarius vibex	KBM, F, x, +
Neosimnia acicularis	CB, +
Nerita fulgurans	KBM, D, +
Nerita peloronta	KBM, D, +
Nerita tessellata	KBM, D, y, +
Nerita versicolor	KBM, D, +
Neritina virginea	DLW, KBM, JR, f, x, y, +, *virgines* [sic] in F, *virginica* [sic] in f

Nitidella nitida	B
Nitidella sp. 2	B
Nodilittorina tuberculata	KBM, D, +
Oliva reticularis	KBM, +
Olivella petiolita	DLW, +
Opalia crenata	CB, B, +
Opalia pumilio	B, *pumilo* [sic] in B
Petaloconchus sp. cf. *erectus*	y
Pisania pusio	KBM, +
Planaxis lineatus	CB, D, F, +
Planaxis nucleus	D, F
Polinices hepaticus	o, x
Polinices lacteus	KBM, B, + *lactens* [sic] in f
Prunum guttatum	KBM, JR, +
Psarostola monilifera	B
Purpura patula	KBM, B, o, +
Risomurex muricoides	KBM, B, JR, +
Risomurex roseus	JR, +
Risomurex sp.	JR, CB, +
Rissoina bryerea	B
Rissoina decussata	KBM, B, F, f, +
Rissoina multicostata	KBM, +
Smaragdia viridis	+, *S. viridis* in KBM, B
Strombus gigas	x
Strombus pugilis	JRY, f, +
Strombus raninus	B, f, x, +
Tectarius muricatus	KBM, D, +
Tegula fasciata	KBM, B, JR, f, +
Thais deltoidea	B, JR, o, +
Thais haemastoma, var A	CB, B, D, JR, +
Thais haemastoma	o
Thais rustica	o
Tonna maculosa	KBM, +
Tricolia adamsi	DLW, KBM, B, +

Tricolia bella	KBM, CB, B, F, +
Tricolia thalassicola	KBM, +
Trivia quadripunctata	DLW, KBM, JR, +
Turritella exoleta	KBM, +
Vasum muricatum	DLW, B, +
Vermetidae	y
Voluta musica	DLM, +

GASTROPODA: OPISTHOBRANCHIA (by order)

Anaspidea

Aplysia dactylomela	EK, KBM
Aplysia parvula	KBM
Aplysia sp.	KBM
Bursatella leachii pleii	EK, y, KBM
Dolabrifera dolabrifera	KBM
Petalifera ramosa	KBM
Phyllapylsia engeli	KBM
Stylocheilus longicauda	KBM

Cephalaspidea

Aglaja evelinae	KBM
Atys riiseana	x
Bulla occidentalis	KBM, x
Bulla striata	KBM, f, +
Chelidonura spp.	KBM
Haminoea antillarum	x
Haminoea elegans	KBM
Ildica sp.	KBM
Micromelo undata	DS, SW, KBM

Sacoglossa

Bosellia marcusi	KBM
Bosellia memetica	KBM
Caliphylla mediterranea	KBM

Cyerce antillarum	KBM
Elysia ornata	KBM
Elysia papillosa	KBM
Elysia picta	KBM
Elysia tuca	KBM
Lobiger souverbii	KBM
Oxynoe antillarum	KBM
Placida dendritica	KBM
Phyllobranchillus sp.	KBM
Stiliger sp.	KBM
Tridachia crispata	KBM, +

Notaspidea

Berthella tupala	c
Berthellina quadridens	KBM
Pleurobranchus areolatus	v, KBM

Nudibranchia

Aegires sublaevis	h, KBM
Aphelodoris antillensis	h
Berghia coerulescens	KBM
Berghia creutzbergi	KBM
Bornella calcarata	KBM
Cadlina rumia	j
Catriona tina	KBM
Chromodoris clenchi	h, KBM
Chromodoris kempfi	h, KBM
Chromodoris sp.	y
Coryphella dushia	KBM
Dendrodoris krebsii	KBM
Discodoris evelinae	h
Discodoris mortenseni	j
Dondice occidentalis	KBM

Doriopsilla nigrolineata	h
Doto divae	KBM
Felimare bayeri	h, KBM
Glaucus atlanticus	KBM
Godiva rubolineata	KBM
Hexabranchus sanguineus	h, KBM
Hypselodoris ruthae	h, KBM
Okenia evelinae	h, KBM
Phidiana lynceus	KBM
Phyllidiopsis molaensis	h
Platydoris angustipes	h
Scyllaea pelagica	KBM
Spurilla neopolitana	KBM
Tambja oliva	h, KBM
Tritonia bayeri	KBM
Tritonia wellsi	KBM

GASTROPODA: PULMONATA

Melampus coffeus	KBM, +

BIVALVIA

Americardia media	x
Anodontia pectinata	x
Anomia simplex	DLW, JR, +
Arca imbricata	IT, KBM, B, x, +
Arcopsis adamsi	IT, B, F, f, x, +
Asaphis deflorata	KBM, +
Barbatia domingensis	CB, B, +
Barbatia tenera	BM, B, +
Brachidontes modiolus	JR
Brachidontes citrinus	B
Brachidontes exustus	F, *exhustus* [sic] in ii, y
Brachidontes recurvus	B

Brachidontes sp.	jj
Chama macerophylla	KBM, B, +
Chione cancellata	x
Chlamys imbricata	+
Codakia costata	B, f
Codakia orbicularis	B, F, x
Codakia orbiculata	B, F, f, x, (as *Ctena* in ii), +
Codakia pectinella	x
Coralliophaga coralliophaga	B, f, +
Corbula caribaea	x
Corbula contracta	B, x
Corbula cubaniana	x
Crassinella martinicensis	JR, +
Crassinella lunulata	ii
Crassostrea rhizophorae	y
Crassostrea sp.	jj
Ctena orbiculata	ii
Cumingia antillarum	JR, B, x, +
Cyathodonta semirugosa	CB, +
Diplodonta punctata	B, F, x
Diplodonta semiaspera	JR, +
Donax denticulatus	CB, +
Echinochama arcinella	CB, +
Erycina emmonsi	B
Erycina periscopiana	B
Gastrochaena hians	B, f
Gouldia cerina	x
Gregariella coralliophaga	B
Isognomon alatus	CB, y, +
Isognomon bicolor	CB, B, F, +
Isognomon radiatus	CB, B, D, +
Laevicardium laevigatum	DLW, +
Lima pellucida	B
Lima scabra	DLW, +
Lima scabra form *tenera*	DLW, +

Lioberus castaneus	B
Lithophaga antillarum	KBM, f, +
Lithophaga bisulcata	B, F, f
Lithophaga nigra	B, F, f
Lucina leucocyma	x
Lucina pensylvanica	B
Macoma constricta	x
Macoma tenta	B
Modiolus americanus	KBM, B, +
Musculus lateralis	JR, f, +
Ostrea equestris	DLW, JR, +
Phacoides muricatus	x
Phacoides pectinatus	KBM, CB, B, F, ii, +
Pinctada radiata	KBM, B, F, +
Pinna carnea	JR, +
Pseudochama arcinella	B
Pteria colymbus	DLW, KBM, JR, +
Sphenia antillensis	B, +
Spondylus americanus	SW
Solemya sp. aff. *occidentalis*	x
Strigilla sp.	B
Tellina alternata	ii
Tellina exerythra	x
Tellina fausta	DLW, JR, f, x, +
Tellina listeri	x
Tellina nitens	x
Tellina promera	ii
Tellina versicolor	x
Tellina vespusiana	x
Teredo sp.	y
Trachycardium muricatum	DLW, +
Venericardia sp. aff. *tridentata*	x

CEPHALOPODA

Octopus sp.	E75, K

ECTOPROCTA (BRYOZOA)

Arborella dichotoma	JD, +
Bugula sp.	y
Caberea carabaoda	JD, +
Caulibugula dendrograpta	JD, +
Celleporaria albirostris	JD, +
Chlidonia pyriformis	JD, +
Gemillipora sp.	y
Gemelliporidra multilamellosa	JD, aa, +
Lichenopora buskiana	JD, +
Retoporelliria evelinae	JD
Steganoporella magnilabris	JD, aa, +
Stylopoma informata	JD, +
Trematooecia aviculifera	JD, aa, +
Trematooecia turrita	JD, aa, +
Tubucellaria cereoides	JD, +

BRACHIOPODA

Discinisca strigata	B, + (specimen in collection from Pacific)

ECHINODERMATA
(by class)

ECHINOIDEA

Arbacia punctulata	DLM, +
Brissopsis elongata	DLM, +
Brissus unicolor	DLM, B, E76, k, +
Diadema antillarum	B, E74, E75, E76, k, o. v, x,
Echinometra lucunter	B, E74, E75, E76, k, o, x

Echinometra viridis	B, E74, E75, E76, k, o
Echinoneus cyclostomus	B, E76, k, +
Eucidaris tribuloides	DLM, B, E76, k, o, y, +
Halodeima floridana	x
Lytechinus variegatus	DLM, B, E74, E75, E76, k, o, p, x, y, +
Lytechinus williamsi	DLM, +
Meoma ventricosa	DLM, +
Paraster floridiensis	DLM, E76, k, +
Plagiobrissus grandis	DLM, +
Tripneustes ventricosus	DLM, E76, k, v, x, +, *T. esculentus* in B

ASTEROIDEA

Ophidiaster guildingii	B
Oreaster reticulatus	DLM, B, +

OPHIUROIDEA

Amphiodia repens	B
Amphiodia sp. L	B
Amphipholis sp. A	B
Amphipholis sp.	B
Amphipholis gracillima	x
Amphiura (Monamphiura) sp.	B
Amphiura (Nullamphiura) sp.	B
Axiognathus squamata	B
Ophiactis savignyi	DLM, B, x, +
Ophiocantha ophiactoides	B
Ophiocoma echinata	DLM, B, +
Ophiocoma pumila	DLM, B, +
Ophiocoma sp.	y
Ophiocoma wendti	DLM, B, +
Ophioderma appressum	DLM, B, y, +

Ophioderma brevicaudum	DLM, B, +
Ophioderma brevispinum	DLM, B, +
Ophioderma cinereum	DLM, B, +
Ophioderma rubicundum	DLM, +
Ophiolepis paucispina	DLM, B, F, +
Ophiomyxa flaccida	DLM, +
Ophionereis reticulata	DLM, B, +
Ophiothrix angulata	DLM, B, +
Ophiothrix cf. *lineata*	DLM, +
Ophiothrix suensonii	DLM, +
Ophiozona impressa	DLM, +
Ophiozonoida (?) sp.	B (this may be new genus; EK, pers. comm.)

CRINOIDEA

Comactinia echinoptera	DLM
Comactinia echinoptera: cf. var. *valida*	cc
Comactinia echinoptera cf. var. *meridionalis*	cc
Comactinia meridionalis	DLM, +
Nemaster rubiginosa	cc
Nemaster discoidea	cc

HOLOTHUROIDEA

Euapta lappa	JC
Holothuriid sp.	JC

CHORDATA

ASCIDICEA

Ascidia interrupta	DS

Clavelina sp.	y
Clavelina picta	RHM
Cystodytes dellechiajei	RHM
Didemnum spp.	DS
Didemnum sp. B	RHM
Didemnum sp. C	RHM
Didemnum sp. D	RHM
? *Didemnum* sp. E	RHM
Distaplia (? *bermudensis*)	RHM
Ecteinascidia conklini var. *minuta*	DS
Ecteinascidia turbinata	RHM
Eudistoma sp. A	RHM
Eudistoma sp. B	RHM
Pyrua vittata	DS
Polysyncraton (? *amethysteum*)	RHM
Rhopalaea abdominalis	RHM
Trididemnum cyanophorum (= *T. solidum*)	RHM, RO, v, w
Trididemnum sp. A	RHM

NOTE: RHM identifications are provisional.

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HERMATYPIC CORAL DIVERSITY AND REEF ZONATION AT CAYOS ARCAS, CAMPECHE, GULF OF MEXICO

BY

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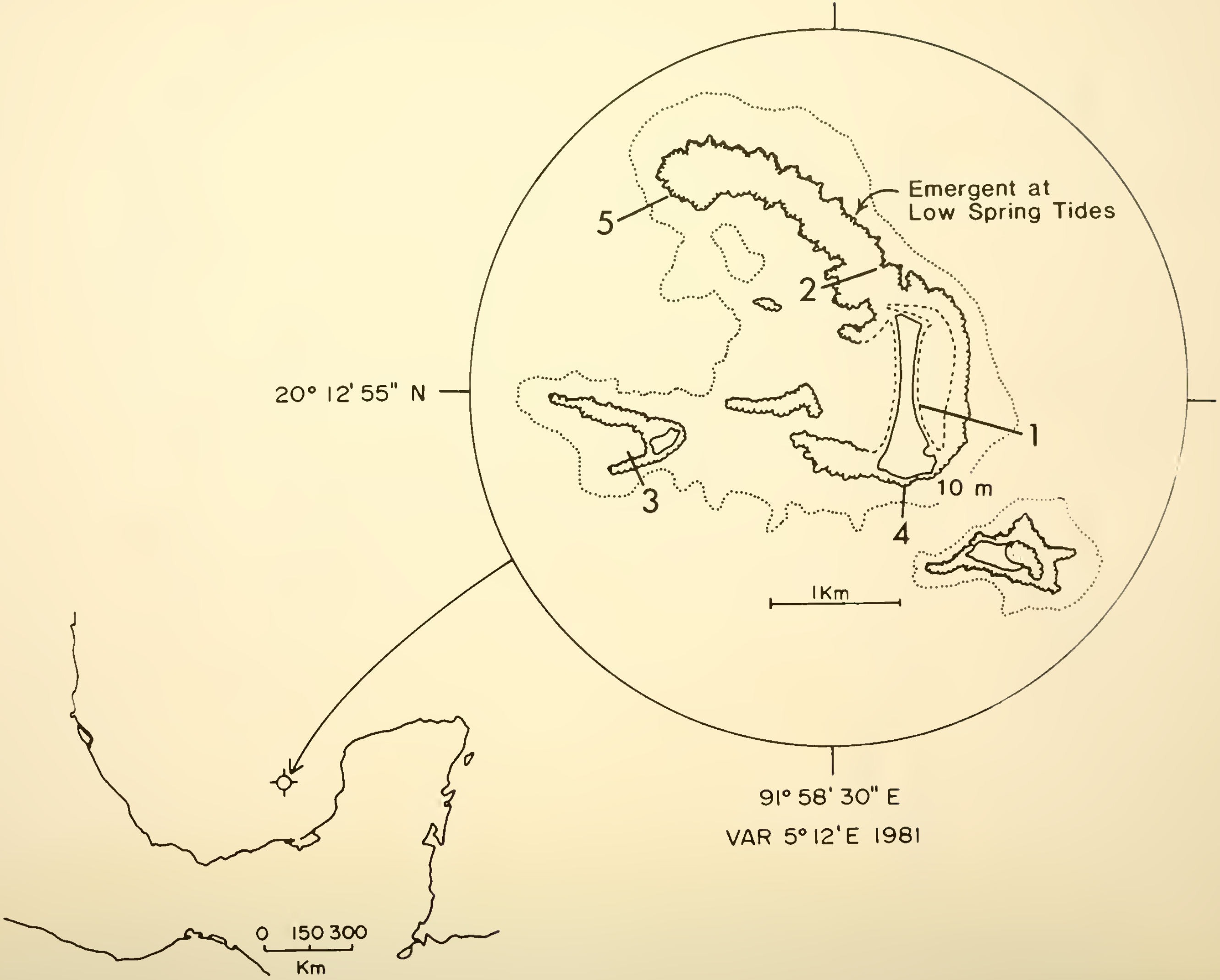

Fig. 1. Location of Cayos Arcas and survey transects.

HERMATYPIC CORAL DIVERSITY AND REEF ZONATION AT CAYOS ARCAS, CAMPECHE, GULF OF MEXICO

by Terence M. Farrell[1,3], Christopher F. D'Elia[1],
Lawrence Lubbers, III[1], and Lawrence J. Pastor, Jr.[2,4]

Abstract

Ecological features of emergent coral reefs in the Campeche Bank region of the Gulf of Mexico are not well described. In a study of reef zonation and diversity of Cayos Arcas, the most southerly of these, the coral reefs surrounding three sand cays were found to exhibit a greater diversity of scleractinian coral species than has been reported previously for the Campeche Bank region. Hermatypic coral coverage was high and coral growth appeared vigorous. However, calcareous algae of the genus *Halimeda*, that are known to be abundant and therefore important producers of calcareous material in emergent reef structures to the north, were not evident. Noteworthy aspects of reef zonation included: 1) a non-emergent reef crest composed of unconsolidated coral rubble and encrusting calcareous algae, but no algal ridge, 2) extensive monospecific stands of *Acropora cervicornis* on the shallow reef flats, 3) proliferation of *Acropora palmata* at depths where one might typically find *Acropora cervicornis* in other localities, and 4) poor representation and coverage by species of the genus *Agaricia*. This zonation and the component species' growth forms suggest that high energy wave action is an important environmental factor determining community structure.

Introduction

Relatively few published reports relate to the species composition and ecology of recent bioherms in the Gulf of Mexico. One reason for this is that the Gulf of Mexico does not contain extensive areas of coral reef. Nonetheless, in addition to the reefs off of Veracruz (Smith, 1954) there are six well developed emergent reef structures in the Campeche Bank region off of the western shore of the Yucatán Peninsula (Glynn, 1973; Logan, 1969). The largest and most northerly of these is Alacrán Atoll which has been the site of several geologically oriented studies (Hoskin, 1963; Kornicker et al., 1959; Kornicker and Boyd, 1962; Folk, 1967). The others are less well known, but have been

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described to some extent (Agassiz, 1888; Logan et al., 1969).

We visited on two occasions the most southerly of the Campeche reef structures, Cayos Arcas. The cays comprising this structure are at the northern boundary of Mexico's offshore petroleum resources, and a deepwater oil terminal has been built in the sheltered waters south of the cays since our last visit (Orme, 1982). In the course of performing an environmental survey focusing on reef development and zonation, we found well-developed reefs with greater diversity of hermatypic corals than has been reported previously for the Campeche Bank region. In the present paper we document and discuss these and other relevant ecological observations.

Study Site

Cayos Arcas consists of three coral and sand cays on a shallow water platform about 3 to 4 sq. km. in area which rises above the Campeche Bank west of the Yucatán Peninsula, Mexico (Fig. 1). Water depth around the cays is about 40 m. The cays envelop a small, protected lagoon that is a popular refuge for local shrimp and shark fisherman located at 91° 58'30"E long. and 20° 12'55"N lat., about 300 km SW of Alacrán Atoll.

Logan et al. (1969) and Ginsburg and James (1974) have characterized Cayos Arcas and neighboring reefs and cays as isolated prominences capped by zoned reefs at the shelf margin. Kornicker and Boyd (1962) have described the geological origin of the Campeche Bank as an "underwater extension of the Yucatán Peninsula... [that is] probably Miocene limestone" with a thin cover of Pleistocene and Recent calcareous sediments. Campeche Bank reefs have apparently been able to keep pace with the Holocene transgression; this implies that reef accretion there occurred at the substantial rate of 20 to 40m during the last 9,000 years (Logan, 1969) or perhaps faster: more recently Mcintyre et al. (1977) proposed that Yucatán reefs have approached the emergent-reef status within the last 2,000 to 3,000 yrs. In any case, it is clear that accretion is rapid on the Yucatán reefs.

Easterly to northeasterly trade winds prevail and probably account for the typical northwest trend of arcuate windward reef margin characterizing Cayo del Centro (Fig. 1). Such reef orientation has been reported for other bioherms on the Campeche Bank (Kornicker and Boyd, 1962; Folk, 1967). From April to September, winds in the area are lighter and more variable (20 to 30 km/hr) than they are from October to March when speeds of 30 to 35 km/hr are common and are often associated with cold fronts or "northers" (Folk, 1967). Hurricanes are not uncommon to the area, Hurricane Allen having passed several hundred km to the north of Cayos Arcas several months before we performed our survey. The tidal range is small (~1.0 m). We do not have mean minimum water temperature for Cayos Arcas; however, we suspect it is between 20° and 22° C, close to those reported for nearby Veracruz and Progresso, Mexico (Milliman, 1973) and by the U. S. Fish and Wildlife Service (1954). Thus reefs at Cayos Arcas probably experience mean minimum temperatures near 21°C, below which optimal reef development does not occur (Milliman, 1973). Glynn (1973) reports that the thermal climate of the reefs on the margin of the Campeche Bank is probably more favorable than it is closer to shore, citing the suggestion of Logan et al. (1969) that the absence of coral reefs on the eastern sector of the shelf is due to the periodic upwelling of cold water there.

Materials and Methods

Surveys of the coral community were carried out by skin and SCUBA diving. We used a transect method keyed to changes in depth and distance offshore and selected a major topographical feature, i.e., beach, reef crest, deep trench as a benchmark for the starting point for a compass bearing traversing various zones of the benthic community. We chose the transects as being generally representative of reef zonation at Cayos Arcas.

A check list of the most abundant sessile invertebrates (primarily hermatypic corals) was developed after an intensive survey of the first transect. At this site a 30 m long chain marked at one meter intervals was laid on the bottom starting at the reef crest and moving towards deep water. We noted species composition and dominance within ten meters of this chain and estimated the total percent living coverage, depth in meters and any significant changes in topography or coral composition with distance from the starting point. Aerial photographs of the transects taken from a helicopter at an altitude of about 200 m were used to confirm our estimates of percent coverage and the representativeness of the transects chosen.

Results

Table 1 gives a summary list including all coral species identified in all five transects during our study. The list contains 20 species we identified and 5 species we suspect were present and is certainly indicative of the most common corals in the shallower (<20 m) zones of the reef. Had the study lasted longer and extended to deeper areas, more species would undoubtedly have been found (see Discussion). In fact, it would be surprising if species reported by Smith (1954) to be present off Veracruz are not also present at Cayos Arcas (Table 1). Observations along transects were completed at 5 locations (Figure 1). These data have been summarized in graphic form (Figure 2).

The most developed reef at Cayos Arcas, in terms of physical structure and coral coverage, occurs as a three kilometer long, arcuate structure to the northwest of the central cay (Figure 1). This reef can be seen in the upper right portion of Plate 1, an aerial photograph viewing Cayos Arcas from the southeast. We investigated reef flat and lagoonal areas of this reef in Transect 2. Transect 1 encompassed the reef crest and fore reef of a nearby section of reef that was similar in physical and biological structure to the fore reef area along arcuate reef face (Plate 2). Taken together Transect 2 and the fore reef section of Transect 1 provide a good picture of the main biological and structural zones occurring on the major Cayos Arcas reef.

The most obvious feature of the reef was an extensive reef flat, over 100 meters wide, almost completely covered by a dense, monospecific stand of *Acropora cervicornis*. To the lee of this stand the bottom gradually sloped from less than one meter to three meters. On this slope a more diverse assemblage of hermatypic corals existed (predominantly members of the genera *Acropora*, *Montastrea*, and *Diploria*), in which substratum coverage ranged from 20-60% and decreased with distance from the reef flat. This back reef area gave way to sandy substrata in the lagoon that harbored numerous patch reefs not crossed by the transect.

To the windward side of the reef flat a small, non-emergent reef crest existed. The crest was composed of unconsolidated coral rubble encrusted with calcareous red algae. No true algal ridge was present. On the forereef the zoanthids *Palythoa caribbea* and *Zoanthus sociatus* were the dominant epibenthic fauna between one and three meters. Below this zoanthid zone, at depths between three and seven meters, *Acropora palmata* was the dominant scleractinian, covering nearly 75% of the substratum (Plate 3). Massive corals, dominantly the genera *Montastrea* and *Diploria* and gorgonians were abundant below seven meters (Plates 4 and 5) in a diverse community extending to approximately 350 meters from the crest, and to a depth of 18 meters where sand substratum was again encountered.

To the lee of the reef crest in Transect 1 the reef flat was absent and the back reef area consisted of a shallow (one meter) expanse of sandy substratum in front of the largest cay, in which scleractinians were scarce.

Transect 3 crossed a nearby, small, protected reef. Its zonation pattern was very similar to the previously discussed larger, exposed reef but it lacked a reef crest and its zonation was both horizontally and vertically compressed.

The remaining two transects were completed at each end of the largest reef. Transect 4, located at the more protected southern end, displayed zonation that was similar to the exposed forereef, except that it was horizontally compressed so that the *Montastrea* - *Diploria* community occurred in water several meters shallower than it did on the windward face of the reef. Transect 5, located at the northwestern end of the reef, traversed an eight meter deep channel that curved around the edge of the reef flat. In this channel the bottom was composed of unconsolidated coral rubble and sediment. The face on the far side of the channel rose to within three meters of the surface. Benthic cover on top of this rise was dominated by the zoanthid *Palythoa caribbea*. Species distributions on this crest and the slope beyond it were similar to those seen on the exposed reef face. However, the slope was more gradual and coral coverage was more extensive. Substratum coverage was 70 to 90% beyond 500 m at a depth of 20 m. Here was one of the few places we observed extensive growth of *Acropora cervicornis* below three m depth: a 30 m wide stand occurred at 8 m depth.

