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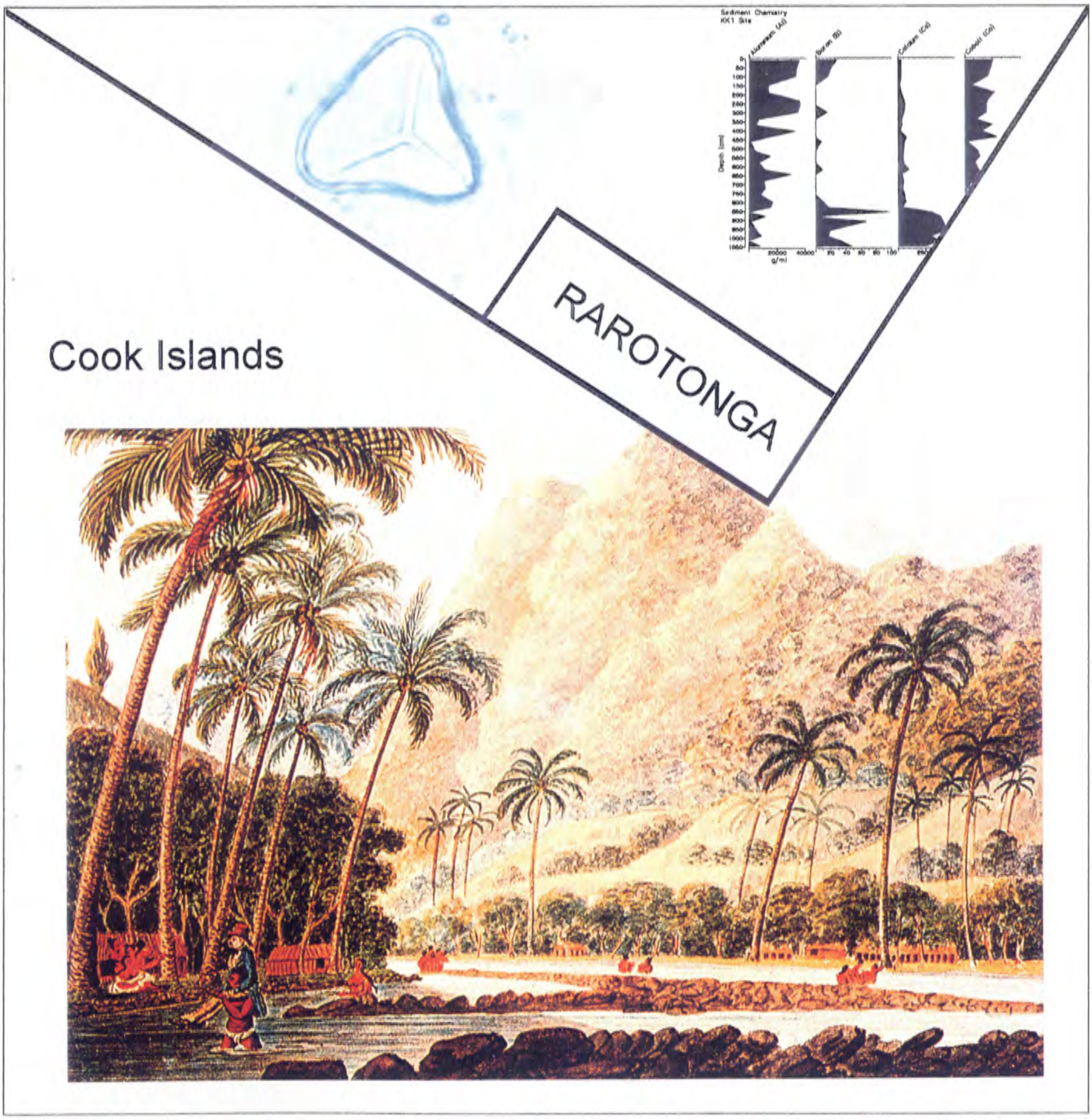

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1998

Publishers Preface:

Some years ago the publisher and the author met on an archaeological excavation near Leipzig in Germany and discussed some aspects of palaeo- and ethnobotany. Having a look on the exhaustive manuscript of the original thesis, we both decided to publish it, somewhat shortened in the type of the manuscript and with smaller letters, but principially without any revisions.
The manuscript is worth to be published because today we can understand the change caused by man on an island, which was discovered by Cook some hundred years ago.
The pollenprofiles give an impression of the vegetation today and yesterday and an analysis can lead to the understanding of changing biotopes and cultures, landscapes and vegetations.
This work is not only useful for botanists, for ethno- and archaeobotanists but also for ecologists, geologists and palynologists.
The title of the original manuscript was changed a bit and minor corrections were made, concerning the manuscript with all the footnotes, tables, figures and plates - but only in composition, not in any aspect of changing sentences or opinions.

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HUMAN SETTLEMENT, VEGETATION HISTORY AND LANDSCAPE CHANGE ON RAROTONGA, SOUTHERN COOK ISLANDS

by C. PETERS

Doctoral Thesis in Anthropology, University of Auckland

original manuscript title 1994:
„Human settlement and landscape change on Rarotonga, southern Cook Islands

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ABSTRACT

This thesis seeks to examine certain aspects of those changes which occurred in the landscape of Rarotonga during the period it has been occupied by humans. Because the exact date of human arrival is as yet uncertain, part of the problem has been to try to establish this by attempting to detect initial human interference with the landscape, in particular the vegetation.

A number of different approaches have been used in the investigation of these problems: swamp deposits were analysed by stratigraphic and palynological studies. Modern vegetation surveys and modern pollen rain studies provided a statement of the present landscape and comparisons for the fossil data and ethnographic and historical sources contributed information about the last two hundred years, and generated ideas and models for earlier periods and helped establish control over any changes to the landscape that were of more recent origin. Finally, archaeological evidence and oral tradition, where available, establish as far as possible what changes may have occurred in landscape usage and manipulation from first settlement to European contact. In addition, from late 1992, a series of techniques were brought to bear on the swamp sediments, in order to clarify questions raised by the pollen evidence. These include X-ray analysis, chemical analysis and particle-size analysis.

The early Holocene rising sea-level could have caused lake formation at Karekare before 8137 BP. Accruing sediment and local hydrology reduced the depth of the lake, consequently forming a marsh, though other factors may also have been involved. Falling sea-level could have been a vital factor too. With the formation of a marsh from 4,500 BP, there followed what is interpreted as a hydrosere beginning with swamp ferns, then some swamp forest, finally being replaced by drier elements after 3000 BP. Factors such as truncation, shrinkage and compaction due to cultivation and drainage by colonizing people between 2700 and 800 BP brought the sequence to an end.

A four phase model based on biogeographic theories is proposed for landscape change on Rarotonga, starting with the island before humans arrived, then with the first Polynesian settlement and later developments therefrom (up to European contact), then the arrival of Europeans and finally the late twentieth century. Wider implications for Pacific Islands emerging from this thesis are discussed under the following headings: extinction, problems with other sites, plant distribution history, sea-level change and climatic change, dating of human arrival and the influence of the environment on settlement history.

It could well be that whilst some extinctions are related to initial colonization of islands and later expansion therefrom, others may be associated with the economic, religious and social changes brought about by missionaries, merchants and colonial authorities. It is suggested here that whilst early Polynesian settlers no doubt altered their landscapes, it is not necessary to invoke quite as much alteration by them as is sometimes inferred. It is proposed that early Polynesian colonists adapted their economy to the landscape and did not attempt to impose a totally alien system on the local ecology of newly settled islands. Some plants were discovered to have existed on Rarotonga before humans arrived, others formerly had different distributions than today. Oral tradition (see Chapter 6) and missionary records show that breadfruit trees and plantains were grown in the lower-lying areas because they are better adapted to the warmer, drier conditions, whilst the taro and mountain plantains were grown further up the valleys, where reliable all-the-year-around supplies of freshwater were available.

Clark *et al.* (1978) and Clark and Lingle (1979) proposed that sea-levels in the mid-Pacific Ocean (Zone 5) rose from the end of the last glaciation to reach a mid-Holocene highstand of between 1 and 2 metres about 5000 years ago. Later studies have produced evidence supporting that hypothesis, though with the highstand being a little later in date than theorised. The swampland data from Rarotonga could well confirm the idea of a mid-Holocene highstand, followed by a fall to present levels. In Karekare Swamp, the freshwater lens, resting on the ocean's saltwater, could have risen causing, or at least facilitating, a transition from a lake to a marsh. The lowering sea-level from 5-4000 BP may have affected the water table in Karekare Swamp, leading to drier conditions and allowing plants to colonize its surface.

Human arrival on Rarotonga, at least in the area of Karekare Swamp, postdates 2730 BP and antedates 791 BP From lake sites on _tiu and Mangaia, where such factors have not been a problem, mid-first millennium AD dates have been obtained. These dates relate to pollen and sediment changes interpreted as being the result of gardening and clearance activities. They could be considered as minimum dates for initial colonization, because settlement may have taken place on other parts of these islands first and/or gardening activities may have assumed a lesser role in the initial stages of settlement. Such dating would not be incompatible with Karekare Swamp. The first colonization of Rarotonga would have involved the ecotones between valley, freshwater stream, coastal plain, lagoon and reef passage. Thence, expansion (between arrival and European contact) would have continued up the valleys and along the terraces, over which the *Ara Metua* passes (though leaving contested and sacred areas free of interference, following the prime agricultural land. Other advantages of these areas would have been greater protection against cyclonic winds and floods, and droughts such as occur on the lower and more coastal parts of the plain. Perhaps these could be considerations for other high islands. Any early settlement before 1500-2000 BP, if it existed, may have had to have been influenced by higher sea-levels, because except for a stretch of land between Avarua and Ng_Tangi`ia, the lowland plain may well have been inaccessible due to submergence.

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Firstly, I would like to thank the Cook Islands Government and the landowners of Karekare Swamp for their kind permission to undertake this research, and for their interest and encouragement....*meitaki ma`ata* !

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CHAPTER 1 INTRODUCTION

1.1 Aims

This thesis seeks to examine certain aspects of those changes which occurred in the landscape of Rarotonga during the period it has been occupied by humans. It explores how these changes have affected human settlement and the degree to which humans have had some part in them. This involves an investigation into what the environment of Rarotonga would have been like before human arrival and what effects colonization by Polynesians and later developments in their culture had, especially in terms of the vegetation. The effects of the later European influences and more recent changes also need consideration.

Because the exact date of human arrival is as yet uncertain, part of the problem has been to try to establish this by attempting to detect initial human interference with the landscape, in particular the vegetation. In pondering what human effects would have been, due attention had to be paid to natural changes and their relative contributions over the period covered: the last 8,000 years.

Other important issues were the past distribution histories of plant species (to find out among other things what plants were introduced by people), pre-human palaeoecology (in order to help distinguish natural from human-induced change), climatic and sea-level history, and the effects of local ecology on human settlement history.

The taphonomic model provided by Spriggs' work on Aneityum (Groube 1975; Spriggs 1981; 1986)[1], bolstered by investigations on Lakeba (Hughes *et al.* 1979), suggested that early sites belonging to an initial colonization phase might be obscured by later deposition of sediment, itself the product of erosion caused by human activity (Sutton *et al.* **in press**). On high islands, it has been suggested, the ratio of the height of the mountainous interior to the width of the coastal plain should provide a general idea of how much later deposition would have buried colonization-age sites, especially if precipitation is great (Sutton *et al.* **in press**), though this would not work for all cases[2].

Rarotonga was chosen because of its key location in the southern Cook Islands. As such it lies between West and East Polynesia on the likely course of west to east colonization, with the nearest neighbouring islands to West Polynesia being colonized first (Biggs 1972; Irwin 1992). The current late dating for initial colonization of 800 to 1000 AD could be too young, due to the same factors as for Aneityum and Lakeba. Some dating from West Polynesia and from French Polynesia and the Hawai`i Islands, on either side of the southern Cook Islands along the suspected migration route, also suggest there should be sites earlier than those found up to now.

Given the lack of convincing archaeological evidence for the period before 800 to 1000 AD (Allen and Steadman 1990; Ellison 1993; Kirch 1986b; Kirch *et al.* 1992; Walter 1990), palynological investigations were at this time thought to offer greater opportunities for defining the period of primary colonization. The object of the first stage of fieldwork was to locate polliniferous deposits securely extending back to before initial colonization[3].

A number of different approaches have been used in the investigation of these problems.

Firstly, examination of swamp deposits was undertaken from a stratigraphic and palynological point of view. Modern vegetation surveys and modern pollen rain studies were used to assess the present state of the landscape and provide comparisons for the fossil[4] data.

Secondly, ethnographic and historical sources were consulted to provide information about the last two hundred years, and to generate ideas and models for earlier periods. Such sources help to establish control over any changes to the landscape that are of more recent origin.

Thirdly, archaeological evidence and oral tradition[5], where available, were used to establish as far as possible what changes may have occurred in landscape usage and alteration prior to European contact.

In addition, from late 1992, a series of techniques were brought to bear on the swamp sediments, in order to clarify questions raised by the pollen evidence, such as X-ray analysis, chemical analysis and particle-size analysis.

This thesis is divided into ten chapters. The first chapter deals with the background information about Rarotonga, placing it in its cultural and natural historical context. The second chapter poses questions about the status of the modern day vegetation and how it has come to be what it is, while also providing comparative modern pollen data.

---

1 Similar views have since been expressed for the New Zealand situation (Chester 1986; Sutton 1987).

2 On Lakeba, for example, the soils of the coastal plain appear to have been created by the emergence of marine sediments such as calcareous sand and mangrove deposits within the last 2-4000 years (Best 1984, p.30). Also, in New Zealand, Jones (1991) argues in his study of the Rangitaiki plains, that natural alluviation and significant volcanic activity have been so great that human impact has been slight in comparison.

3 Rock shelters had not been investigated on Rarotonga until 1991, when Chikamori discovered 3 m of cultural deposits, as yet undated, 6 m a.s.l. in the Avana Valley (cf. Sutton *et al.* **in press**).

4 The term *fossil* is used in this thesis in preference to *sub-fossil* because the strict meaning of the word refers to the object's having been buried, not its chemical replacement. The addition of the prefix `sub' to the word, as is sometimes used, is thus superfluous (Geikie 1903, p.825).

5 `Tradition' is used in this thesis as meaning `culture and custom recorded in ethnographic literature and oral tradition, which probably originated before European contact'.

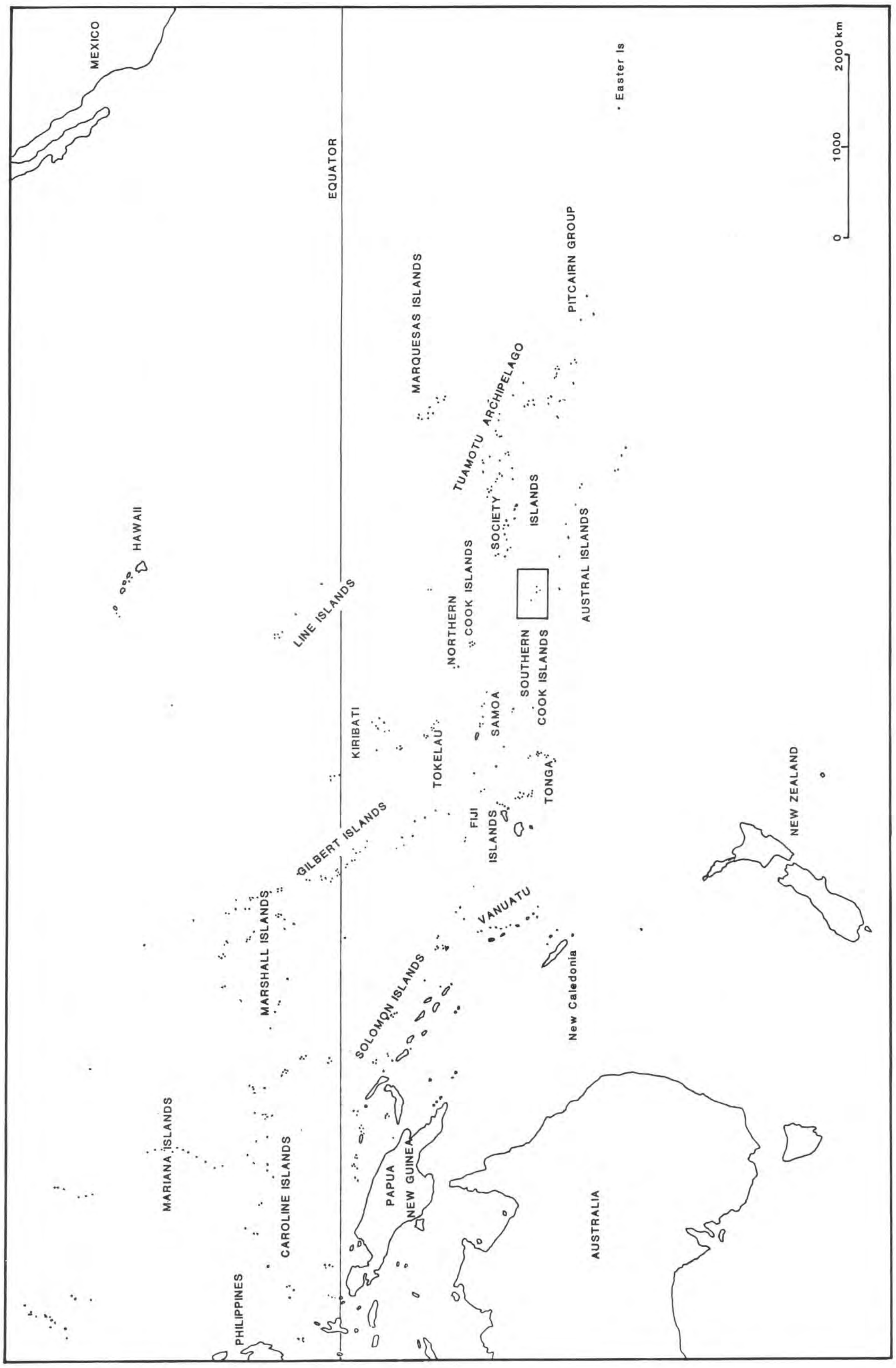

Figure 1.1 Location Map of the Cook Islands in the Pacific Ocean.

The third chapter is a statement of the current climate and status of opinion and research from a number of disciplines relevant to this thesis in Polynesia. The fourth chapter narrows the research area to the southern Cook Islands. The fifth chapter outlines the aims and techniques used in the fieldwork. The sixth chapter analyses the historical and ethnographic evidence (including data collected by the author on Rarotonga) for landscape change following human settlement. This is investigated further by the seventh chapter on lithostratigraphy and the eighth on biostratigraphy. The ninth chapter draws all the evidence together in a discussion of the major issues. Finally, the tenth chapter is a summary of the main conclusions reached.

1.2 Location

Rarotonga[6] is the principal (and largest) island of the Cook Islands. This political grouping of islands is composed of the northern and the southern Cook Islands (Figure 1.1). Stretched out over approximately 2 million square kilometres of the Pacific Ocean, they are located between 9 degrees South in latitude and the Tropic of Capricorn, and between 167 degrees and 155 degrees West in longitude. The land area of the Cook Islands is only 240 square kilometres. The southern group is about 3-4 degrees south of the northern group.

Rarotonga is located at 21°12´S in latitude and 159°46´W in longitude. The distances to some of the other islands of the southern group are: Atiu, 187 km; Ma`uke, 241 km; Miti`aro, 229 km; Mangaia, 177 km; Aitutaki, 141 nautical miles (Figure 1.2). The current population of the Cook Islands is about 17,200 residents. Rarotonga is the most populous island with 9,281, followed by Aitutaki with 2,400 (though Mangaia is the second largest island), Mangaia with 1,270, and Atiu with 1,040. All the others have populations less than 1,000 down to Palmerston with 50 residents. Takutea and Suwarrow are National Parks and not inhabited.

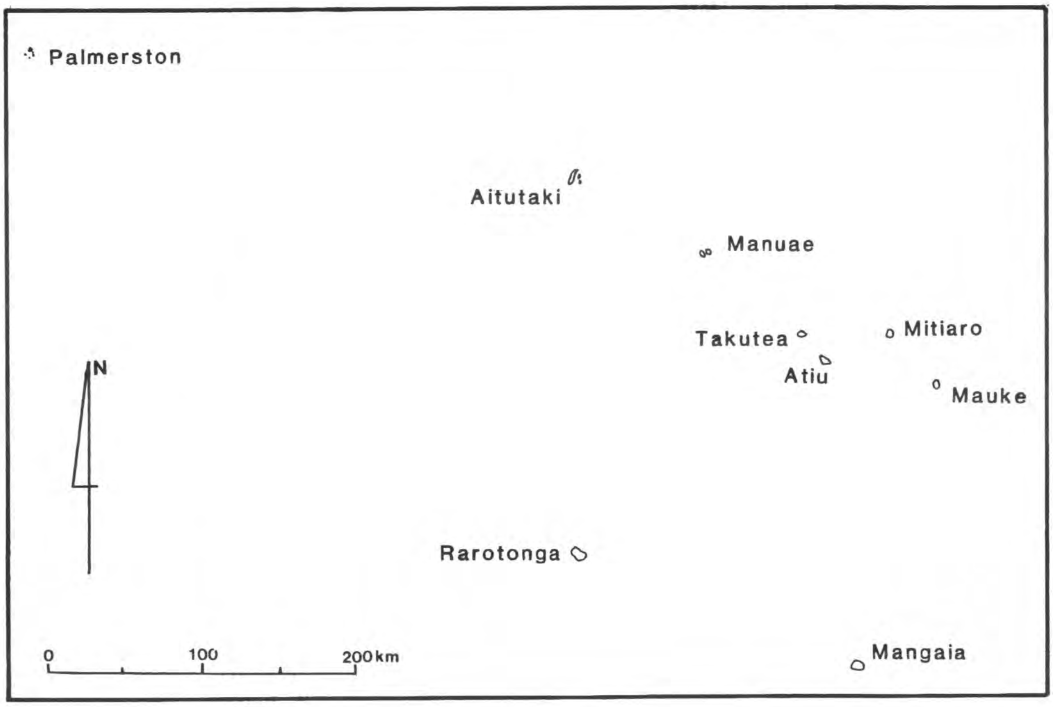

Figure 1.2 Location Map of Rarotonga in the southern Cook Islands.

1.3 Topography (Figure 1.3)

Rarotonga consists of a mountainous interior, dissected by stream valleys and gulches, and a coastal plain, surrounded by continuous reef flats and a discontinuous lagoon. On the leeward side to the west the mountains are lower and more level, and on the eastern and southern windward sides the mountains are higher and peaked. The highest mountain is Te Manga at 653 m a.s.l.. The valleys on the western and southern sides tend to be very constricted, whereas those on the eastern and northern sides are broader and much more open with extensive alluvial soils.

The coastal plain is tilted towards the landward side. On the eastern side this is at its most extreme as there is a high (4-5 m a.s.l.) storm ridge of coral rubble and sand, whereas elsewhere there is only a low ridge up to 2 metres composed mainly of well-sorted coral sand (Richmond 1990; 1992).

In the immediate vicinity of Karekare swamp, from which the main pollen cores were taken, there is a small mountain, Oro`enga, with 3 small ridges radiating out from it. The two nearest stream valleys, the Tupapa valley and the Matavera Valley, exit on to the coastal plain on either side of this mountain.

6 Cook Islands Maori orthography follows Rangi Moeka`a in Simiona (n.d.), McCormack (1990), McCormack and Künzle (1990; 1991) and Biggs (pers. comm. 1993). `Maori' is taken to mean `Cook Islands Maori' except where otherwise stated.

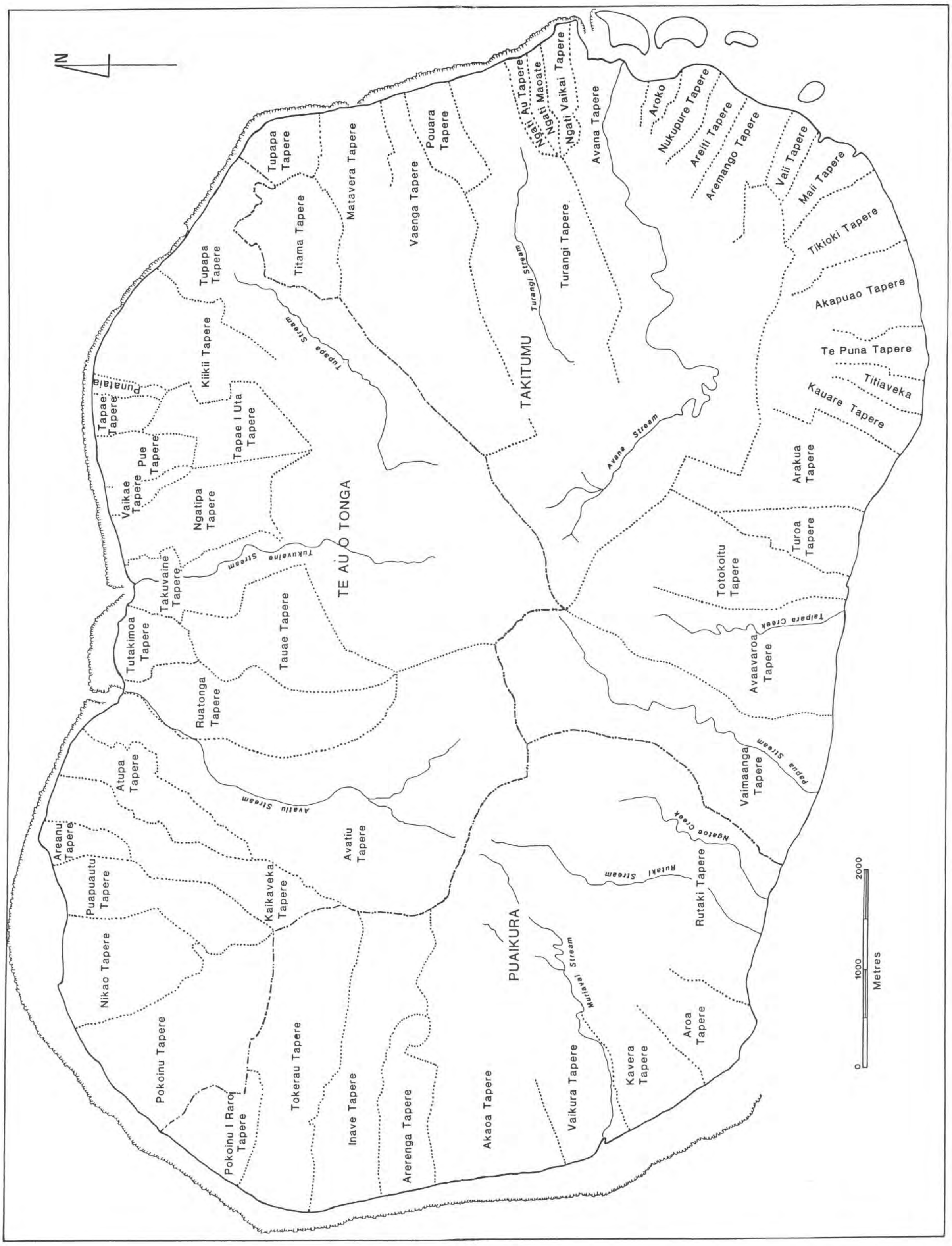

Figure 1.3 Map of Rarotonga, showing *vaka tangata* and *tapere*.

1.4 Geology

1.4.1 *Cook-Austral Chain*

Rarotonga forms part of the Cook-Australs Chain (Turner and Jarrard 1982). Although politically separate, the southern Cook Islands and the Austral (or `Tubuai') Islands are geologically related.

The group has been thought to have been formed due to the Pacific Plate passing westward over a `hot-spot' under the Earth's crust. This produced Avarau (Palmerston) at the older end and Marotiri (Îlots de Bass) at the other (Turner and Jarrard 1982). The `hotspot' would have caused volcanic activity which led to a crater rising out of the sea. This then weathered producing soil. The underwater volcanic slopes attracted coral where the shallow water meets its sides. This is the typical `high island'.

A low island is where the crater starts to sink and the coral reef grows upwards to keep pace with the subsidence. At times, this leads to the formation of an extensive shallow lagoon. An atoll is where the crater is completely submerged, but the coral reef has continued to keep pace with rising water. In the centre of the ring of coral reef is a lagoon, often deep, and on the reef flats banks of coral rubble and sand form *motu*[7] or lagoon islets.

Finally, there are the makatea islands, which are formed when a low island or atoll re-emerges out of the ocean. This exposes cliffs of fossil coral reef (the `makatea') surrounding a volcanic hill or mountain in the centre. Freshwater swamps develop at the junction of the volcanic hill and the coral cliffs, where drainage through the karst formations in the cliffs is sluggish (Marshall 1930).

In the southern Cook Islands, Rarotonga is a high island; Aitutaki is a low island; Avarau (Palmerston), Manuae/Te au o tu and Takutea are atolls; Atiu, u`aro, Ma`uke and Mangaia are makatea islands (Wood and Hay 1970).

1.4.2 *Rarotonga*

Rarotonga has the youngest exposed rocks in the Cook-Australs Chain - from $\geq$ 2.27 $\pm$0.08 to 1.10 $\pm$0.04 Ma, though it lies at the older end of that range. It has been suggested that Rarotonga emerged at a later stage, imposing a great weight on the plate at that point, causing, in turn, some of the other islands to re-emerge, like Mangaia and Ma`uke (Turner and Jarrard 1982). Later lava flows can mask underlying layers of greater age, and so the chronology may only reflect when the various volcanoes ceased to be active. The ocean floor in this region is of much greater antiquity, and it has been argued that the islands should be much closer in date to the ocean floor (Turner and Jarrard 1982).

Rarotonga's volcanic core consists of basalts (including trachytes, phonolites and nepheline basalts) and breccias. Around the rim of Rarotonga just below sea-level, there is a fringing reef, extending in the south-east and southern part of the island to include a shallow lagoon up to about 1.5 metres deep, except in the reef passages. In the north-west corner, Tuoro (Black Rock) and in the south-east corner, the *motu* of Ta`akoka are lava flows intrusive into the area of the reef flat.

Coral formations, fossil reefs, former algal rims and coral rubble storm ridges provide evidence of former sea-levels, not just on Rarotonga and the Cooks Islands (e.g. Scoffin *et al.* 1985; Schofield 1970), but also throughout the tropical Pacific. The relationship transcends other geological relationships as it relates to regional sea-levels and biological activity. Local tectonic movements can, however, interfere with this sea-level correlation. Schofield (1970) dated a raised fossil coral outcrop 1 metre above present sea-level to 2,030 $\pm$60 BP, though the event may well be earlier due to recrystallisation. This correlates well with the works of Scoffin *et al.* (1985) on Suwarrow and Yonekura *et al.* (1988) on Mangaia. Schofield (1970) dated the coral rubble ridge - the `Aroa Sands' of Wood and Hay (1970) -(below the A-horizon at the highest points) at Kavera to 3,510 $\pm$50, at Matavera to 2,470 $\pm$63 BP, and at the Black Rock (Tuoro) to 1,235 $\pm$57. This may suggest a fairly late marine high stand, if the Kavera date represents a minimum date for when the ridge stabilised. The coral element of the geology on Rarotonga is represented by some apparently remnant areas of makatea, and a modern active reef, which is continuous around the island apart from 6 reef passages. Former reefs relating to times of lower sea-level no doubt exist at various levels under the sea. The makatea is found on either side of Ngatangi`ia Passage (the coastal plain on the northern side and the *motu*, Motutapu, on the southern side) on the south-east side of Rarotonga, and by the Meterological Office at Nikao, on the north-west side. Schofield (1970) dated these to the Last Interglacial.

1.5 Soil

The soils of Rarotonga were first investigated by Grange and Fox (1953). This was improved upon and elaborated by Leslie (1980) - see Figures 1.4 and 1.5. Leslie's classification divided the soils into those of the coastal margin and those of the interior uplands. The coastal margin consists of 8 general types based on formation processes: estuarine margins, beach ridges, poorly drained depressions, moderately drained depressions, younger flood plains, older flood plains, terraces and fans. The interior uplands consist of 2 general types of soil: hilly land soils and steep and very steep land soils.

The soil of the estuarine margins (Koromiri Soils - Km) comprises muds and sands derived from basaltic alluvium and reworked coral particles. It is poorly drained, saline, carbonatic, subject to tidal flooding and significantly disturbed by crabs.

The soils of the beach ridges (Muri Soils - Mu; Muri Soils, stony phase - Mut) are based on reworked coral sands and have a weak profile development. These are drought-prone carbonatic soils with a low nutrient content. The stony phase

[7] Cook Islands Maori words are explained in the Glossary (see Appendix A.1).

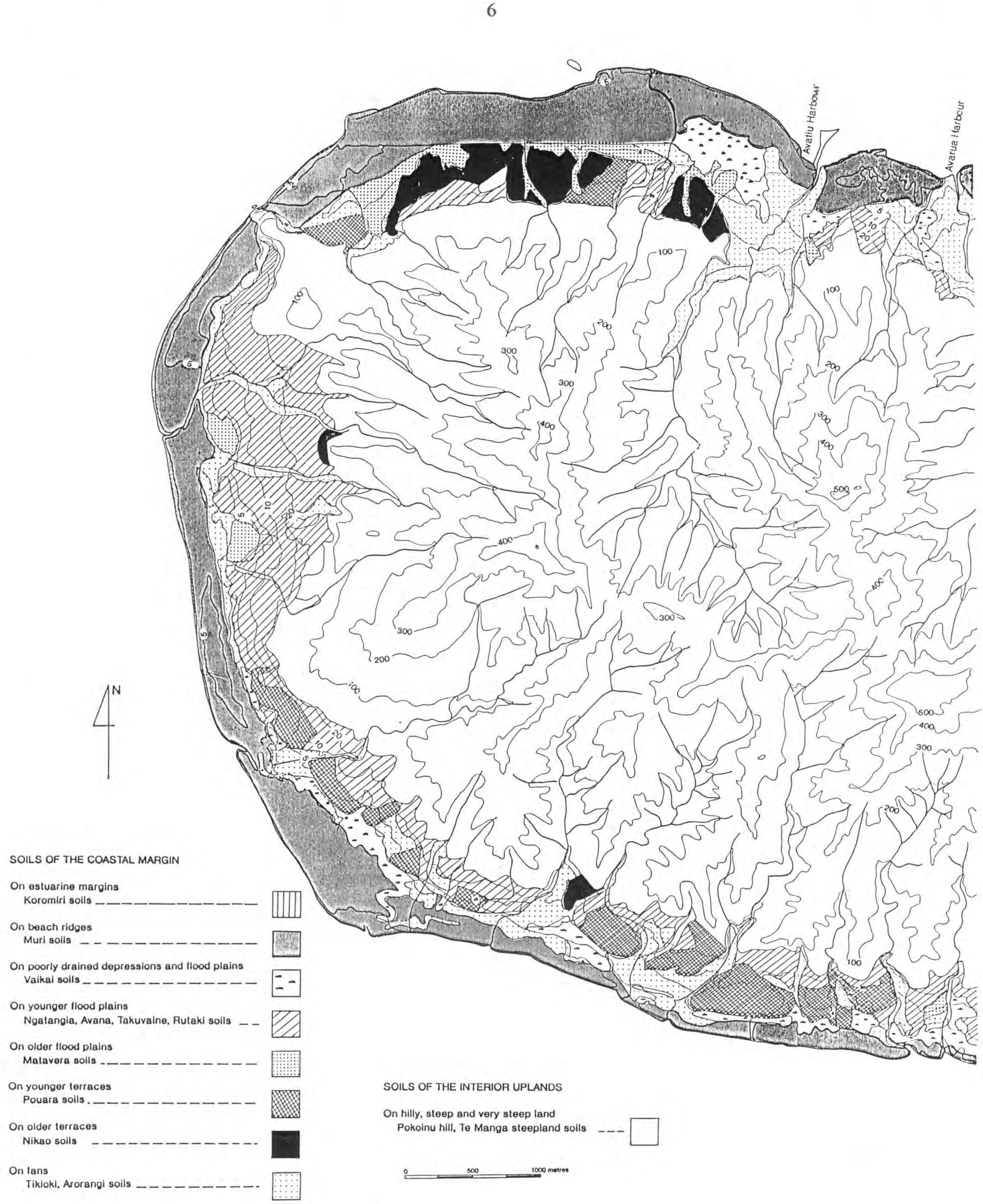

Figure 1.4 Map of the Western side of Rarotonga, showing contours and soils.

soils have lost much of their fine fraction and continually receive fresh coral detritus so that their profiles are even more weakly developed and coarse textured.

The soils of the poorly drained depressions (Vaikai Soils - Vk; Vaikai Soils, mottled variant - Vkm) are derived from moderately pre-argillised basaltic alluvium with a small contribution of coral fragments. These soils are poorly drained, kaolinitic, heavy in texture, sticky in consistency and poorly aerated. They have neutral to slightly alkaline pH, high

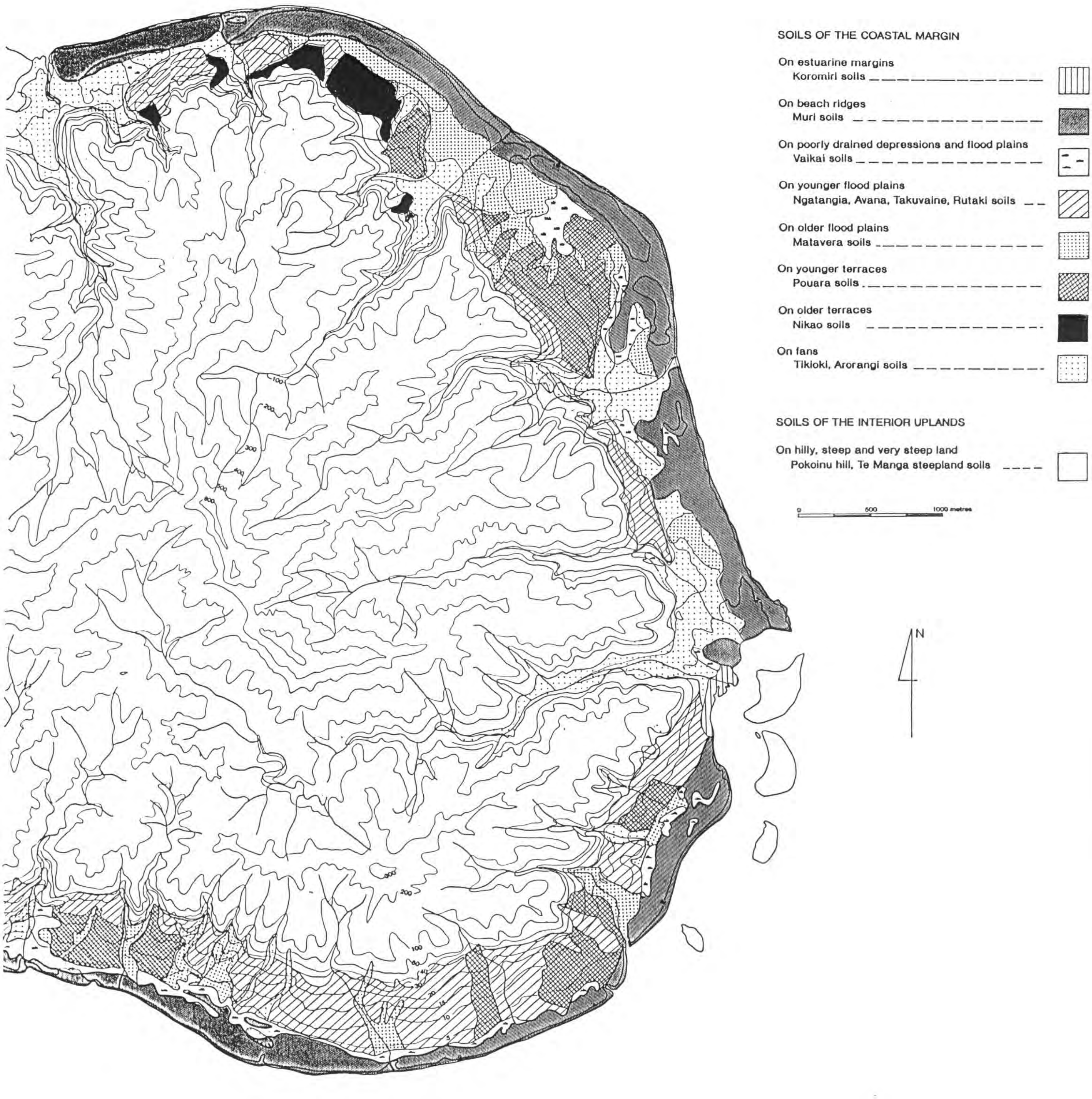

Figure 1.5 Map of the Eastern side of Rarotonga, showing contours and soils.

exchangeable cation, phosphorus and potassium values, though low values for total carbon, nitrogen and absorbed sulphate.

The soils of moderately drained depressions (Ngatangiia Soils - Nt) consist of moderately pre-argillised fine basaltic alluvium and coral sand over coral sand. They do not experience the long periods of flooding that Vaikai soils do, and the coral sand component ensures better drainage. Adequate, though low nutrient levels exist for plant growth (high amounts for shallow rooting crops), though flooding limits the range of plants that can be grown.

The soils of the younger flood plains (Avana Soils - Av; Takuvaine Soils - Tv; Rutaki Soils - Ru) are derived from basaltic alluvium of varying textures and are undergoing active formation. They are well drained, and while some flooding occurs, the water rapidly drains away. These soils are high to moderate in nutrients, the only real limitation to cropping being stoniness in places. Rutaki Soils have good moisture retention and are montmorillonitic.