Four transects were located on the large arcuate reef. From these transects and less detailed observations made from a helicopter, the distribution of major reef zones on the reef have been mapped (Figure 3).

Discussion

The hermatypic scleractinian coral diversity of Cayos Arcas consists of at least 20 species from 13 genera. This diversity is greater than is believed to exist off Veracruz or has been reported for Alacrán Reef: for the former there are records of 14 to 16 species and for the latter there are records of 18 species (Glynn, 1973). Given the geographical isolation of this site, this diversity seems surprisingly high, but is not, of course, as high as has been recorded in Jamaica (Wells, 1973), in Curacao (Bak, 1974; cited in Loya, 1976), in Cuba (Zlantarzsky, cited in Loya, 1976), in Belize (Cairns, 1982), and on the Atlantic coast of Panama (Porter, 1972). Relatively little is known about reefs in the southern Gulf of Mexico, but we believe that nearshore turbid water conditions and a lack of suitable substratum affect growth; it is also likely that minimum winter temperatures are close to the lower limits at which extensive reef growth may occur, especially near the coast where occasional upwelling is believed to occur (cf. Logan et al., 1969). It is possible that seasonal temperature lows exclude species unable to tolerate them; however, the presence of species of the genus *Acropora*, which are unable to tolerate the colder temperatues encountered in Bermuda, indicates that minimum temperatures are considerably higher than in Bermuda.

Our field work was most extensive in shallow water; additional study in deeper waters could most probably increase the number of species found. Loya (1976) has discussed the increase in known species richness which occurred with increasing study in other areas.

Logan (1969), who made the only published ecological observations on Cayos Arcas that we encountered, made generally similar observations to ours about community structure. However, Logan (1969) did not report seeing the presence of a very dense monospecific stand of *Acropora cervicornis* on the shallow reef flat as we note here. Similar zonation is also found off Belize (Cairns, 1982) and off the east coast of the Yucatán peninsula (W. Adey, J. W. Porter, pers. comm.). There is no doubt that Logan (1969) would have recognized and commented on that impressive stand of *Acropora* had it been present during his study. We cannot explain this difference, but suspect that a real change in community structure occurred in the interim.

Neither we nor Logan (1969) observed calcareous green algae of the genus *Halimeda*. This observation was unexpected as *Halimeda* is extremely common on the nearby Alacrán reef (Hoskin, 1963; Kornicker and Boyd, 1962). We searched for this coralline algae but did not encounter living *Halimeda* nor obvious skeletal remains. However, we were unable to examine sediments microscopically to verify our field observations. *Halimeda* is the dominant producer of carbonate sediments on a reef off

Belize (Wallace et al., 1977) and presumably Alacrán (Hoskin, 1963). Its absence at Cayos Arcas may result in lowered rates of calcium carbonate deposition.

High wave energy levels may account for some of the species distributions observed on these reefs (Logan, 1969). The depth to which the forereef *Palythoa* and *Acropora palmata* dominated zones extended, and the lack of *Acropora cervicornis* and members of the genus *Agaricia* on the forereef is probably a result of intense wave action during storms. In backreef areas, where lower wave intensities predominate, the zonation was compressed so that the coral-head communities existed closer to the water surface.

Our observations indicate that well developed reef communities exist at Cayos Arcas. These communities contain the most diverse hermatypic coral assemblage found to date on the western Yucatán shelf. Further investigation will be necessary to determine if this apparent difference in diversity is real or due to the limited study most other locations in this region have received. However, we suspect that coral diversity throughout the area is richer than it is generally perceived to be. A continuing environmental monitoring program was instituted before the construction of the oil terminal, and further studies to assess the ecological impact of the facility have been discussed by Orme (1982).

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Table 1. Hermatypic scleractinian coral species occurring at Cayos Arcas. "?" indicates probable identification. "*" indicates species reported found at Cayos Arcas by Logan et al. (1969) that we did not encounter. Species in parentheses were reported present at Veracruz by Smith (1954) are probably also present, but we did not observe them at Cayos Arcas in our survey.

- Suborder Astrocoeniida
  - Family Pocilloporidae
    - *Madracis decactis*
  - Family Acroporidae
    - *Acropora palmata*
    - *Acropora cervicornis*
- Suborder Fungiida
  - Family Agariciidae
    - *Agaricia agaricites*
  - Family Siderastreidae
    - *Siderastrea siderea*
    - *Siderastrea radians*
  - Family Poritidae
    - *Porites asteroides*
    - *Porites porites*
    - (*Porites furcata*)
- Suborder Faviida
  - Family Faviidae
    - *Favia fragum*
    - *Diploria clivosa*
    - *Diploria labyrinthiformis*
    - *Diploria strigosa*
    - *Colpophyllia natans*
    - *Colpophyllia breviserialis*
    - *Montastrea annularis*
    - *Montastrea cavernosa*
    - *Solenastrea* sp.*
    - *Manicina areolata*
    - (*Cladocora arbuscula*)
  - Family Meandrinidae
    - *Meandrina meandrites*
    - *Dichocoenia strokesi* ?
  - Family Mussidae
    - *Mussa angulosa*
    - *Mycetophyllia lamarckiana*
  - Family Oculinida
    - (*Oculina diffusa*)
- Suborder Caryophylliina
  - Family Caryophylliidea
    - *Eusmilia fastigiata*

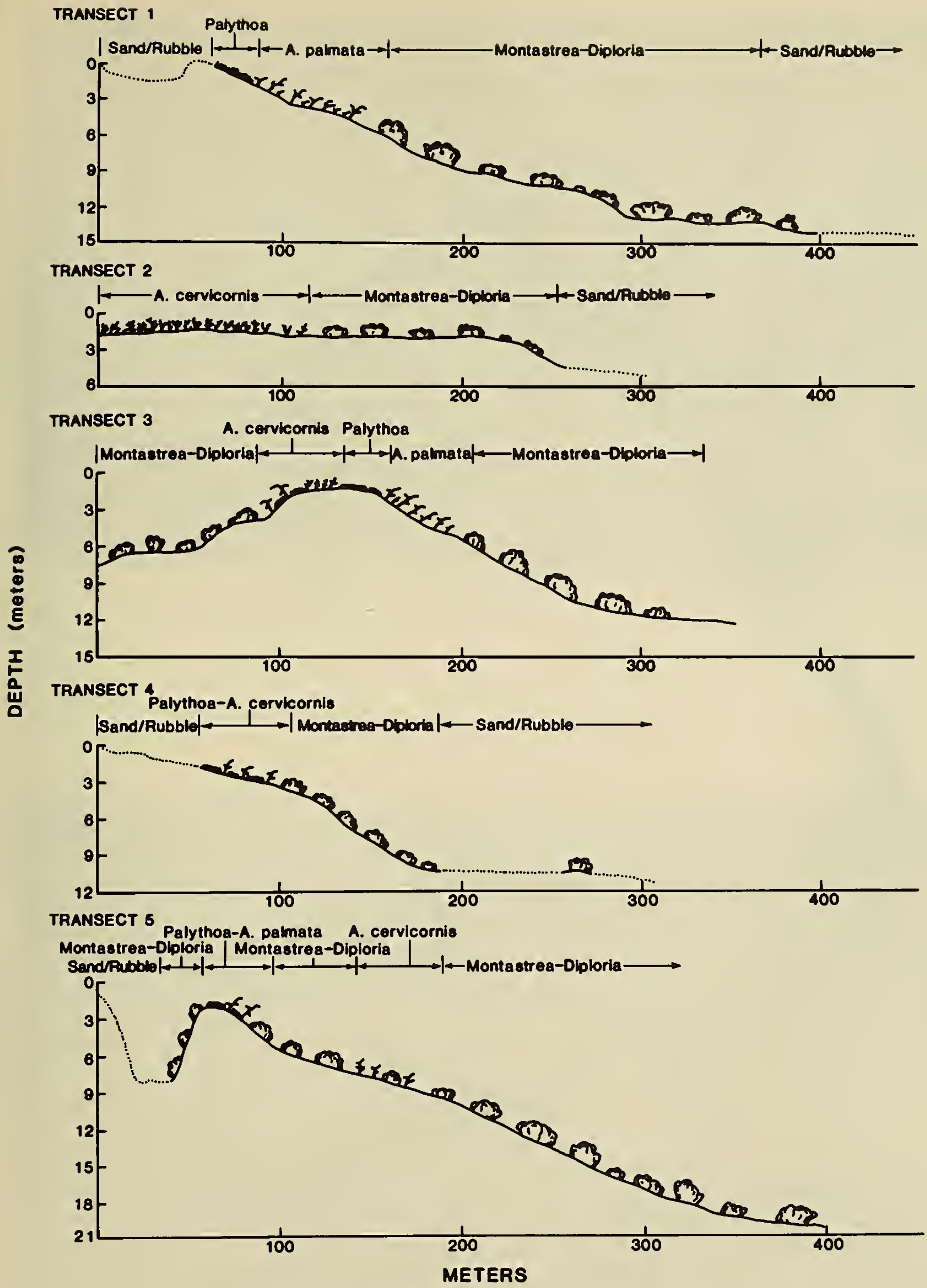

Fig. 2. Transect profiles at Cayos Arcas.

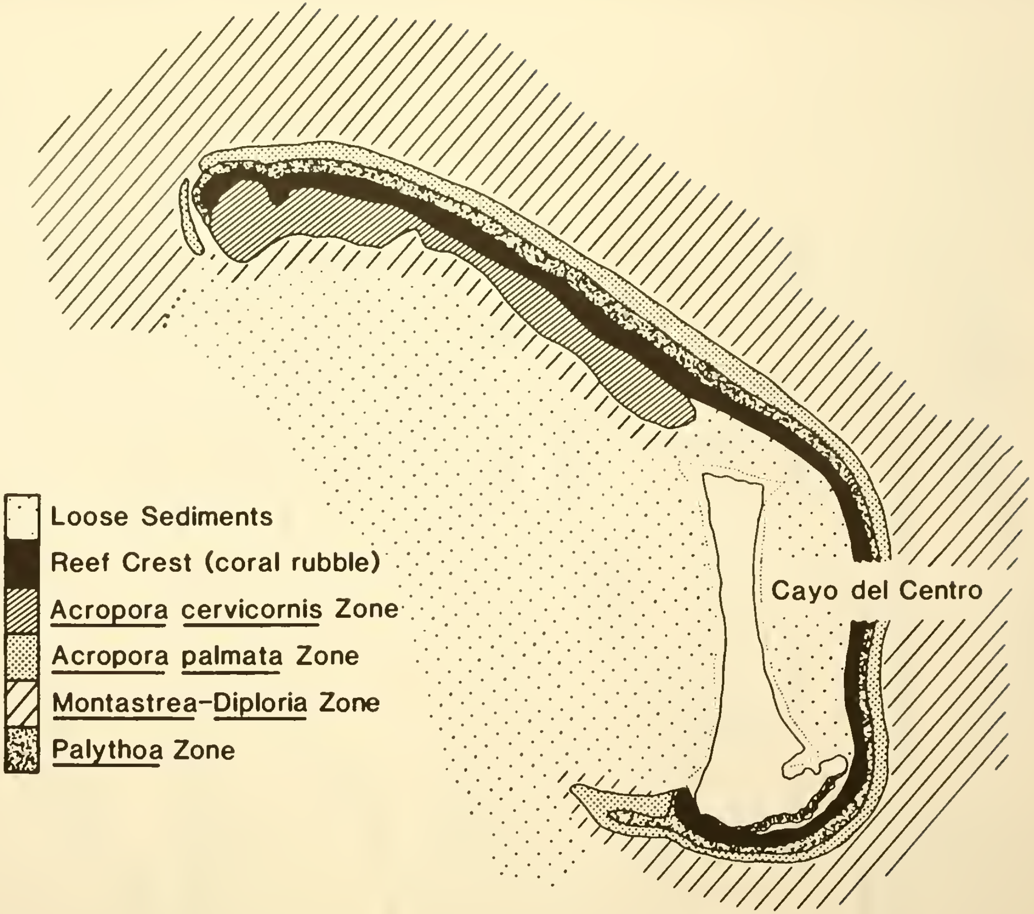

Fig. 3. An overhead drawing of the central cay and its associated reef showing the approximate distribution of the major reef zones.

Plate 1. Aerial view of the Cayos Arcas from the southeast

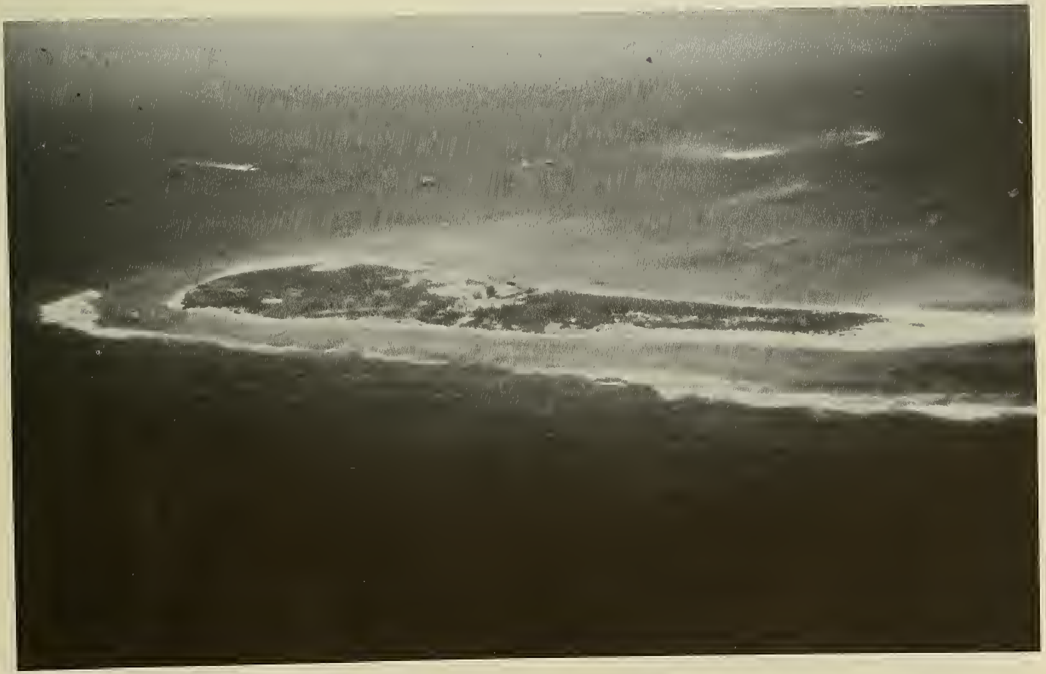

Plate 2. Aerial photograph of the central cay and the reef viewed from the east

Plate 3. Underwater photograph of the *Acropora palmata* zone on Transet 1. Taken at approximately 4 m depth

Plate 4. Photograph of the *Montastrea-Diploria* zone taken in water 10 m deep (Transect 1)

Plate 5. Photograph of the *Montastrea-Diploria* zone taken in water 10 m deep (Transect 1)

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CAY SAL BANK, BAHAMAS: A BIOLOGICALLY IMPOVERISHED, PHYSICALLY CONTROLLED ENVIRONMENT

BY

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CAY SAL BANK, BAHAMAS: A BIOLOGICALLY IMPOVERISHED PHYSICALLY CONTROLLED ENVIRONMENT

by Walter M. Goldberg[1]

ABSTRACT

Cay Sal Bank is a shallow water, oceanic platform whose lagoonal surface is 9-16m below sea level. Benthic communities on the bank are divided into four major zones based upon biotic composition and substrate. These are (1) rubble- *Lobophora* (2) *Sargassum*-gorgonian-sponge (3) *Halodule* and associates and (4) a patchy *Thalassia* zone. Sediment is largely restricted to the western portion of the lagoon, especially in zone 3. Although occasional patch reefs are noted, the bank lagoon is virtually devoid of coral reefs and coral communities. The submerged, leeward bases of islands and cays represent the principal substrate for the development of scleractinian corals, but these do not appear to form a reef framework. Scleractinian development on the windward sides of the islands is negligible. Patch reefs and spur and groove systems are usually poorly developed on the outer bank slope to depths approaching 30m. The best developed coral communities occur below this depth with the exception of the southwestern sector where reefs are smothered in sediment.

The biological structure of the bank lagoon is interpreted as being controlled largely by wind and periodic storm forces that result in frequent resuspension and eventual offbank transport of sediment, especially to the southwest. Cay Sal is not a drowned bank; it is a submerged platform on which biological impoverishment appears to be maintained through disturbance phenomena engendered by an open and poorly developed rim. These stresses prevent establishment of more complex coral reefs or coral communities, and promote domination by fleshy algae and other more tolerant organisms.

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INTRODUCTION

Cay Sal Bank is a shallow, detached carbonate bank lying roughly 100 km south of the Florida Keys, 54 km north of Cuba and 50 km west of the Great Bahama Bank (Fig. 1). It is 105 km by 66 km in its greatest dimensions, and constitutes an overall area of nearly 4000 km^2. The rim is lined with a scattering of islands and rocks especially along the northern and eastern margins. Over 99 percent of the bank including the southern flank and the entire center are completely submerged, primarily in depths ranging from 9-16m.

Few studies have been made of this region in spite of its size and proximity to U.S. coastal waters. Agassiz (1894) visited the bank, briefly describing some of its geomorphic features; a description of the bathymetry of the bank slope (Malloy & Hurley, 1970) and stratigraphic studies from a well drilled to 5766m by Standard Oil Company (Myerhoff & Hatten, 1974) have made more recent contributions to our knowledge of the area. However, descriptions of the marine communities of Cay Sal Bank have apparently not been published.

This paper describes the nature and distribution of the shallow-water communities of Cay Sal Bank by aerial and satellite photography, coupled with ship-based bottom truthing by SCUBA observation and dredge sampling. Physical factors including storm tracks and frequency, wind and wave data and sediment depths on the bank lagoon are analyzed and related to community structure.

Materials and Methods

A total of 18 days were spent on Cay Sal Bank, primarily during the summer months of 1980-1982. Biological observations were made at 97 stations scattered across the shallow lagoon and outer margin to a depth of 60 m (Fig. 2). These consisted of simple visual surveys to confirm composition of the benthos, hand collections assisted by SCUBA, and 5 minute Capetown dredge tows. Samples of all identified materials have been deposited in the FIU museum. All species except as noted were identified by the author.

Sediment depths were recorded at 27 stations (1982 only) using a steel probe. Where sediments exceeded a depth of one meter, a 2 1/2 HP water pump was employed to force seawater through a 5 meter length of PVC pipe. Sediment fluidized in this manner enabled the pipe to quickly penetrate to bedrock.

The names of emergent islands used in this paper correspond to those given in British Admiralty Chart No. 1217 (Fig. 2). Coordinate locations have been modified according to more recent data (see appendix).

RESULTS

a. The Lagoonal Environment

The lagoonal surface of the bank can be divided into four major biotic zones (Fig. 3). The northwestern sector with its included sand ridges is characterized by a sparse but consistent cover of seagrasses and algae including Halodule wrightii, Caulerpa spp., Syringodium filiforme and various species of calcareous chlorophytes (Fig. 4A). Members of this community (hereafter referred to as the Halodule community) are summarized in Table 1. A denser Halodule community appears to be responsible for several of the large dark patches noted in satellite imagery of this zone.

The sediment cover of this quadrant ranges from 2 cm to 1 m. The deeper sand accumulations occur behind and south of Double Headed Shot Cays, (hereafter referred to as DHS Cays) particularly in association with the intersecting sets of bedforms prominent in the western part of the zone, and those trending NE to SW 20 km to the east. The Halodule zone grades into a sediment-bare, rubble bottom east of Muertos Cays. This northeastern sector is covered by a mixed Sargassum-gorgonian-sponge community.

The rubble characteristic of the northeast bank lagoon continues throughout the southeast sector but without as much vegetation. The bottom is covered primarily by a scattering of the brown alga Lobophora variegata, with an occasional cluster of sponges and gorgonians as above. Along the southern and eastern borders of this zone the rubble is interspersed with aggregations of corals, especially Diploria spp., Agaricia agaricites and Montastrea annularis, together with sponges and gorgonians (Fig. 4B). For the most part these do not form patch reefs (i.e., no appreciable relief above bottom). However, two reef areas are encountered along the western edge of this zone as noted in figure 3. One of these near 23°34' and 79°48' consists of numerous but small (1-2m^2) Diploria, Porites and Montastrea patches rising 1m above the bottom (depth = 7-8m). The most significant patch reef area, several km^2 in extent, is located 10 km southwest of Damas Cays. This subzone was characterized by thickets of Acropora cervicornis rising to a depth of 6m from a 10m bottom (Fig. 4C). Scattered colonies of Montastrea annularis, Agaricia agaricites and Colpophyllia natans contribute to the framework. It may be significant that much of the rubble substrate in this zone consists of what appears to be recent Acropora cervicornis. There is little evidence of recolonization.

The last zone consists of a sigmoidally shaped area extending across the bank from Cay Sal to the Damas Cays. This area is characterized by patches of Thalassia testudinum which become somewhat more extensive toward the southwestern (leeward) side. Turtle grass becomes particularly well developed in the lee of larger islands on the bank, especially the Double-Headed Shot Cays and the Anguilla Cays (Fig. 4E). Farther behind the latter group, Thalassia grades into a Halodule-calcareous green algae subzone (Fig. 3).

At the edges of this area Thalassia intermingles with other communities. This is particularly notable west of Damas Cays where zonation overlap is extensive (Fig. 3). The Damas Cays area is also notable for the existence of several "blue holes" (Capt. Bob Klein, pers. comm.). One of these located at 23°49'87 and 70°47'28, 2.4 km west of the islands, was briefly investigated. It measures approximately 100m across and 100m deep, beginning on the bank at a depth of 10-13m (surface to bottom = 110-113m). The surrounding area is a Thalassia-gorgonian-sponge bottom, grading into colonies of Montastrea cavernosa and Agaricia agaricites at the edge of the blue hole. The vertical walls are covered with Lobophora variegata to a depth of 18m, below which Halimeda goreauii dominates. Submersible observations at the bottom reveal numerous Strombus gigas shells apparently the result of the animal becoming entrapped while migrating through the surrounding turtle grass (E. Shinn, pers. comm.). A wider and slightly deeper blue hole is located a few km farther west (Fig. 4F).

The sediment cover of the Thalassia zone is highly variable. Through most of this region the range is 2-5cm, increasing to 20-60cm under Thalassia itself. Just north of Cay Sal Island in an area covered by a mixed community of scattered angiosperms and calcareous green algae, a sand body 4-4.5 meters deep was encountered (Fig. 4G). The area covered by this accumulation was not determined, but several sediment stations taken around the periphery of Cay Sal indicates that it is highly localized.

b. The Bank Rim and Slope

The only areas characterized by substantial coral development are the bank slope below 30m and the submerged portions of the islands. Most of the larger cays have been examined and appear to be uniform with regard to their flora and fauna from the littoral zone to the base of the island (Table 1). The sublittoral portions are characterized by an intertidal bench cemented with an unidentified encrusting coralline alga. Immediately below this surge zone, dropping vertically to a depth of 7-8 m, is a coral community consisting of yellow and purple sea fans (Gorgonia ventalina and G. flabellum) plus a variety of other gorgonians, corals and hydrocorals, especially Millepora complanata (Fig. 5A). In general the amount of scleractinian development is greater along the northern border of islands, but only along the lagoonal side where Montastrea annularis, Diploria spp. Siderastrea siderea, Agaricia agaricites and Porites porites become especially numerous (Table 1, Fig. 5B). However, the coral communities appear to be insufficiently developed under the best of circumstances to prevent erosion of the underlying substrate. Large blocks of island material are usually found adjacent to the cays and these serve as substratum for additional albeit superficial coral development (Fig. 5C,D).

Shallow water coral development along the oceanic side of the islands is not appreciable. Acropora palmata, for example, is found only in isolated pockets (e.g. between Water Cays and some of the Damas Cays. There is no "palmata zone" (cf. Geister, 1977) characteristic of any of the islands. Along the eastern bank there is little difference between exposed and sheltered sides of the islands with regard to coral development. The same species of coral as noted above form spurs <1m in height in 10m depth directly in front of many islands along the Santaren Channel. However, even this limited amount of coral growth does not occur on the ocean side of the DHS Cays where the bottom at 10m is composed of rock colonized by Sargassum spp., Dictyosphaeria cavernosa and Microdictyon sp., along with occasional gorgonia and sponges (Fig. 5E). Coral communities are not developed on either the exposed nor the sheltered sides of south Anguilla Cay or Cay Sal due to accumulation of sand.

In depths of 15 to 25m along the eastern bank, spurs 3m high are covered by Acropora cervicornis, Siderastrea siderea, Montastrea annularis along with large quantities of gorgonians, Halimeda spp. and Lobophora variegata. South of south Anguilla Cay (in the Nicholas Channel) spur and groove development is somewhat greater (Fig. 6A) but similar in composition and in coral density to those at Dog Rocks. There appear to be no comparable coral communities in these depths along the DHS Cays or near Cay Sal.

Outer reef slopes have been investigated briefly on several sides of the bank in depths ranging from 25-60m. At 25m the angle of slope begins to increase, allowing a relatively dense algae-sponge-gorgonian community. Some scleractinian coral development is also in evidence but is not strongly represented (Fig. 6B). The outer reef escarpment ("dropoff") begins at 44-46m on the eastern side of the bank and at 38-40m on the western and northwestern sides. There is a substantial difference in the structure of the deep reefs developed on these slopes. Off south Anguilla, for example, the dominant organisms are *Lobophora variegata* and *Halimeda* spp. interspersed by sponges, some coral (primarily *Montastrea* spp.), whip-like gorgonians (*Ellisella* and *Eunicea* spp.) and antipatharians (*Cirrhipathes luetkeni*). The diversity of deep reef organisms here is relatively low; the face of the escarpment is smooth, without appreciable development of ledges, caves and overhangs. The same description applies to the deep reefs off southern Dog Rocks, however diversity of organisms and relief in the slope is somewhat greater off the northern Dog Rocks group.

Scleractinian coral development at depths below 25m is greatest off the northwestern and western border of the bank, along the edge of the Straits of Florida. Off Elbow Cay, for example, an appreciable development of *Montastrea* spp. *Porites astreoides* and *Agaricia agaricites* begins at 25m (Fig. 6C). The latter species forms an extensive cover that continues over the escarpment to depths of at least 50m. The central portion of the western bank margin drops precipitously into the Straits of Florida. The outer reef slope here is as well developed as I have seen it in this area. The escarpment beginning at 38m is characterized by spurs extending seaward more than 10m from the wall. From the amount of coral cover these appear to be the result of recent growth although no cores have been taken. Flat, platey forms of *Montastrea* spp. and *Agaricia lamarcki*, along with large colonies of *Colpophyllia natans* dominate these structures along with numerous sponges, gorgonians and antipatharians (Fig. 6E). In direct contrast, the outer slope around Cay Sal island has no reef development at all; off the northern end in particular, the outer reef slope is totally inundated with sediment (Figs. 6D,7).

DISCUSSION

Unlike the larger Bahamian banks, Cay Sal has a largely submerged, poorly developed rim. Agassiz (1894) and Davis (1928) refer to the bank as a drowned atoll emphasizing the apparent inability of coral growth to keep pace with subsidence or rise in sea level. The process of drowning may be initiated by a variety of factors (reviewed by Schlager, 1981) which commonly result in bank or platform surfaces 50m or more below present sea level (Davis, 1928). In such cases the use of the term "drowning" may be justified because processes operating in the past have placed reef-associated organisms out of their effective depth range for photosynthesis. Cay Sal Bank lagoon, on the other hand is only 9-16 m deep, submerged, but well within the range of appreciable carbonate production (Schlager, 1981) and reef growth (Macintyre, 1967; Porter, 1973; Goreau & Land, 1974; Rützler & Macintyre, 1982). As noted above, reef growth is occurring on at least some of Cay Sal's deeper margins. Therefore the notion of reef drowning as means of accounting for this bank's present biotic composition is untenable.

The antithesis of platform drowning is physical control by shallow water processes. Shallow water is subject to a wide variety of environmental alterations inimical to reef development. These may include exposure and thermal disturbances (Glynn, 1968; Roberts et al., 1982) chemical alterations (Newell et al., 1959; Voss & Voss, 1960; Milliman, 1973) and floods of fresh or turbid water (Goodbody, 1961; Lighty et al., 1978). Although none of these processes is likely operative on Cay Sal Bank today, such stresses may have served to reduce early Holocene reef growth enough to account for its poorly developed rim. The lack of a protective rim, in turn, may have promoted conditions which account for the sparsely colonized, low diversity, ahermatypic environment typical of the bank shallows.

Although the mechanisms and trends of the sequential replacement of communities through time are controversial (Connell & Slayter, 1977; Sousa, 1980; Greene & Schoener, 1982), the process of succession is generally understood to culminate in one or more communities called climaxes. Such communities are widespread in a given climatic regime and are typically characterized by an equilibrium between production and respiration, a relatively high diversity of species, a well-developed spacial structure and a complex food web (Odum, 1969). In the coral reef environment, the normal successional process predicts eventual stabilization of soft bottom communities by Thalassia (Ginsburg & Lowenstam, 1958; Patriquin, 1975) or coral communities (Jones, 1977). However, it is generally recognized that local conditions may often prevent the succession to climax. In these cases, terms such as edaphic climax, cyclic climax, disclimax or subclimax have been applied (Odum, 1971). Species diversity as one of the more readily measurable ecological parameters, is often employed as a standard by which the degree of community complexity can be gauged. High diversity is maintained by some measure of disturbance or non-equilibrium conditions that prevents monopolization of resources by superior competitors (Connell, 1978; Pearson, 1981; Sheppard, 1982). However, frequent and/or severe disturbance can return the community to an immature (early successional) stage or perhaps inhibit succession entirely. For example Dollar (1982) found that wave and storm stress caused frequent mass mortalities on an Hawaiian reef, resulting in a low diversity, relatively simple coral reef community. Frequently after disturbance by storms or other stresses, damaged reefs will be colonized by fleshy algae; their continued dominance is limited by the time required for recovery of the coral community (Pearson, 1981 and contained references). Thus algal-dominated reefs may be viewed as an indication of disturbance to a degree that does not allow the normal process of succession or recovery to occur. Lighty (1981) has described such an environment in the northern Bahamas (which he unfortunately refers to as a "climax community") and correlates this condition with high energy stress. A somewhat similar situation is described by Adey *et al*. (1977) in the Lesser Antilles. The following evidence suggests that Cay Sal Bank's low coral diversity (Table 1) and dominance by fleshy algae as well as other flora, is also a function of environmental stress.

The lagoon of Cay Sal is dominated by the seagrass *Halodule wrightii* and associates. *Halodule* is an opportunist species that colonizes areas either unsuitable for *Thalassia* or areas where *Thalassia* has become disturbed by storms or other factors (den Hartog, 1977). As a pioneer, *Halodule* is a poor competitor and under normal conditions is replaced by species with more extensive, stabilizing blade and rhizome systems (Scoffin, 1970; Burrell and Schubel, 1977). This succession is not evident at Cay Sal where *Thalassia* is strongly developed only in the lee of larger islands.

The distribution of sediment on the bank (Fig. 3) corresponds roughly with the general description given by Enos (1974). One of the more striking aspects of this distribution is the amount of bank surface with little or no sediment. More than half of the lagoon is sediment-bare especially the eastern side. The sediment cover generally increases toward the west, and is concentrated largely in the form of sand waves behind DHS Cays, and in a relatively deep (>4m) sand body restricted to the north side of Cay Sal Island. The virtual absence of sediment on the eastern margin and its accumulation toward the southwest suggests active transport. Moreover, the smothering of the outer reef slope coral communities around Cay Sal Island provides evidence that this transport is offbank, as confirmed recently by seismic profiles (Hine, personal communication).

Wind and storm generated flows are likely agents of offbank sediment transport (Hine *et al*., 1981; Hubbard *et al*., 1981). Two categories of storms to consider are acute, periodic tropical storms occurring in summer and the more regular, chronic disturbances associated with the passage of winter frontal systems. A chart depicting the approximate path of tropical storm and hurricane systems passing within 100 km of Cay Sal Bank is presented in Figure 8. Although no data are given on storm intensities, 32 cyclonic storms have been noted since 1871, plus an additional 4 tropical depressions. Nine storms or hurricanes have crossed the southeastern bank in the vicinity of the Anguilla Cays, 9 more have crossed (or passed parallel) in an east-west direction, while another 7 crossed the bank near Cay Sal. Given the openness of the bank, severe storms and hurricanes are certain to effect damage, even on deeper reefs (cf. Woodley, 1980). However, the overall importance of tropical storms on Cay Sal is difficult to assess. With an average of 3 storms per decade, Cay Sal is less frequently affected by such systems than the Florida Keys or Little Bahama Bank where an average of 7-8 storms per decade occurs (Neumann _et_ _al_., 1977; Hine, 1977). During the last decade only one hurricane has passed near this area (1981); moreover, the pattern of storm crossings does not correspond with either the degree of community development or the pattern of observed sediment accumulation.

The small amount of hydrographic/meteorological information available for the area is summarized in Figure 9. Winds are principally from the east during most of the year but display a prominent shift to the north and northeast during the winter. This change corresponds with the increase in percent of sea and swell near the bank. The passage of frontal systems from the north and northeast is a reliable and persistent winter phenomenon in this region (U.S. Naval Weather Service Command, 1975) and may account for the following observations.

1) _Acropora_ _cervicornis_ rubble is common in the southeastern sector of the bank while living colonies are relatively uncommon. Storm forces may provide rubble substratum through recurrent cycles of _Acropora_ growth and recovery (Gilmore & Hall, 1976; Tunnicliffe, 1981) followed by storm destruction. The dominance of an unstable rubble substrate in turn reduces the chance of coral survival and recolonization (Goreau, 1959; Stoddart, 1974; Pearson, 1981).

2) The best developed shallow coral communities are on the protected lagoon side of the northern cays; the poorest development is on the unprotected ocean side. The reason for this contrast may be the abrupt transition between shallow and deep water that allows large waves to pound the outside of these cays. For example, a 50 km hr^{-1} wind from the north or northeast will produce waves at least 3.2 m high (U.S. Army CERC, 1973). Such wind/wave conditions are probably common near Cay Sal (see below).

3) A *Thalassia* zone first noted in 8m depth behind northern Dog Rocks during July, 1981, was replaced by rubble twelve months later. Aerial photographs taken during May, 1982 revealed crescentic "blowout" structures in *Thalassia* beds behind Water Cays in 8-9m depth (Figs. 6D,E), and north of Cay Sal in similar depths (Fig. 4C). These are known to result from storm damage and indicate the direction of energy propagation (Patriquin, 1975). The blowouts on Cay Sal Bank are concave from the north.

Storm-induced bottom currents and wave activity, are capable of considerable sediment resuspension and transport (Hine *et al.*, 1981; Murray *et al.*, 1977) known to be detrimental to coral development (Dodge *et al.*, 1974; Loya, 1976). The amount of transport can be estimated using established relationships (Figs. 3-15, 3-29, 4-20 and 4-21 in U.S. Army CERC, 1977) between wind stress and maximum induced motion on the sea floor (Umax(-d).

Northeast and easterly winds near Cay Sal reach speeds of 50 km hr^{-1}, 20-25% of the time during October-April. Winds during the other months approach this speed only 6-12% of the time (U.S. Naval Weather Service Command, 1975). Winds of 50 km hr^{-1} from the east in 11m water depth (average lagoon depth) will generate waves 1.4m high, with periods of 4.7 sec and will produce Umax(-d) of 25 cm sec^{-1} on the lagoon floor. This is within the generally accepted range of 15 - 30 cm sec^{-1} required for fine to moderate sized sand grain motion (U.S. Army CERC, 1977; see also discussion in Hine *et al.*, 1981). The principal limitation to bottom current generation with easterly winds on Cay Sal is the limited fetch (65 km). However, with winds from the northeast, fetch increases 2 1/2 fold. Thus a 50 km hr^{-1} wind will produce waves 1.6 m high, with periods of 5.2 sec and will produce Umax(-d) of 47 cm sec^{-1}. This figure is well above critical velocity and may account for accumulation of sediment toward the southwest, as well as disturbance to the lagoon and SW bank slope communities.

Thus the physical environment of Cay Sal Bank appears to be sufficiently vigorous to produce direct wave stress as well as current-induced sediment stress. These conditions, while by no means unique, combine with the historically derived lack of a protective rim to produce high energy channels into the bank interior. The result is the maintenance of a virtually reefless environment.

Table 1. Marine plants and invertebrates characteristic of Cay Sal Bank Lagoon. Zones: 1 = Halodule, 2 = Thalassia, 3 = Rubble-Lobophora, 4 = Sargassum-gorgonian-sponge, 5 = Island-littoral

Angiosperms	Zone
Halodule wrightii Ascherson	1,2
Thalassia testudinum Koenig	1,2
Syringodium filiforme Kutzing	1,2
Algae	
Avrainvillea nigricans Decaisne	1,5
Caulerpa prolifera Lamoroux	1,2
Caulerpa cupressoides Agardh	1,2
Cladophora sp.	5
Dasycladus vermicularis Krasser	1,2,4
Dictyopteris justii Lamoroux	2,4
Dictyosphaeria cavernosa Boergesen	3
Dictyota dentata Lamoroux	5
Galaxaura squalida Kjellman	5
Halimeda incrassata Lamoroux	1,2,4
Halimeda lacrimosa Howe	1,2,4
Halimeda opuntia (Lamoroux)	1,2,4
Laurencia papillosa (Forsskal)	5
Lobophora variegata Womersley	1,2,3,4
Microdictyon sp.	2,4
Padina sanctae-crucis Boergesen	5
Penicillus capitatus Lamarck	1,2
Penicillus dumetosus (Lamoroux)	1,2
Penicillus pyriformis Gepp	1,2
Rhipocephalus phoenix Kutzing	1,2
Sargassum cymosum Agardh	3
Sargassum hystrix Agardh	1,2,4,5
Sargassum polyceratium Taylor	4
Sargassum vulgare Agardh	2
Stypopodium zonale Papenfuss	5
Turbinaria turbinata Kuntze	5
Udotea spinulosa Howe	1,4,5
Sponges	
Anthosigmella varians var. incrustans (D&M)	5
Spheciospongia vesparium (Lamarck)	1,2,3,4
Gorgonians	
Eunicea spp.	1,2,3,4,5
Gorgonia flabellum Linn.	5
Gorgonia ventalina Linn.	5
Muricea muricata (Pallas)	3,4,5
Muriceopsis flavida (Lamarck)	3,4,5

Plexaura flexuosa Lamoroux	3,4,5
Plexaura homomalla (Esper)	5
Plexaurella spp.	2,4
Pseudopterogorgia americana (Gmelin)	1,2,3,4,5
Pterogorgia anceps (Pallas)	1,2,3,4,5

Scleractinians

Acropora cervicornis (Lamarck)	3
Agaricia agaricites (Linn.)	3,5
Diploria labyrinthiformis (Linn.)	5
Diploria strigosa (Dana)	3,5
Montastrea annularis (E&S)	2,3,5
Porites astreoides Lamarck	3,5
Porites porites Lamarck	3,5
Siderastrea siderea (E&S)	5

Molluscs

Acanthopleura granulata Gmelin	5
Acmea antillarum Sowerby	5
Antigonia listeri Gray	1
Chione paphia Linn.	1
Chiton squamosus Linn.	5
Echininus nodulosus Pfeiffer	5
Glycymeris undata Gmelin	1
Laevicardium laevigatum (Linn.)	1
Littorina zic-zac Gmelin	5
Livona pica Gray	5
Nerita peloronta Linn.	5
Nerita versicolor Gmelin	5
Purpura patula Linn.	5
Strombus costatus Gmelin	1,4
Strombus gigas Linn.	1,2,4
Tais rustica Lamarck	5
Tectarius muricatus Linn.	5

Arthropods

Grapsus grapsus (Linn.)	5
Metapenaeopsis cf. goodei (Smith)	1
Portunus bahamensis Rathbun	1,2
Portunus ordwayi (Stimpson)	1,2,3
Portunus spinimanus Latreille	1,2
Tetraclita sp.	5

Echinoderms

Astichopus multifidus (Sluiter)	1
Astropecten duplicatus Gray	1
Oreaster reticulatus (Linn.)	1,2

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FIGURE LEGENDS

Figure 1. Geographic position of Cay Sal Bank from ERTS/LANDSAT imagery. Scale bar = 10 km.

Figure 2. British Admiraly Map No. 1217 (Rev. 1977). Inset: Station positions on Cay Sal Bank.

Figure 3. ERTS/LANDSAT composite depicting the biological zones and subzones of Cay Sal Bank. Encircled numbers indicate thickness of sediment in cm. Sand waves in northwest lagoon are covered with *Halodule* as are NE-SW oriented sand waves to the east. Dark region between these structures is result of denser accumulations of *Halodule* and calcareous green algae. Note sand accumulation near Cay Sal on the southwest corner. Double Headed Shot Cays, Dog Rocks, Damas Cays and Anguilla Cays are also visible along the bank margin.

Figure 4. Communities of Cay Sal Bank Lagoon:

(A) *Halodule*-*Caulerpa*-calcareous green algae community typical of the central lagoon. Note numerous volcano-like burrows, possibly of callianassid shrimp; Sea star *Oreaster reticulatus* lies next to scale bar, = 60cm; depth = 13m at 23°50'N and 80°20'W 13 km SE of Elbow Cay.

(B) Rubble dominated bottom along southeast bank is occasionally colonized by coral clusters composed of gorgonians, especially *Pseudopterogorgia* spp., and scleractinians *Montastrea annularis*, *Agaricia agaricites* and *Porites porites* (vertical view, Depth: 13m).

(C) *Acropora* patch reef southwest of Damas Cays in 7-8m depth at 23°34'N and 79°48'W.

(D) Aerial view of *Thalassia* development, eastern Water Cay; scale bar = 5m. Note crescentic blowouts indicating bankward storm direction from the north.

(E) Underwater detail of above; crescent is 10m in diameter; depth = 8-9m.

(F) Blue hole 5-6km west of Damas Cays; note coral patches developed on edge under boat; scale bar = 100m.

(G) Sand body 4.0-4.5m deep in 8m of water, 2km north of Cay Sal. Divers are measuring sand depth by inserting 5m length of PVC pipe. Note oriented megaripples indicating sand motion, and sparse colonization of sediment by *Halodule* and calcareous green algae.

Figure 5. Communities of the Bank Rim:

(A) Intertidal bench with typical wave resistant *Gorgonia* spp. from lagoon side of Bellows Cay (see appendix map).

(B) Coral development below the surge zone with extensive cover of *Agaricia agaricites* and large (≈1m^3) colony of *Montastrea annularis*: lagoon side Crenula Cay, 0-6m (see appendix map). Scale bar = 60cm.

(C) Eolianite blocks broken from lagoon side of northernmost Dog Rocks; scale bar = 2m.

(D) Colonization of above by *Millepora complanata* and small colonies of *Diploria strigosa* and *Montastrea annularis*; scale bar = 60 cm.

(E) Ocean side Elbow Cay showing lack of coral development on island base. Note spur and groove-like system and scour holes; scale bar = 60 cm, depth = 3-10m.

Figure 6. Communities of the Outer Reef Slope:

(A) Deep spur systems in Nicholas Channel south of Anguilla Cays, 23°22'N and 79°34'W. Note profusion of gorgonians and sponges. Scleractinian development is occasionally moderate but generally poor. Spur height = 3-4m; Depth = 20-25m.

(B) Edge of escarpment at above location. Note gorgonians and sponges but poor scleractinian development; Depth = 35m.

(C) Development of *Agaricia agaricites* and *porites astreoides* on the edge of the escarpment off Elbow Cay; flabellate gorgonian is *Iciligoria schrammi*. Depth = 30m.

(D) Escarpment off north Cay Sal blanketed in fine sediment of undetermined thickness. Coral at center is mud-dwelling sclearactinian, *Meandrina danae* ≃ 12 cm long. Note conch trails (*Strombus gigas*) above; Depth = 30m.

(E) Deep spurs on the escarpment north of Rompidas Ledge composed largely of platey growths of *Montastrea annularis*.

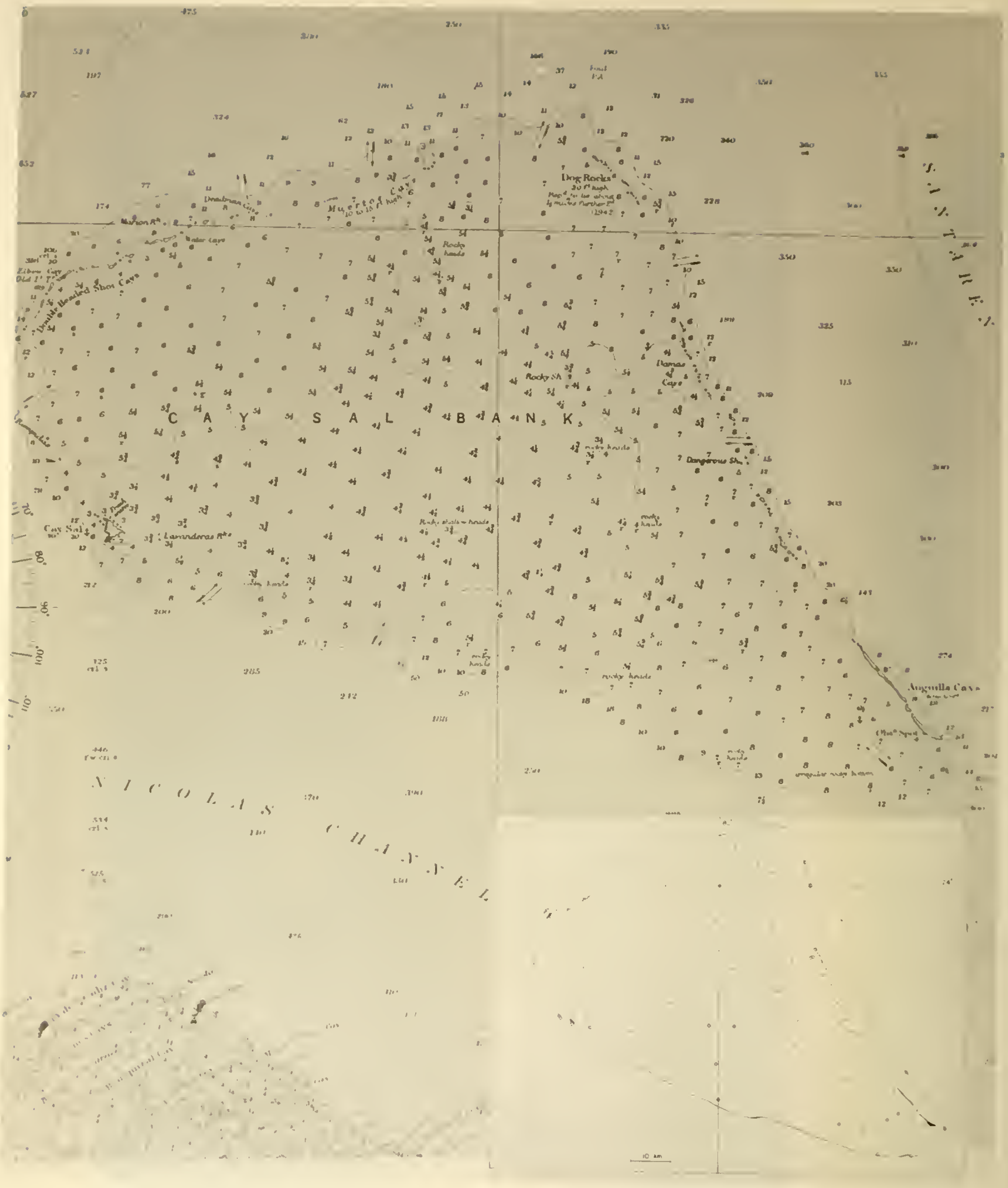
Figure 7. Comparison of fathometer profiles from Cay Sal Island northward at 15 to 30m depth. Arrow indicates increased inflection of outer reef slope at 20m. Distances north of Cay Sal: 1 = 3km, 2 = 4km, 3 = 5.5km, 4 = 6.5km, 5 = 8km. Note smooth surfaces indicative of sediment drowning near Cay Sal and increased reef development toward Rompidas.

Figure 8. Tropical storm and hurricane track passing within 100 km of Cay Sal Bank, 1871 through 1981. Year

of each track indicates direction of continued motion. Data from Neumann et al. (1978) with additions from NOAA Mariner's Weather Log (1977-1982).

Figure 9. Climatic and hydrographic conditions near Cay Sal Bank. Data compiled from West Indies Pilot (1957), Wüst (1964), NOAA (1973) and U.S. Naval Weather Service Command (1975).