The soils of the older flood plains (Matavera Soils - Mt) stem from moderately argillised basaltic alluvium, and the most stable and mature of the flood plain soils. They are deep, well drained, well aerated with a well matured structure and friable consistency. The risk of flooding only occurs near hill margins during cyclones. They have good water retention and moderate nutrient values. These are the best soils for gardening on the island.

Soils of the terraces (Pouara Soils - Pa; Nikao Soils - Ni) are developed on basaltic alluvium on the two terrace systems formed in the Pleistocene (Wood and Hay 1970). The younger terrace (Pouara Soils) has deep, moderately well drained and mature soils with a moderate nutrient status. The older terrace (Nikao Soils) has sticky, compact, montmorillonitic and poorly drained soils with a low nutrient status.

Soils of the fans (Tikioki Soils - Tk; Tikioki Soils, stony phase - Tkt; Tikioki Soils, mottled phase - Tkm; Arorangi Soils - Ag) are derived from strongly argillised basaltic gravels. Active colluviation does not occur today, except for a minor contribution during cyclones. These soils are moderately well drained, except for the Tikioki Soils, mottled phase, with moderate nutrient levels. Limitations of the Tikioki Soils (stony phase and mottled phase) are their stony nature and poor aeration, with poor drainage in the case of the Tikioki Soils (mottled phase).

The soils of the interior uplands are highly complex and were not as finely differentiated as those of the coastal margin. They have extreme slope and low nutrient limitations.

The soils of the hilly land (Pokoinu Hill Soils - PkH) are based on strongly argillised basic volcanic rocks with slope inclinations up to 30°. They are located on the lower hills. These soils are low in nutrients, and are argillous and stony. Attempts at cultivation with pineapple, dryland taro and kumara have resulted in significant loss of topsoil and sometimes exposure of the subsoil due to the combination of severe cyclones, slope and removal of vegetation cover.

The soils of the steep and very steep land (Te Manga Steepland Soils - TmS) are derived from basic volcanic rocks or the colluvium derived therefrom and are weakly to moderately argillised montmorillonitic soils. Slopes vary from 30° to 50°, and average about 37°. Profiles range from practically non-existent to mature. These soils have extreme limitations due to steepness of slope, high erosion risk and low nutrient levels.

Leslie (1980) also produced soil use classifications: for tree and tree-like crops and for subsistence dryland tuber crop production. These classifications are based on soil properties (physical and chemical).

Firstly, there is the tree crop soil use classification. The tree crops considered included bananas, breadfruits and coconuts.

Class 1 were soils of flat to undulating land with minimal to slight soil limitations and included:

1A Avana Soils, Takuvaine Soils, Rutaki Soils, Matavera Soils, Pouara Soils, Tikioki Soils, Tikioki Soils, stony phase, and Arorangi Soils with slight limitations of nutrient status.

Class 2 were soils of flat to undulating land with moderate soil limitations and included: 2A Muri Soils with low nutrient status and available moisture capacity 2B Nikao Soils and Tikioki Soils, mottled phase with low nutrient status and poor drainage

Class 3 were soils of flat to undulating land with severe soil limitations and included:

3A Koromiri Soils, Vaikai Soils, Vaikai Soils, mottled phase and Ngatangiia soils with poor drainage, high water table and/or salinity

3B Muri Soils, stony phase with severe soil moisture deficit and/or shallow or very shallow soil depth

Class 4 were soils of hilly and steep land with severe soil limitations and included:

4A Pokoinu Hill Soils and Te Manga Steepland Soils with low nutrient status, slope and erosion risk

Secondly, there is the dryland tuber crop soil use classification. The crops considered included dryland taro (*Colocasia* sp.), yams (*Dioscorea* sp.) and kumara (*Ipomoea* sp.).

Class 1 were soils of flat to undulating land with minimal to slight soil limitations, and included:

1A Takuvaine Soils, Rutaki Soils, Matavera Soils and Pouara Soils with slight limitations

Class 2 were soils of flat to undulating land with moderate soil limitations and included:

2A Vaikai Soils, mottled phase and Tikioki Soils, mottled phase with poor drainage

2B Tikioki Soils, Ngatangiia Soils and Arorangi Soils with medium to low nutrient status

2C Muri Soils with a seasonal moisture deficit

Class 3 were soils of flat to undulating land with severe soil limitations and included:

3A Nikao Soils with very low nutrient status and drainage

3B Muri Soils, stony phase with severe soil moisture deficiency and/or very shallow depth

3C Avana Soils and Tikioki Soils, stony phase with limitations of stoniness

3D Koromiri Soils and Vaikai Soils with a high water table, poor drainage and/or salinity

Class 4 were soils of hilly and steep land with severe soil limitations and included:
4A Pokoinu Hill Soils and Te Manga Steepland Soils with severe erosion risk and/or low nutrient status
It is interesting to note that the areas with the best soils were the flood plains, the younger terrace and the fans: in other words the valleys and either side of the *Ara metua*, where the surface archaeological evidence is concentrated (Trotter 1974). Also, one should note that more areas are suitable for tree crops than dryland tubers, for which the best soils are all among the areas also suitable for tree crops. The interior mountainous core of the island is considered the worst area for cultivation for both tree crops and dryland tubers.

1.6 Climate and Weather

Four main factors influence the general circulation in the tropical south Pacific Ocean (Thompson 1986): the sub-tropical high pressure zone; the trade winds; the equatorial doldrum belt and the intertropical convergence zone; and the south Pacific convergence zone.

The first is a high pressure belt, centred on 25 - 30°S, across the Pacific. A semi-permanent anticyclone is to be found in the eastern part of the belt, and in the west, there are eastward migrating anticyclones. The trade winds blow consistently from the east along a broad belt north of the high pressure belt. The Equatorial Doldrum Belt (EDB) of the western Pacific Ocean is characterised by light perennial winds, high rainfall with much seasonal variability and lies within 5° of the Equator. The Intertropical Convergence Zone (ITCZ) is where northern and southern hemisphere trade winds meet (Barry and Chorley 1982). It is a region of cloud and drizzle due to the rising air currents. The South Pacific Convergence Zone (SPCZ) is where the south-easterly trade winds converge with the equatorial winds from the east. It is north of the southern Cook Islands, and south and west of Samoa, Tahiti and Easter island. It is an area of cloud and cyclonic wind shear.

In the area of the trade winds (Thompson 1986), strong temperature inversions occur between 1200 and 2500 metres. Above this, westerly winds are prevalent, with dry descending air. This prevents the formation of convective clouds at high altitudes, because clouds are unlikely to infiltrate the inversion. Showers are therefore not to be expected, except where mountains are encountered such as on Rarotonga. In the austral summer when the EDB is in its most southerly position, a trough of low pressure forms from Northern Australia and the Coral Sea, leading to westerly winds bearing the monsoon rains. The location of SPCZ depends on the value of the Southern Oscillation Index (SOI). When the SOI is negative, the SPCZ lies north and east of its mean position, and this means that dry conditions are experienced in the southern Cook Islands.

Precipitation is in the form of rain (Thompson 1986), with rare occurrences of hail, and is seasonally variable; higher precipitation takes place in the austral summer. The higher elevations on Rarotonga receive the greatest rainfall, the southern part of the island between Aro'a and Muri is the wettest part and the north-east corner is the driest part.

On the basis of information from weather surveillance from 1969 to 1986 (Thompson 1986), tropical cyclones occur in the southern Cook Islands at the rate of 1.4 a year. The southern Cook Islands lie in the trade wind zone, so winds from the east blow for over 50 per cent of the time. The most frequent directions are between 80° and 140°.

Valley winds, caused by eddies from the southerly Trade Winds, spill out in different directions after crossing the mountains. It is in the form of dense air which crosses the mountain ridges at high velocity and then slumps down on to the plain, where it spreads out. Easterly Trade Winds would counteract any valley winds (Ngari pers. comm. 6/08/92).

1.7 Flora and Vegetation[8]

1.7.1 *The Pacific Islands*

The vegetation of the mid-ocean islands of the Pacific Ocean owes its origins largely to Island South-east Asia, though in those areas on the margins, there are increasing contributions from Australia, North and South America respectively (Van Balgooy 1971). There is a gradient of decreasing diversity as one moves from east to west and major groups reach abrupt limits along this gradient (Briggs 1987). However, a large number of endemics occur at familial, generic, specific and sub-specific levels, so although ultimate origins may be found elsewhere, the vegetation represents local adaptation rather than simply a depauperate version of the Malesian region with some mixing at the peripheries. The migration of vegetation across the Pacific Ocean has a considerably greater time depth than that of humans, though there is as yet little evidence as to its nature prior to the late Pleistocene. One of the few studies undertaken was that of Cranwell (1962; 1964) on Tertiary deposits from Rapa (Iti), in the Austral Islands, and even this was limited in its extent. The central Pacific Ocean has a very different environment from South-east Asia: greater oceanicity, less precipitation, smaller landmasses (further

[8] For Latin, Maori and English names of organisms, see Glossary in Appendix A.2.

apart) and less diversity of landforms, soil types and climatic zones in other words, much harsher environments, especially those out of the tropical zone, such as Rapa (Iti) and Rapa Nui (Easter Island).

Three major boundaries affect biotic distributions in the Pacific Ocean. Firstly, Wallace's Line or Huxley's Line (Briggs 1987) separate Sahulland (Australia and New Guinea) and Sundaland (the western part of Island South-east Asia), two large continuous landmasses during times of low sea-level, but flooded and divided when sea-level is high. Secondly, the boundary between Sahulland and the open ocean. Thirdly, the Andesite Line forms an important distributional boundary (Figure 1.6): i.e., it divides andesitic volcanics from basaltic volcanics, where the Indo-Australian and Philippine plates have met at sometime, if not the present, the Pacific Plate to their east. To the west of the Line, landmasses are larger and closer together and are composed more of continental rocks, whereas to the east, they become smaller, further apart and composed simply of basaltic and coralline rocks.

A sorting process selected and selects for those plant categories meeting the criteria for dispersion (Carlquist 1967): these categories are thus better represented than they are in the source area of Malesia. Pteridophytes and angiosperms are the best colonizers. Gymnosperms, due to their heavy seeds and lack of fruit, rapidly decline after leaving Sahulland and failed entirely to cross the Andesite Line until they were artificially conveyed over in the nineteenth century (Van Balgooy 1971). The light spores of Pteridophytes are easily transported by wind and water. Those angiosperms producing edible fruit attractive to birds or bats, or seeds that can in some way attach themselves to birds or bats are transported by such means, and other angiosperms have adapted to water transport (Carlquist 1965; 1967).

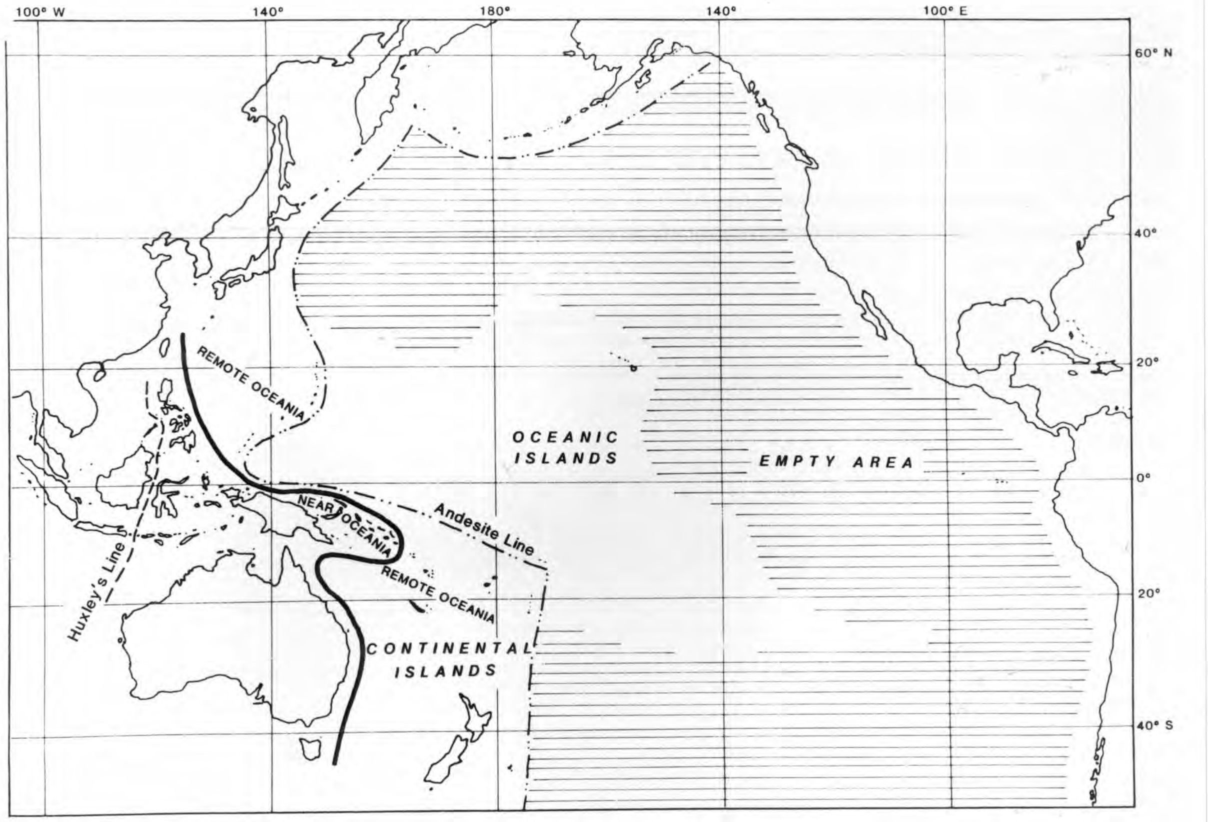

Figure 1. The Pacific basin and some biogeographic divisions in relation to Near and Remote Oceania.

Figure 1.6 The Pacific basin and some biogeographic divisions in relation to Near and Remote Oceania [*After Green (1991), fig.1, p.492*].

Founder-effect would have caused some of the variation between islands. Also, there is the consideration of later hybridisation between closely related species or subspecies. Adaptive radiation of one plant in a new island may lead to different varieties of that plant occupying separate niches. This leads to the potential for hybridisation at the junction of these niches, and thus creates the opportunity for greater genetic variation. This assists plant adaptation to changing circumstances in a restricted ecological situation.

Adaptive radiation has led to a number of pioneering plant groups of a normally shrubby or herbaceous type that have managed to traverse the oceans, for example members of the Compositae, developing into trees in the absence of their competitors on the continents (Carlquist 1965).

Vegetation groups into a number of zones: Alpine, Cloud Forest, Rain Forest, Slope Forest and Coastal Forest, as well as Swamplands, Fernlands and Savannahs (e.g., Merlin 1985; Sykes 1983).

1.7.2 *Rarotonga*

Rarotonga has 73 tree and shrub species, which have been suggested as being possibly or probably present before European contact (Cheeseman 1903; McCormack 1990; Sykes 1983; Wilder 1931). Some of these, like the breadfruit (*Artocarpus altilis*) and the paper mulberry (*Broussonetia papyrifera*)[9], were Polynesian introductions (Merlin 1985). Many species have been introduced since European contact, and these are largely confined to the lowlands (Sykes 1983). Some have had a limited success on higher ground such as the tree maniota (*Cecropia palmata*) and the guava (*Psidium guajava*).
For zonation, see Chapter 2.

1.3 Animals

1.8.1 *The Pacific Islands*

Similar factors to those described for the plants influence animal distributions. The Wallace Line generally separates placental from marsupial mammals, though a few exceptional placental mammals have crossed it. Marsupials were unable to colonize further than mainland Sahulland (at low sea-level) until transported by humans (Bellwood 1985: 14-15). Bats colonized right the way through to the Andesite Line and beyond. In central East Polynesia, there is only one bat (or `flying fox'), *Pteropus tonganus*.

Reptiles were able to cross beyond the Andesite Line, though this only includes gekkonids and scincids (Gibbons 1985; Crombie and Steadman 1986). Few amphibians colonized beyond Sahulland, and none passed the Andesite Line (Gibbons 1985). True freshwater fish hardly occur beyond the Wallace Line, except for New Zealand (Briggs 1987).

Successful colonists across these boundaries include birds, spiders, insects and small species of terrestrial molluscs (Briggs 1987). Land crabs are also very successful colonizers (Burggren and McMahon 1988), including the large Coconut Crab (*Birgus latro*). Birds are able to fly, and the others could survive on floating vegetation or be transported over by attaching themselves to birds or bats.

Sea birds are well-dispersed. Land birds vary in their readiness to cross barriers. Some will not even cross breaks in forest canopy, whilst others will migrate over kilometres of ocean (Diamond 1969; 1984b). The Reef Heron (*Egretta sacra*), which is a bird of marsh, swamp, dry fields and the coastal reef flats, and which is an all year round breeder, is thus well-adapted to colonization. It has a distribution right across the Pacific Ocean as far as the Marquesas Islands (Holyoak 1980).

One other group of birds are the migratory birds, which include the long-tailed cuckoo (*Urodynamis taitensis*) and various sorts of wading birds like plovers, such as the lesser golden plover (*Pluvialis dominica*) and the grey plover (*Pluvialis squatarola*) and sandpipers, such as the wandering tattler (*Heteroscelus incanus*) and the bristle-thighed curlew (*Numenius tahitiensis*)[10]. These birds do not nest in the central Pacific, but are either in transit from a summer in the northern temperate zone to a summer in the southern temperate zone and *vice versa* or they over-winter from the southern temperate zone, where they breed and nest.

There is evidence that some seabirds, like frigate birds for instance, do migrate from East to West and back (Watling 1982). Some birds, like the boobies, frigate birds and some terns, only breed on those islands which have little or no human settlement (Holyoak 1980; McCormack and Künzle 1990), whilst others, like the herald petrel (*Pterodroma heraldica*), nest where there are high mountains. Other seabirds have greater tolerance such as the noddies, the white tern (*Gygis alba*) and the tropic birds.

Land birds of prey, represented by the Falconiformes, were only able to disperse naturally as far as Samoa and Tonga. A harrier has been introduced to Tahiti since European contact by humans (Bruner 1972). Elsewhere, in central East Polynesia, there are still no such birds.

Successful colonists are represented by Columbiformes, including *Ducula pacifica*, and a number of fruit doves and ground doves, by Rallidae, Alcedinidae, Apodidae, Psittacidae, Sturnidae, *Anas superciliosa*, Sylviidae, Monarchidae and *Egretta sacra*.

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9 Nomenclature follows Sykes (1983).

10 Nomenclature for birds mentioned in the text follows McCormack and Künzle (1991), and failing that, Holyoak (1980). For extinct species, Steadman (1989b) is used.

1.8.2 *Rarotonga*

Rarotonga has at present 4 species of land bird, which pre-date human colonization: the *'i'oi* or rarotongan starling (*Aplonis cinerascens*), the *rupe* or pacific pigeon (*Ducula pacifica*), the *kukupa* or Cook Islands fruit dove (*Ptilinopus rarotongensis*) and the *kakerori* or rarotonga flycatcher (*Pomarea dimidiata*). The starling and the flycatcher are endemic to Rarotonga, the fruit dove is endemic to the southern Cook Islands and the pigeon is merely indigenous. A fifth, the *mokora rere-vao* or grey duck (*Anas superciliosa*), died out earlier this century (McCormack and Künzle 1991). The *Manu kura* or Red Lorikeet (*Vini kuhlii*) is recorded in oral tradition (Nightingale 1835; Savage 1962), and its feathers were used in headdresses collected by missionaries and collectors in the nineteenth century (Buck 1944). *karavia* or long-tailed cuckoos (*Eudynamis taitensis*) migrate to Rarotonga from New Zealand and over-winter there. A few birds, probably juveniles, even spend the summer in Rarotonga (Holyoak 1980; McCormack and Künzle 1990).

The Polynesians introduced the domestic fowl (*Gallus gallus*), and it subsequently established a feral population in the mountains (Holyoak 1980). European contact brought the *manu kavamani* or mynah bird (*Acridotheres tristis*) in 1906. It was introduced to control pests by the government, hence its Maori name (McCormack and Künzle 1990). It has since achieved high numbers in the lowlands. Only a small number are to be found at higher altitudes.

1.9 Historical Background

1.9.1 *Polynesia*

Oral tradition in the islands of the south Pacific records eastward movement of people, with the later exceptions of Hawaii to the north, New Zealand to the south and the Polynesian outliers in Melanesia (Kirch and Yen 1982) off the main direction of colonization. West Polynesian traditions record their westerly ancestral land as *Pulotu* and East Polynesian traditions record theirs as *Hawaiki* or variants thereof (Burrows 1938; Smith, S.P. 1921).