Figure 1



Dog Rocks
Muertos Cays
Deadman Cays
Water Cays
Elbow Cay
Double Headed Shot Cays
Rocks heads
Rocky Sh.
Damas Cays
C A Y S A L B A N K
Dangerous Sh.
Cay Sal
Laminderas Rks
Anguilla Cays
N I C O L A S C H A N N E L
10 km

Figure 2


1
SARGASSUM-
GORGONIAN-
SPONGE
10
thalassia 90
75
5
1
100
4
HALODULE
22
80
2
67
MIXED
4
acropora
patch
reefs
2
37
414
d
3
1
60
THALASSIA
RUBBLE-
LOBOPHORA
5
MIXED
5
patch
reefs
thalassia
halodule
60
5

Figure 3

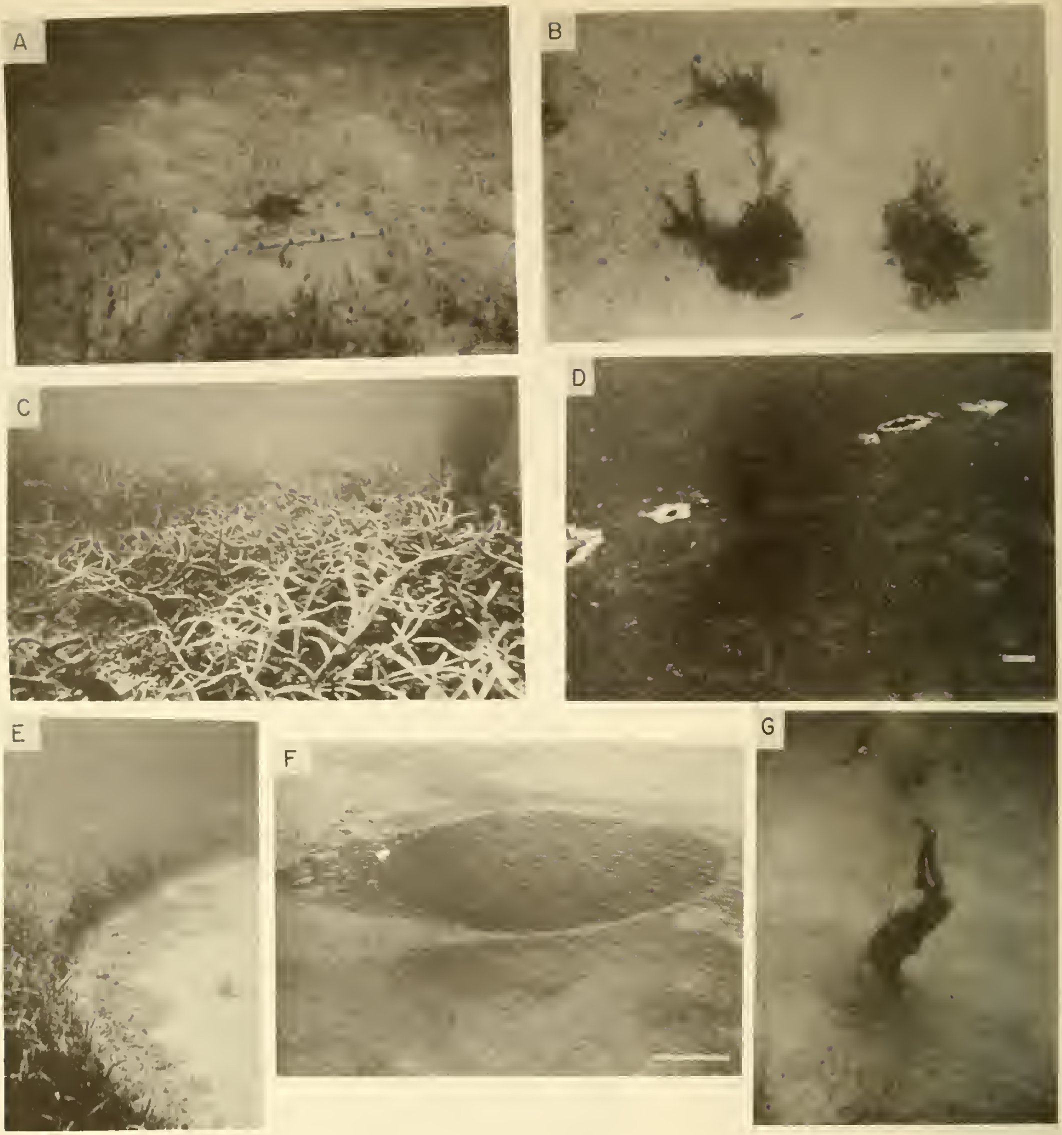


Figure 4

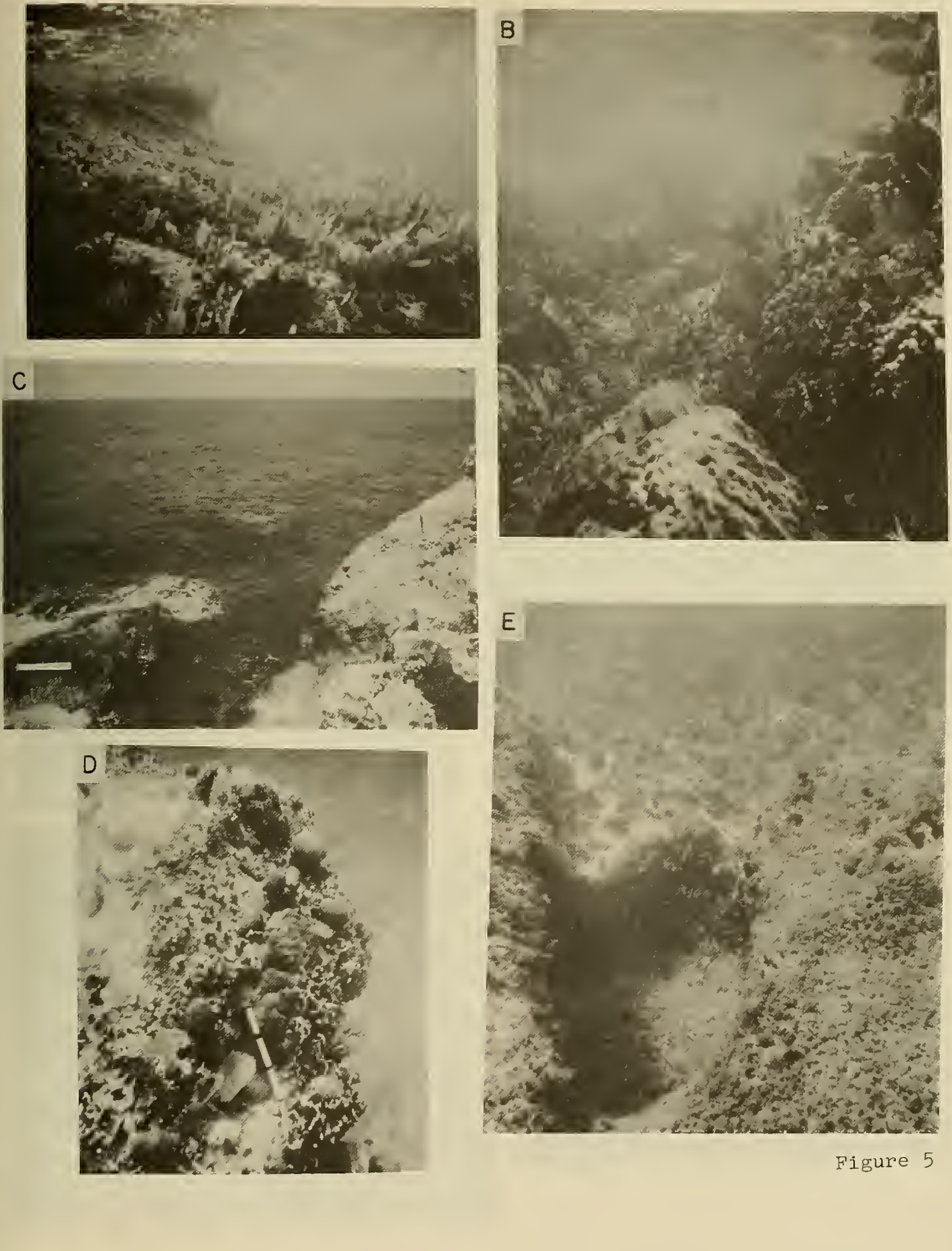


Figure 5

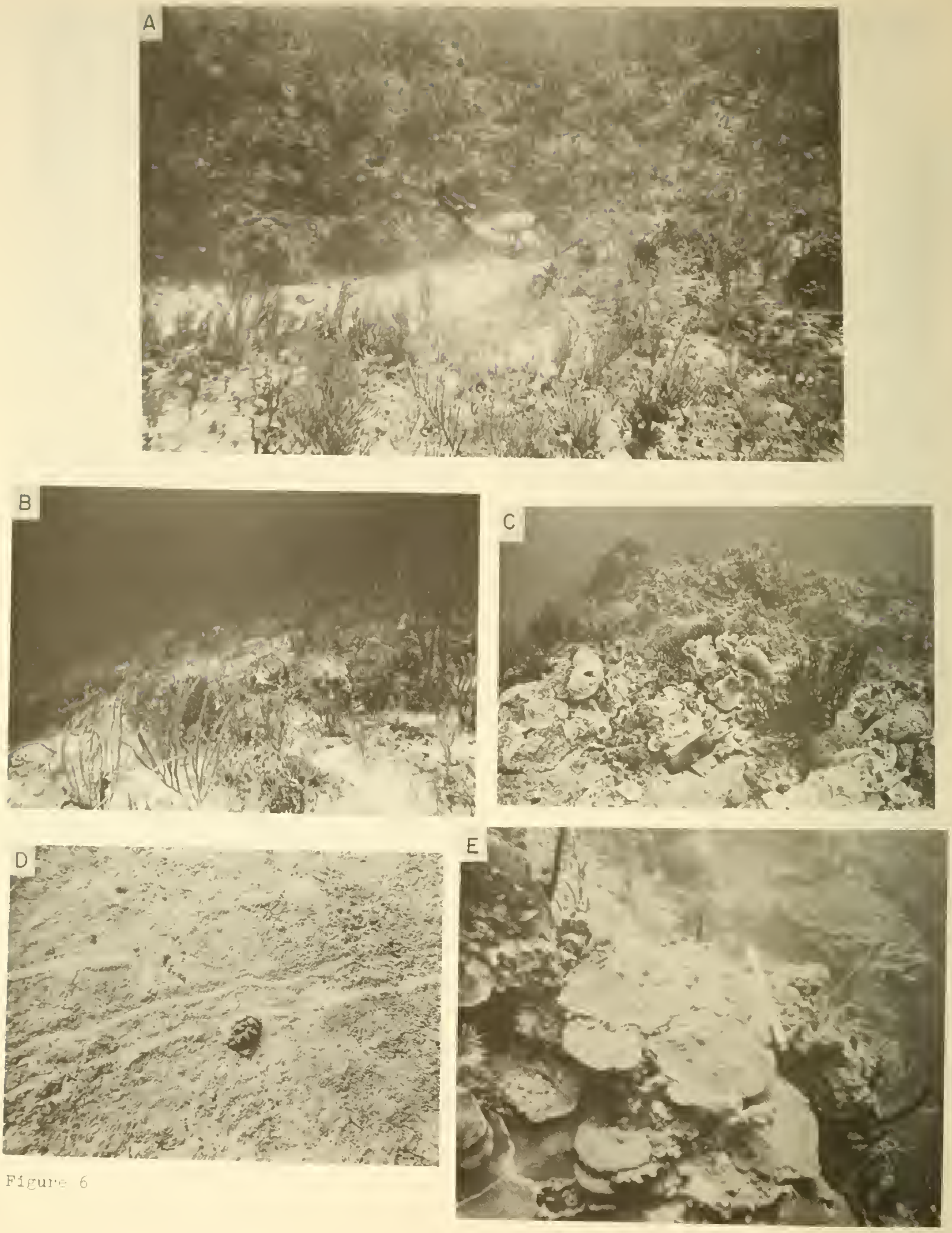


Figure 6

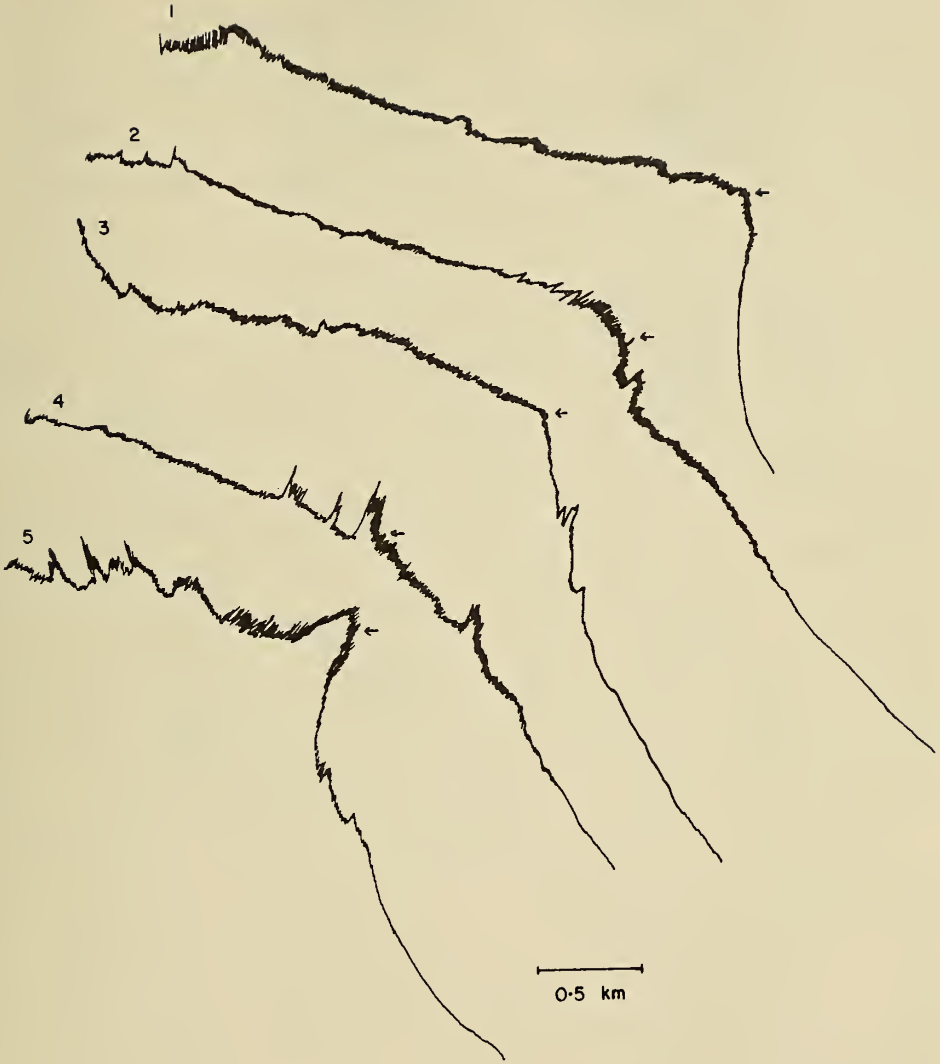


Figure 7

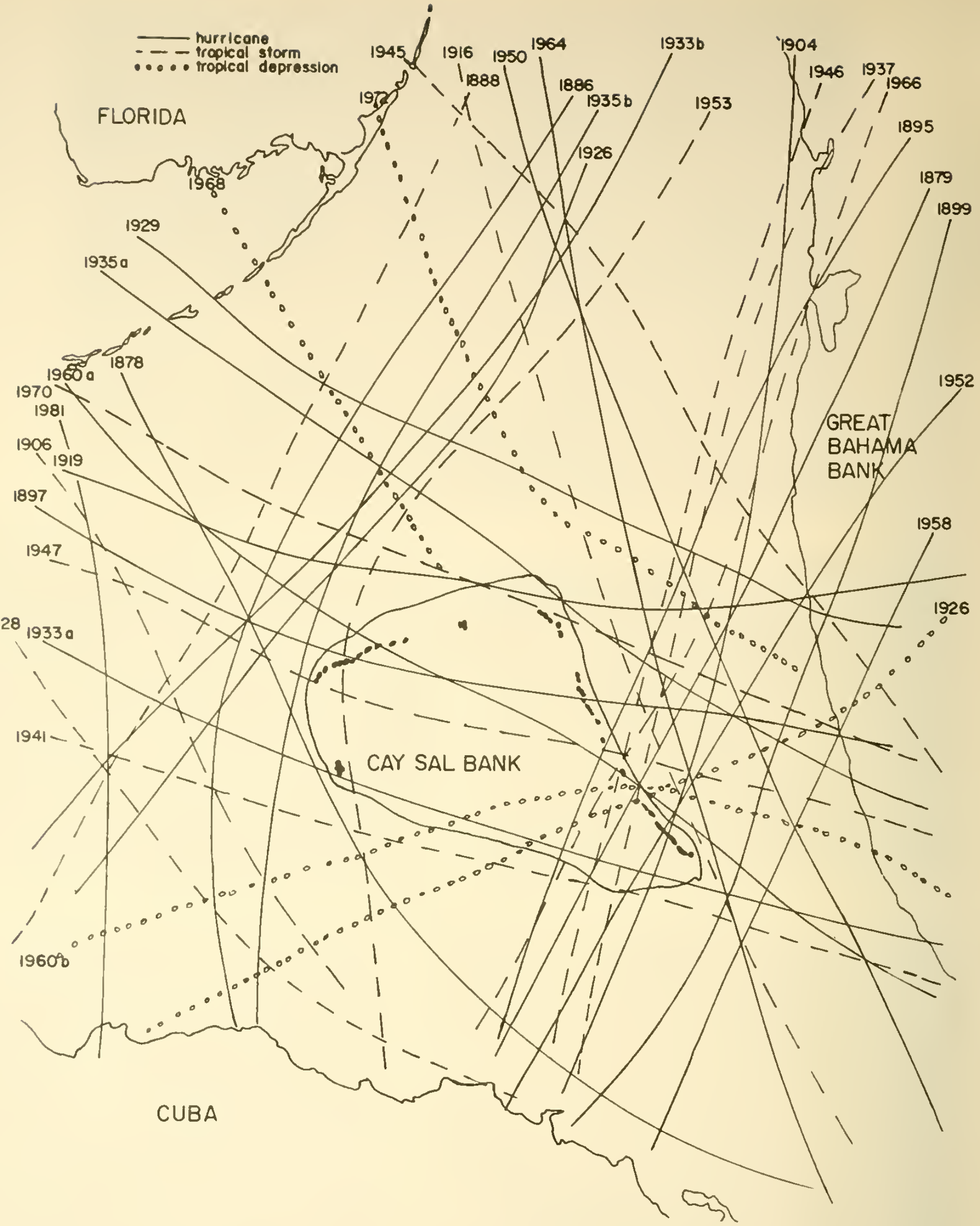
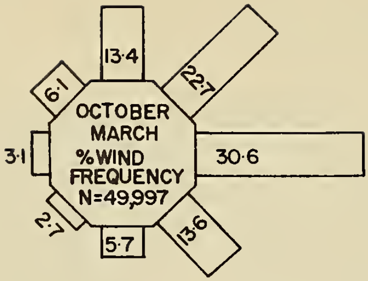

hurricane
tropical storm
tropical depression
FLORIDA
1945
1916
1888
1950
1964
1886
1935 b
1933b
1953
1904
1946
1937
1966
1895
1879
1899
1972
1926
1968
1929
1935a
1960a
1878
1970
1981
1906
1919
1897
1947
1928
1933a
1941
1960b
GREAT
BAHAMA
BANK
1952
1958
1926
CAY SAL BANK
CUBA

Figure 8

% Sea and Swell Conditions >2 m

month	sea	swell	observations
May	18	8	4,448
August	15	6	6,417
November	25	15	5,338
February	20	12	4,667



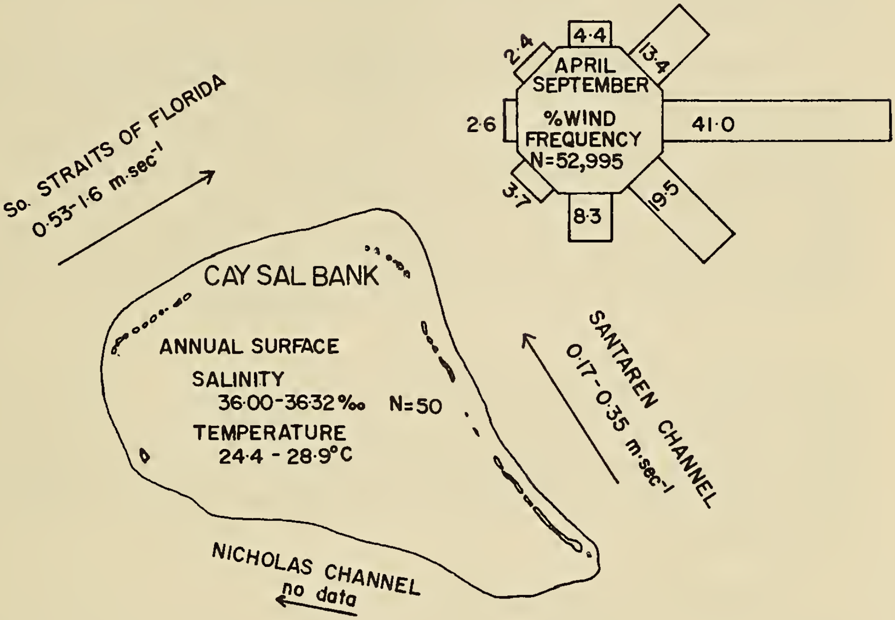


Figure 9

APPENDIX

The lack of basic information on Cay Sal Bank is perhaps no better reflected than by considerable errors in its charted position (British Admiraly 1217; Defense Mapping Agency 11451; NOAA 11013). The purpose of this note is to correct mapping errors by employing aerial and satellite photography coupled with ship-based navigational techniques and bottom soundings. Additional information is presented on the biotic composition and morphology of major islands.

Data on the bank were obtained during three cruises of the R/V Bellows in the summers of 1980 through 1982. Position fixing aboard the vessel employed by simultaneous use of a 7100 Micromarine LORAN C Navigator computer, plus a Micrologic ML-320 LORAN-C Navigator as a backup. An ITT Decca Marine 801 satellite navigation computer and a Decca RM 914 radar unit (77 km range) were used to confirm LORAN data. Bathymetry information was obtained using a Raytheon Explorer III recording fathometer (to 75 fathoms) and a Raytheon DE-731 recording fathometer to (410 fathoms).

All islands and rocks were surveyed by oblique aerial photography from an altitude of 600 meters. These were supplemented by aerial photographs of the Anguilla Cays made available by the U.S. Defense Intelligence Agency. The low altitude photographs were employed in conjunction with ERTS/LANDSAT imagery and shipboard position fixing in the construction of a map of the bank, accurate to within ± 300 meters.

Results of the mapping of Cay Sal Bank are depicted in Figure 1. Comparison with the 1890 British Admirality Chart (Fig. 2) shows an error between 1 and 5 km in the position of the islands, the magnitude of which is greatest in the southeastern portion of the bank. The shape of larger islands has been more accurately depicted and some have been named (Crenula Cay, North and South Dangerous Rocks and Bellows Cay). The bathymetry of the bank as originally presented appears to be essentially correct for the relative position of the 5 fathom curve. Only minor corrections have been inserted. The position of the 25 fathom (=100 F) curve has been fitted using satellite imagery (text fig. 3).