Cultural divergence began to appear after Polynesia was settled (Burrows 1938; Smith, S.P. 1898; 1921). The divisions among the island groups of East Polynesia, for example, occurred as a result of arguments between the various lineages of *Hawaiki*, who then went off to found colonies on new islands (Tara`are 1898). Later, there are examples of attempts to extend control over larger territories by some chiefs (Tara`are 1899). Multiple colonization took place, according to oral tradition, stretching out even into times separated by many generations from the original settlement, for example on Rarotonga (Tara`are 1899; 1917; More-Taunga-O-Te-Tini 1910) and Mangaia (Buck 1934).

The period of European contact began in the sixteenth century with the Spanish, and to a lesser extent Portuguese, exploration of the Pacific Ocean in their search for a short and trouble-free route to the Indies (Spate 1979). This included explorers such as Magellan, Mendaña and de Quiros. At least in the extant contemporary literature, there does not seem to be much evidence for contacts with Polynesian islands, except for the Marquesas Islands and possibly the northern Cook Islands or the northern Tuamotu Islands. However, the Spanish may have kept such information secret (Langdon 1975; Salmond 1991). The Dutch followed in the seventeenth and early eighteenth centuries with explorers such as Tasman, Le Maire, Schouten, and Roggeveen. Then, from the late eighteenth century onwards, English and French explorers like Wallis, Bougainville and Cook explored the rest (Howe 1984).

The next phase of contact involved traders, whalers, beachcombers and missionaries, whose visits were more frequent and longer. This phase appears to have led to much economic, political and social change. In Samoa and the islands of central East Polynesia, (apart from a brief episode in the 1770's on Tahiti with a Spanish Catholic mission - Corney 1913-19) the missionary organisation was the London Missionary Society (LMS), which began its work in Tahiti in 1797 and thence spread out to the other islands. The first long-term Catholic missions started with the Picpus fathers on Mangareva in 1837 and Tahiti in 1841 (Howe 1984: 121). In the southern Cook Islands, the LMS was only challenged by the Marist (Catholic) mission and other denominational missions in the latter part of the nineteenth century (Lovett 1899). The missionaries passed on not only religious beliefs, but also European arts, crafts, customs and laws. They were politically active too (Howe 1984). Merchants, whalers and beachcombers were also agents of the transmission of European technology and economic practices (Howe 1984; Martin 1817).

Imperialist expansion by the European states in Polynesia started with the British in New Zealand in 1840 and the French in Tahiti in 1844 and ended with New Zealand in the Cook Islands in 1901. This meant the seizure of political and military control, and the imposition of new laws, customs and economic practises. Sahlins suggests that unlike the previous contacts which led to the incorporation of European ideas into traditional culture, this latter form of contact was perceived by indigenous people as more of an attempt to replace indigenous culture with European culture (Sahlins 1992).

In the latter part of the twentieth century, varying degrees of self-determination have come about in Polynesia. For example, the Cook Islands became a self-governing dependency of New Zealand in 1965 (Gilson 1980) and Western Samoa became independent in 1971 (Howe 1984).

1.9.2 *The Southern Cook Islands*

The southern Cook Islands present an interesting case, because of their location between East and West Polynesia. Cook mentions the presence of some Ra`iateans on Atiu who had apparently drifted there by accident a number of years previously and did not wish to return (Beaglehole 1967). Such records in the literature have helped to generate ideas about so-called `drift voyaging' (for example, Sharp 1963). However, Walter (1990) has evidence from Ma`uke, at least for the earlier stages of settlement, for trade in pearl shell and basalt for adzes. This has received some support from the work of Allen and Schubel (1990) on Aitutaki. There are well-established traditions in Atiu of extensive pre-European contacts with the Societies, especially with Tahiti (e.g. Buck 1944; Marsters pers. comm. 1992). Rarotongan oral traditions narrated by Tara`are (1898; 1899; 1917) show extensive links around the Polynesian world, including `Amoa (Samoa), `Iva (Marquesas or Ra`iatea?), `Avaiki Tautau (New Zealand) and especially, Ta`iti (Tahiti). Some of this is confirmed by references in Savage (1962).

Tangi`ia and Karika, two chiefs who came to Rarotonga at a time when it was already settled, appear to be responsible for the political and administrative structure of the island up until European contact according to Tara`are (1899; 1917), Nicholas (1892) and Te Aia (1893).

The first recorded European visits to the southern Cook Islands after Cook in 1777, were the *Bounty* in 1789 to Rarotonga (possibly mentioned in oral tradition), and then the *Endeavour* (not Captain Cook's *Endeavour*), followed by the merchant Philip Goodenough, who, in about 1813, came looking for sandalwood on Rarotonga (Maretu 1911a; 1911b). Finally, the LMS missionary, John Williams, arrived in Nga Pu Toru (Atiu, Miti`aro and Ma`uke) in 1821 to convert the inhabitants to Christianity.

Tahitian preachers trained by the LMS were landed on Rarotonga in 1823 to convert the population and prepare the ground for white missionaries who came in 1827.

The missionaries not only converted Rarotonga to Christianity, but introduced a number of plants and animals, and a variety of European cultural influences and technology. The visits of traders helped to reinforce some of these cultural and technological influences. Economic change meant that goods, such as cotton and coffee, began to be produced *en masse* for trade (Gill, W. 1856; Gilson 1980; Moss 1889). Sometimes the traders, such as Henderson and Macfarlane and `Bully' Hayes would indulge in acts of aggression, manipulation and exploitation in order to achieve their ends, even more radically changing the lives of Cook Islanders (Moss 1889; Scott 1991).

The missionaries also brought diseases against which Cook Islanders had little resistance, and many died. Rarotonga is one of the best documented cases of population decline due to European-introduced diseases in the Pacific Islands (McArthur 1967). Williams (1838) estimated the population of Rarotonga to have been between 6000 and 7000 people when he first visited in 1827. It is difficult to assess the accuracy of this statement, except to say that with a stated potential error of 1000, it can only be taken as a rough guide. Gill (1856) mentions that from an estimated 4000 people, the population dropped to 3,300 during the course of the 1830's. From the 1840's more accurate information becomes available as the missionaries, and then later the colonial authorities, kept proper records. By the end of the nineteenth century, the population decline was levelling off, and the population steadily rose up again through the course of the twentieth century (Gilson 1980).

The Cook Islands were annexed as a British Colony under the jurisdiction of New Zealand in 1901. A land court, modelled on that of New Zealand, was set up in order to individualise land so that it would become easier to rent it out to European traders and planters[11]. This is clearly evidenced by the writings of the then Resident Commissioner, Colonel Gudgeon (see quotes in Scott 1991: 90). The colonial government tried to effect a greater move towards a capitalist economy and persuade Cook Islanders to cultivate more land, far more intensively (Gilson 1980; Scott 1991). Some of the landscape that can be seen today may well be attributable to the changes made in this period.

In 1965, the Cook Islands became a self-governing dependency of New Zealand (Gilson 1980; Scott 1991). Since then, there have been the competing factors of increasing outside influences, especially economic and social ones, and increasing interest in promoting and reviving traditional culture. These later changes too have exerted an influence on the landscape.

1.10 Ethnographic Background

1.10.1 *Polynesia*

The Pacific Islands, from Island South-east Asia and Taiwan in the west, to the Hawaiian Islands, New Zealand and Easter Island in the east, were colonized by Austronesian-speaking people, and speakers of various other languages (once collectively known as `Papuan', though now thought to be too diverse to be grouped as a language family) in some areas

[11] Land in the Cook Islands was not allowed to be sold to non-Cook Islanders (Crocombe, R.G. 1961).

in and to the west of the Solomon Islands (Bellwood 1985). Austronesia divides up into a number of regions the most easterly of which is Polynesia. Polynesia forms an area roughly in the shape of a triangle, except for a number of small westerly outliers (Bellwood 1987). The Polynesian Triangle extends from New Zealand to Easter Island to the Hawaiian Islands.

Physically, Polynesians are genetically related to South-east Asian populations, with Melanesia having more complex origins (Hill and Serjeantson 1989). The genetic and osteological evidence from Houghton (1980), Hill and Serjeantson (1989) and Matisoo-Smith (1990) indicates that Polynesia was genetically fairly homogenous, although there is some clustering among regions therein, indicating regions with greater genetic interaction. It is often suggested that the distancing of the different groups is due to an initial period of close contact, followed by lessening contact until a state of limited or no contact was reached, as recorded at European arrival. Polynesian cultures have closely related languages, descended from a common theoretically reconstructed ancestor, Proto-Polynesian (PPN) (Clark 1979) Their settlements prior to European contact were rarely nucleated and they lived in scattered dwellings usually close to their food gardens. Social organisation was based, albeit weakly in some cases, on a kinship system. Inheritance was ambilineal, though preferentially patrilineal. An efficient and well-developed maritime technology had enabled them to locate and settle their islands (Irwin 1990; 1991; 1992). They cultivated plants and kept domesticated animals, and introduced new species sometimes deliberately and sometimes inadvertently. Cultivated plants included yams (*Dioscorea* spp.), taro (*Colocasia esculenta*), breadfruit (*Artocarpus altilis*), and bananas (*Musa* spp.); domesticated animals were represented by dogs, pigs and domestic fowls. Clothing was made from bark cloth, cordage and leaves.

Polynesian culture is distinguished more by its homogeneity than by large internal differences that occur elsewhere in Austronesia, say, within the region of Melanesia, where diversity is emphasized. This being said, some broad divisions of Polynesia have been suggested. The main one is that between West and East Polynesia (Jennings 1979; Bellwood 1987) - originally `Central-Marginal Polynesia' as defined by Burrows (1938). West Polynesia consists of Tonga, Samoa, the Wallis Islands, and the Polynesian Outliers (speaking Samoic languages). East Polynesia consists of the Cook Islands, except Pukapuka, the Society Islands, the Tuamotu (or `Paumotu') Archipelago, the Austral (or `Tubuai') Islands, the Marquesas Islands, the Gambier Islands, East Island, the Hawaiian Islands and New Zealand. Among the main differences apart from linguist considerations were an emphasis on godhouses in West Polynesia instead of the court, platform and uprights of *marae* in East Polynesia, and one-piece shell fishhooks, and tanged adzes and food-pounders, which occurred only in East Polynesia.

Within East Polynesia, the central area consisting of the southern Cook Islands, the Society Islands, the Tuamotu Archipelago, the Marquesas Islands, and the Austral Islands have much closer cultural links with each other than do the outlying parts of East Polynesia. The outlying parts or `Marginal Polynesia' have stronger cultural differences that mark themselves from each other and from the central area.

1.10.2 *Rarotonga*

Rarotonga is linguistically part of Cook Islands Maori, which is spoken throughout the southern Cook Islands, except Palmerston, which was settled later by the English-speaking Marsters family in the nineteenth century. Rarotonga has its own dialect, which nowadays is used as the standard version of Cook Islands Maori. New Zealand Maori is a close relative together with Tahitian (Biggs **in press**).

As far as genetic evidence is concerned, it suggests that the Cook Islands, the Society Islands and the Marquesas Islands were in contact to a degree significant enough for them to form a close genetic unit (Matisoo-Smith 1990). West Polynesia appears to be more distinct genetically, though the Cook Islands, especially the northern group, are more intermediate and have some similarities with West Polynesia. Indeed, Katayama working on physical features such as cephalic index and finger whorls has shown that the Cook Islanders have strong links with West Polynesia (Katayama 1987).

Religion consisted of a number of gods found elsewhere in East Polynesia, though the cult of Tangaroa was especially important (Buck 1944). Local gods also existed. The gods expressed their wishes through atavars such as lizards or birds or through the *ta`unga* or priests. Religious ceremonial took place on the *marae*, which consisted of a courtyard with a platform (*atarau*) or platforms, stone uprights and *unu* or sacred wooden carved boards. The *koutu* were a more specialised ceremonial monument for the installation of chiefs.

Chiefs had a number of religious functions, like the setting up of *ra`ui* or sacred prohibitions on the use of certain resources either to prevent famine or to build up that resource for some community occasion or project.

The main crops grown by Rarotongans were bananas, mountain plantains, coconuts, taro, atoll taro, giant taro, Polynesian arrowroot, yams, breadfruit, and Tahitian chestnut. Both Williams (1838) and Buzacott (Sunderland and Buzacott 1866) confirm that the kumara or sweet potato was introduced by themselves, though Hather and Kirch (1991) have found the carbonised remains of kumara on the neighbouring island of Mangaia in an archaeological context between dates of 988-1155 AD and 1409-1440 AD and Captain Bligh mentions it on the neighbouring island of Aitutaki in 1792

(Oliver 1988). Pigs, domestic fowls and possibly dogs were the domestic animals kept (Buck 1944; Williams 1838). Rats were found in abundance (Williams 1838), but were apparently not eaten anywhere in the southern Cook Islands, except Mangaia (Buck 1944).

Many wild plants were used on Rarotonga as well as will be discussed in Chapter 6 (6.3).

Rarotonga was traditionally divided up into the three tribal areas (*vaka*) of Te-Au-O-Tonga, Takitumu, and Puaikura as recorded ethnographically since European contact (Crocombe, R.G. 1961). These were further divided into *tapere*. When the missionaries arrived they created the *oire* or villages, as settlement was not nucleated up to that time. The head of a *vaka* was an *ariki*, and the *ngati* or lineages occupying the *tapere* were headed by either a *mata`iapo* or a *rangatira* (Crocombe, R.G. 1961).

1.11 Résumé

Rarotonga has now been placed in its context from the point of view of location, topography, geology, soils, climate, flora and fauna, history and ethnography in order that the reader may better comprehend the problems discussed. The basic aims of the thesis have also been set out, and in the next three chapters the major issues are presented in detail, beginning with the status of the vegetation.

CHAPTER 2 MODERN VEGETATION SURVEY

2.1 Aims

In the first part of this chapter, an assessment of the present day vegetation of Rarotonga was undertaken to establish why it exhibits such a disjointed nature. The assessment was also required to pose informed questions on the details of its composition and distribution. Suspicions were that human beings had much to do with its modern structure and, to a certain extent, its composition.

The second part of this chapter deals with modern pollen rain studies from the vegetation plots in order to provide comparative material with the fossil samples from the swamp cores. This makes allowance for the dichotomy that often exists between the actual vegetation structure in a given area and its representation in the pollen rain of that same area.

Sykes (1983) divided the vegetation of Rarotonga into three broad zones: the coastal, the lowland and the upland zones. Merlin (1985) subdivided the upland zone by means of dendrogram analysis in to three basic plant associations: the *Homalium* montane forest, the *Fagraea-Fitchia* ridge forest and the *Metrosideros* cloud forest.

For the purpose of this analysis, the vegetation has been divided into six zones, five have a `natural' appearance (1-3, and 5) and one (4) has a distinctly anthropogenic aspect. The other five, too, may well have some varying degrees of human disturbance or influence attached to them. The first of these is the Cloud Forest (Merlin 1985), which veers towards open woodland and contains plant types associated with temperate climes, as well as some more catholic species such as *Weinmannia samoensis* and *Fagraea berteriana*. This occurs usually from 400m (though from as low as 200m in some places) to 653m a.s.l. (Sykes 1983) on very thin volcanic soils (Te Manga Steepland Soils - Leslie 1980) and rock with extreme limitations due to steepness, high erosion risk and low nutrient levels. It is quite exposed to strong wind, and steep inclines create potential problems of subsidence.

Secondly, the Slope Forest from 50m to 400m (Merlin's *Homalium* montane forest and *Fagraea-Fitchia* ridge forest) is the most diverse and the most dense vegetation type. The most common trees here are *Homalium acuminatum*, *Canthium barbatum* and *Fitchia speciosa*. The substrate is Te Manga Steepland Soils (Leslie 1980); a volcanic moderately argillised montmorillonitic soil, or Pokoinu Hill Soils (Leslie 1980) with argillous and stony soils on the lower slopes, both of which are well drained because of the slope, although this is not as severe as in the Cloud Forest. At the back of the valleys, including tributary valleys, there are local concentrations of *Inocarpus edulis* and, occasional *Alocasia macrorrhiza*.

In stream beds, especially in constricted valleys, there is a fairly low diversity flora (Philipson 1971) - mainly *Hibiscus tiliaceus* and *Angiopteris longifolia*: two pioneer species (Philipson 1971; Sykes 1983). The ground is covered in boulders, pebbles and gravel, with some sand and soil (stonier phases of the younger flood plains - Leslie 1980). This irregular and ill-sorted medium is also subjected to flash-flooding during the hurricane season.

Thirdly, on some lower ridges, there are *Dicranopteris linearis* fernlands (Sykes 1983), containing mostly *D. linearis* with occasional small shrubs. Some Cloud Forest elements occur here (Merlin 1985): for example, *Metrosideros collina* and *Mussaenda raiateensis*, though these are only of small shrub size. The substrate is Pokoinu Hill Soils (Leslie 1980).

In the fourth zone, cultivation and housing are not significantly demarcated: in cultivated parts of the zone, there are traditional crop plants, like taro and breadfruit, more recently introduced cultigens, such as cassava and oranges, a few indigenous plants and many exotic weeds; on the house plots, there are hedge and border plants like *Codiaeum* and *Crinum asiaticum*. Exotic ornamentals abound in the gardens, together with a number of putative Polynesian introductions, such as *Cordyline terminalis*, and indigenous plants, like *Barringtonia asiatica*. Some crops may also occur in the gardens. In this zone, there are abandoned house sites and strictly cultivation plots. Where these are covered by herbaceous regrowth, adventive wayside weeds and weeds of cultivation are the most common, whereas arborescent pioneers are almost exclusively represented by *Hibiscus tiliaceus*.

The substrate in this zone comprises five different types: terrace soils (Pouara Soils and Nikao Soils - Leslie 1980), developed on basaltic alluvium; younger and older flood plains (Avana Soils; Takuvaine Soils; Rutaki Soils and Matavera Soils - Leslie 1980), also based on alluvium; fans (Tikioki Soils; Tikioki Soils, stony phase; Tikioki Soils, mottled phase and Arorangi Soils), based on strongly argillised basaltic gravels; swamps (Vaikai Soils and Vaikai Soils, mottled variant - Leslie 1980), based on moderately pre-argillised basaltic alluvium with a small contribution of coral fragments; and coastal sands and gravels (Muri Soils and Muri Soils, stony phase - Leslie 1980). Although this zone mostly does not respect these edaphic boundaries, some of the indigenous plant elements in this zone do. For instance, *Hernandia nymphaeifolia* does not appear off the coastal sands and gravels, and *Homalium acuminatum* does not occur on the sand substrate.

Fifthly, the coastal zone (Sykes 1983) has patchy and discontinuous drought resistant woodland, growing on the coastal sands and gravel mentioned above and those of estuarine margins (Koromiri soils - Leslie 1980). These are formed on basaltic alluvium and reworked coral particles. The *motu* across the lagoon from Muri, in the south-east, are the least disjointed parts of this zone. The vegetation is highly variable with different species achieving only localised dominance, though *Hernandia nymphaeifolia* trees are invariably a significant part of it, and *Barringtonia asiatica* are dominant trees except on the *motu*. Stretching from zone edge to the lagoon are a number of shrubs, like *Scaevola taccada* and *Argusia argentea*, and vines like *Ipomoea pes-caprae* and *Wedelia biflora*. This occurs on the coastal sands and gravels only, which are arid, alkaline, salty and low in nutrients. Their location means they are highly exposed to disturbance from winds, storms and flooding.

Vegetation surveys were undertaken to investigate the relative composition of the different plant species in these zones. Because pollen samples were taken from within each of these vegetation survey plots, they provide models for comparison with the former vegetation represented by pollen cores.

2.2 Methodology

A technique employing plots permitted comparison of modern pollen samples with fossil ones. Plot size was large to handle the diversity, especially of the uplands. Rectangles tackled the nature of the topography for forest, such as on upland ridges and the linearity of the coastal forest; squares simplified estimation of small herbaceous plot percentages.

Basal area was used to measure abundance because cover, frequency and density measurements would have been too time-consuming (Greig-Smith 1964). Cover methods, because they measure the vertical projection of trees, can involve different levels of vegetation or in the case of *top cover* just the highest level: both, but particularly the former, are laborious and impractical given the precipitous topography and time restrictions of the project. These problems occur with, for example, point quadrats, the Braun-Blanquet technique (cover methods), and plotless sampling (a frequency and density method). Plots were preferred to the point-centred quarter, `variable-radius' and transect procedures also due to these problems. Classification and ordination methods like principal components analysis (pca) and factor analysis, were not justified by the limited data that could be collected (*cf.* Arriaga *et al.* 1988; Greig-Smith 1964). The fact that some plots had no species in common would, in any case, have produced `arch' effects if pca had been used (Greig-Smith 1964: 261).

The method follows Greig-Smith (1964). Plots were selected subjectively for representative plots of vegetation types to avoid problems associated with difficult terrain in the mountains and the patchy nature of vegetation types on the lowlands. Herbaceous plots were 4 m^2, and arborescent plots were ideally 50 m by 10 m, though in practice, they were altered to deal with local conditions. Herbaceous plots were surveyed as estimates for each individual species' percentage cover of the plot. Arborescent plots surveys measured the circumference of all tree and shrub trunks at breast height (1.5 m). Only where they were greater than 0.15 m in diameter were they noted and a further calculation made of the basal area in square metres for each tree trunk. The totals for each species were added up. The portion of the basal area each species took up was then calculated as a percentage of the total area of tree trunk for the plot. Where relevant, slope was also measured.

Complete coverage of all the zones was achieved by selecting plots from each of the 5 zones identified above. Extra plots were taken from the following zones. Zone 6 has two plots (a,c) because this zone is highly variable. A second plot

(d) was selected for zone 2 because it is at the meeting of this zone with zone 4, and is under more human influence. Zone 4 has four plots (b,f,g,j) to reflect different types of human influenced vegetation, which is of major importance to this thesis.

The collection of moss, leaf litter and soil samples from the vegetation plots was surveyed for evidence of the modern pollen rain. These have the advantage over pollen traps that they tend to represent longer timescales in the same way sediment samples do. Pollen traps can give more seasonal information, though shortage of fieldwork time and funding precluded this. The collection of voucher specimens for identifications was undertaken.

2.3 Results

2.3.1 The vegetation plots[12] by zone[13] in a series of tables follows (for the raw data consult Appendix A.9):

With the vegetation of each zone now described in terms of an estimate of canopy cover, the pollen rain studies from the same vegetation plots are presented in order to assess how representative the fossil samples are likely to be of past vegetation.

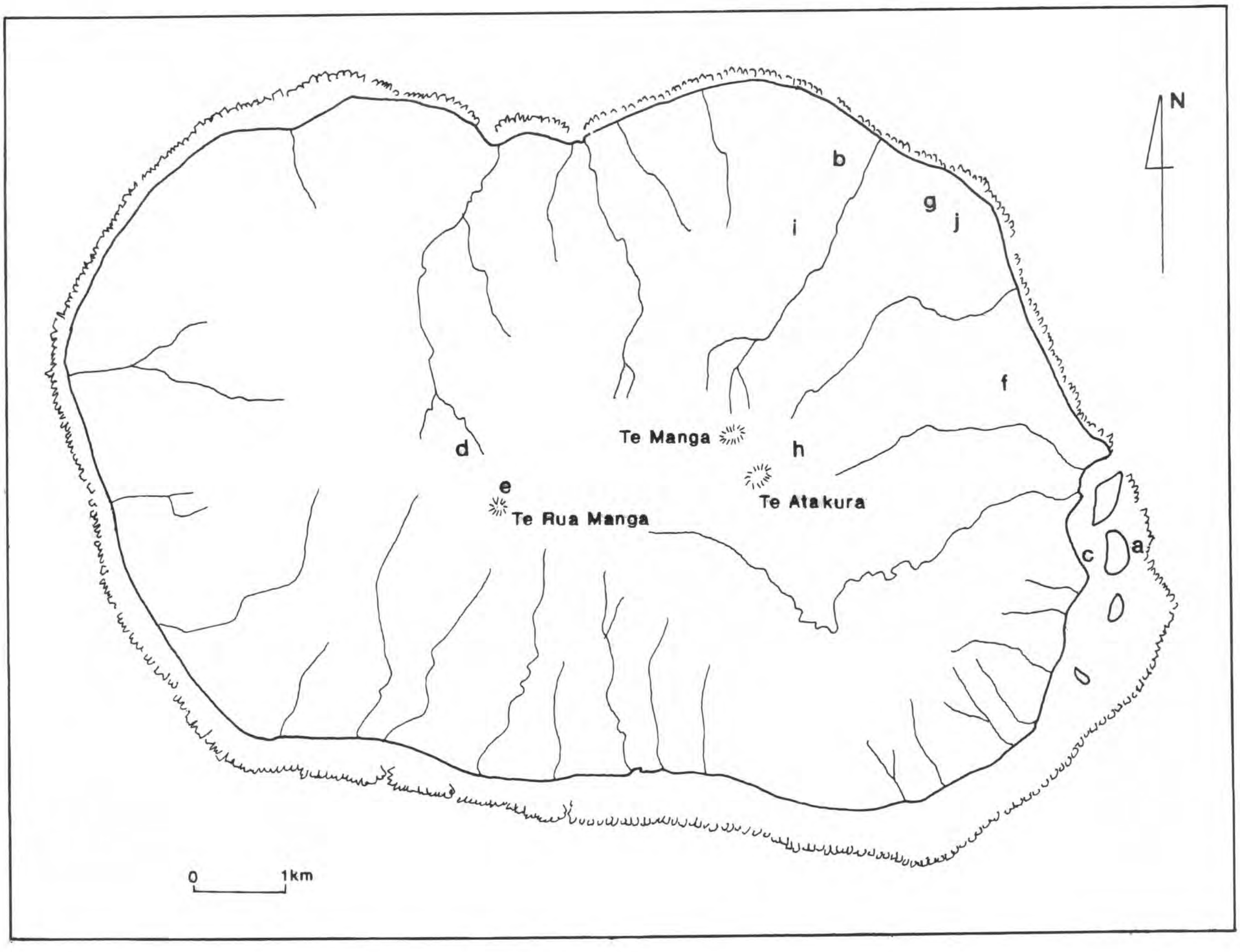

Figure 2.1 Location Map of the Vegetation Plots.

[12] 0.15 (circumference in m)=0.1795 (basal area in m^2)

[13] The location of vegetation plots is marked on Figure 2.1.

Table 2.1 a) Oneroa plot 1. - the seaward side of the *motu*(*Zone 5*)

Taxon	basal area (m^2)	Percentage of total
Casuarina equisetifolia	383.85	77.1
Cocos nucifera	2.46	0.5
Guettarda speciosa	62.87	12.6
Hernandia nymphaeifolia	46.50	9.3
Leguminosae sp.	0.41	0.1
Morinda citrifolia	0.38	0.1
Scaevola taccada	1.53	0.3
Total	498.00	

Table 2.2 b) Regeneration plot near Ariana Bungalows, Tupapa (*Zone 4*).

Taxon	basal area (m^2)	Percentage of total
Ceiba pentandra	32.47	14.0
Hibiscus tiliaceus	163.33	70.4
Syzygium sp.	35.36	15.3
Hibiscus rosa-sinensis	0.68	0.3
Total	231.84	

Table 2.3 c) Oneroa Plot 2. - the landward side of the *motu* (*Zone 5*)

Taxon	basal area (m^2)	Percentage of total
Casuarina equisetifolia	14.01	6.3
Cocos nucifera	195.81	88.3
Guettarda speciosa	0.26	0.1
Hibiscus tiliaceus	0.47	0.2
Argusia argentea	6.38	2.8
Scaevola taccada	4.83	2.2
Total	221.76	

Table 2.4 d) *Inocarpus* dominated Forest at the top of the Avatiu Valley. 14° of slope up the ridge, and 18° of slope on either side of the ridge (*Zone 2*).

Taxon	basal area (m^2)	Percentage of total
Bischofia javanica	5.90	0.5
Canthium barbatum	1.47	0.1
Cecropia palmata	32.68	2.9
Elaeocarpus tonganus	0.23	0.02
Fagraea berteriana	30.41	2.7
Hibiscus tiliaceus	0.29	0.02
Homalium acuminatum	228.99	20.7
Inocarpus edulis	805.70	72.7
Angiopteris longifolia	2.43	0.2
Total	1108.10	

Table 2.5 e) Slope and Ridge Forest: Avatiu side of the Cross-Island Track - *Homalium* and *Fitchia* dominated. *Circa* 200 m a.s.l.. 22° of slope up the ridge and 30° (*Zone 2*).

Taxon	basal area (m^2)	Percentage of total
Alstonia costata	2.15	0.6
Canthium barbatum	13.13	3.6
Elaeocarpus tonganus	16.14	4.4
Fagraea berteriana	70.30	19.2
Glochidion ramiflorum	6.81	1.9
Hernandia moerenhoutiana	12.63	3.4
Hibiscus tiliaceus	3.24	0.9
Homalium acuminatum	195.28	53.3
Weinmannia samoensis	12.65	3.5
Fitchia speciosa	19.96	5.4
Ixora bracteata	2.37	0.6
Meryta paucifolia	2.71	0.7
Pittosporum rarotongense	3.89	1.1
Xylosma suaveolens	4.64	1.3
Angiopteris longifolia	0.36	0.1
Total	366.26	

Table 2.6 f) Weed covered wasteground behind Ara Metua, Matavera (*Zone 4*)

Taxon	Percentage of total
Bracharia muticali[14]	80.0
Grass 2.	8.0
Mimosa pudica	<<1.0
Spermacoce	10.0
The rest, including *Stachyterphata* and *Vernonia cinerea*	1.0

Table 2.7 g) *Commelina* dominated patch - Karekare swamp (*Zone 4*)

Taxon	Percentage of total
Commelina diffusa	99.9
4 Others, including *Eclipta prostrata* ?	0.1 or perhaps less

14 Grass 1.

2.3.2 Pollen Rain Study

This study was undertaken to interpret the fossil data. The fossil record will have been biased by various means over time (see the Taphonomy section - 8.3). Two of these biases are the differential pollen output of separate plant species and their means of pollen dispersal. By carrying out a modern pollen rain survey, one can allow for these two factors. Such studies used in connection with fossil assemblages are well documented: for example, Moore and Webb (1978) and Southern (1986). In this study, moss samples were used instead of pollen traps because of limited time available to carry out field research on Rarotonga. Moss samples are also advantageous in that they are more likely to reveal the trend rather than the quirks of a season or year, though pollen traps allow for a more controlled timescale.

Table 2.8 h) Cloud Forest - ridge on Old Te Manga Track. *Circa* 440m a.s.l.. 22° of slope up the ridge and 50° of slope down from the ridge top. The other side of the ridge top was not surveyed as it was a sheer drop. *Zone 1*.

Taxon	basal area (m^2)	Percentage of total
Alstonia costata	0.32	0.1
Ascarina diffusa	3.49	0.8
Canthium barbatum	0.46	0.1
Cecropia palmata	2.58	0.6
Elaeocarpus tonganus	5.83	1.4
Fagraea berteriana	151.81	36.6
Homalium acuminatum	0.26	0.1
Metrosideros collina	160.38	38.7
Weinmannia samoensis	88.82	21.4
Angiopteris longifolia	0.77	0.2
Total	414.72	

Table 2.9 i) *Dicranopteris* dominated fernland ridge on the side of Tupapa Valley (*Zone 3*)

Taxon	Percentage of total
Melastoma dichotoma	5.0
Dicranopteris linearis	94.0
Nephrolepsis hirsutula	1.0
The rest (*Paspalum orbiculare, Ipomoea littoralis, Elephantopus mollis*)	<1.0

Table 2.10 j) Sedge dominated patch - Karekare swamp (*Zone 4*)

Taxon	Percentage of total
Commelina diffusa	22.0
Cyperus javanicus	78.0

2.3.2.1 Pollen results

As with the vegetation composition estimates, the corresponding pollen rain summaries are set out in a series of tables and a pollen diagram (Figure 2.2):

Table 2.11 Oneroa plot 1. - the seaward side of the *motu*

a) Taxon	Percentage	Numbers
Casuarina equisetifolia	88.0	177.0
Cocos nucifera	2.5	5.0
Guettarda speciosa	2.0	4.0
Podocarpus	1.0	2.0
Moraceae/Urticaceae	3.0	6.0
Pipturus argenteus sim.	0.5	1.0
Gramineae	0.5	1.0
Monolete Spores	2.5	5.0
Total		**201.0**

Table 2.12 Regeneration plot near Ariana Bungalows, Tupapa.

b) Taxon	Percentage	Numbers
Moraceae/Urticaceae	31.0	5.0
Gramineae	12.0	2.0
Monolete Spores	56.0	9.0
Total		**16.0**

Table 2.13 Oneroa Plot 2. - the landward side of the *motu*

c) Taxon	Percentage	Numbers
Casuarina equisetifolia	71.0	145.0
Cocos nucifera	18.5	38.0
Guettarda speciosa	1.5	3.0
Pisonia grandis	0.5	1.0
Argusia argentea	1.0	2.0
Moraceae/Urticaceae	0.5	1.0
Pipturus argenteus sim.	0.5	1.0
Compositae	1.5	3.0
Gramineae	3.5	7.0
Monolete Spores	1.5	3.0
Total		**204.0**

Table 2.14 *Inocarpus* dominated Forest at the top of the Avatiu Valley

d) Taxon	Percentage	Numbers
Bischofia javanica	1.0	2.0
Cocos nucifera	0.5	1.0
Elaeocarpus tonganus	2.5	5.0
Homalium acuminatum	6.5	14.0
Inocarpus edulis	76.0	168.0
Fitchia speciosa	0.5	1.0
Macropiper latifolia	4.0	9.0
Compositae	4.0	9.0
Gramineae	3.0	6.0
Tetrad	0.5	1.0
Davallia	1.0	2.0
Monolete Spores	0.5	1.0
Nephrolepis	0.5	1.0
Trilete Spores	0.5	1.0
Total		**221.0**

Table 2.15 Slope and Ridge Forest: Avatiu side of the Cross Island Track - *Homalium* and *Fitchia* dominated

e) Taxon	Percentage	Numbers
Elaeocarpus tonganus	20.5	41.0
Fagraea berteriana	0.5	1.0
Homalium acuminatum	4.0	8.0
Inocarpus edulis sim.	18.5	37.0
Weinmannia samoensis	3.0	6.0
Ixora bracteata	1.5	3.0
Macropiper latifolia	1.0	2.0
Moraceae/Urticaceae	2.0	4.0
Compositae	1.5	3.0
Gramineae	3.5	7.0
Davallia	23.0	46.0
Monolete Spores	10.0	20.0
Nephrolepis	5.0	10.0
Trilete Spores	6.0	12.0
Total		**200.0**

Table 2.16 Weed covered wasteground behind *Ara Metua*, Matavera

f) Taxon	Percentage	Numbers
Cocos nucifera	2.0	1.0
Inocarpus edulis sim.	7.5	4.0
Podocarpus	2.0	1.0
Moraceae/Urticaceae	2.0	1.0
Pipturus argenteus sim.	7.5	4.0
Compositae	4.0	2.0
Gramineae	36.5	19.0
Ipomoea batatas	29.0	15.0
Monolete Spores	4.0	2.0
Trilete Spores	6.0	3.0
Total		**52.0**

Table 2.17 *Commelina* dominated patch - Karekare swamp

g) Taxon	Percentage	Numbers
Cocos nucifera	3.0	6.0
Inocarpus edulis sim.	3.0	6.0
Moraceae/Urticaceae	1.5	3.0
Pandanus	0.5	1.0
Commelinaceae	78.5	168.0
Gramineae	1.5	3.0
Monolete Spores	8.0	17.0
Total		**204.0**

Table 2.18 Cloud Forest - ridge just above 400m on Old Te Manga Track

h) Taxon	Percentage	Numbers
Alstonia costata	0.5	1.0
Ascarina diffusa	0.5	1.0
Canthium barbatum	0.5	1.0
Casuarina equisetifolia	0.5	1.0
Elaeocarpus tonganus	0.5	1.0
Homalium acuminatum	0.5	1.0
Moraceae/Urticaceae	1.0	2.0
Gramineae	2.0	4.0
Davallia	13.5	28.0
Monolete Spores	17.0	35.0
Nephrolepis	4.0	8.0
Trilete Spores	56.0	117.0
Total		**200.0**

Table 2.19 *Dicranopteris* dominated fernland ridge on side of Tupapa Valley

i) Taxon	Percentage	Numbers
Casuarina equisetifolia	0.5	1.0
Melastoma dichotoma	0.5	1.0
Dicranopteris linearis	98.0	208.0
Monolete Spores	1.0	2.0
Total		212.0

Table 2.20 Sedge dominated patch - Karekare swamp

j) Taxon	Percentage	Numbers
Cocos nucifera	24.0	16.0
Inocarpus edulis sim.	4.5	3.0
Macropiper	1.5	1.0
Moraceae/Urticaceae	3.0	2.0
Pandanus	1.5	1.0
Compositae	4.5	3.0
Gramineae	7.5	5.0
Paspalum	1.5	1.0
Monolete Spores	34.5	23.0
Trilete Spores	9.0	6.0
Cyperaceae	7.5	5.0
Total		**66.0**

With these results, it is now possible to evaluate more precisely how the modern rain relates to its corresponding vegetation types.

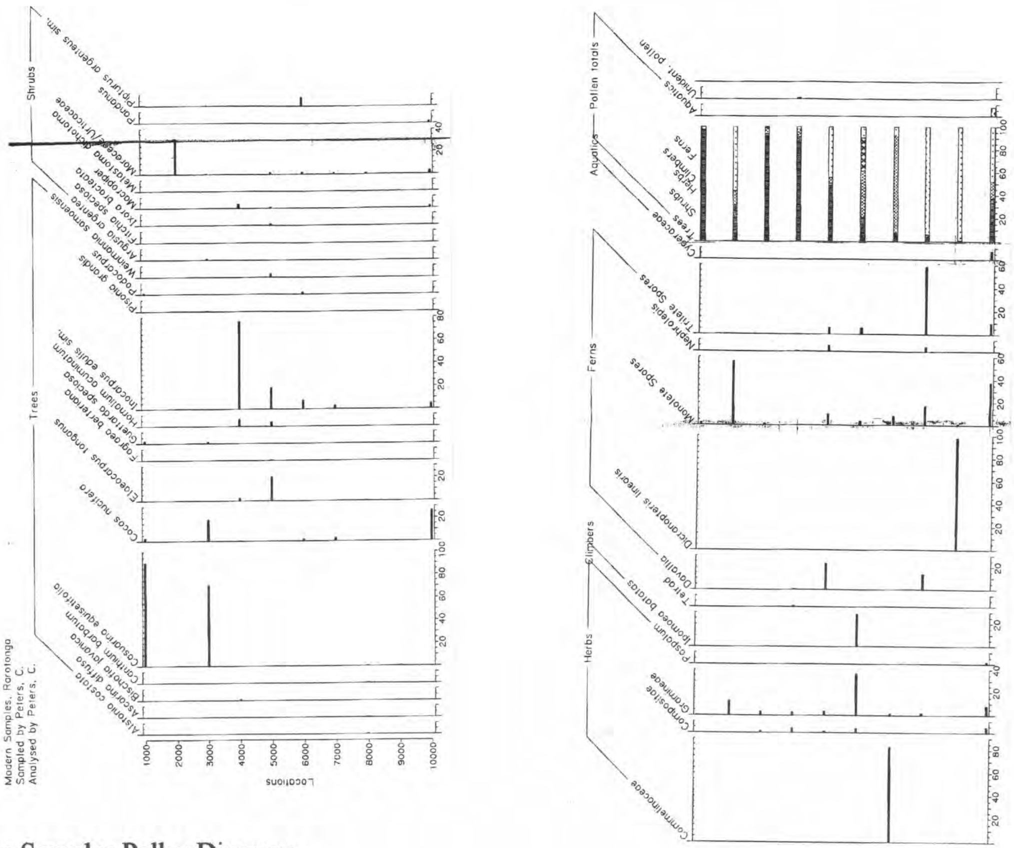

Figure 2.2 Modern Samples Pollen Diagram

see larger scale diagram on Appendices II, B.1

2.4 Comments on pollen rain/vegetation plot correlation

The various plots each highlight a different kind of bias in the modern pollen rain samples, and the comments are designed to highlight this.

a) Oneroa plot 1. - the seaward side of the *motu*
   Casuarina equisetifolia is well represented, even better than its trunk space suggests. *Cocos nucifera* is slightly better represented too. However, *Guettarda speciosa* is very much under-represented and *Hernandia nymphaeifolia* is not represented at all.
b) Regeneration plot near Ariana Bungalows, Tupapa.
   Hibiscus tiliaceus, despite 70.45 % of the trunk space, is not recorded at all from the pollen record. In fact, none of the trees noted on the ground are found as pollen. Weedy pollen is predominant, with grasses, ferns and the Moraceae/Urticaceae.
c) Oneroa Plot 2. - the landward side of the *motu*
   Casuarina equisetifolia is well over-represented, and *Cocos nucifera* well under-represented. *Hibiscus tiliaceus* is again unrecorded. *Guettarda speciosa* and *Argusia argentea* in the vegetation plot occur in the pollen rain too. *Pisonia grandis* from outside the plot and a number of weedy taxa are found in the pollen rain.
d) *Inocarpus* dominated Forest at the top of the Avatiu Valley
   Inocarpus edulis is over-represented, though it is also the largest single component of the trunk space. *Homalium acuminatum* is well under-represented, and some species simply are not represented like *Fagraea berteriana* and *Hibiscus tiliaceus*. *Fitchia speciosa* and a number of weedy taxa are represented in the pollen rain despite not being a significant component of the trunk space.
e) Slope and Ridge Forest: Avatiu side of the Cross Island Track - *Homalium* and *Fitchia* dominated
   Homalium acuminatum and *Fagraea berteriana* are seriously under-represented in the pollen rain. *Elaeocarpus tonganus* and *Inocarpus edulis* are over-represented, despite *Inocarpus edulis* being unrepresented in the vegetation plot. *Canthium barbatum* is not represented at all, which is significant (see Chapter 8 and Chapter 9). Many of the

others are recorded despite their low frequencies, such as *Weinmannia samoensis*. Some weedy taxa are recorded at relatively high percentages.

f) Weed covered wasteground behind *Ara Metua*, Matavera
Ipomoea batatas is well represented, presumably from the last usage of the field before it was left fallow. This suggests that the pollen should be represented in the fossil record if it was present, unless it does not preserve well in the long-term. Grasses are not as well represented as the percentages from the vegetation plot might have suggested. The pollen of some tree and shrub species has become incorporated into the local pollen record.

g) *Commelina* dominated patch - Karekare swamp
Commelinaceae are very well represented, though a little less than in the vegetation plot. The pollen of some arborescent taxa are again recorded, no doubt via wind and rain.

h) Cloud Forest - ridge just above 400m on Old Te Manga Track
Metrosideros collina, *Fagraea berteriana* and *Weinmannia samoensis*, despite their significant presence in the vegetation plot are not recorded. Some of the other tree taxa are represented, despite fairly low percentages, like *Canthium barbatum* and *Alstonia costata*. Ferns are prevalent like *Davallia*. The pollen of *Casuarina equisetifolia* is present despite its lack of representation, probably having been blown up from the fernlands or the coast.

i) *Dicranopteris* dominated fernland ridge on side of Tupapa Valley
Dicranopteris linearis is even slightly better represented than in the vegetation plot, and *Casuarina equisetifolia* is recorded, no doubt its pollen coming from specimens elsewhere on the fernland. *Melastoma dichotoma* is a little under-represented.

j) Sedge dominated patch - Karekare swamp
Cyperaceae are poorly represented, due to the presence of arborescent pollen from elsewhere. Thus, the low frequencies of Cyperaceae in the fossil record, as compared with arborescent pollen, need not imply the swamp had only meagre stands of Cyperaceae.