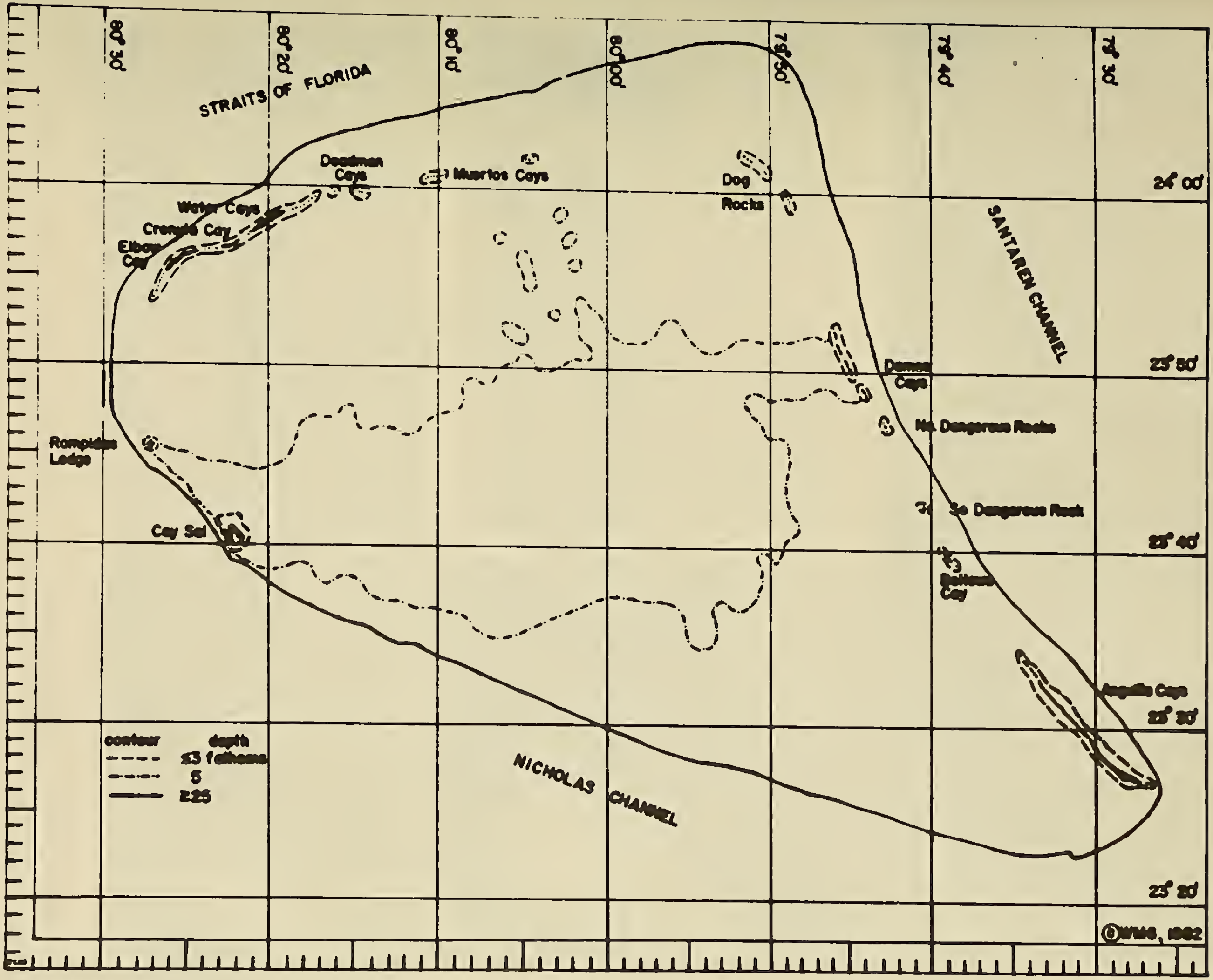
Some of the shoal water areas depicted on the British chart (and copied on all other charts) could not be located despite numerous attempts. Most notably, areas such as Lavanderas Rocks, east of Cay Sal and "Dangerous Shoal" depicted on the central eastern border (Fig. 2) are no shallower than 3.5 to 4 fathoms. This is also true for the shoal areas near the center of the bank. Repeated crossings have indicated that the lagoon is generally no shallower than 3.5 fathoms (6.4m) at MSL. The exception to this rule is a small ($\sim 1 km^2$) area on the western bank referred to as Rompidas Ledge, where the bottom shoals to less than two fathoms, and large scattered heads of *Montastrea annularis* project close to the surface. Navigational maps place Rompidas over 5km from its actual position. However, the site is now marked by a cargo ship, M/V Cork that ran aground on Rompidas in 1983. The location of this submerged shoal can now be seen clearly from a distance of over 15km.

APPENDIX
FIGURE LEGENDS

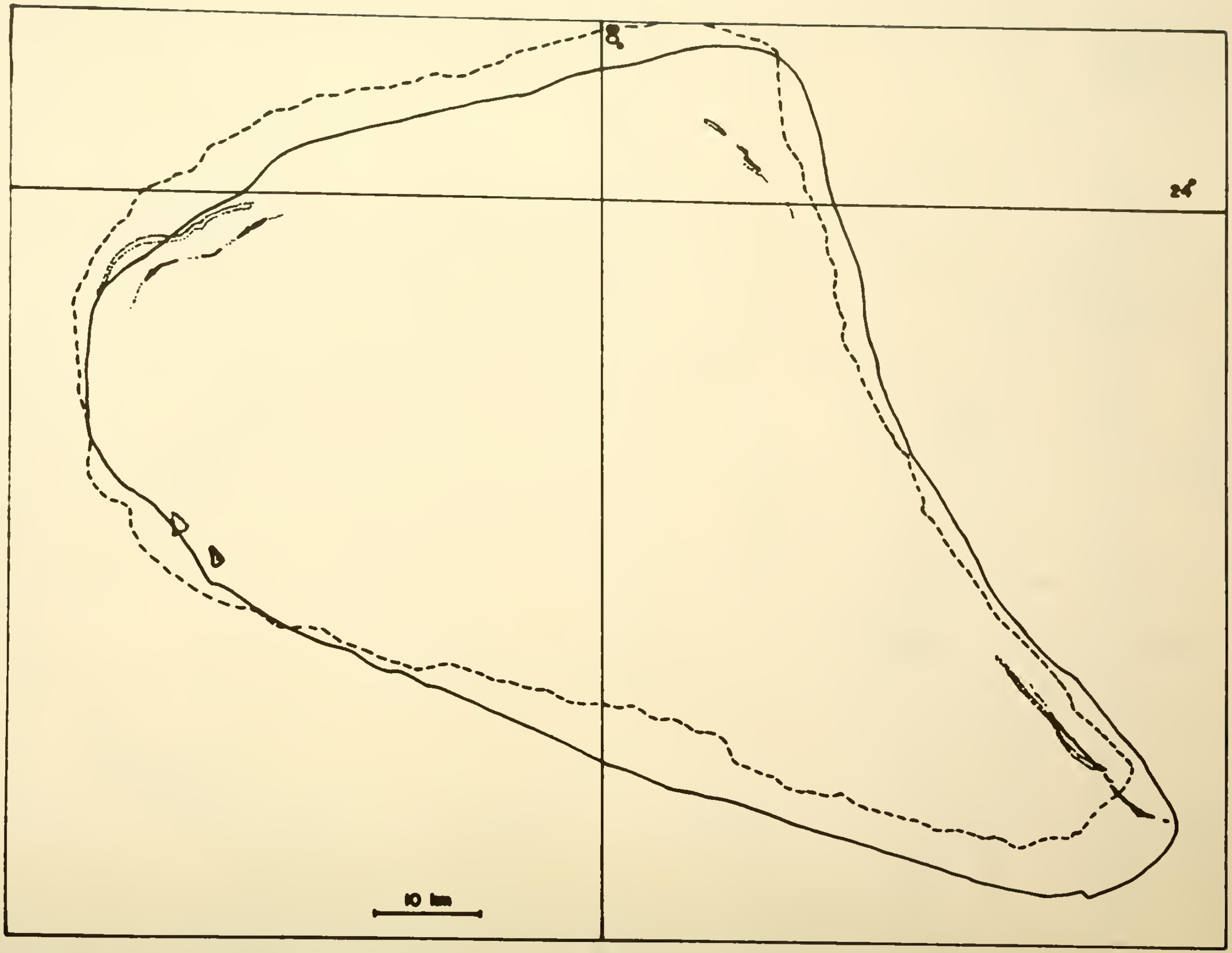
Figure 1. Chart of Cay Sal Bank with revised coordinates according to LORAN and radar positioning; twenty-five fathom (=100F) curve fitted from satellite imagery.

Figure 2. Comparison of new chart (solid lines) with British Admirality Chart No. 1217 (dashed lines) showing 25 fathom curve and position of major islands. When the 24° and 80° coordinates of the two maps are overlapped errors of up to 5km are shown along the southeastern sector of the bank. U.S. Defense Mapping Agency No. 11461 is virtually identical with the British map.

Figure 3. Islands of Cay Sal Bank.
(A) U.S. Air Force photograph of south Anguilla Cay; scale bar = 500m. Note embayed margins and sand shoals. Salinity of saline lake in June, 1982 was 37.0‰ by conductivity. Lake margins are covered with cyanobacterial mats (*Oscillatoria* sp.) along with those of an unidentified red photosynthetic bacterium. A similar lake on north Anguilla Cay retained a salinity of 45‰.
(B) Surface of south Anguilla Cay from eastward facing dune crest looking north: Development of palms (*Coccothrinax argentata Brown*) and scrub vegetation. Eastern dune face is steeply sloping and eroded. Poorly cemented eolian sand grains are typical of the windward side.
(C) Lagoon (western) side of south Anguilla Cay: bedded structure of well-cemented eolianite cliffs.
(D) Cay Sal from 600m looking toward southern Florida Straits. Unpaved airstrip at northern tip of island ends at edge of hypersaline lagoon. Highest portion of island is 10m ridge at the eastern tip (lower left). Note sandy shoals around island and weakly developed blowout structures at lower right corner. Scale bar = 150m.
(E) Elbow Cay is typical of most islands on Cay Sal Bank, consisting of karstified eolianite and coral rubble colonized by maritime vegetation, primarily *Sesuvium portulacastrum* Linn. and *Tournefortia gnaphalodes Brown.* See Wilson (1909) and Gillis (1976) for additional notes on Cay Sal Bank terrestrial flora. This and other rocky islands of the bank serve as nesting sites for enormous numbers of sooty and brown noddy terns during the summer months. See Buden and Schwartz (1968) for a review of herpeto- and avifauna of Cay Sal.



Appendix Fig. 1



Appendix Fig. 2

Appendix Fig. 3

ATOLL RESEARCH BULLETIN
No. 272

HENDERSON ISLAND (SOUTHEASTERN POLYNESIA): SUMMARY OF CURRENT KNOWLEDGE

BY

F. R. FOSBERG, M.-H. SACHET AND D. R. STODDART

ISSUED BY

THE SMITHSONIAN INSTITUTION
WASHINGTON, D. C., U.S.A.

SEPTEMBER 1983

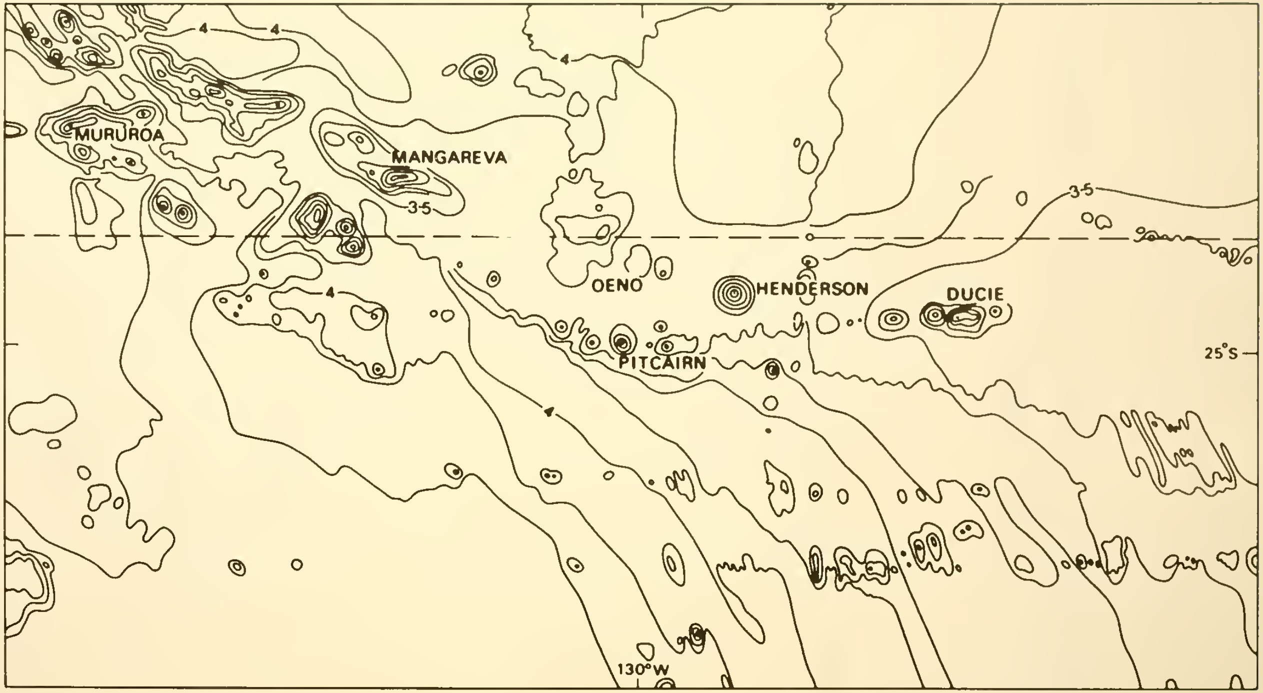


Fig. 1. Henderson Island and surrounding area, South Pacific Ocean, based on the General Bathymetric Chart of the Ocean, 5th edition, sheet 5-11, 1980.

Contents

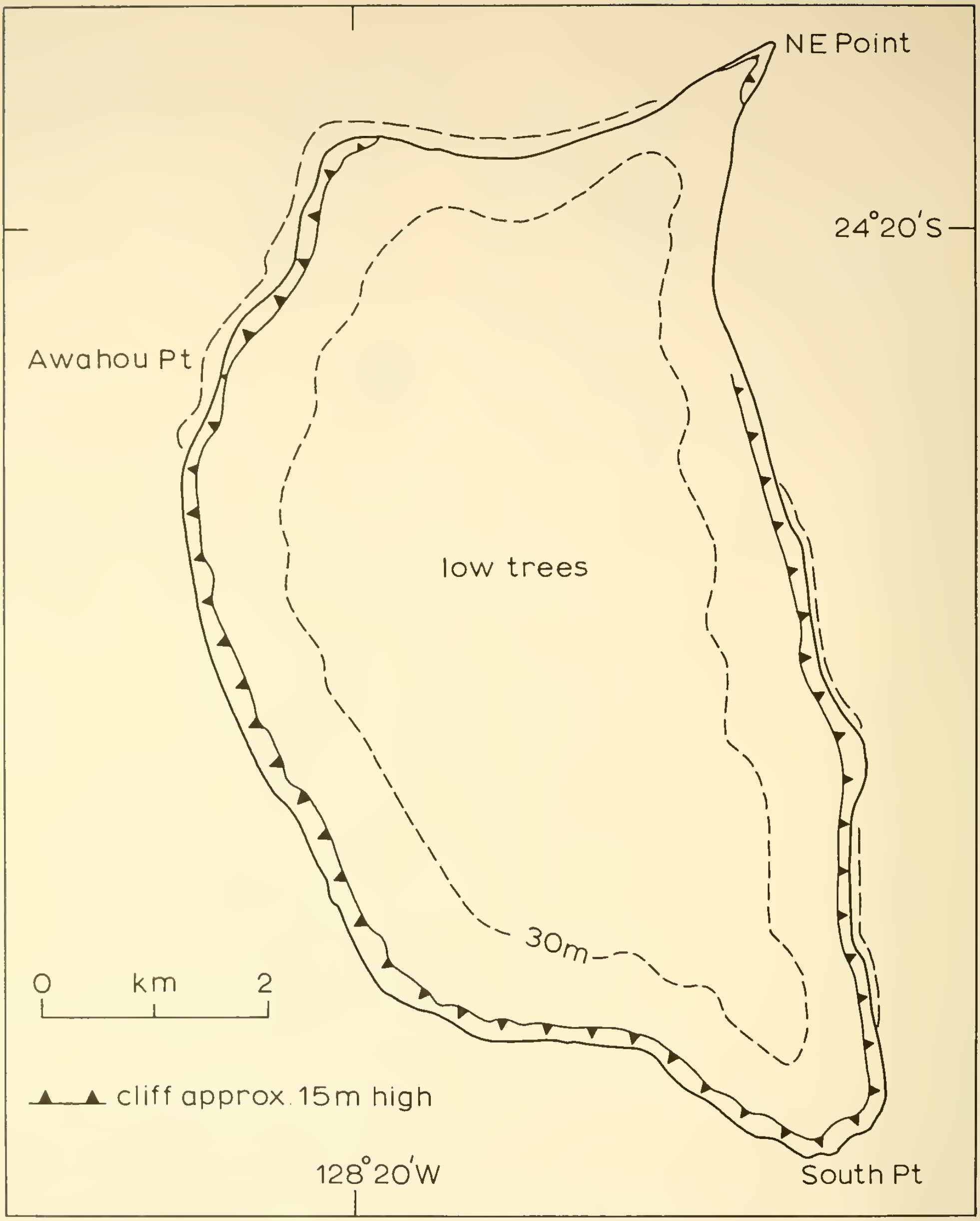


Fig. 2. Henderson Island (from the Admiralty chart).

HENDERSON ISLAND (SOUTHEASTERN POLYNESIA): SUMMARY OF CURRENT KNOWLEDGE

by F. R. Fosberg*, M.-H. Sachet* and D. R. Stoddart**

INTRODUCTION

The tropical seas are liberally sprinkled with coral islands. Many of them are associated with continents and large continental islands, in relatively shallow water, rising from continental shelves. Many, also, are in deep water - atolls, barrier reef islets round high islands, 'almost atolls', tops of drowned karsts, and a few moderately elevated atolls. These last are among the most fascinating of all, scientifically.

There is no obvious reason to think that these are anything but ordinary atolls that have been tectonically elevated a few tens of metres above present sea level. Yet several features are frequently observed that are not evident on the sea-level atolls which are present in the coral seas in such large numbers. Terra rossa soils cover the limestone tops of some of them. Phosphate, earthy or indurated, or both, covers the tops and fills pits and crevasses of some, occasionally in enormous quantities, and is present at least in some quantities on most or all of them. Fantastically eroded, deeply and sharply pinnacled and pitted limestone surfaces are common. Endemic species of plants and animals, very rare on low atolls, are found in some numbers on almost all raised atolls of which we have even meagre knowledge. Whether or not these phenomena are related is at present not clear. Much further work on as many as possible of these islands is needed to elucidate this problem.

The basic difficulty of the above statement is that, of the 20 or 30 such 'oceanic' islands or groups of islands, most have been greatly altered by long-established human occupancy, or phosphate mining, or both. Of the exceptions, the 'Rock Islands' of Palau and the Lau Group of Fiji are rugged karst, not comparable with raised atolls; Medinilla has been used as a bombing target; only Aldabra and Henderson remain reasonably unaltered. We are not here considering the many 'continental' limestone islands.

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**Geography Department, Cambridge University

Aldabra and Henderson are topographically and physiographically very different, though both are probably raised atolls. Aldabra has been studied intensively during the past 17 years, is now well-known, and is legally protected. Henderson is relatively poorly known, and protected only by its remoteness and unsuitability for human habitation.

During the past year the isolation and pristine condition of Henderson have been and are seriously threatened by a project of a wealthy American to build a house, landing facilities, and an airstrip on it. This is being opposed by scientific and conservation bodies, which are petitioning the British Government to deny permission to carry out this project. This circumstance has brought out and underscored the paucity of reliable scientific information, except of a reconnaissance nature, about Henderson. This has caused the ARB editors to bring together a summary of what is known of the geography, history, ecology, flora and fauna of this island, with a bibliography of pertinent literature. This paper is, therefore, a factual record of the published information on Henderson: it sets down what has been discovered, at what time, and by whom, about the island.

GEOGRAPHY

Henderson is an elevated limestone island situated in 24°22'S and 128°20'W. Its nearest neighbours are Pitcairn, 200 km to the west-southwest; Oeno, 200 km to the west; and Ducie, 360 km to the east. It rises as an isolated conical mound from depths of ca 3.5 km, on a trend line which continues that of the Tuamotus and Gambiers eastward to Ducie, and is presumably a reef-capped volcano.

The island has a greatest length of 9.6 km and greatest width of 5.1 km, based on the Admiralty chart; its area is 37 sq km. It is usually said to rise about 33 m (100 ft) above sea level. Early authors stressed the flatness of its summit, but those on the Mangarevan Expedition were impressed by a central depression which they interpreted as a former atoll-lagoon. The upper surface consists of an intricate dissected limestone, with pits and crevasses 3-7 m deep. The island is surrounded by steep cliffs of bare limestone, with occasional pocket beaches. There is a fringing reef 200 m wide, at least on the north and northwest sides backed by a wide beach (St John and Philipson (1962)).

No meteorological records are available, but the island lies in the Southeast Trades, and from its location probably has a mean annual rainfall of 1500 mm. The tidal range at springs is probably close to that of the Gambiers and eastern Tuamotus (1.0 m) (Admiralty Tide Tables 1983). Tidal measurements at Ducie by Rehder and Randall (1975) showed a regular semidiurnal tide.

The top of the island, as well as any land at the bases of the cliffs, is densely vegetated by tangled scrub and scrub-forest, but the central part of the depression and the makatea are more sparsely covered. In places, where the forest is taller and the canopy more complete, it is possible to walk freely for short distances. The tallest trees are

Pandanus tectorius Parkinson, which in places rises as an emergent above the general canopy. The crowns of such emergents are conspicuously pyramidal or conical. The dried fallen leaves of Pandanus cover the ground in many places.

The scrub and much of the scrub-forest is in many areas so dense and tangled that walking through it is impossible without the constant and vigorous use of a machete, and exhausting and slow even with the use of one. Such scrub is as likely to be on dissected limestone as on solid soil, adding to the difficulty of traversing it. In some parts the difficulty is increased by the presence of Caesalpinia bonduc, a tangled vine beset with hooked prickles, which amply explain and justify a name used in Hawaii for this widely-distributed species, 'wait-a-bit'.

Fresh water is almost completely absent. Slight dripping has been observed from the roofs of certain caves. A spring from a rock cleft below high tide level at the north end of the island has been reported (Naval Intelligence Division 1943, 92), but its degree of permanence is unknown. Presumably there is some development of a Ghyben-Herzberg lens within the island, but nothing is known of this.

Biogeographically the island is very interesting because of its remoteness from obvious source areas. Comparison of its habitats with those of sea level and slightly-elevated atolls in the Tuamotus, in terms of effective salinity, proportions of different substrata (sand, dissected limestone, cliffs, level soil, etc.) is of great potential interest, but has yet to be considered except in a very preliminary manner. Study of the effects of geologically long continuous exposure above water, compared with the very short history of emergence of the sea-level atolls, could be rewarding. None of these lines of research can develop very far without much more information about the island than we have at present. Comparison with Aldabra would then be profitable.

ARCHAEOLOGY

As noted above, Henderson has been, in historic times, uninhabited, with only brief visits by Pitcairn Islanders and occasional scientific parties. However, on one such visit, in 1971, Dr Yosi Sinoto, of the Bishop Museum, discovered and made preliminary investigations on an archaeological site at the north end of the island. With his kind permission we quote his preliminary account of this discovery from a paper read in Nice in 1976:

"Henderson Island, known also as Elizabeth Island, is located about 105 miles northeast of Pitcairn Island. This tiny, raised, coral-limestone island is flat-topped with 100-ft-high cliffs rising from the shorelines. Since some time before its discovery by Quirós in 1606, the island has been uninhabited (Markham 1904). In 1971, while prospecting on the north shore, we found five shelters, one of which included burials, and a cave. The cave is situated at the base of a cliff at the back of the beach flat. Test pits in front of the cave revealed three cultural layers. The top of Layer II was a hard, coral-pebble-paved layer indicating an occupational floor. At the bottom of Layer III we found a fireplace on top of the sterile deposit.

"More than 250 portable artifacts were uncovered from the excavations. These included 100 fishhooks and blanks, of which 75 are pearl-shell, and 90 coral (Porites sp.) abraders for making fishhooks. There were 36 basalt adz sections and fragments. This is striking because basalt rocks and pearl shells are not available from the island, and the distribution of these artifacts in the three cultural layers is revealing. The lowest layer yielded only pearl-shell fishhooks, Hawaiian-Marquesan-type coral files, and basalt adzes, all broken beyond type identification, except that cross sections could be recognized as quadrangular to trapezoidal. The quantity of these artifacts decreased in the middle layer and was drastically reduced in the top layer, where hammer-oyster-shell hooks and Henderson-type coral files appeared. In the top layer, fossilized Tridacna-shell adzes appeared. Gradual material adaptation - the gradual change from the use of imported materials to the use of local resources - is excellently demonstrated here. Pearl-shell fishhook types found were early Marquesan, Phase II, and coral files were Hawaiian-Marquesan types, previously found only in those two island groups. There is no doubt that the early Henderson material culture had a close affiliation with the early Marquesan culture; as the materials that were brought to Henderson were exhausted, the locally available resources were exploited. There were eight pieces of volcanic glass, resembling pitchstone fragments, associated with basalt adzes and pearl shells. These are also foreign to the island but may suggest contact with Pitcairn Island, where pitchstone is available. Another shelter yielded artifacts made only of local materials.

"A charcoal sample collected at the bottom of the cave site was dated at A.D. 1160±110 (I-6344) and charcoal from the top of the middle layer was dated at A.D. 1455±105 (I-6343). Thus the span of the occupation at this site was more than 300 years. Quirós's party landed on Henderson in 1606 and found pandanus trees, but no inhabitants. Whatever the reason for the disappearance of the inhabitants, it must have happened just prior to Quirós's visit."

DISCOVERY

The island is named after Captain James Henderson, of the Hercules, who called there on 17 January 1819: Beechey (1831, I, 64) proposed that Henderson's name be applied to it, rather than that of the vessel Elizabeth, then used on charts, on the grounds that the Hercules visit preceded that of the Elizabeth by several months. Beechey also erroneously suggested that both ships had been preceded by the crew of the wrecked whaler Essex. In fact Hercules was first, followed by Elizabeth, Captain Henry King, on 1 March 1819, and members of the crew of the Essex from 20 December 1819 until 5 April 1820. Beechey's vessel H.M.S. Blossom called on 3 December 1825, and was responsible for the first scientific observations.