2.5 Conclusion

A number of different types of vegetation were investigated, and their composition assessed in terms of basal area or ground cover, as appropriate. Plots were taken from all five zones indicated in section 2.1 above. It should be noted that the Zone 1 (cloud forest) and the Zone 2 plots (the slope forest and *Inocarpus*-dominated forest) were quite diverse in comparison to the other vegetation plots, and contained an overwhelming preponderance of species which occurred before European contact. The coastal forest plots (Zone 5) are not greatly affected by exotic species, though it should be remembered that the coastal forest is now very limited in extent. The investigation of Zone 4 (the cultivation and housing zone) revealed a regeneration plot, dominated by pioneer species and exotic species (albeit woody ones), and other plots of primarily herbaceous vegetation with a high proportion of exotic species.

Three of the main problems for the purpose of this thesis are to find out why these vegetation types occur in Zone 4, why they are located where they are (in the lowlands) and how far back into the past can they be traced. In addition, this raises the problem of why the coastal forest is so restricted in distribution, and is this connected with the appearance of the above more open or scrubby vegetation types. These factors may all be related to human influences. Conversely, the mainte-nance of apparent indigenous forest in the inland should be investigated. If, for example, humans were involved in the clearance of the lowlands, including the coast, why did the inland forest remain largely undisturbed (*cf.* Sykes 1983; Merlin 1985) ? One other question concerns the former extent of the inland forests and the coastal forest, and whether another (and now vanished) vegetation type once existed in between. This includes the issue of the origin of the fernlands. In this respect, it should be noted that the species found in the fernlands, including *Dicranopteris linearis*, can all be found in the inland forests (author's observation 1990 and 1992), especially where there are breaks in the canopy cover.

As for correlation with the pollen data, many problems arise with the comparison of fossil pollen with that from modern samples. Some taxonomic factors such as patterns of decay and preservation do not affect modern samples as much, whilst climatic factors affecting dispersal such as humidity and windiness may have altered. Also, the location and circumstances of the modern plots are in most of the cases very different from the fossil sites: the fossil sites are from a swamp that was once a lake.

Herbaceous plants, having been effectively excluded from measurement in the forest plots, were consistently present in the pollen results, though percentages were low (see Tables 2.21 and 2.22). Arboreal pollen occurred in herbaceous plots which reveals that species with wind-blown pollen in nearby woodland can still be represented. *Casuarina equisetifolia* and *Cocos nucifera*, particularly the former, are represented a fair distance from where they are actually present. Other trees, being subject to insect pollination, are either underrepresented or more or less correctly so, except *Elaeocarpus* *tonganus* and *Inocarpus edulis*. This may be due to their small light pollen being easily transported by wind and rain, or perhaps the flowers produce large amounts of pollen.

Zone 1 is unlikely to be well represented in any lowland pollen diagram as its main pollen types are not even well represented locally, and if any thing is likely to be represented it would be from the herbaceous taxa. In Zone 2, forest dominated by either *Homalium acuminatum* and *Fagraea berteriana* or *H. acuminatum* and *I. edulis* is most likely to be represented by pollen tables dominated by *E. tonganus*, *I. edulis* and ferns.

Zone 3 vegetation is relatively accurately represented by its local pollen sample though this does not guarantee a representation in more distant sites. Zone 4 plots covered mainly herbaceous taxa, and for the most part, the pollen results reflect this, albeit tempered by the influx of coconut pollen. The one plot dominated by arboreal taxa was dominated by herbaceous taxa, though the low pollen count makes this result dubious (eg. the local environment may have caused pollen to degrade rapidly). Finally, although the diversity of the coastal vegetation in the Zone 5 plots is obscured in the pollen results, the dominant types are well represented with some minor types being present. The overwhelming representation of

plot		*Alstonia costata*	*Ascarina diffusa*	*Bischofia javanica*	*Canthium barbatum*	*Casuarina equisetifolia*	*Cocos nucifera*	*Elaeocarpus tonganus*	*Fagraea berteriana*	*Guettarda speciosa*	*Hibiscus tiliaceus*	*Homalium acuminatum*	*Inocarpus edulis*	Zone
a	1%	0	0	0	0	77.1	0.5	0	0	12.6	0	0	0	5
	2%	0	0	0	0	88.0	2.5	0	0	2.0	0	0	0	
b	1%	0	0	0	0	0	0	0	0	0	70.4	0	0	4
	2%	0	0	0	0	0	0	0	0	0	0	0	0	
c	1%	0	0	0	0	6.3	88.3	0	0	0.1	0.2	0	0	5
	2%	0	0	0	0	71.0	18.5	0	0	1.5	0	0	0	
d	1%	0	0	0.5	0.1	0	0	0.02	2.7	0	0.02	20.7	72.7	2
	2%	0	0	1.0	0	0	0.5	2.5	0	0	0	6.5	76.0	
e	1%	0.6	0	0	3.6	0	0	4.4	19.2	0	0.9	53.3	0	2
	2%	0	0	0	0	0	0	20.5	0.5	0	0	4.0	0	
f	1%	0	0	0	0	0	0	0	0	0	0	0	0	4
	2%	0	0	0	0	0	2.0	0	0	0	0	0	0	
g	1%	0	0	0	0	0	0	0	0	0	0	0	0	4
	2%	0	0	0	0	0	3.0	0	0	0	0	0	0	
h	1%	0.1	0.8	0	0.1	0	0	1.4	36.6	0	0	0	0	1
	2%	0.5	0.5	0	0.5	0.5	0	0.5	0	0	0	0	0	
i	1%	0	0	0	0	0	0	0	0	0	0	0	0	3
	2%	0	0	0	0	0.5	0	0	0	0	0	0	0	
j	1%	0	0	0	0	0	0	0	0	0	0	0	0	4
	2%	0	0	0	0	0	24.0	0	0	0	0	0	0	

Table 2.21 Relationship between basal area (1%) and pollen rain (2%) for the main pollen types

plot		*Metrosideros collina*	*Weinmannia samoensis*	*Argusia argentea*	*Ixora bracteata*	*Melastoma dichotoma*	Commelinaceae	Cyperaceae	Gramineae	*Angiopteris longifolia*	*Dicranopteris linearis*	Zone
a	1 %	0	0	0	0	0	0	0	0	0	0	5
	2%	0	0	0	0	0	0	0	0.5	0	0	
b	1%	0	0	0	0	0	0	0	0	0	0	4
	2%	0	0	0	0	0	0	0	12.0	0	0	
c	1%	0	0	2.8	0	0	0	0	0	0	0	5
	2%	0	0	1.0	0	0	0	0	3.5	0	0	
d	1%	0	0	0	0	0	0	0	0	0.2	0	2
	2%	0	0	0	0	0	0	0	3.0	0	0	
e	1%	0	3.4	0	0.6	0	0	0	0	0.1	0	2
	2%	0	3.0	0	1.5	0	0	0	3.5	0	0	
f	1%	0	0	0	0	0	0	0	88.0	0	0	4
	2%	0	0	0	0	0	0	0	36.5	0	0	
g	1%	0	0	0	0	0	78.5	0	0	0	0	4
	2%	0	0	0	0	0	99.9	0	1.5	0	0	
h	1%	38.7	21.4	0	0	0	0	0	2.0	0.2	0	1
	2%	0	0	0	0	0	0	0	0	0	0	
i	1%	0	0	0	0	5.0	0	0	0	0	94.0	3
	2%	0	0	0	0	0.5	0	0	0	0	98.0	
j	1%	0	0	0	0	0	0	78.0	0	0	0	4
	2%	0	0	0	0	0	0	7.5	7.5	0	0	

Table 2.22 Relationship between basal area (1%) and pollen rain (2%) for the main pollen types

Casuarina, even in the plot where it was physically present only as a minor component is noteworthy. If it were on the coral rubble beach ridge beside Karekare Swamp, one might expect some sort of representation for it.

Tables 2.21 and 2.22 reveal general trends of pollen presence, such as arboreal pollen occurring on patches of herbaceous growth, and the differing degree to which pollen represents its source plants, such as *Casuarina equisetifolia* always being overrepresented and *Homalium acuminatum* being consistently underrepresented. Section 2.4 amply demonstrates the potential error that can afflict crude comparisons between the fossil pollen data and the modern vegetation. Pollen percentages do not necessarily correspond exactly to percentages of species in the immediate area; in some cases, not at all. This information will be used in the interpre-tation of the fossil pollen data presented in Chapter 8 and Appendix A.4.

CHAPTER 3 CURRENT VIEWS AND RESEARCH IN POLYNESIA

This chapter presents the position attained by research into the archaeology, past environments and present environments of Polynesia, where relevant to the issues covered by this thesis.

3.1 Archaeology

Lapita is discussed to show its relevance to models of early settlement in East Polynesia, and because it covers the earlier settlement of Western Polynesia. The debate over chronology and order of settlement is presented as this thesis has a bearing on it. Issues concerned with the form, location and economy of the earliest settlements in East Polynesia, and later changes are raised with a view to later discussion on how they may relate to changing human-environment relations.

3.1.1 *The spread of Lapita*

Before 3500 BP, settlement in the Pacific Ocean was confined to large islands from the Solomon Islands westwards (Green 1991). In this region, whence the ancestors of the Polynesians were to come, there are settlement dates of about 30,000 to 50,000 years for Australia, Solomon Islands, New Guinea and the Bismarck Archipelago (Allen, Jim 1993; Kirch 1986a). Later, people with a material culture termed the Lapita Culture Complex migrated east into as yet uninhabited island groups (Golson 1971; Green 1979; Kirch 1984). `Culture complex' has been preferred to `culture' due to the temporal and geographic heterogeneity in both ceramic and non-ceramic elements (Green 1992). The Lapita Culture Complex stretched from the Bismarck Archipelago to West Polynesia, and is important in theories about the nature of early colonisation in the Pacific Islands.

Definitions of Lapita have varied from "a technological trait (i.e. dentate-stamped pottery) to a meaningful cultural unit based primarily on commonalities in its ceramic design system to a ceramic series which included both a design system, vessel shapes, and a plain ware component...to a full culture complex" (Green 1992: 11). The ceramic series is a crucial determining factor even in the last sense. Lapita material can occur without pottery (Spriggs 1991: 237-238), though non-ceramics have not gained the same level of analysis (Kirch 1988).

Lapita was a maritime society, which fished, kept certain domestic animals (pigs, dogs and domestic fowls), gardened and hunted, had distinctive artefacts such as pottery (sand-tempered, fired in an open fire, sometimes red-slipped and with dentate-stamped decoration), obsidian tools, stone adzes, bone tattooing chisels and shell fishhooks (Kirch and Hunt 1988). It must also have had an efficient voyaging technology (Irwin 1980; 1989; Irwin, Bickler and Quirke 1990). The increased distribution of the Polynesian rat is associated with Lapita colonization (Roberts 1991).

Lapita sites occur on former shore lines and in caves with 2-4 m of deposits from Vanuatu to West Polynesia, and often have evidence of extinct animals (Green 1992). They are usually shallow, but cover wide areas (at least ten are about 10,000 m^2 or more - Kirch 1987). The people lived in internally differentiated settlements up to village level, and had long distance exchange systems over vast areas (Kirch and Hunt 1988). Settlement types included caves, rockshelters, small hamlets and medium to large villages (Green 1992). Enright and Gosden (1992) suggest they had a maritime focus both in subsistence and external contacts. Island sequences like those from Lakeba (Best 1984), Tongatapu (Spennemann 1987) and northern Ha`apai (Shutler *et al.* 1994) portray this marked coastal distribution. Enright and Gosden (1992) imply that major vegetation changes, animal extinctions and erosion are associated with Lapita.

People bearing this cultural complex spread rapidly from the Bismarck Archipelago into the mid-Ocean island groups of Vanuatu, New Caledonia, Fiji, Tonga and Samoa by 3000 BP (Kirch and Hunt 1988). The Lapita Culture Complex has been equated with a significant migration of people across the Pacific Ocean (Green 1979), who were ancestors of the Polynesians and other Oceanic peoples. Any suggestion of settlement in East Polynesia in the period 3500 to 3000 BP would therefore need to consider this culture complex and how it colonized new areas. The Lapita Culture Complex gave rise to a series of regional successor pottery traditions throughout the area it occupied in addition to new areas settled after c. 3000 BP.

Various models have been proposed for Lapita colonization. The Strandlooper model, suggested by the coastal distribution of assemblages, stated that before the emergence of agricultural settlements, communities had an economy restricted largely to marine and lagoonal resources (Groube 1971). Clark and Terrell (1978) identify four main models: the Strandlooper model, the Supertramp model (*cf.* Diamond 1977), a Population Growth model and a Trader model. The Trader model (Green 1973; 1979), perhaps because trade items such as obsidian are more easily detectable, suggested that Lapita colonists were specialist traders with a highly developed maritime technology and a settlement pattern geared to long distance communication.

Irwin (1980) indicated that the models had flaws: the Population Growth model since people had expanded faster than required when population densities were low anyway; the ecological solutions to the Strandlooper model were deficient as it turned out that the Lapita economies had included agriculture; the Lapita economy's rapidity and continuity were not caused by ecological factors (Standlooper and Supertramp models) or trade (Trader model). Green (1982) investigated the variables on which the models in Clark and Terrell (1978) were based, selecting those variables from the individual models actually corresponding to archaeological evidence. He then presented a new model based on the new combination of variables, the Coloniser model, which listed the features that such a colonizing culture would have. Its distribution would be widespread, with cultural homogeneity, and would be of long duration; its rates of change would be affected by rapid dispersion, resistance to extinction or cultural replacement, and frequent interaction with neighbouring communities up to 600 km away; it would be caused by a generalised economy with both maritime and horticultural components, with effective colonisers, skilful voyagers, with rapid population growth and with an effective communication network.

Ancestral Polynesian Society is seen as having arisen out of the Eastern Lapita division comprising Fiji and West Polynesia, without needing to invoke later cultural influxes (Kirch 1984). Material evidence for a common ancestor of all Polynesian societies, like Polynesian Plain ware pottery and one-piece fishhooks, is, for example, manifested in the To`aga site, American Samoa (Kirch *et al.* 1990; 1993). In Polynesia, Polynesian Plain Ware (Green 1979) had replaced Lapita by about 2500 BP (Kirch 1984), and lasted till the early centuries AD in Western Polynesia (Irwin 1992), and the earliest archaeological levels in Eastern Polynesia (Bellwood 1987). This ware also forms part of the earliest cultural assemblage that is generally accepted as having occurred in East Polynesia, the `archaic' or `Early East Polynesian' assemblage (Walter 1990; 1993). Succeeding assemblages contain no pottery[15]. Walter (1990) has suggested that many of the variables in Green's Coloniser model (1982) are also valid for East Polynesian colonization (see below). Recently, more evidence from northern Ha`apai (Shutler *et al.* 1994) has filled in part of the gap between Tongatapu and Niuatoputapu as regards Lapita, and supports Green's idea of continual and deliberate dispersal of settlement to adjacent islands.

3.1.2 *The settlement of East Polynesia*

There has been much debate on how colonization happened. S.P. Smith (1921), using evidence of oral traditions to produce an account of `fleets' of canoes traversing the Pacific Ocean. Sharp (1963) questioned this view, and, drawing on evidence of historical `drift voyages', suggested no systematic or controlled discoveries took place. Levison *et al.* (1973) using computer simulations showed such haphazard voyaging could not have led to widespread settlement of the Pacific Islands, and experimental voyages have succeeded since (Babayan *et al.* 1987; Finney 1985; Finney *et al.* 1989; Lewis 1966; 1972). The computer simulations of Irwin, Bickler and Quirke (1990) later showed how directed voyages could have led to the settlement of the Pacific islands.

Till recently, the `orthodox view' (Irwin 1981) was that a `bottleneck' (`The Pause') in colonization, around Samoa (settled by 3000 BP[16] - Bellwood 1987; Jennings 1979), led to a consolidation in settlement before the advance into Eastern Polynesia 1000 years later. Sinoto (1968, 1970) proposed the first settled group in Eastern Polynesia was the Marquesas Islands (in 300 AD) with dates from his excavations at Hane, on Ua Huka, and Suggs'(1961) at Ha`atuatua, on Nuku Hiva. Sinoto (1970) suggested the Marquesas Islands became a secondary dispersal centre (joined later by the Society Islands) for the rest of Eastern Polynesia. Easter Island was settled first in 400 AD, the Hawaiian Islands in 750 AD and the Society Islands in 800 AD; the Cook Islands and New Zealand being settled from the Society Islands around 900-1000 AD. Secondary migrations from the Society Islands to the Hawaiian Islands and from the Marquesas Islands to New Zealand were allowed for.

Linguistics was deemed to verify this argument. Pawley (1966, 1967) and Green (1966) provided evidence that Tonga was the first part of Polynesia to be settled, and that the degree of separation was greater between Proto-Tongan (PTO) and Proto-Nuclear Polynesian (PNP) than between Proto-Samoan (PSM) and Proto-East Polynesian (PEP). A timescale was attached to the points of separation and divergence partly by calibration from archaeology (Green 1966; Clark 1979). Green (1981; 1985) later argued for a regional homeland including Fiji and West Polynesia. The idea of a Pause between Samoan settlement and the colonization of East Polynesia emerged (Pawley and Green 1973: 18-19), and was put at about 3000-2000 BP (Bellwood 1987).

Biggs (1972) suggested voyaging to the Marquesas Islands, by-passing all islands on the way, was implausible, and logically people colonize the closest islands without epic voyages. He criticised the A to B to C model of colonization too,

15 Polynesians stopped boiling their food in bowls and emphasized earth-oven baking instead in which containers were made from natural fibres and wood (Leach, H. 1982). There is a lack of good quality clay on crossing the Andesite Line, except for Tonga and Easter Island - the line that separates islands in the Pacific Ocean with continental rocks and those with only recent volcanic and coral rocks (Claridge 1984; Leach, H. 1982).

16 Initially, there was also a proposal that there had been a long pause in migration between Tonga and Samoa Groube 1971), until the discovery of the submerged Mulifanu`a Ferry Berth site, a Lapita pottery site dating to 3000 BP (Jennings 1974; Green 1981).

ignoring possible return voyages and continued inter-island contacts: archaeologists were applying historical linguistic models of language subgroupings to archaeological sequences of different islands and island groupings far too liberally, and without examining enough of the problems (Biggs 1972; Clark 1979).

Further challenges came from archaeology: Irwin (1981) criticised the idea of the `pause', because it did not make sense given the rapid and continuous dispersal of the Lapita Culture Complex across Remote Oceania. He pointed out that a previous pause model (Groube 1971) had foundered when more information came to light. The `pause' was too inflexible a model in the context of a limited history of research: the risk of sampling error was too high.

Kirch (1986b), reviewing evidence accrued thus far, suggested settlement in Polynesia was older than usually thought. He indicated many features of the `Archaic East Polynesian Culture' of Sinoto (1970) did not occur in the earliest layer at Hane (Layer VII). The `archaic' assemblages did not closely match contemporary ones in Western Polynesia as would be expected if they were of the initial colonization phase. On the other hand, the assemblage of Layer VII at Hane included Polynesian Plain Ware, one-piece fishhooks, untanged adzes and a stone octopus-lure, which ties in with Western Polynesia to a greater extent. Pottery sherds were few and judged to be in a secondary context, which led to hopes that even earlier sites, rich in pottery, were yet to be found. Kirch (1986b) suggested that the `Archaic East Polynesian Culture' of Sinoto (1970; 1983) dated consistently to the period 700-1100 AD, including the Marquesas Islands, Society Islands, Hawaiian Islands and New Zealand, when he reviewed the dating evidence.

The radiocarbon dates from early sites, including those form the Marquesas Islands and the Hawaiian Islands, were reviewed. The possible range of the earliest dates from these sites included some much earlier dates than those usually accepted: Kirch suggested human colonization for the Marquesas Islands by the late first millennium BC, and for the Hawaiian Islands, 2-300 AD. The Society Islands were postulated to have undergone subsidence due to tectonic activity, because the Vaito`otia-Fa`ahia site on Huahine was below the water table (Kirch 1986b)[17]. The absence of sites earlier than 850 AD was due to the sites being submerged, and the absence of early dates from the Cook Islands, Austral Islands and other areas was due to lack of investigation, and masking by later sedimentation, itself a product of human activities.

Sutton too (1987; 1988) proposed that the possibility of settlement in New Zealand in the interval between 0 and 500 AD should be pursued actively. He suggested multiple colonization before *circa* 1500 BP had occurred. The proposition was later deposits could have overlaid the early sites, and palynological and geomorphological evidence could suggest earlier settlement. The evidence from Chester's study (1986) was seen as supporting this. She submitted that her pollen sequences from the Bay of Islands, New Zealand, showed human impact at around 1500-1400 BP, much earlier than previously expected, though there are problems with the dating of the Kaharoa Ash layer, which was present in the sediments and was used in the time *versus* depth calibration for the pollen core. The dates for the Kaharoa Ash were reviewed by Froggatt and Lowe (1990) who proposed a more recent date than that used by Chester (1986). Bulmer (1989) also argued earlier episodes of deforestation represented human interference with the environment.

Walter (1990) extended the range of Polynesian Plain Ware outlined by Kirch *et.al* (1988) by discovering this pottery at Anai`o, on Ma`uke, though the pottery was late in date (later in fact than its supposed loss in Tonga or Samoa). Walter thought the `archaic' assemblages represented an early phase of widespread contacts, as did Kirch (1986b), continuing from after the period of initial settlement until about the 13th to 14th centuries AD, when islands supposedly became more reliant on and protective of local resources, and long-distance contacts were no longer pursued. Only where islands were clumped together, with short distances between them, did inter-island contact continue. Walter (1990) identified the early part of the Anai`o assemblage and other early assemblages from the southern Cook Islands as fitting in with this assemblage and timescale.

Hunt and Holsen (1991) reviewed the radio-carbon sequence for the Hawaiian Islands, and suggested that humans may have been present as early as the first century AD., though there was still a potential for erroneous dates deriving from inbuilt age in charcoal samples.

However, radio-carbon sequences have been receiving strict scrutiny and criticism. In Southeast Asia, Spriggs' work undermined some of the early dates for agriculture, and brought about changes in the relationships suggested by the pattern of radiocarbon dates (Spriggs 1989). Spriggs (1990) reviewed the dating of Lapita sites, and found a broader definition of the Lapita culture allowed its beginnings to be dated from 3850-3450 BP. The spread of Lapita beyond the Bismarck Archipelago was placed at about 3200 BP and its spread to the eastern part of Lapita distribution, including West Polynesia, from about 3050-2950 BP onwards. This implied that the process of colonization had involved a series of pauses. In New Zealand, Anderson, applying Sprigg's ideas of `Chronometric Hygiene' to the dating sequence, proposed that the timescale of human settlement could be reduced from 1000 to 700 years ago (Anderson 1991: 792).

Irwin (1989, 1990) has suggested settlement was systematic and continuous, increasing in pace as it gathered momentum (Fig. 3.1). Improved technology and voyaging skills accumulated as greater experience was gained (Irwin 1989; Keegan

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17 New evidence from the `Opunohu Valley, Mo`orea, suggests a date of settlement by 650 A.D. (Lepofsky *et al.* 1992). A coconut from a partially domesticated variety of coconut tree was found preserved in valley alluvial deposits, and radio-carbon dated.

and Diamond 1987). Populations did not have to build up to a stage where excess inhabitants had to leave to find new lands: once enough surplus had accrued, people could afford to set up new colonies (Keegan and Diamond 1987). Using existing dates and the idea of systematic colonization, Irwin (1990) proposed a series of dates for the colonization of areas including undated ones. He estimated the discovery (and settlement) of Central-eastern Polynesia occurred between 3000 BP and 1500 BP; South America[18], Norfolk Island, the Kermadec Islands and New Zealand were reached by Polynesians by 1000 BP and the Chatham Islands by 500 BP. Some smaller islands with harsher conditions and further away from nearest neighbours were later deserted, because of the greater difficulties of existence. Alternatively, they may never have been settled on a permanent basis and may have only been used as an extra, possibly seasonal resource for people from elsewhere (Irwin 1991).

This debate continues with counter-challenges from Kirch, Flenley and Steadman (1991) regarding an early date in Mangaia, southern Cook Islands, and work being presently undertaken by Sutton, Flenley, Elliot and Striewski in Northland, New Zealand (Elliot 1992).

Finally, Spriggs and Anderson (1993) have employed `chronometric hygiene' in reassessing the C-14 chronology of East Polynesia. Their conclusion was there was no conclusive evidence of settlement in East Polynesia before AD 300-600, and this only in the Marquesas Islands where the evidence was still questionable. Anderson *et al.* (1994) suggest that the evidence in the Marquesas Islands that more reliable evidence favours a mid-first millennium AD date on the basis of the artefactual assemblages, the faunal evidence and stratigraphic indications of a short period of occupation. The radiocarbon chronology was not considered clear enough to settle the dating issues. Other than this, the colonization was dated to AD 600-950 in the central, northern and eastern archipelagoes, and AD 1000-1200 at most in New Zealand. The idea of a `pause' between the settlement of West Polynesia and East Polynesia was resurrected due to an apparent 1300-1600 year discrepancy between their respective settlement dates.

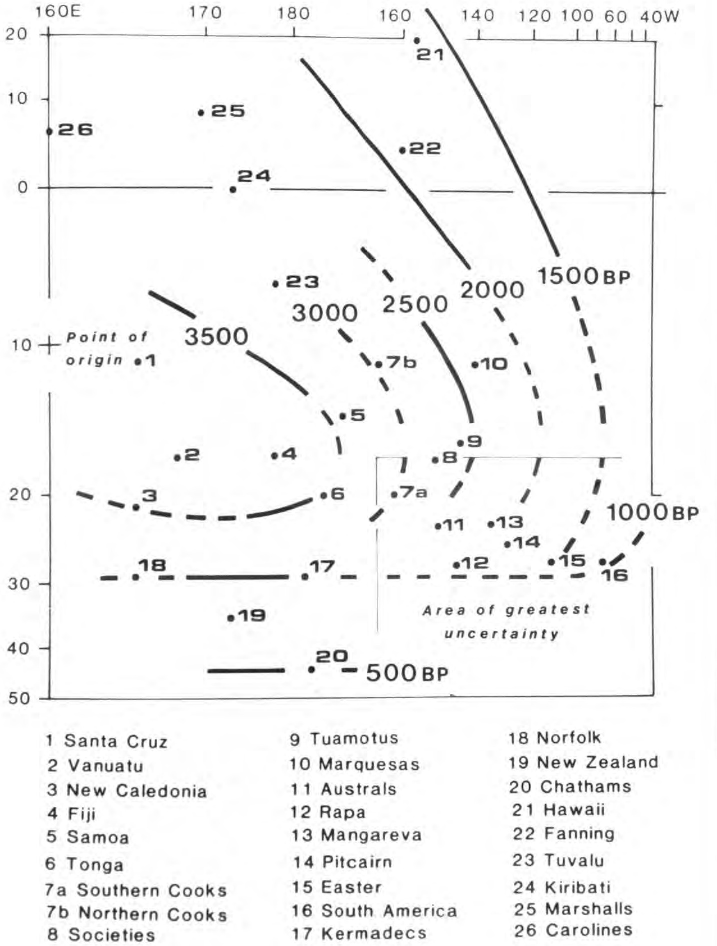

Figure 3.1 Diagram showing the chronology of settlement hypothesized by Irwin. *After Irwin (1990), fig.1. p. 91*

The earliest archaeological dates from the southern Cook Islands accepted by Spriggs and Anderson (1993) are AD 810-1170 (Allen and Steadman 1990) and AD 890-1240 (Bellwood 1978) both from Urei`a, Aitutaki. An accepted date (AD 780-1160) from Rakahanga in the northern Cook Islands taken by Chikamori (Spriggs and Anderson 1993) may be significant for the southern group because oral tradition states that Rakahanga, and its neighbouring island of Manihiki, were settled from Rarotonga (Buck 1932a).

However, Spriggs and Anderson (1993) challenge dates from lake and swamp sediments from the Cook Islands, the Society Islands and Easter Island as being contaminated. On Mangaia, the Lake Tiriara sequence was thought to be affected by leached CO^{-2}_3 from the makatea, because of the dichotomy between the later period of extinctions on such a small island and the apparently earlier period of deforestation and settlement by Polynesians. C_{14}-deficient carbonate rocks are known to be disruptive of limnic chronologies (MacDonald *et al.* 1991), though there is surprisingly little irregularity and much consistency about the swamp and lake chronologies from the southern Cook Islands (see Chapter 9) which may well meet criterion P from Spriggs and Anderson's (1993) list for acceptance of radiocarbon dates.

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18 South America was probably visited by Polynesians, hence the dispersal of the kumara across the Pacific, though they did not settle there (Irwin 1992, p.100).

Ellison **(in press)** has recently proposed a date of 2500 BP for the first human-induced deforestation episode on Mangaia. This was on the basis of a series of radiocarbon-dated swamp pollen sequences. Kirch and Ellison (1994), though not directly challenging the methodology of `chronometric hygiene' (except to say that it was `overzealously applied'- p.311), attempt to use the Mangaian data to demonstrate a case for an environmentally-constructed chronology of early colonization. This time a more cautious date of between 2450±80 and 1640±50 BP is suggested, though as pointed out in 9.3.2, this could well be an artefact of truncation. However, two other points made by Kirch and Ellison may well caution against too swift a dismissal of other aspects of the Mangaian evidence: firstly, the avifauna could have survived to the extent it did due to the impenetrability of the *makatea*; and secondly, that the consistency of the radiocarbon dates from the Mangaian cores contests the claim that they have been contaminated by calcium carbonate from the *makatea* (Spriggs and Anderson 1993: 211).

3.1.3 *Models of early settlement and economy*

The form of early settlement and economy is crucial in determining former human-environment relations. The first models of settlement form, location and economy conjectured that, because of an assumed short chronology (Buck 1944; Smith, S.P. 1898; 1921), there would have been no change since the initial settlement. Such change would have meant changes in human-environment relations too. With the onset of radiocarbon dating and the growth of archaeology, early sites seemed to be coastal, right from Lapita through to the colonization of East Polynesia (Bellwood 1979a). These early sites were found to involve a large amount of the remains of birds, bats and marine animals, including presently extinct or endangered species (Steadman 1989b).

Earlier models assumed that island sequences developed in isolation on the basis of the `drift' voyaging ideas of Sharp (1963). Kirch (1984) advanced the view that, for example on high islands, small populations would have begun on the shoreline, dividing into senior and junior lineages till they occupied each valley section of the island, and then they would have spread up the valleys, exploiting the different resources located at separate points along that catena. This was then applied to the case of the Hawaiian Islands, where these valley sections, *ahupua`a*, had earlier and later sites located at the coast with progressively only later and later sites found further and further up the valleys (Cordy 1974; Green 1980; Kirch 1985).

Walter (1990) drawing on the evidence of the existing archaeological literature for the southern Cook Islands, showed that there seemed to be a correspondence between the early sites and reef passages too, because of the importance of marine resources and long-distance trade in the early economies. Basalt and pearlshell had been imported from at least the neighbouring islands of Rarotonga or Aitutaki. Imported pearlshell was also found at Tangata Tau rockshelter on Mangaia (Kirch *et al.* 1992). Allen and Schubel (1990) investigated a basalt quarry site on a *motu* of Aitutaki which was suggested as having some sort of involvement in such inter-island trade, though P.J. Sheppard (pers. comm. 1993) questions whether it can really be called a quarry. Recently however, Weisler *et al.* (1994) carried out XRF analysis on some suspected quarries on Mangaia, Aitutaki and Rarotonga as well as basalt adzes from a well-dated rockshelter on Mangaia. It was found that the source for the basalt adzes was a quarry on Mangaia 3 km away. The Lapita Culture Complex had also developed a network of long-distance trade in obsidian (especially from the Talasea source, New Britain), pottery and chert (Best 1987; Kirch 1988; Sheppard and Green 1991). This connects well with increasing evidence for return voyaging as a factor in the colonization of the Pacific Islands (Anderson and McFadgen 1990; Irwin 1990).

Walter (1990: 21-22) also proposed a ten point outline of Eastern Polynesian settlement, influenced by the earlier Coloniser model developed by Green (1982) for Lapita:

1) Eastern Polynesian colonization commenced soon after that of Western Polynesia as a result of the continuation of Lapita voyaging and colonization strategies.
2) Colonization followed a basic west to east orientation with the first Eastern Polynesian colonies established in the Northern or Southern Cook Islands.
3) By about 2500 BP most of the islands of central East Polynesia had been discovered and many of these settled.
4) Voyaging continued unabated, despite the decline in successful discovery voyages, until a point at which an effective communication system was in place.
5) As innovation in material culture and language appeared, they were spread throughout the communication network. There was no `centre' (single or otherwise) within which these innovations developed.
6) Trade in raw materials also took place through the medium of the communication network.
7) This network would have incorporated distance decay factors so that islands closer together would have been in more regular contact. This resulted in the development of overlapping interaction spheres possibly marked linguistically as dialect chains or as isogloss ares. These, however, may not be marked archaeologically in a form that is amenable to study under the recent schemes of artefact trait comparisons (ie Duff 1959, Emory 1968, 1970, Bellwood 1970, Sinoto 1970).

8) At a point sometime after the 14th century the frequency of voyaging decreased, the network contracted to the point where some island became isolated and regular voyaging continued only in the most densely packed regions.
9) The decline in regular inter-island interaction would have accelerated and two major subgroups of PCE developed out of dialect areas focused on two spheres of major interaction which became increasingly isolated from one another. Smaller linguistic units such as `Tahitian' and `Cook Islands Maori', which in turn composed of several loosely defined dialects, also developed within these major subgroups through the same process of constriction. The use of imported materials would have fallen off at about the same time. This would have brought about a change in the material culture of those islands that had an increasingly limited access to specialist resources.
10) By the beginning of the 19th century, many islands were in a state of near total isolation. The individual island sequences had diverged and regionally specific adaptations in economic and political organisation were well established.

From his work in the southern Cook Islands, Walter (1990; 1991; 1993; **in press**) suggested that the initial pattern of nucleated coastal villages was replaced by scattered settlement over inland horticultural areas as kin-based groups began to be associated with specific land areas and it became important to be resident on the land claimed. Maritime links with other islands then waned and became less significant. This model in particular has influenced the development of the model proposed by the author in section 9.2.

Another view is once marine resources and bird stocks were reduced, greater attention was directed to agriculture, and control over land gradually became more important (Kirch 1984). A slightly different scenario has been mooted for Mangaia (Kirch *et al.* 1992). Here, it is suggested that people deforested the interior by practising swiddening, reducing the bird and bat population to refugia in the makatea, where they were then hunted out. Finally, the population turned to the swamp lands, between the other two zones, to plant taro, which became their main staple.

Initial settlement in inland valleys of the Hawaiian Islands, Tahiti, Mo`orea and Rarotonga seems not to appear until after about 1200 or even 1300 AD (Bellwood 1987; Kirch 1990). In some windward valleys of the Hawaiian Islands, there is some evidence of agricultural activity as early as 1000 AD, though large scale developments do not appear until 1400 AD (Allen, Jane 1991). The lack of early inland sites is seen as supporting the idea of coastal settlement being the first sort of settlement. This pattern is also evident from Fiji, where Lapita sites are all coastal, and the subsequent pottery sites are both coastal and inland until relatively late (Best 1984; Crosby 1988). On Tongatapu, all the early Lapita sites are in the form of coastal middens (Spennemann 1987). In Samoa, the only Lapita site found so far is coastal (Bellwood 1987).

Evidence for human presence, especially agricultural activity, is important in establishing a chronology of settlement. Another problem is whether earlier coastal settlement involved widespread clearance or did this occur later. The case of Mangaia having early inland settlement, if true, seems more an exception.

Rolett (1993) has identified four models for the colonization of the Marquesas Islands and East Polynesia in general: cultural continuity in isolation, innovation in isolation, interaction and cultural continuity and interaction and innovation. The first saw immigration from West Polynesia around 200 BC, with the Marquesas Islands and the Society Islands acting as "centres of diffusion", though thereafter the archipelagoes remained highly isolated with significant change only occurring 1000 years later (Suggs 1961). The second (Sinoto 1968; 1970; 1983) suggested that after settlement around 300 AD from West Polynesia, cultural change developed more rapidly into a cultural complex that Sinoto and McCoy (1975) have called the "Archaic East Polynesian" and Bellwood (1979b) the "Early East Polynesian". The Marquesas Islands remained in this model the main centre of dispersal in East Polynesia. The third model identified two-way voyaging and rapid exploration (Finney *et al.* 1989; Irwin 1990) as the process of colonization. Continued interaction with exchange systems and regular two-way voyaging hindered diversification (Walter 1990: 21-22). The final model (Kirch 1986) sees the East Polynesian homeland as a region (including the Society Islands and the Marquesas Islands) which was colonized as part of a continuous chain of settlement from West Polynesia. Cultural innovation occurred in this region firstly before the settlement of the more distant islands such as Hawai`i and Easter Island, and secondly after the settlement of such islands (*c.* 700-1100 AD).

3.1.4 *The Diversification of East Polynesian Culture*

Later periods (post 1400 AD) varied in social, political, economic, technological and religious relations. These later developments generally included higher populations, more internal island expansion and a growth in distinctive regional cultures. In many cases, there appears to be increased stratification in society. Divergence in material culture between East and West Polynesia is clear (Burrows 1938): some of this due to change in both areas since initial colonization of East Polynesia, and is best illustrated in the archaeology record (Bellwood 1987).

This is the period which received the first archaeological attention, because of the highly visible remains and connection with the more accessible, and interpretatively informative, immediate pre-European contact society. Emory undertook the first archaeological surveys in Polynesia: in the Hawaiian, Society and Tuamotu island groups (1928; 1933; 1934). He classified the forms of the *marae* in the Society and Tuamotu groups into types. Detailed areal excavations and settlement pattern studies to investigate the structural relationships were carried out later by Green (Green *et al.* 1967) and Descantes (1993) in the `Opunohu Valley on Mo`orea, by Green and Davidson (1974a; 1974b) and Jennings *et al.* (1980) in Western Samoa, by Kirch and Kelly in the Halawa Valley, on Moloka`i (1975), by McCoy on Easter Island (1976), by Green in the Makaha Valley, on O`ahu (1969; 1970), and Kirch *et al.* in the Anahulu Valley, on O`ahu (1992). These have assisted in the analysis and interpretation of sequences of settlement, economy and sociopolitical change on individual islands (for instance, Kirch 1985).

Kirch (1984) noted in some areas, powerful, more centralised chiefdoms arose, such as in Hawai`i and Tonga, whereas others had much less stratification and centralisation. In all areas, the society remained dominated by kin-relations, though weakening in Hawai`i as chiefs and their more immediate families sought to distance themselves genealogically from the commoners - though some of the later changes were due to European contact, and it is not clear how far these changes would have gone otherwise (Kirch 1984). These differences in societies were thought to have arisen from such factors, deduced from the archaeological record, as population increase, intensification of agriculture, environmental change (human-induced as well as natural), reduction in availability of resources and increasing warfare (Bahn and Flenley 1992; Kirch 1984).