Beechey's account of the discovery of Henderson has been followed by several later authors, including the Admiralty Handbook (Naval Intelligence Division 1943, 92) and St John and Philipson 1962, 176). As early as 1837, however, Moerenhout suggested that Henderson was among the islands discovered by Pedro Fernândez de Quirós in 1606, a proposal adopted by Meinicke (1876), Beltran y Rózpide (1882-3), Caillet (1884), Markham (1904) and Sharpe (1960). Maude (1968, 66) commented that 'there can be no doubt as to the identification of these islands'.

Accounts of the Quirós expedition

Quirós sailed from Callao, Peru, on 21 December 1605, in his flagship San Pedro y San Pablo, together with the Almiranta and San Pedro. He gives the following account in his Narrative, edited by Markham (1904):

> "On the 25th [January 1606] we saw the first weeds; and on the 26th we saw birds of several kinds flying together. On this day, at 11 o'clock, we discovered the first island in latitude 25°, and reckoned it to be 800 leagues [ca 4740 km] from Lima. It has a circumference of 5 leagues [30 km], many trees, and a beach of sand" (Markham, ed. 1904, I, 192).

This island, subsequently identified as Ducie Atoll, was variously termed Luna-Puesta and La Encarnación. Quirós stood off to westward without landing.

> "Still steering on the same course, on the 29th of January, at dawn, we sighted another island near, and presently stood towards it. The launch to the S.W. found a port in a small bay, where she anchored in 27 fathoms, and almost on shore. The ships did the same. ... Three men were sent from the Almiranta in a dingey to land. Fearing to remain they came back quickly, bringing certain fruits known to some on board, which were too unripe to eat. They said that the landing was very bad for a dingey, and would be much worse for larger boats. This island was supposed to be 870 leagues [5160 km] from Lima. It is 10 leagues [60 km] round. It is massive, moderately high, open, having groves and plains. It is steep, too, and its beaches are rocky. It is only inhabited by birds. Its latitude is 24°45'. It was named 'San Juan Bautista'; and as it had no port where we could get wood and water, we continued our voyage to the W.N.W." (Markham, ed. 1904, I, 193).

San Juan Bautista is the island identified as the present Henderson.

The discovery of the two islands is also described by the Chief Pilot, Gaspar de Leza. The first, Ducie, which he called Anegada, was met with on 26 January 1606 in latitude 25°S, 1000 leagues [5900 km] from Callao. During the 27th they sailed on, and at 10 leagues [60 km]

NW by N determined their latitude as 24°50'S. On the 28th they made 30 leagues [180 km] on a westerly course. 'This day we again saw a great number of birds of many kinds, chiefly grey gulls and terns.' The discovery of Henderson is described as follows:

> "29th. Second Island: Sin Puerto. - 24°45'S., 1075 leagues [6375 km] from Callao. In the morning we saw another island, about 6 to 7 leagues [35-42 km] long, N. and S., all flat, with a hill to the S. It is all clean rock round the coast. The distance from the 'Anegada' is about 75 leagues [445 km]. ... This island is very green, and full of trees and open spaces. The wind which blew over this island brought a smell of flowers and herbs: for they were abundant. The Almiranta got out a skiff, and sent it to the shore with three persons. They jumped on shore, but were afraid to leave the boat. They brought back certain fruits and herbs, and said that they saw pebbles of different colours on the beach, and stones which they did not know, but which were pleasant to the sight. ... To the NE. of the place where we had been there was a beach, which appeared to be larger than the first; and if any one should chance upon this island at any time, the N.E. side should be taken to find this beach." (Markham, ed. 1904, II, 330-331).

Yet a further name for Henderson is provided by the second-in-command, Luis Vaez de Torres, when he states that the second island discovered was 'about 10 leagues [60 km] in circumference. We named it San Valerio' (Markham, ed. 1904, II, 465). Juan de Iturbe on the same voyage describes Henderson as 'seventy leagues [415 km] distant from the first, completely round and uniform of aspect with sheer cliffs. It would be seven leagues [42 km] in circumference' (Kelly, ed. 1966, II, 281).

Finally, Fray Martin de Munilla, chaplain to the fleet, gives a more circumstantial account:

> "an island, a little over ten leagues [in circumference] [60 km] was sighted rising from the sea about eight varas [6.7 m; 1 vara = 84 cm]. It was flat and round, the higher parts bore a uniform aspect, but formed after the manner of riven rock with some high cliffs facing the sea. ... We saw a small beach between two morros [bluffs]. ... Two men went ashore and brought back a fruit like a green pineapple [Pandanus]. Two Chinese who were on board the capitana said that the fruit was edible and that it was plentiful in China. Returning presently they reported that the harbour was not suitable, but that there were fish in abundance. There, too, they found some trees, though these were small, but they had seen no sign of people. ... This island would be sixty leagues from the other [355 km from Ducie] and in relation to each other they stood E W 1/4 N W SE. It lies in latitude 24-3/4°S ." (Kelly, ed. 1966, I, 153-155).

Account of Captain King

After the Quirós expedition there are no further recorded visits to Henderson until that of the Hercules on 17 January 1819: we have seen no account of that occasion. However, King (1820) has described his visit with the Elizabeth on 1 March 1819. He found

> "a large island on the weather-beam, ... as level as a bowling-green. ... [We] endeavour to land at a sandy-beach not far distant from the ship, which, after some difficulty, we accomplished. After hauling the boats up among the trees, we all went up in different directions; within hail of each other, in quest of vegetables or animals; but, after a search of four and a half hours, we returned to the boats, having seen one parrot, and shot a few pigeons. The island abounded with young trees and underwood, nor did we observe the smallest appearance of quadrupeds, except here and there a rat; the ship's name Elizabeth, was now given to the island. The British Colours were displayed on the island, and greeted with three cheers, and a bumper of grog was drank to the health of his Majesty. While these ceremonies were performing, a proper person was employed in carving the ship's name, and the other particulars upon a tree, near the spot we landed. ... We landed on the south-west part of the island, among some coral rocks, at the back of which is the beach before mentioned. It appears about six leagues in circumference, and we found no anchorage. ... The latitude of Elizabeth's Island is 24°26'S., longitude west of Greenwich 127°50'." (King 1820, 381-382).

The wreck of the Essex

The destruction of the whaler Essex, Captain George Pollard, by a whale on 20 November 1819 on 0°40'S., 119°0'W, and the subsequent voyage in small boats of the survivors to Henderson and beyond provided the origin of the Moby Dick story made famous by Melville. The boats arrived at Henderson on 20 December, after drifting for a straight-line distance of 2100 km. Most of the party left again for the Juan Fernandez Islands after a few days at Henderson. Their boats became separated and the survivors suffered appalling privations: in the captain's boat the cabin boy, Owen Coffin, was selected by lot to be killed and eaten after the food was finished, and another man who died was also cannibalised. The first mate's boat was finally rescued in 33°45'S, 81°03'W, close to their destination, after a voyage of some 4000 km. The three crew members who had remained on Henderson were finally taken off on 5 April 1820.

Chase (1821; Gibbings, ed. 1935) wrongly identified their first landfall as Ducie, but it was clearly Henderson: first, because of their description of the island, and second, because they found there a tree carved with the words 'The Elizabeth' (Gibbings, ed. 1935, 60) which had been there ten months before.

The island was described by Chase as "about six miles long and three broad; with a very high ragged shore, and surrounded by rocks; the sides of the mountains were bare, but on the tops it looked fresh and green with vegetation" (Gibbings, ed. 1935, 52). Chappel described it as "about eight or nine miles round, low and flat, nearly covered with trees and underwood" (ibid, 78). Of particular interest is Chase's record of a "fine white beach" in the northwest (ibid, 70).

The Essex narrative is retold by Heffernan (1981), and mention is made below of other observations made on the island.

Account of Captain Beechey's visit

The most graphic and detailed accounts of Henderson in the early literature are those resulting from the hydrographic survey made by H.M.S. Blossom under Captain F. W. Beechey during a single day in December 1825. Beechey's own account is as follows:

> "At noon on the 2d of December, flocks of gulls and terns indicated the vicinity of land, which a few hours afterwards was seen from the mast-head at a considerable distance. At daylight on the 3d, we closed with its south-western end, and dispatched two boats to make the circuit of the island, while the ship ranged its northern shore at a short distance, and waited for them off a sandy bay at its north-west extremity.
>
> "We found that the island differed essentially from all others in its vicinity, and belonged to a peculiar formation, very few instances of which are in existence. ... The island is five miles in length, and one in breadth, and has a flat surface barely eighty feet above the sea. On all sides except the north, it is bounded by perpendicular cliffs about fifty feet high, composed entirely of dead coral, more or less porous, honeycombed at the surface, and hardening into a compact calcareous substance within, possessing the fracture of secondary limestone, and has a species of millepore interspersed through it. These cliffs are considerably undermined by the action of the waves, and some of them appear on the eve of precipitating their superincumbent weight into the sea; those which are less injured in this way present no alternate ridges or indication of the different levels which the sea might have occupied at different periods, but a smooth surface, as if the island, which there is every probability has been raised by volcanic agency, had been forced up by one great subterraneous convulsion. The dead coral, of which the higher part of the island consists, is nearly circumscribed by ledges of living coral, which project beyond each other at different depths; on the northern side of the island the first of these had an easy slope from the beach to a distance of about fifty yards, when it terminated abruptly about three fathoms under water. The next ledge had a greater descent, and extended to two hundred yards from the beach, with twenty-five fathoms water over it, and there ended

> as abruptly as the former, a short distance beyond which no bottom could be gained with 200 fathoms of line. Numerous echini live upon these ledges, and a variety of richly coloured fish play over their surface, while some cray-fish inhabit the deeper sinuosities. The sea rolls in successive breakers over these ledges of coral, and renders landing upon them extremely difficult. It may, however, be effected by anchoring the boat, and veering her close into the surf, and then, watching the opportunity, by jumping upon the ledge, and hastening to the shore before the succeeding roller approaches. In doing this great caution must be observed, as the reef is full of holes, and the rugged way is strewn with sea-eggs, which inflict very painfull wounds; and if a person fall into one of these hollows, his life will be greatly endangered by the points of coral catching his clothes and detaining him under water. The beach, which appears at a distance to be composed of a beautiful white sand, is wholly made up of small broken portions of the different species and varieties of coral, intermixed with shells of testaceous and crustaceous animals.
>
> "Insignificant as this island is in height, compared with others, it is extremely difficult to gain the summit, in consequence of the thickly interlacing shrubs which grow upon it, and form so dense a covering that it is impossible to see the cavities in the rock beneath. They are at the same time too fragile to afford any support, and the traveler often sinks into the cavity up to his shoulder before his feet reach the bottom. The soil is a black mold of little depth, wholly formed of decayed vegetable matter, through which points of coral every now and then project.
>
> "The largest tree upon the island is the pandanus, though there is another tree very common, nearly of the same size, the wood of which has a great resemblance to common ash, and possesses the same properties. We remarked also a species of budleia, which was nearly as large and as common, bearing fruit. It affords but little wood, and has a reddish bark of considerable astringency: several species of this genus are to be met with among the Society Islands. There is likewise a long slender plant with a stem about an inch in diameter, bearing a beautiful pink flower, of the class and order hexandria monogynia. We saw no esculent roots, and with the exception of the pandanus, no tree that bore fruit fit to eat." (Beechey 1831, I, 61-64).

A more succinct account was provided by Lieut. Peard, also on board H.M.S. Blossom:

> "On the 2nd December [1825] several Noddies and Boatswains' birds were seen about the Ship, and we made Elizabeth Island which like the last [Ducie] is of coral and uninhabited; but I suppose 70 feet high and 16 or 18 miles in circumference. The cliffs in many parts, more particularly the North part are

> washed by the sea into curious and fantastic Arches, and large caverns are formed into which the waves dash and force a passage through wide openings in the top. A Beach of the most dazzling whiteness and apparently composed of the finest sand every here and there presented itself, and seemed to invite us to the shore. Our boats however made the circuit of the Island and found it by no means an easy access, some of the Officers landed by wading through the Surf, and discovered that the beach was composed of coral, madrepore and shells bleached by the sun." (Gough, ed. 1973, 75).

LATER HISTORY

Apart from scientific investigations by visiting expeditions, much of the later history of Henderson is connected with that of neighbouring Pitcairn, discovered by Carteret in 1767 and settled by the *Bounty* mutineers in January 1790. The settlers remained unaware of Henderson until the arrival of the *Elizabeth* in 1819 (hence the currency of the name Elizabeth on Pitcairn until at least mid-century), and did not visit the island until 4-11 March 1843, according to the Pitcairn Island Register (Murray 1854, 281). The visit led to 'a very unfavourable report' on the island. The visit is described in some detail by Brodie (1851, 17-18):

> "Not long ago, eleven of these islanders, along with John Evans (one of the three resident Europeans), were carried to Henderson's, or Elizabeth Island, in an American whaling vessel, on an exploring expedition. The landing was anything but good, and the soil not near so rich as that of their own island, being of a much more sandy nature. Water there appeared to be none; but, after a long search, they found a fresh-water spring below high-water mark. Some cocoa-nuts, which had been purposely carried there, were planted upon the best ground they could find. Several goats had been likewise shipped for turning out, but were actually forgotten until some time after they were returned on board. They were only a few hours on the island, and, therefore, were unable to form or give any detailed description of it. Elizabeth Island is of a peculiar formation, very few instances of which are known, viz., dead coral, more or less porous, elevated in a flat surface, probably by volcanic agency, to the height of eighty feet. It is five miles in length, one in breadth, and thickly covered with shrubs, which makes it difficult to climb. It was called Henderson's Island after the captain of the ship *Hercules* of Calcutta, though first visited by the crew of the *Essex*, an American whaler, two of whom landed on it after the loss of their ship, and were subsequently taken off by an English whaler, who heard of their fate at Valparaiso. They are very anxious to procure a small vessel or large boat, of about twenty tons burden, to enable them to visit this island at pleasure, and bring off house-timber as required, as likewise to convert it into a run for their live stock; thus relieving their little island from

> that burden, and enabling them to direct the whole of its capabilities to the use of man. They have established a sort of Bank among themselves, in which a large part of the money paid by vessels for refreshments, is suffered to accumulate for the purpose of purchasing a small vessel."

The next visit from Pitcairn to Henderson did not take place until 16 August 1851:

> "Twelve of the inhabitants sailed in the Joseph Meigs for the purpose of visiting Elizabeth Island. On their arrival at the island they discovered a human skeleton, and as nothing could be found that may lead to discover who this unfortunate individual was, it must remain a mystery." (Pitcairn Island Register, in Murray 1854, 295).

This visit was followed by another on 11 November 1851:

> "Thirty-eight of the inhabitants sailed in the ship Sharon, of Fairhaven, for the purpose of visiting Elizabeth Island. On Friday, 14th, after a boisterous passage of three days, they landed upon Elizabeth Island, when they immediately set about wooding the ship, and exploring the country, which is evidently of coral formation. The soil is very scanty, and totally unfit for cultivation. Various specimens of marine shells are dispersed all over the surface of the island, which, in combination with the thickly scattered pieces of coral, renders travelling both difficult and dangerous. Water is found on the north-west part of the island slowly dripping from the roof of a cave, which cannot be reached without the aid of ropes. The island rises about sixty feet above the level of the sea. Eight human skeletons were also found upon the island, lying in caves. They were doubtless the remains of some unfortunate seamen, as several pieces of a wreck were found upon the shore." (Murray 1854, 295-296).

Since then, Henderson has been visited by Pitcairn Islanders on a fairly regular basis, chiefly to cut miro wood, Thespesia populnea, from which carvings are made for sale to visitors.

Formal possession of Pitcairn for the British Crown, as a British Colony by settlement, was taken by Capt Russell Elliott, H.M.S. Fly, on 29 November 1838, and the island came under the administration of the Western Pacific High Commission in 1898. Although Capt King, of the Elizabeth, had informally raised the British flag on Henderson in 1819, the island was not formally annexed (at the same time as Oeno and Ducie) until 1902, when a party from Pitcairn raised the flag on 10 July. All three islands were included with the administration of Pitcairn in 1938. Pitcairn itself is governed by an Island Council, under the authority of a Governor resident at the British Consulate-General in Auckland, New Zealand. Henderson and the other two islands remain, of course, uninhabited.

Table 1. Visitors to Henderson Island: summary

Date	Visitor	Activity	Main publication
1606 29 Jan	Quirós	Discovery	Markham, ed. 1904; Kelly, ed. 1966
1819 17 Jan	James Henderson *Hercules*	Re-discovery	
1819 1 Mar	Henry King *Elizabeth*	Re-discovery	King 1820
1819 20 Dec - 1820 5 Apr	Crew of the *Essex*	Survival	Gibbings, ed. 1935 Heffernan 1981
1825 3 Dec	F. W. Beechey H.M.S. *Blossom*	Survey	Beechey 1832 Hooker and Arnott 1841
1827 9 Oct	Hugh Cuming	Biological collections	St John 1940 and various papers on shells
1838 29 Nov	Capt R. Elliott H.M.S. *Fly*	Possession	
1843 4-11 Mar	First visit by Pitcairn islanders		
1851 16 Aug	Second visit by Pitcairn islanders		
1851 11 Nov	Third visit by Pitcairn islanders		
1877	Wreck of *Allen Gowie*		
1881	Grice, Summer & Co	Phosphate survey	
1900	G. Ellis	Phosphate survey	
1902 10 July	Visit by Pitcairn islanders	Accession	
1907 Sept	G. C. Ellis, J. T. Arundel, A. E. Stephen	Phosphate survey; bird collection	North 1908
1912 Aug-Sept	D. R. Tait, J. R. Jamieson	Phosphate survey; various collections	Ogilvie-Grant 1913a, 1913b; St John and Philipson 1962; Tait 1912, Smith 1913

1922 Mar-Apr	Whitney South Sea Expedition R. H. Beck, E. H. Quayle, C. C. Curtis	Birds; plants	Murphy 1924a and later papers; Brown 1931, 1935; Brown and Brown 1935
1934 16-22 June	Mangarevan Expedition - H. St John, F. R. Fosberg, E. C. Zimmerman, C. M. Cooke, D. E. Anderson	Plants, insects, molluscs	St John and Philipson 1962
1937 Aug	J. R. Rivett-Carnac, H.M.S. *Leander*	Survey	
1943 Nov.	Adm Richard E. Byrd and party	Survey	
1948 Aug	Capt G.S. Webster H.M.C.S. *Awahou*	Survey, light built	
1957 3-4 Feb	W. H. Lintott	Plants, birds	St John and Philipson 1962; Williams 1960
1957	R. Tomarchin with chimpanzee		McLoughlin 1971
1971 Jan	H. A. Rehder, J. E. Randall, Y. Sinoto	Archaeology, marine biology	
1981	A. M. Ratliff(e?)	Survey	

All the islands were visited during a defence reconnaissance by H.M.S. Leander, Capt J. R. Rivett-Carnac, in August 1937, when Beechey's chart of Henderson was revised and a flagpole raised. According to Bourne and David (in prep.) further visits are said to have taken place by United States parties in 1943 and 1966.

A light was erected on a steel tower 6.7 m tall at a height of 38 m by the Colonial Vessel Awahou, Suva, Capt G. J. Webster, on 11 August 1948. Because of maintenance difficulties it was abandoned in 1954 (this information is provided from Admiralty archives by Lt Cdr David).

SCIENTIFIC STUDIES

The first formal scientific studies were those carried out during the visit of H.M.S. Blossom in 1825 when plant collections were made and subsequently reported by Hooker and Arnott (1832) and Hemsley (1885).

On 9 October 1827 Mr. Hugh Cuming visited the island on a general collecting trip, gathering specimens of plants, mollusk shells, and various other groups of animals. He spent only one day there, according to the following, from a letter to Wm. J. Hooker dated "March 21st, 1832":

> "On the 9th made Elizabeth [Henderson] Island, a high coral island without a lagoon, covered with shrubs and palms [Pandanus] principally. Jessamines [probably Jasminum didymum] and Laurels [probably Pittosporum sp. with aromatic foliage] but few in flower. In the clefts of rocks collected some fine ferns. On the 11th made Pitcairn Island. ..." (St John 1940).

During phosphate explorations in September 1907, A. E. Stephen collected birds and made incidental observations, both reported by North (1908). The first substantial study and collections, however, were those carried out by D. R. Tait and J. R. Jamieson in August and September 1912. No full account of this investigation has appeared, but birds were reported by Ogilvie-Grant (1913a, 1913b), marine molluscs by Smith (1913), and plants by St John and Philipson (1962). Extracts, at least, from Tait's diary and report exist in a manuscript letter to Sir John Murray (1913).

The two major studies of the island are: (1) That of the Whitney South Sea Expedition in March and April 1922. E. H. Quayle and C. C. Curtis collected plants and birds, the former reported in Brown's Flora of Southeastern Polynesia (1931-1935) and the latter in a wide range of publications cited below. (2) The Mangarevan Expedition in 1934 spent the period 16-22 June on Henderson. H. St John and F. R. Fosberg collected plants, reported by St John and Philipson (1962), E. C. Zimmerman insects, and C. M. Cooke land molluscs. The invertebrate collections were reported in a wide range of systematic papers. No formal ornithological observations were made during this visit, though notes on birds were made, but not published, by Fosberg.

In 1957 W. H. Lintott visited Henderson with several Pitcairn Islanders on 3-4 February. His bird observations were reported by Williams (1960) and his plant collections by St John and Philipson (1962). Finally, in January 1971, two brief visits were made by H. A. Rehder, J. E. Randall and Y. Sinoto, aboard the Westward, during the National Geographic Society-Oceanic Institute Expedition (which also made the first comprehensive study of Ducie: Rehder and Randall 1975). It was during this expedition that Sinoto made the first preliminary studies of pre-European Polynesian habitation on Henderson.

GEOLOGY

Most writers on Henderson state that it is an elevated atoll with original lagoonal summit depression preserved; some have speculated on the recency of its uplift. It appears, however, to be very similar to other makatea islands in the central and east Pacific, in which the main limestones are broadly of mid-Tertiary age and in which the topography results from post-uplift erosion. McNutt and Menard (1978) have suggested that many of these islands have resulted from crustal loading by an adjacent volcano, which in the case of Henderson would be Pitcairn. Pitcairn stands only 347 m above sea-level, but rises 3.5 km from the ocean floor. Two phases of surface vulcanism have been identified, with K-Ar ages of 0.46-0.63 and 0.76-0.93 million years (Duncan et al. 1974). The total span of volcanism for the whole Pitcairn cone must be much greater, however, and the crust on which it stands has an age of roughly 30 million years. McNutt and Menard (1978) calculate the amount of uplift of Henderson caused by the Pitcairn loading to be 32 m (compared with an actual uplift which they state to be 30 m); Oeno and Ducie are not uplifted, because the former is in Pitcairn's moat and the latter beyond the arch.

The location of Henderson along a prolongation of the Tuamotu-Gambier axis has already been mentioned. Basalts at Mururoa in the eastern Tuamotus have been dated at 6-8 million years at a depth of 438 m (Labeyrie et al. 1969). The surface volcanics of the Gambier Archipelago (maximum elevation 441 m) are also of similar age (4.77-5.98 m yr: Bellon 1974; 5.33-7.15 m yr: Brousse et al. 1972). These and the dates for Pitcairn suggest a volcanism migration rate of 11 cm/yr.

It seems likely that the limestones of which Henderson are composed are of late Tertiary age, and may have been exposed for a few million years. The 'lagoonal' topography may well be a karst erosion feature, and the columns and pinnacles within the depression also karst features rather than patch reefs. The low-lying areas surrounding the high core at least on the leeward side could (by comparison with makatea islands elsewhere) be a last interglacial reef.

Actual geological investigations of Henderson are limited to prospecting for phosphate deposits. The first such survey was carried out in 1881 by Grice, Summer and Co of Melbourne (then lessees of Malden); they found only 200 tons of guano. A permit to exploit was held by Capt J. Rasmussen during 1903-1907, but was not taken up. G. C. Ellis and J. T. Arundel of the Pacific Phosphate Company, aboard the *Tyrian*, made a brief survey in 1907. No useful deposits were found, but Hutchinson (1950, 213) quotes analyses of two samples with Ca_3P_2O contents of 8.5 and 18.0% respectively.

In 1908 a twelve-month license to prospect on Henderson, Oeno and Ducie was issued to James Banks and James Watt, who made a preliminary visit to the first of these (these details are derived from papers in the Ministry of Defence Hydrographic Department archives very kindly made available by Lt Cdr A. C. F. David to Dr W. R. P. Bourne, who drew them to our attention). A license for them to exploit guano was issued to them on 14 December 1909, to extend from 1 April 1912 to 31 March 1924, with the right to occupy the island, erect buildings, and to cut and use timber and other vegetable growth, and the obligation to plant quick-growing trees on two conspicuous points, and to erect a beacon 25 ft high. Banks visited Henderson in July 1912 at the time of the survey of the island by D. R. Tait and J. R. Jamieson. On 11 October 1912 the rights were transferred to a new company, Henderson Island Limited, under the chairmanship of Sir John Murray, and Banks became the Company's agent. During this survey a house and six sheds were built of corrugated iron to house the survey party. Tait's own report, dated 20 January 1913, in the Hydrographic Office archives, was extremely disappointing, and on 30 January Watt reported the Company's intention to give up the lease: 'the island was useless not only in regard to the supply of phosphates, but for any other purpose.' The lease was accordingly terminated, and the Company dissolved.

VEGETATION AND FLORA

What was evidently *Pandanus* was reported at Henderson by Munilla during the Quitós expedition in 1606, and again by Beechey in 1825. The first collections were made by Lay and Collie during the Beechey expedition: four species were reported from these collections by Hooker and Arnott (1841, 64-69) and three more by Hemsley (1885, 15). These were:

Asplenium nidus L. (in Hemsley 1885, 15)

Euphorbia sparrmannii Boiss. (as *E. ramosissima* Hooker and Arnott, the Henderson specimen being their type)

Glochidion pitcairnense (F.Br.) St. J. (as *Bradleia*? *glochidion* in Hooker and Arnott 1841, 69)

Tournefortia argentea L. (in Hemsley 1885, 15)

Canthium odoratum (Forst.f.) Seem. (as *Chiococca odorata* in Hooker and Arnott 1841, 65)

Guettarda speciosa L. (in Hemsley 1885, 15)

Ixora fragrans (Hooker and Arnott) Gray (as *Cephaelis*? *fragrans* in Hooker and Arnott 1841).

Since then, four major collections of plants have been made. First, D. R. Tait collected 91 numbers representing 55 species in August-

September 1912; the collection was determined by St John nearly fifty years later (St John and Philipson 1962). Second, E. H. Quayle and C. C. Curtis collected some twenty species, including four ferns, during the Whitney Expedition in 1922. This material was included in Brown's *Flora of Southeastern Polynesia* (Brown 1931, 1935; Brown and Brown 1935), where *Santalum hendersonense* was described as a Henderson endemic. Most of the Whitney collections were also cited by St John and Philipson (1962), though curiously these authors do not include the Whitney Expedition in their list of botanical collections. Third, large collections were made by St John and Fosberg during the Mangarevan Expedition in 1934, and published both in numerous systematic papers and as a comprehensive listing by St John and Philipson (1962). Finally, W. H. Lintott collected 25 species in 1957, and these too were reported by St John and Philipson (1962). St John and Philipson mention that J. H. Maiden collected 'a few common species', said to be reported in his 1896 paper on Pitcairn, but this paper does not in fact mention Henderson plants.

The flora listed by St John and Philipson (1962) includes 8 ferns and 55 angiosperms; to these should be added *Sesuvium portulacastrum* L., and *Capparis sandwichiana* DC. collected during the Whitney Expedition and by Lintott, and inadvertently omitted from their list. The plants are listed with some revision of nomenclature in Appendix 1. In addition to the main listings by Brown (1931, 1935), Brown and Brown (1935), and St John and Philipson (1962), Henderson plants collected by the Mangarevan Expedition have been included in many systematic papers, notably by Copeland (1938), five species of ferns; Skottsberg (1937), two species of Liliaceae; von Poellnitz (1936), *Portulaca*; Skottsberg (1938), *Santalum*; Heimerl (1937), *Peperomia*; and Sherff (1937), *Bidens*. It is of interest that no less than eight species, or 12 per cent of the recorded flora, have only been collected on one occasion, by D. R. Tait in 1912.

Six species and five varieties of angiosperms are described as endemic to Henderson, not including the new variety of *Korthalsella margaretae* defined by Brown (1935) but reduced to *K. vitiensis* by St John and Philipson (1962, 180), or the new variety *Polypodium europhyllum* C. Chr. var. *hendersonianum* E. Br. (in Brown and Brown 1931) which they reduce to *Microsorium vitiense* (Baker) Copeland. The endemic species and varieties presently accepted are:

Peperomia hendersonensis Yuncker (in Yuncker 1937, 16-17)

Celtis paniculata Planch. var. *viridis* F. Br. (in Brown 1935, 32)

Santalum hendersonense F. Br. (in Brown 1935, 66)

Myrsine hosakae St John (in St John and Philipson 1962, 189-190)

Nesoluma st-johnianum H. J. Lam and Meeuse (in Lam and Meeuse 1938, 153-154)

Geniostoma hendersonense St John (in St John and Philipson 1962, 190)

Heliotropium anomalum Hooker and Arnott var. candidum St John (in St John and Philipson 1962, 192)

Canthium barbatum (Forst. f.) Seem. var. christianii Fosb. forma calcicola Fosb. (in Fosberg 1937)

Bidens hendersonensis Sherff (in Sherff 1937, 6)
var. hendersonensis Sherff (in Sherff 1937, 6)
var. subspathulata Sherff (in Sherff 1937, 7)

Comments on some of these species are given in Appendix 1. Other taxa originally defined from Henderson Island material, but not endemic to the island, include Euphorbia ramosissima Hooker and Arnott (= E. sparrmannii Boiss. in Appendix 1), Cassia glanduligera St John (in St John and Philipson 1962, 181-184), also in the Australs; and Dianella intermedia Endl. var. gambierensis F. Br. (in Brown 1931, 152), also on Mangareva.

Four adventive species are listed:

Cocos nucifera. This is recorded as being planted as early as 1843 by the Pitcairn Islanders (Brodie 1851, 17). Trees were found by Stephen in 1907 (North 1908), by Bank (1909) (a dozen trees divided between the north and west landings), and by Tait (1912). Collected by the Mangarevan Expedition in 1934, when Fosberg noted that the trees were 'all young'. Probably repeatedly planted by the Pitcairn Islanders over the years.

Cordyline terminalis, collected only by the Mangarevan Expedition in 1934, when Fosberg noted half a dozen plants.

Aleurites moluccana, collected only by the Whitney Expedition in 1922.

Achyranthes aspera, collected only by Tait in 1912, and the only one of the four not a deliberate introduction.

In addition James Bank in his report of 5 January 1909 records planting limes and oranges, and these are mentioned, together with potatoes, by Maude (1951, 63).

Besides the vascular plants, the Mangarevan Expedition also collected three species of Fungi, five lichens and ten bryophytes, all listed by St John and Philipson (1962). An earlier list of the bryophytes was given by Bartram (1940).

MAMMALS

There are no native mammals on Henderson. Several have, however, been landed since the island was discovered. Goats were first taken to Henderson from Pitcairn in 1843, but through inadvertence were not landed before the vessel left (Brodie 1851, 17). Three were, however, released during the visit of the Whitney Expedition in 1923 (Beck 1923), but had disappeared by the time of the Mangarevan Expedition in 1934.

Pigs were landed by D. R. Tait in 1912, but of these there is no subsequent record. Mice are mentioned as being numerous at the north landing by James Bank (1909), but are not otherwise recorded. The only numerous introduced mammal is the Polynesian Rat. King (1820) found it there in 1819. Bank mentioned it as numerous at the north landing in 1909, and Stephen had also found it present in 1907 (North 1908). Specimens were collected by the Whitney Expedition and listed under *Rattus exulans* (Peale) by Tate (1935).

BIRDS

The Quirós expedition recorded seabirds in the neighbourhood of Henderson - Gaspar de Leza specifies 'grey gulls and terns' - in January 1606. Much later, in 1819, King (1820) recorded a parrot and a few pigeons, and later in the same year the castaways from the *Essex* recorded tropicbirds in holes, with young and eggs, and also 'small birds, about the size of a blackbird', roosting in the trees (Gibbings, ed. 1935, 55, 79).

The first collections of birds, however, were made by A. E. Stephen in 1907, and the specimens described by North (1908). D. R. Tait and J. R. Jamieson also made collections in 1912, and these were reported by Ogilvie-Grant (1913a, 1913b). The major contribution to the ornithology of Henderson was, however, the Whitney Expedition in 1922, which resulted in a long series of papers referred to below. Subsequently, W. H. Lintott made some observations in 1957, and these were incorporated in Williams's (1960) paper on the birds of Pitcairn.

A comprehensive summary of knowledge of the birds of Henderson is in preparation by Bourne and David. This section therefore simply keys the published literature on the seabirds, shorebirds and land birds, and the manuscript records by Beck and Quayle of the Whitney Expedition. Nomenclature follows that of du Pont (1976) who listed most or all of the birds known from the island.

Seabirds

Pterodroma ultima Murphy	Murphy's Petrel, Oeno Petrel

Recorded by du Pont (1976).

Pterodroma neglecta (Schlegel)	Kermadec Petrel

Collected by Beck and Quayle in 1922.

Recorded by Murphy and Pennoyer (1952, 27); as breeding by Williams (1960). *P. ultima* and *P. neglecta* are regarded as distinct by Williams and du Pont (1976) and both recorded by them for Henderson.

Pterodroma alba (Gmelin)	Phoenix Petrel

Collected by Quayle and Beck in 1922, called Henderson Petrel.

Recorded by Murphy and Pennoyer (1952,33); and as breeding by Williams (1960) and King (1967).

Pterodroma arminjoniana heraldica (Salvin) Herald Petrel

Recorded by Murphy and Pennoyer (1952, 39); and as breeding by Williams (1960) and King (1967).

Puffinus nativitatis Streets Christmas Shearwater

Shearwaters of undetermined species were recorded as 'very plentiful' by Stephen in 1907 (North 1908). This species recorded as probably breeding by Williams (1960) and King (1967). Apparently not collected on Henderson by the Whitney Expedition in 1922.

Puffinus pacificus pacificus (Gmelin) Wedge-tailed Shearwater

Collected by Beck in 1922.

Recorded as breeding by Murphy (1951) and Williams (1960).

Gygis alba candida (Gmelin) White Tern

Noted as 'plentiful' and egg reported by Stephen in 1907 (North 1908). Recorded as G. candida (Gmelin) by Ogilvie-Grant (1913a, 1913b). Collected and noted as a white-footed form by Quayle and Beck in 1922. Recorded as breeding by Williams (1960).

Anous stolidus pileatus (Scopoli) Common Noddy

Noted as 'not so plentiful' by Stephen in 1907 (North 1908). Recorded as A. leucocapillus (Gould) by Ogilvie-Grant (1913a, 1913b). Collected by Beck and Quayle but not common in 1922. Recorded as breeding by Williams (1960) and Baker (1951).

Anous tenuirostris minutus Boie Black Noddy

Rare, one collected by Beck or Quayle in 1922.

Procelsterna coerulea skottsbergii Bonaparte Blue-grey Noddy,
Grey Ternlet

Seen and collected by Beck and Quayle in 1922, not common. Recorded as P. coerulea (Bennett) by Ogilvie-Grant (1913a, 1913b) and as P. c. skottsbergii in Peters (1934). Recorded as breeding by Williams (1960).

Phaethon rubricauda subsp. (Gmelin) Red-tailed Tropicbird

Recorded as breeding by Beck in 1922, and Williams (1960), based on local reports.

Sula dactylatra personata Gould Masked Booby

One individual collected by Quayle in 1922. Recorded as common, with chicks, in January 1957, by Lintott (Williams 1960).

Sula leucogaster plotus (Forster) Brown Booby

Sight record in 1957 recorded by Williams (1960).

Sula sula rubripes Gould Red-footed Booby

Recorded by Ogilvie-Grant (1913a, 1913b) (as *S. piscator*) and by Murphy (1936); noted as probably breeding by Williams (1960). Henderson specimens were included by Grant and Mackworth-Praed (1933, 118) under their new species *S. nicolli*, but this is now regarded as a colour phase of *S. sula*.

Fregata minor subsp. (Gmelin) Greater Frigatebird

Described as 'numerous' by Stephen in 1907 (North 1908). Seen and collected by Beck and Quayle in 1922. Recorded as probably breeding by Williams (1960), based on local information.

Shorebirds

Numenius tahitiensis (Gmelin) Bristle-thighed Curlew

Summer migrant, collected by Quayle and Beck in March-April 1922 (Stickney 1943).

Heteroscelus incanus incanus (Gmelin) American Wandering Tatler

Summer migrant, recorded in March-April 1922 (Stickney 1943).

Calidris alba (Pallas) Sanderling

Recorded by Stephen in 1907 (Ogilvie-Grant 1913a, 1913b); seen but not collected by Quayle in 1922.

Wading birds

Egretta sacra sacra Gmelin Reef Heron

One individual seen by Beck and Quayle in 1922.

Land birds

Porzana atra North Henderson Island Rail, Henderson Island Crake

Collected by Stephen in 1907, who noted it as 'plentiful', and described as *Porzana atra* n.sp. Black Water Crake by North (1908). Collected by Tait in 1912 and independently described by *Porzana murrayi* n.sp. by Ogilvie-Grant (1913a), a name abandoned by Ogilvie-Grant (1913b). Recollected in 1922 by Quayle and Beck of the Whitney Expedition and assigned to a new endemic genus as *Nesophylax ater* (North) by Murphy (1924). Described under North's name, with a colour plate, by Ripley (1977, 235, plate 29), without reference to Murphy (1924). Listed as breeding by Williams (1960).

The widespread and closely related *Porzana t. tabuensis* Spotless Crake occurs on nearby Oeno (Murphy 1924, Amadon 1942, Williams 1960).

Ptilinopus purpuratus insularis (North) Henderson Island Fruit Pigeon

Described in flocks of twenty or more by Stephen in 1907, and named as *Ptilopus insularis* n.sp. by North (1908). Collected by Tait in 1912 and described as *Ptilopus coralensis* Peale by Ogilvie-Grant (1913a). Listed as *Ptilopus insularis* North by Ogilvie-Grant (1913b). The Whitney collections in 1922 were listed under the same name by Murphy (1924). Named as an endemic subspecies of *Ptilinopus purpuratus* (Gmelin), widely distributed in the Societies and the Tuamotus, by Ripley and Burckhead (1942). Listed as still common and breeding by Williams (1960).

Vini stepheni (North) Henderson Island Parrot

Noted as 'not very plentiful' by Stephen in 1907, and described as *Calliptilus*(?) *stepheni* n.sp. by North (1908). Collected by Tait in 1912 and described as *Vini hendersoni* n.sp. by Ogilvie-Grant (1913a). Named as *Vini stepheni* (North), with a colour plate, in Ogilvie-Grant (1913b). Collected by Beck and Quayle of the Whitney Expedition in 1922 and said to be common; and listed by Amadon (1942). Listed as breeding but apparently not very common by Williams (1960). An endemic species.

Acrocephalus vaughani taiti (Ogilvie-Grant) Henderson Island Warbler

Collected by Tait in 1912 and named *Acrocephalus taiti* n.sp. by Ogilvie-Grant (1913a, 1913b). Collected by Quayle and Beck of the Whitney Expedition in 1922, said to be very common; and listed as *Conopoderas vaughani taiti* (Ogilvie-Grant) by Murphy and Mathews (1929). Listed as breeding by Williams (1960), who also notes the presence of *A. v. vaughani* (Sharpe) on Pitcairn. An endemic subspecies.

REPTILES

Lizards were apparently first observed by Stephen in 1907, when he found them 'very plentiful' (North 1908). Six skinks were collected by the Whitney Expedition in 1923 and listed by Ortenburger (1923) and later by Burt and Burt (1932) as *Emoia cyanura* (Lesson), a widespread species. A gecko has been seen but we do not know of specimens or an identification. The green sea turtle, *Chelone mydas* (L.), comes ashore to lay its eggs on the few beaches (Quayle 1922).

TERRESTRIAL ARTHROPODA

No special effort has ever been made to collect any of the Henderson Island arthropods, except the insects, which were gathered by Zimmerman in 1934. Even this can only be regarded as preliminary, being the results of one man's work for only six days. A longer, less hurried effort, with light traps, Berlese funnels and other special methods, could be expected to yield a tremendous increase in the known invertebrate fauna of the island.

A discussion written by Dr. Frank G. Howarth, of B. P. Bishop Museum, Honolulu, states the case very well:

"The [terrestrial] arthropod fauna of Henderson I. is still quite poorly known. Only about [40] species have been recorded to date, of which about [a third] are likely endemics. Judging from the recorded lushness and diversity of the flora, the insect fauna should be at least an order of magnitude greater. Zimmerman (1935) wrote that a number of endemic species were collected during the week's stay of the Mangarevan Expedition. Apparently, only a few taxonomic groups have been worked up from those collections, as only 15 families of arthropods are represented in the published records. Based on the known faunas of other small Pacific islands, one would expect to find at least 100 families and a total arthropod fauna of a few hundred species of which approximately 50% would be endemic to Henderson or perhaps also to Pitcairn I. For example, there are apparently no published records of Lepidoptera (moths), which is second only to the Coleoptera in numbers of species on other Pacific islands. Neither are there any records for Collembola, Orthoptera, Myriapoda, or native Hymenoptera, all of which should be expected there.

"Many insects and relatives are probably endemic to the Pitcairn Group. As the fauna and flora on the inhabited island of Pitcairn itself become more ravaged by goats and other man-caused perturbations, Henderson Island will become more important as a refuge or Noah's Ark for many of these restricted species.

"A number of special habitats, which undoubtably occur there, have not been faunistically surveyed. For example, being a raised coralline island a subterranean fauna should exist there, of which the aquatic or 'anchialine' underground fauna should be especially well developed with many native species. A significant terrestrial cave fauna may also have evolved there.

"Distant described 3 new species of Issidae in 1913, and none of these species have been subsequently reported on again. Their status may be problematical. Fennah, 1958, reviewed the fulgorid fauna of SE Polynesia but apparently missed Distant's 1913 paper (!). Fennah described a 4th Issidae as an endemic subspecies with the type subspecies endemic to Pitcairn I. Zimmerman collected a nice series of *Catacanthus taiti* on the Mangarevan Expedition. The species is still known only from Henderson (based on our collections). Related species occur in the Society and Marquesas Is., and based on the impressive, conspicuous size and color of *C. taiti*, the fact that it hasn't been found elsewhere, suggests that it is endemic. Both *Coleotichus* and *Ugyops* have many native restricted species in the Pacific, thus, it is probable that these unidentified specimens represent at least native species, and may be endemic. The weevils are among the best known groups of arthropods in the Pacific; therefore the 2 listed species are undoubtedly endemic and are of special interest to biogeographers, evolutionists, ecologists and others.

"Based on the above lack of entomological data and the possibility of environmental disturbance, if not by the current venture then by some fool liberating goats or the like, I think it is abundantly clear that we should attempt to launch or assist in a modern entomological/ecological expedition to this island to fill this critical lacuna. Of equal import to science is the predictable occurrence of excellently preserved and highly significant paleontological material in the limestone sinkholes."

Insecta

Stephen found a butterfly abundant in 1907 (North 1908), and Tait states that he sent insects to the British Museum (Natural History) in 1912, but of these we have found only a few published records (Distant 1913). Otherwise most of the insect records published for Henderson are of collections made by Zimmerman on the Mangarevan Expedition in 1934. According to Frank J. Radovsky (in litt.) there are at least 33 species of insects recorded from the island, of which 11 (acc. Frank G. Howarth in litt.) are, so far as known, endemic. We are only able to give a partial list of these, with sources.

Thysanoptera

Thrips albipes Bagnall (in Moulton 1939).

Rhynchota

Atylana parmula thalna Fennah (1958). Endemic.

Catacanthus taiti Distant (1913). Endemic.

Coleotichus sp. (Distant 1913). Possibly endemic.

Devagama fasciata Distant (1913). Endemic.

Devagama insularis Distant (1913). Endemic.

Devagama maculata Distant (1913). Endemic.

Lallemandana insignis insignis (Distant) (Hamilton 1980). Endemic.

Peregrinus maidis Ashmead (Fennah 1958).

Ugyops sp. (Fennah 1958). Possibly endemic.

Coleoptera

Hypothenemus eopolyphagus Beeson (1940).

Microcryptorhynchus orientissimus Zimmerman (1936). Endemic.

Nesonos brunneus Zimmerman (1938).

Notioxenus cylindricus Jordan (Zimmerman 1938).

Rhyncogonus hendersoni Van Dyke (1937). Endemic.

Stephanoderes pacificus Beeson (1940).

Stephanoderes vafer Blandford (Beeson 1940).

Hymenoptera

Cardiocondyla nuda Mayr subsp. *nereis* Wheeler (1936).

Monomorium floricola (Jordan)(Wheeler 1936).

Tapinoma melanocephalum (Fabr.) var. *australe* Santschi (Wheeler 1936).

Technomyrmex albipes (F. Smith) (Wheeler 1936).

Tetramorium guineense (Fabr.)(Wheeler 1936).

Nylanderia vaga Forel var. *crassipilis* Santschi (Wheeler 1936).

Diptera

Dacus setinervis Malloch 1938 (Drew 1975).

Arachnida

Three species of spiders collected by the Mangarevan Expedition are listed for Henderson by Berland (1942):

Thorellia ensifera (Thorell)

Theridion paumotui Berland

Cyrtophora moluccensis Doleschall.

Crustacea

No land crabs have been recorded from Henderson. A very large cenobite, perhaps *Birgus*, was captured by a member of the party in 1934, but the specimen may not have been saved. Four species of terrestrial isopods, none of them endemic, are recorded from Mangarevan Expedition collections by Jackson (1938). They are *Philoscia truncata* Dollfus, *P. fasciata* Jackson, *Spherillo montivagus* Budde-Lund, and *S. marquesarum* Jackson.

LAND MOLLUSCA

Land Mollusca were collected by C. Montague Cooke, Jr., during the Mangarevan Expedition. One species was previously recorded, but at least 12-15 additional species were found (Cooke 1934, 44). Cooke and Kondo (1960, 256) estimated the fauna at 18 species. The following records have been published:

Achatinellidae

Tornatellides (Tornatellides) oblongus parvulus n. subsp. (in Cooke and Kondo 1960, 255), endemic subspecies.

Tubuaia hendersoni n.sp. (in Kondo 1962, 36-38), endemic species.

Endodontidae

Minidonta hendersoni n.sp. (in Solem 1976), endemic species.

Helicarionidae

Diastole (Diastole) glaucina Baker (in Baker 1938, 50), endemic species.

Helicinidae

Orobophana solidula (Gray) (in Cooke and Kondo 1960, 255).

In addition, Cooke and Kondo (1960, 256) mention specimens from Henderson in the following genera: Elasmias, Lamellidea and Tornatellinops (Achatinellidae); Syncera (= Assiminea) (Assimineidae); Melampus (Ellobiidae); Georissa (Hydrocenidae); Nesopupa and Pupisoma (Pupillidae); and Thaumatodon.

MARINE FAUNA

As mentioned above, the schooner Westward made only brief stops at Henderson Island on her trip from Pitcairn to Ducie Atoll and back. Actually only one full day and two afternoons were spent there, and the only extensive collection made was of mollusks.

Fishes

The diving group spent their time searching for and collecting fishes and checking for the presence of Acanthaster planci (Linnaeus), the Crown-of-Thorns. J. E. Randall (pers. comm.) received the impression during the diving operations that the fauna was richer than that of Ducie (Rehder and Randall, 1975, 21-26). He has made no list of species collected and seen, feeling that such a list would be without value considering the shortness of the stay at the island.

Mollusks

See Appendix 2.

Other Invertebrates

No material other than mollusks were collected during the Westward visit, in large measure due to the absence of Dennis M. Devaney during this segment of the trip. One noteworthy comment is that no specimens of *Acanthaster planci* were seen by the divers despite the fact that one of the programs carried out on the Westward was a survey of the presence of the Crown-of-Thorns in southeastern Polynesia. Beechey (1833, 49) mentions the presence of 'numerous *echini*' on the reef flat, probably *Diadema savignyi* Michelin or *D. setosum* (Leske), as he comments on their capability of inflicting 'painful wounds.'

Beechey also mentions seeing some 'cray-fish' in the cavities on the reef (*Panulirus* species).

SCIENTIFIC IMPORTANCE AND CONSERVATION

Access to Pitcairn Island (and thus to other islands of the group) requires a license issued by the Office of the Commissioner for Pitcairn, issued by the Governor after the visit has been approved by the Pitcairn Island Council; casual visitors may land at the discretion of the Island Magistrate. There are no conservation measures applicable to Pitcairn or to its associated islands. In 1969 Henderson, Ducie and Oeno were all included in a list of Pacific islands proposed for international scientific supervision, possibly under the proposed 'Islands for Science' Convention (Douglas 1969, 463). No action was taken on this proposal.

In 1982 it became known that proposals had been made to the British Government by a wealthy American citizen, who wished to take up residence on Henderson in exchange for development assistance on Pitcairn. This proposal, when it became known, led to considerable concern in the scientific community, which was openly voiced at the XVth Pacific Science Congress in Dunedin, New Zealand. Appendix 3 gives the text of a resolution on Henderson Island adopted at this Congress.

There has been a growing interest in island biology, first taking on a scientific character with the work of Charles Darwin, but in the last few decades receiving greater and greater scientific attention. One of the preoccupations of this interest has been to determine what the conditions were on different types of islands before humans and especially before Europeans arrived and brought about drastic changes in the nature and functioning of these ecosystems. Very inadequate historical evidence exists, and for most islands none at all. In Henderson we have, preserved, a fine example of one of the most interesting types of island. It has the advantages of being small and remote, and of having a simple enough biota that its relationships, processes and functioning may possibly be understood with adequate investigation.

It is certain that undescribed species exist, especially of smaller and less conspicuous animals. It is equally certain that many of the species inhabiting the island, known or unknown, are threatened by the proposed disturbances, and will immediately become endangered if the development project is carried forward. The amount of attention being given to endangered species at present indicates that, whether for philosophic or practical reasons, a real value is attached to our co-inhabitants of the globe by the better elements of our Western culture. This should not lightly be brushed aside.

The study of islands as microcosms of more complex ecosystems has the practical significance of enabling us to gain some insight into the functioning of the larger and infinitely more complex ecosystems in which the majority of humanity live. Hence it would seem folly to permit the destruction of the only remaining intact example of one of the most important classes of islands that could form an important component of this study. Even its very scarcity or uniqueness would seem to enhance its value, as it does with so many other, mostly less important things.

ACKNOWLEDGEMENTS

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Note

While the present report was being assembled, other naturalists expressed their concern for the future of Henderson Island natural ecosystems in the following report:

Serpell, J., Collard, N., Davis, S. and Wells, S. 1983.
Submission to the Foreign and Commonwealth Office on the future conservation of Henderson Island in the Pitcairn Group. London: World Wildlife Fund-UK, International Union for Conservation of Nature and Natural Resources, and International Council for Bird Preservation. 26 pp.

The need for more adequate knowledge of the biota and ecology of Henderson Island is of such urgency that the Smithsonian Institution, in cooperation with the Royal Society, is actively planning a biological and geomorphological survey of the island, to take place during 1984 if the necessary permits can be secured and funds can be raised.

Appendix 1. A revised list of the vascular plants of Henderson Island.

No additional collections have come to our attention since the account of the flora by St John and Philipson (1962) was published, but much work has been done on the Pacific flora since then, and some names have been changed. Two species collected by Lintott were inadvertently omitted by St John and Philipson. Also our concepts of some taxa differ from those of the authors of that account. Such revisions and changes are presented, with a few explanatory remarks and comments, in the following list.

Asplenium lobulatum Mett.

Asplenium nidus L.

Asplenium obtusatum Forst.f.

Davallia solida (Forst.f.) Sw.

Nephrolepis biserrata (Sw.) Schott

Nephrolepis exaltata (L.) Schott

Perhaps an alternative identification of the preceding.

Cyclophorus blepharolepis C. Chr.

Polypodium vitiense Baker

Microsorium vitiense (Baker) C. Chr.

Polypodium euryphyllum var. *hendersonianum* E. Br.

We do not see much to be gained from extreme segregation of the genus *Polypodium*.

Polypodium scolopendria Burm.f.

Phymatodes scolopendria (Burm.f.) Ching

Pandanus tectorius Parkinson

Pandanus sp. of St John and Philipson (1962)

Lepturus repens (Forst.f.) R. Br.

Thuarea involuta (Forst.f.) R. and S.

Henderson is the eastern extreme of this widespread Indo-Pacific beach grass.

Fimbristylis cymosa R. Br. (s.l.)

Fimbrystylis sp. of St John and Philipson (1962)

*Cocos nucifera L.

A few trees, originally planted.

*Cordyline fruticosa (L.) Chev.

Cordyline terminalis (L.) Kunth

(Cordyline fruticosa Goepp.) (nom. nud.)

This has frequently been called C. terminalis under the assumption that C. fruticosa (L.) Chev. is an illegitimate later homonym of C. fruticosa Goepp., but that was based only on a reference to a name Dracaena fruticosa H. Berol. that was apparently never published.

Dianella intermedia var. gambierensis F. Br.

Peperomia hendersonensis Yuncker

Endemic to Henderson.

Celtis paniculata var. viridis F. Br.

Procris pedunculata (Forst.) Wedd.

Korthalsella rubescens (v. Tiegh.) Lecomte

Korthalsella vitiensis (v. Tiegh.) Engler

Santalum hendersonense F. Br.

Endemic to Henderson.

*Achyranthes aspera var. pubescens (Moq.) Townsend

From the brief descriptive remarks by St John and Philipson (1962) this seems to be the widespread var. pubescens (Moq.) as defined by Townsend, Kew Bull. 29 (1974), 473.

Boerhavia tetrandra Forst.f.

Boerhavia diffusa var. tetrandra (Forst.f.) Heimerl

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*Species thus marked are introduced.

Pisonia grandis R. Br.

Portulaca lutea Sol. ex Forst.f.

Sesuvium portulacastrum L.

Represented by _Lintott H 22_ (CHR), not listed by St John and Philipson (1962).

Cassytha filiformis L.

Hernandia sonora L.

Capparis sandwichiana DC.

Represented by _Lintott H 24_ (CHR), not listed by St John and Philipson (1962).

Lepidium bidentatum Mont.

Pittosporum arborescens Rich. ex Gray

Caesalpinia bonduc (L.) Roxb.

Cassia glanduligera St John

Close to and formerly considered identical with _C. gaudichaudii_ H. and A., of Hawaii. _C. glanduligera_ is also known from the Austral Islands.

Sesbania coccinea (L.f.) Poir.

Sesbania speciosa (Soland.) R. Br. var. _tuamotuensis_ R. Br.

Sesbania atollensis St John

The specimen, _Lintott H 1_ (CHR) on which the Henderson Island record of _Sesbania atollensis_ St John is based could not be located at Christchurch in 1983 according to Miss B. M. Macmillan (pers. comm.).

Suriana maritima L.

*_Aleurites moluccana_ (L.) Willd.

Euphorbia sparrmannii Boiss.

Euphorbia ramosissima H. and A. (non Loisel.)

Glochidion pitcairnense (F. Br.) St John

Glochidion tahitense var. _pitcairnense_ F. Br.

Endemic to Henderson and Pitcairn Islands.

Triumfetta procumbens Forst.f.

Thespesia populnea (L.) Sol. ex Correa

Xylosma suaveolens subsp. *haroldii* Sleumer

Pemphis acidula Forst.

Eugenia rariflora Benth.

Meryta brachypoda Harms

Endemic to Henderson and the Austral Islands.

Myrsine hosakae St John

Endemic to Henderson; tree 7 m tall.

Nesoluma st-johnianum Lam and Meeuse

Endemic to Henderson.

Geniostoma hendersonense St John

Tree 3-8 m tall; endemic to Henderson. Beechey's (1825, 63-64) 'species of budleia'.

Jasminum didymum Forst.f.

St. John (1940) suggests that Cuming's "Jessamine" may be this, but does not include it in the 1962 paper. We have no definite record based on a specimen. No complete list of Cuming's "Elizabeth Island" plants has come to our attention.

Alyxia stellata (Forst.) R. and S.

Ipomoea macrantha R. and S.

Ipomoea grandiflora sensu F. Br. non (Choisy) Hallier

Ipomoea glaberrima Bojer

Cordia subcordata Lam.

Heliotropium anomalum var. *candidum* St John

Endemic to Henderson.

Tournefortia argentea L.f.

Messerschmidia argentea (L.f.) I. M. Johnst.

Argusia argentea (L.f.) Heine

This seems merely to be a *Tournefortia* adapted to saline strand habitats rather than related to *Argusia*.

Premna obtusifolia R. Br.

Premna integrifolia L.

Lycium carolinense var. *sandwicense* (A. Gray) Hitch.

Lycium sandwicense A. Gray

There seem to be almost no differences between the Central Pacific strand *Lycium* and its relative on both coasts of southern North America.

Canthium barbatum f. *calcicola* Fosb.

Canthium odoratum (Forst.f.) Seem.

Guettarda speciosa L.

Ixora fragrans (H. and A.) A. Gray

Cephaelis fragrans H. and A.

Morinda umbellata var. *forsteri* (Seem.) Fosb.

Timonius polygama (Forst.) Robins.

Scaevola sericea var. *tuamotuensis* (St John) Fosb.

Bidens hendersonensis Sherff var. *hendersonensis* Sherff

Perhaps the only species of *Bidens* that reaches tree size. Endemic to Henderson.

Bidens hendersonensis Sherff var. *subspathulata* Sherff

Endemic to Henderson, if indeed distinct from var. *hendersonensis*.

Fitchia nutans Hook.f.

Not found on Henderson since the original collection by Hugh Cuming, which is suspected to have actually come from Tahiti. The labels of some of Cuming's collections are known to have been mixed.

Senecio stokesii F. Br.

Appendix 2. A revised list of the marine mollusks of Henderson Island by Harald A. Rehder.

In 1913 a list of marine mollusks collected at Henderson Island was published by E. A. Smith (1913). This collection was made by J. R. Jamieson and D. R. Tait during their stay on the island while carrying out a survey of the phosphate deposits. Before this list the only species known from this island were those described by Broderip and Sowerby from specimens collected here by Hugh Cuming and possibly also by Beechey.

In January 1971 I spent parts of two days on the island making collections on the reef flat at the large beach on the north coast and also on the adjoining cliffs.

In the following list those species collected by me and not appearing in the 1913 paper by Smith are marked with an asterisk*. The names in Smith's publication, when different, are cited under the presently accepted name.

Haliotis pulcherrima Gmelin, 1791

Patelloida conoidalis (Pease, 1868)

Acmaea conoidalis Pease

Patella flexuosa Quoy and Gaimard, 1834

Patella stellaeformis Reeve, 1842

Broderipia iridescens (Broderip, 1834)

An examination of a large number of specimens of this genus leads me to believe that *Broderipia rosea* (Broderip, 1834) and *B. subiridescens* Pilsbry, 1890, represent growth stages of *iridescens*.

Pseudostomatella (*Stomatolina*) *speciosa* (A. Adams, 1850)

Stomatella speciosa A. Adams

Cantharidus marmoreus (Pease, 1867)

Calliostoma roseopictum E. A. Smith, 1913

Turbo petholatus Linnaeus, 1758

Turbo argyrostomus Linnaeus, 1758

Nerita morio (Sowerby, 1833)

Nerita melanotragus Smith, 1884

In my Ducie report (Rehder and Randall, 1975, 29) I erroneously reported this species as *Nerita haneti* Recluz, 1841.

Nerita plicata Linnaeus, 1758

- _Littorina coccinea_ (Gmelin, 1791)
  - _Littorina obesa_ Sowerby, 1832
- _Nodilittorina pyramidalis pascua_ Rosewater, 1970
  - _Littorina trochoides_ Gray, 1839
- _Royella sinon_ (Bayle, 1880)
- _Rhinoclavis sinensis_ (Gmelin, 1791)
- _Cerithium rubus_ Deshayes, 1843
  - _Cerithium tuberculiferum_ Pease, 1869
- _Cerithium atromarginatum_ Bavay and Dautzenberg
  - _Cerithium nassoide_ Sowerby, 1855
- _Cerithium egenum_ Gould, 1849
  - _Cerithium rarimaculatum_ Sowerby, 1855
- *_Dendropoma maximum_ (Sowerby, 1825)
- _Epitonium torquatum_ (Fenaux, 1943)
  - _Epitonium perplexum_ (Pease, 1868)

    For a discussion of this identification see my report on the marine mollusks of Easter Island (Rehder, 1980, 52).
- _Ianthina ianthina_ (Linnaeus, 1758)
  - _Ianthina communis_ (Lamarck, 1822)
- _Vanikoro plicata_ (Recluz, 1844)
- _Strombus mutabilis_ Swainson, 1821
- *_Lambis truncata_ (Lightfoot, 1782)
- *_Lambis_ (_Harpago_) _rugosa_ (Sowerby, 1842)
- _Polinices_ (_Mamilla_) _simiae_ (Deshayes, 1838)
  - _Mamilla simiae_ Deshayes
- _Natica gualteriana_ Recluz, 1844
  - _Natica dillwyni_ Payraudeau, 1826
- _Cypraea cumingi_ Gray, 1832
- _Cypraea irrorata_ Gray, 1828
- _Cypraea goodalli_ Gray, 1832
- _Cypraea fimbriata_ Gmelin, 1791
  - _Cypraea minoridens_
- _Cypraea childreni_ Gray, 1825
- _Cypraea cicercula_ Linnaeus, 1758
- _Cypraea dillwyni_ Schilder, 1922
  - _Cypraea margarita_ Gray, 1828, not Dillwyn, 1817

- _Cypraea_ _helvola_ Linnaeus, 1758
- _Cypraea_ _poraria_ Linnaeus, 1758
- _Cypraea_ _caputserpentis_ Linnaeus, 1758
- *_Cypraea_ _maculifera_ Schilder, 1932
- _Cypraea_ _subteres_ Weinkauff, 1881
- _Cypraea_ _scurra_ Gmelin, 1791
- _Cypraea_ _isabella_ Linnaeus, 1758
- *_Cypraea_ _mappa_ Linnaeus, 1758
- _Cypraea_ _schilderorum_ (Iredale, 1939)
  - _Cypraea_ _arenosa_ Gray, 1824
- *_Cypraea_ _ventriculus_ Lamarck, 1810
- _Trivia_ _edgari_ Shaw, 1909
  - _Trivia_ _oryza_ Lamarck, 1810
- _Casmaria_ _erinacea_ (Linnaeus, 1758)
  - _Cassis_ (_Casmaria_) _vibex_ (Linnaeus, 1758)
- _Morum_ _ponderosum_ (Hanley, 1858)
- _Bursa_ (_Colubrellina_) _granularis_ (Röding, 1798)
  - _Bursa_ (_Colubrellina_) _affinis_ (Broderip, 1833)
- _Maculotriton_ _serrialis_ (Laborde, 1838)
  - _Maculotriton_ _bracteatus_ (Hinds, 1844) var.
- _Phyllocoma_ _convoluta_ (Broderip, 1833)
  - _Bursa_ (_Craspedotriton_) _convoluta_ (Broderip)
- _Drupa_ _morum_ Röding, 1798
  - _Drupa_ _horrida_ (Lamarck, 1816)
- _Drupa_ _clathrata_ (Lamarck, 1816)
- *_Drupa_ _elegans_ (Broderip and Sowerby, 1829)
- _Drupa_ _ricinus_ (Linnaeus, 1758)
- *_Drupa_ (_Drupina_) _grossularia_ Röding, 1798
- _Morula_ _uva_ (Röding, 1798)
  - _Drupa_ _morus_ (Lamarck, 1822)
- _Morula_ _granulata_ (Duclos, 1832)
  - _Drupa_ _tuberculata_ (Blainville, 1832) var.
- _Morula_ _dealbata_ (Reeve, 1846)
- _Thais_ (_Thalessa_) _intermedia_ (Kiener, 1835)
- *_Thais_ (_Thalessa_) _affinis_ (Reeve, 1846)

Nassa sertum (Bruguière, 1789)

Iopas sertum (Bruguière)

Vexilla vexillum (Gmelin, 1791)

Vexillum vexillum (Chemnitz, 1788)

Vexillum taeniata (Powis, 1836)

Quoyula monodonta (Blainville, 1832)

Quoyula madreporarum (Sowerby, 1834)

Euplica palumbina (Gould, 1845)

Columbella turturina sensu Smith, 1913, not Lamarck, 1822

Euplica varians (Sowerby, 1832)

Columbella varians Sowerby

Pyrene obtusa (Sowerby, 1832)

Columbella obtusa Sowerby

Engina fuscolineata E. A. Smith, 1913

Engina rosacea (E. A. Smith, 1913)

Tritonidea rosacea E. A. Smith

Tritonidea difficilis E. A. Smith, 1913

Without an examination of the holotypes of the last two species I am uncertain of their proper generic assignment.

Caducifer decapitata fuscomaculata (Pease, 1860)

Caducifer cylindrica (Pease, 1868)

Colubraria nitidula (Sowerby, 1833)

Alectrion papillosa (Linnaeus, 1758)

Nassa papillosa (Linnaeus)

Nassarius (*Telasco*) *gaudiosa* (Hinds, 1844)

Nassa gaudiosa Hinds

Latirus nodatus (Gmelin, 1791)

Mitra (*Mitra*) *stictica* (Link, 1807)

Mitra pontificalis Lamarck, 1811

Mitra (*Mitra*) *coffea* Schubert and Wagner, 1829

Mitra fulva Swainson, 1829

Mitra (*Strigatella*) *auriculoides* Reeve, 1845

Mitra (*Strigatella*) *litterata* Lamarck, 1811

Mitra maculosa Reeve, 1844

Vasum armatun (Broderip, 1833)

Neither I nor Jamieson and Tate found this species during our visits to Henderson, although this is the type locality for the species, described by Broderip from material collected by Cuming in 1827. It is found from Rose Atoll, Eastern Samoa, and the Ellice and Phoenix Islands, southeastward to Henderson Island.

Conus lividus Hwass, 1792

Conus ebraeus Linnaeus, 1758

Conus chaldeus Röding, 1798

Conus hebraeus var. *vermiculatus* Lamarck, 1810

Conus miliaris Hwass, 1792

Conus nanus Sowerby, 1833

Conus ceylonensis var. *nanus* Sowerby

**Conus sponsalis* Hwass, 1792

Conus tessulatus Born, 1778

Conus tesselatus Born

Conus rattus Hwass, 1792

**Conus sanguinolentus* Quoy and Gaimard, 1834

Conus retifer Menke, 1829

Conus solidus Sowerby, 1834

Conus tulipa Linnaeus, 1758

Conus tenuistriatus Sowerby, 1856

Conus glans var. *tenuistriatus* Sowerby

Conus pennaceus Born, 1778

Conus pennaceus var. *episcopus* Hwass 1792

Bulla species (juvenile)

Melampus flavus (Gmelin, 1791)

Melampus luteus Quoy and Gaimard, 1832

Arca avellana Lamarck, 1819

Arca maculata Sowerby, 1833

Acar divaricata (Sowerby, 1833)

Arca (*Acar*) *domingensis* sensu Smith, not Lamarck, 1819

Barbatia parva (Sowerby, 1833)

Arca (*Barbatia*) *parva* Sowerby

**Lima lima* (Linnaeus, 1758)

Lima bullifera Deshayes, 1863

Spondylus species

Codakia (Epicodakia) bella (Conrad, 1837)

   Lucina (Codakia) divergens Philippi, 1850

Tridacna maxima (Röding, 1798)

   Tridacna crocea sensu Smith, not Lamarck, 1819

   Tridacna squamosa sensu Smith, not Lamarck, 1819

Trapezium oblongum (Linnaeus, 1758)

   Libitina guiniaca (Chemnitz 1784)

Chama asperella Lamarck, 1819

   Chama jukesii Reeve, 1847

It is with some hesitancy that I assign the many valves that I found on the beach to this species. Both Lamarck's species and Chama spinosa Broderip, 1835, described from the Tuamotus, and with which I had originally identified my specimens, have white interiors. Most of my specimens are strongly tinged with purple within, and Lamarck mentions a variety marked with purple inside. Until a series of fresh, unworn specimens can be compared with the types the proper identification of this species will be in doubt. The true Chama jukesii Reeve from Australia may be a related but distinct species.

Arcopagia (Scutarcopagia) scobinata (Linnaeus, 1758)

   Tellina scobinata Linnaeus

Semele australis (Sowerby, 1832)

The known molluscan fauna, which is twice as large as that recorded from Ducie, is typically Polynesian, and most of the species are those commonly found in the Tuamotus, in which island group Henderson should faunally be included. A few species, such as Nerita morio and Nodilittorina pyramidalis pascua show an affinity with the Easter Island-Pitcairn-Rapa subprovince.

Appendix 3. Resolution of the Pacific Science Association adopted at the XV Pacific Science Congress. Feb. 1-11, 1983. Dunedin, New Zealand.

Henderson Island

WHEREAS, elevated coral islands are few in number and of great biological and geological interests; and

WHEREAS, most such islands have been drastically altered by man through commercial exploitation; and

WHEREAS, Henderson Island, in the Pitcairn Group, is a raised coral island of twelve square miles, uninhabited and untouched except for occasional visits by inhabitants of Pitcairn, 100 miles distant, to obtain wood of the *miro* trees growing at the margin of the wooded interior of the island; and

WHEREAS, Henderson Island is the only habitat of a number of endemic species of angiosperm plants, birds, land snails, and insects, discovered during very limited surveys of the island; and

WHEREAS, Henderson Island, because of its being a raised coral island with narrow fringing reefs, narrow sandy beaches, and steep coral cliffs, has a marine environment unique to that part of eastern Polynesia; and

WHEREAS, preliminary investigations on the island have revealed the presence of important archaeological sites, suggesting early occupation by the Polynesians; and

WHEREAS, a private individual is seeking permission to live on Henderson Island and to build a house, a jet airstrip, and loading facilities for ships;

BE IT RESOLVED that the Pacific Science Association urges the British Government not to permit the proposed development before: (1) a detailed biological survey of the island has been carried out, in which the participation of responsible scientific agencies should be encouraged; (2) the likely ecological effects of the proposed development have been assessed; and (3) the views of Pitcairn Islanders on the proposed development have been obtained.

....

NOTE ON HENDERSON ISLAND RESOLUTION

On March 1, 1983, in the House of Lords, Lord Melchett asked Her Majesty's Government a number of questions on the proposed occupancy of Henderson Island, including whether they agree with the view expressed in the International Biological Programme's Report in 1968 that Henderson Island should be preserved as an "island for science."

Pacific Science Association Information Bulletin 35 (1-2): 17, 18-19, April 1983.

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Plate 1. North coast with low cliffs, beach,and coconut and other vegetation back of beach, from sea (Rehder photo).

2. North coast, from sea, closer up. Pitcairn people on beach preparing to load coconuts and Thespesia wood (Rehder photo).

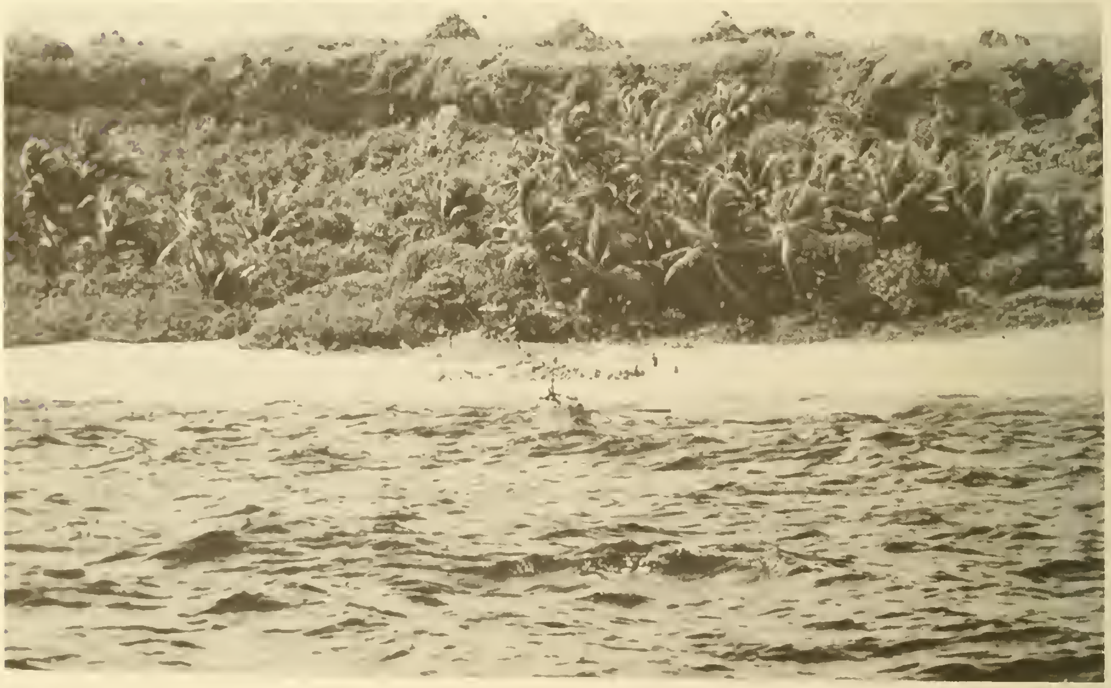

Plate 3. Base of cliff on north coast showing small cave site of archaeological excavation by Dr. Sinoto (Rehder photo).

4. West coast, undercut cliffs (Rehder photo).

Plate 5. West coast, looking north from near south end, from top of cliff (1943 photo).

6. West coast, looking north, near northwest point, from part way up cliff (Fosberg photo).

Plate 7. Cliffs back of North Beach, back-beach scrub in foreground, single coconut tree on top of cliff (1943 photo).

8. Vegetation of interior plateau, from top of large Pandanus tree (Fosberg photo).

Plate 9. Interior of back-beach vegetation, north coast, showing Pandanus (Rehder photo).

10. Tangled interior of vegetation (1943 photo).

Plate 11. Dissected limestone on plateau, forest in background (Fosberg photo).

12. Dissected limestone, on plateau, close-up, surrounded by forest (Fosberg photo).

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