This consolidation and internal intensification can be seen from recent studies in the Hawai`ian Islands which suggest that colonisation into the upper valleys took place from about 1200 AD with rapid expansion after 1400 AD (Allen, Jane 1991; Spear 1992; Williams, S.S. 1992). Earlier activity in these valleys may have occurred by 300 AD and colonisation by 700 AD, but S.S. Williams (1992) suggests that since a gap in data between these dates and later ones, there may be a problem of inbuilt age. Leeward areas were colonized from windward areas after 1200 AD as well (Allen, Jane 1992). In the saddle region, activities may have begun as early as 700 AD, though significant use occurred between 1300 and 1650 AD, the formalising of land tenure eventually leading to a decline in intensity of use (Streck 1992).

Kirch (1990) argued Hawaiian society reached a high degree of sociopolitical complexity by the late nineteenth century by forming larger political units, greater levels of energy extraction (by intensive productive technology), considerable functional specialisation (craft specialisation, artefact standardisation, nascent bureaucracy and warriors) and an evolved political hierarchy. Only three or four Polynesian societies could be said "in Sahlins' terms, to have pushed the limits of tribal society" (Kirch 1990: 312): Hawai`i, Tonga, the Society Islands and possibly Samoa.

Kirch (1984: 101-104, 120-122) applied an evolutionary model, based on models from population biology and evolutionary ecology, tempered by multifactorial approaches, to the processes occurring up to European contact. He proposed that populations began with relatively small founder groups, gradually dividing into different lineages, later subdividing till all the island was settled. These lineages contested resources and status, whilst populations rose, causing ecological disaster as competition led to over-exploitation of resources. This combined with warfare reduced the population (eg. tensions between dryland and wetland cultivation areas were one source of conflict - Kirch 1990), and the process began again. Demographic pressure was thus linked to inherent stresses in the formation and development of Ancestral Polynesian Society.

Bahn and Flenley (1992) have recently suggested a similar model (inspired by the Club of Rome's predictions for global environmental problems) for Easter Island, though more ecologically-based. Some archaeologists like Hommon (1986) and Stevenson (1986) argue population growth was the principal factor underlying cultural, social and economic (and resulting environmental) changes. Stevenson (1986) argued that the decline in ancestral shrines (*ahu*) on Easter Island and the related break down in community solidarity was due to high population densities and the consequent decline in availability of agricultural land.

Such views have not been generally accepted. Kirch (1984) was queried by Sutton and Molloy (1989), who felt that the application of a model based on colonizing animal populations to cultural beings was inappropriate. Algorithms developed since 1983 had suggested that differences in fertility rather than mortality (as Kirch had indicated) were more important, and that shifts in fertility were not dependent on population density. There were cultural restraints on fertility and mortality which had been ignored. Brewis *et al.* (1990) in a study based on New Zealand skeletal evidence have calculated a population growth rate of less than 1% a year, though indicating that the growth rate pattern tended to be more sigmoid than linear.

During this period, a number of islands lost their human populations altogether, so that by the time of European contact, they were empty of people. These `Mystery Islands', such as the Pitcairn, Necker, Nihoa, Raoul and Norfolk Island, have been found to contain structural and artefactual evidence and cultivated plants (Anderson 1980; Bellwood 1987; Emory 1928; Heyerdahl and Skjölsvold 1965; Specht 1984). It may be that the harshness of the environments of these islands, many being small and drought-prone, made survival unacceptably difficult (Bellwood 1987; Irwin 1991). Such islands were found to be too distant from neighbours if plotted out (Irwin 1990). Some uninhabited islands were utilised from time to time (and at some periods had been settled on a permanent basis) if they were close to a larger neighbouring island.

Examples of this are Nassau, near Pukapuka, in the northern Cook Islands (Bellwood 1987). Irwin (1992) noted that lack of accessibility is the common factor behind all the `Mystery Islands', and this could, thus, be the major factor. The reduction in voyaging after 1400 AD suggested by Walter (1990) would have thus diminished their viability as inhabitable islands.

Weisler (1994) found that Henderson Island, one of the `Mystery islands', had indications of voyaging contacts between Henderson Island, Pitcairn Island and Mangareva in the discovery of exchange items dating to before about 1400-1450 AD: imported pearlshell, volcanic oven stones, basalt adzes and flakes and volcanic glass. After this date, local items such as *Tridacna* shells for adzes and limestone cobbles for oven stones replaced the exotic materials. This lends support to the arguments of Irwin (1990) and Walter (1990) above.

The withdrawal from less accessible islands and the process of internal colonization of larger more accessible islands, being argued for, implies that the latter would have been increasingly subject to human pressure from perhaps 1000 AD, and especially after 1400 AD. Other arguments discussed suggest these human pressures derived from factors such as increasing hierarchies, intensification of agriculture and possibly population growth. These would be important considerations in any model for environmental change on Rarotonga.

3.2 Environmental Past

The debate surrounding past environments, including those before human settlement, are explored here to identify the range of potential questions and problems which will be addressed by the research presented in chapters 5 to 9.

Trends in the attitudes of European and European-inspired literature about the relationship of Pacific Islanders and their environments has often had much to do with philosophical and ideological change in Europe and those countries largely populated by people of European descent. Such trends can significantly influence the evidence that is available to researchers. Also, the history of thought in this subject presented here shows how the present debate emerged and what its basis was.

The first attitudes were influenced by the `Enlightenment' of the late eighteenth century, which included the view that humans had once lived in simple harmony and peace, and were at one with their environment. The European explorers at the time, especially Bougainville (1771), who for example named Tahiti, `*Île de Cythère*', interpreted the Pacific Islanders as having remained in this former state of innocence. The artists accompanying the expeditions of Captain Cook between 1769 and 1780 painted Pacific Island landscapes as if they resembled Classical Greek and Roman visions of divine and idyllic scenes (David *et al.* 1988; Joppien and Smith 1985a; 1985b; 1987a; 1987b; Smith, B. 1988).

The next group of Europeans to interpret human-environment relations were the missionaries who were more critical of the achievements of pre-Christian Pacific Islanders (e.g Sunderland and Buzacott 1866; Gill, W. 1856; Gill, W.W. 1876a). Missionaries frequently commented on the amount of waste land not taken up for agriculture (see 9.2), or on the destruction of resources during wars (Lovett 1899).

Merchants, whalers and beachcombers were also active in promoting visions of the Pacific Islands. For example, as early as 1864, Marsh (1864: 49) comments on the way in which Australian and New Zealand landscapes were being transformed at the time: `large tracts of virgin forest and natural meadow are rapidly passing under the control of civilized man'. Marsh feared that the sheer scale of activity might have long-term effects for the environment. These capitalist interests led to calls for colonial rule by the major imperialist powers in order to protect the financial interests of their own nationals operating in the Pacific Islands (e.g. Scott 1991 and Howe 1984). Colonial administrators attempted to improve management techniques and agricultural methods (Moss 1889; Scott 1991).

After the Second World War, accompanying the wave of independence sweeping the Pacific Ocean, there were waves of anti-colonialist sentiment (Ravuvu 1987; Ravuvu 1988; Nunn 1990b) and also anti-technological thought (Nunn 1990b). The former chastised European writings for being insensitive and imposing their cultural norms on the indigenous customs and values, and the latter revived some of the older ideas of a harmonious relationship between Pacific Islanders and their environments.

In this intellectual climate, researchers may have been inclined not to link Polynesian settlement and vegetation change. Selling's (1946-1948) palynological studies of upland bogs in the Hawaiian Islands linked environmental change there in with the climatic periodisation developed for Europe as extrapolated from Hawaiian pollen diagrams. Humans were not regarded as being responsible for the changes he saw as the Polynesian colonization of the islands was not considered to have any great time depth (Selling 1948: 127). Unfortunately, this work preceded the advent of radiocarbon dating, so no dates are available for these environmental changes.

In New Zealand, Raeside (1948) and Holloway (1954; 1964) argued that change in the form of colder, drier climates had caused matai (*Libocedrus bidwillii*) forest of South Island to be replaced by grassland in its uplands regions from about 750 years ago. Human interference was rejected on the basis that the South Island forests were unusually heterogenous and that significant climatic changes were suggested by the fact that warm-climate crops had once been grown in the South Island.

Yen (1961) suggested that a warmer climate prior to 1200 AD, such as mooted by Raeside and Holloway, could have permitted the introduction of the tropically adapted kumara to New Zealand, which was later adapted to winter storage when temperatures declined.

In the 1970's, general sequences for the Holocene in the Pacific were being worked out, which encouraged some authors to consider wider natural changes as having a greater influence on environmental change. Porter's (1975) study of the glacial chronology of Mauna Kea on Hawai`i, in the Hawaiian Islands dealt with the late Pleistocene and early Holocene periods, and successfully linked the chronology with that of mid-latitudes. Actual glaciation of the peak was considered to been short, and over by around 9000 BP. Flenley and Morley (1978) dated the end of glaciation on Mount Kinabalu, on Borneo, to a minimum of 9,186 $\pm$120 BP, suggesting that this represents a more general tropical Pacific trend. Indeed, Löffler (1972) has shown that the glacial sequence from the Highlands of New Guinea also matches the dating from mid-latitude sequences.

A renewal of cold temperatures on Mauna Kea (Porter 1975), though not extreme enough to produce snow banks, occurred within the last thousand years, because solifluction had taken place during the period that humans had quarried Mauna Kea for stone. This may be linked to a cold phase experienced elsewhere in mid to low latitudes in the latter part of the second millennium AD (Porter 1975; Roberts 1989).

Cores from the equatorial Pacific Ocean were analysed (Shackleton and Opdyke 1973) by means of Oxygen Isotope ratios and Palaeomagnetism. These revealed temperature changes over the late Pleistocene and Holocene periods, as well as periods beyond the timescale relevant here.

Based largely on Wardle's (1973) study of glacial advance and retreat and its implications for general New Zealand climate change, Leach and Leach (1979) proposed a `climatic optimum' between around 900 and 1500 AD allowed the cultivation of kumara and gourds in the Wairarapa, which was subsequently abandoned when the climate deteriorated. Burrows and Greenland (1979) show many climatic changes during the period 1100-1900 AD, though their temperature values record a maximum amplitude of $\pm$0.7 °C from 1100 to 1600 AD and $\pm$0.5 °C from 1600 to 1900 AD based on speleothems (Ibid: 363). This need not present too much of a problem for Leach and Leach's view, because speleothems are notoriously conservative (cave environments tend to be buffered against short term temperature changes outside their microenvironment - Evans 1978: 4). Green and Burrows (1979: 363) themselves warn that the speleothem temperatures are only taken at face value.

However, a view that Polynesian colonization was the major contributor to environmental change began to emerge as the dominant view during the course of the 1960's and 1970's. Cumberland (1962) thought that the deforestation of New Zealand was wrought by means of `*Brandwirtschaft*' practised by the Maori. Molloy *et al.* (1963) produced radiocarbon dating evidence from fossil wood and charcoal samples to demonstrate that the New Zealand savannahs, especially the tussock-lands of the South Island, were woodlands at the time of Polynesian settlement. On Easter Island, McCoy (1976) claimed that the landscape had `deteriorated.....following over-exploitation and misuse by man' on the basis that with a population of 7, 000 people (estimated from settlement surveys), Easter Islanders would have been forced to overexploit their resources. Flenley and King (1984) later investigated the pollen record finding evidence for the decline of woodland species, which they interpreted as the result of Polynesian clearance activities. Kirch's (1975; 1976) study of economic practices and their ecological effects in the Wallis Islands challenged the idea that indigenous Polynesian economies were based on sound conservation practices.

A key variable in the change in thought was the study of settlement patterns in archaeology (Kirch 1982). This focused attention on local environments and their relationship with human settlement. Local erosion at Makaha (Green 1969; 1970) and Halawa (Kirch and Kelly 1975), and dwindling woodland at Lapakahi (Tuggle and Griffin 1973) were interpreted as evidence of human mismanagement of the environment.

By the 1980's, the Environmental Degradation view had become orthodoxy:

> In certain academic as well as popular circles, the thesis has arisen that prehistoric Oceanic peoples avidly practised a `conservation ethic' towards their island habitats, and that major ecological changes did not occur until after the advent of Europeans. Recent evidence shows this view to be false, and one suspects that the true scale of prehistoric human impact on the Pacific Islands is not yet fully grasped.... [Kirch 1984: 123].

In New Zealand, McGlone and Topping (1977) noted forest decline from their pollen studies in the Tongariro National Park, North Island. Holloway (1954) had previously suggested that the forest fires of pre-European times were of such a scale that it was unlikely to have been the work solely of human beings. However, McGlone (1983) presented pollen diagrams from both the North and South Islands, showing a decline in forest taxa between around 800 and 500 BP, and argued that Polynesian settlers were responsible.

Grant (1985) countered these assertions with sedimentological studies. The total deposition of sediment in successive erosion periods in the last *circa* 1,000 years in New Zealand had decreased, despite the presence of humans. Grant proposed that the erosion periods, though declining in severity, were caused by increased northerly air flow and atmospheric warming, which led to an increased storminess and more floods, which in turn had caused greater deposition of sediment relative to non-erosion periods. Grant (1985) and McFadgen (1985) also linked these events to coastal sand dune sequences.

Spriggs (1981) influential study on Aneityum, in Vanuatu, proposed the idea that first settlers had gardened the hillsides, due to the swampiness of the valleys and coastal plain. This could have led to erosion which led to alluvial and colluvial progradation of the coastal plain, as well as causing it to be drier and richer in nutrients. Pollen diagrams were used as evidence that the landscape became more open from after 2890 $\pm$60 years ago due to deforestation by humans, which in turn released the topsoil (Spriggs 1986; Hope and Spriggs 1982). Some contribution to the progradation was allowed for from tectonic uplift, though this alternative has been very much down-played (Nunn 1990a).

Coastal progradation has been interpreted as caused by human activities, even if only as a contributing factor such as at To`aga on Ofu, in American Samoa (Kirch *et al.* 1990). Interference with dune systems in the Manawatu, New Zealand, has been mooted (Flenley pers. comm. 1990), though this has not been accepted by all workers (McFadgen 1985, 1989; Shepherd, M. pers. comm. 1990).

Pollen work on Easter Island showed declining values for woodland taxa during the last 1000 years (Flenley and King 1984), including the pollen of an endemic palm tree that no longer exists (Dransfield *et al.* 1984). It was suggested that over-use of resources due to increasing population, monument-building, and warfare led to deforestation. More recently, Bahn and Flenley (1992) even suggest that, bar a few relict trees on the crater rims, over-hanging the sea, every tree was cut down by the time of European contact.

Kirch developed the notion of `transported landscapes' in Polynesia, whereby humans modified new environments by introducing new organisms and landscape concepts from their original homelands (Kirch 1982; Kirch 1983). Some organisms were conveyed to new islands by accident rather than design, for example the weed *Ludwigia octivalvis* and the land mollusc, *Lamellidea pusilla*. Parts of the landscape would be converted into cultivations: for example, valley bottoms would be used for irrigated terracing, and forest would be cleared for shifting cultivation (Kirch 1982; Kirch 1983).

According to Kirch, agriculture in Oceania comprised two systems: pondfields for the cultivation of taro (*Colocasia esculenta*) and atoll taro (*Cyrtosperma chamissonis*) primarily, and swidden systems (`slash-and-burn') involving plants such as kumara (*Ipomoea batatas*), yams (*Dioscorea* spp.) and plantains/bananas (*Musa* spp.) (Kirch 1982; Kirch 1983; Yen 1973). Kirch (1982; 1983) argues that lowlands were conceived of in terms of agricultural systems, and that Polynesian settlers transformed natural lowlands into this preconceived model wherever they went.

Another theory promoted by Kirch (1982; 1984) was evolutionary theory. Populations on newly settled islands would rise exponentially until they out-stretched their resources, the population would crash, over-compensating, by means of famine and war, and thereafter, this pattern would continue, the population naturally adjusting itself according to the limits of the available resources. This process would have led to constant depletion of soils and indigenous biota.

The case of Tikopia (Kirch and Yen 1982) was an attempt to integrate ethnography, ethnobotany, archaeology and geomorphology in order to examine human-environment relations. Humans were again implicated in environmental degradation and overpopulation, with accompanying warfare, leading to exile for some of the people.

At Barbers Point on O`ahu, in the Hawaiian Islands, Christensen and Kirch analysed the terrestrial molluscan fauna from archaeological and palaeontological sites, and extrapolated from the results an impression of the type of vegetation changes that would have been concomitant with the molluscan ones (Christensen and Kirch 1981; Kirch 1984). Their view was that the fauna was suggestive of dry, open woodland and grassland before human arrival, and that this was cleared for cultivations subsequently. A later study by B. Davis (Kirch 1984: 148) confirms this. Erosional events have been detected from sites elsewhere in the Hawaiian Islands, associated with burn layers and extinct land molluscs (Kirch and Kelly 1975; Green 1970; 1980; Yen *et al.* 1972).

Southern's (1986) palynological study of swamps from Viti Levu and a lake from Taveuni, Fiji, detected a reduction in forest taxa and a rise in grasses. In one case, Bonatoa Bog (possibly two, with the less precise information from Melimeli swamp), this took place after 4380 $\pm$180 BP and before 2290 $\pm$75 BP. If sedimentation was constant, this looks like a date of around 3029 BP - consistent with the archaeological date of initial Lapita settlement (3200-3300 BP) - though the rise in grasses which starts before the other pollen changes dates to 3473 BP. However, these two sites are not in the *talasiga* or savannah of the western part of Viti Levu. Southern believed that the *talasiga* may have been partly natural, with later extension due to human intervention, much of it possibly being created as late as European contact since a very high proportion of the species contained therein are European introductions.

Chester (1986) suggested that humans were responsible for clearance in the Bay of Islands, by burning woodland in open areas for cultivation, using evidence from pollen diagrams. This was taken up by Sutton (1987) who suggested that the deforestation episodes over large areas between 0 and 500 AD., associated with a continuous charcoal record, silt influx and certain indicator species (for clearance) like bracken and various grasses, dating earlier than the present archaeo-logical record could be indicative of human presence. Bulmer (1989) also suggested that these deforestation episodes could imply earlier human settlement.

Enright and Osborne (1988) criticised these ideas on the basis that natural events could cause similar effects, and there was no archaeological evidence for earlier settlement, though they conceded that such evidence may just not have been found. The onus was on archaeologists to prove such a case. Grant (1988; 1989) challenged these views as well. He stated that natural change normally affected large areas, and that periods of burning had occurred over the last 8,000 years and earlier. Instead, he proposed that climatic change with periods of increased storminess, higher temperatures and flooding were responsible for the greater levels of erosion and alluviation.

Nunn (1991) denied that human influence was so crucial in New Zealand in the period when settlement was generally accepted to have occurred on the basis that it was an abrupt occurrence after a long period from the time of initial settlement, and that it coincided with the Little Climatic Optimum when conditions might be expected to have been drier and vegetation, therefore, more susceptible to fire. Nunn's (1991) paper, also challenging the orthodoxy of human primacy amongst agents of environmental change in the Pacific Islands, draws a comparison with a study in the northern Amazon Basin where evidence for large fires since 6260 BP was found, and the authors proposed that humans were responsible, even though evidence of human occupation only dated to 3750 BP. The conclusion had been based on assumptions about human behaviour rather than solid material evidence.

3.2.1 *Sea Level Change*

Sea level change is important not only in altering land area and coast line, but can also affect the moisture regime of islands (Enright and Gosden 1992). This presents a major natural source of environmental change in the past.

At the end of the last glaciation, glaciers melted and the resulting meltwaters affected relative sea level even at great distances from the glaciers. This is not only due to increased water volume but also to loading of the sea floor by the same meltwater, causing it to depress (e.g. Walcott 1972).

Clark *et al.* (1978) and Peltier *et al.* (1978) created a worldwide model dividing the world into regions where certain defined sequences of past relative sea level were to be expected. The model was based on the concept of the earth being a viscoelastic sphere, altered by northern hemisphere glaciers melting and ocean basins consequently filling up. Observed sea level was considered in terms of the difference between the ocean floor and the ocean surface, the latter being at constant gravitational potential. Clark and Lingle (1979) revised the model by taking the effects of the melting of the Antarctic glaciers into account.

At the height of the Last Glacial, sea level at least in the south-west Pacific was about 120 metres below the present level (Nunn 1991), and then meltwaters from the distant glaciers began to fill up the Pacific Ocean. In terms of Polynesia, the area falls within Zone V (Clark *et al.* 1978; Clark and Lingle 1979; Peltier *et al.* 1978). Islands in this area are suggested as having experienced slight mid-Holocene emergence. A peak in this emergence should have been in the order of up to 2 metres above current sea level around 5000 years ago. Nakada (1986) added the qualification that for islands with a radius larger than 10 km, the relative sea level is almost independent of the upper mantle rheology, whereas islands with a radius less than 10 km simply fall in line with the global isostatic adjustment. This latter group includes the Cook Islands.

Support for this model of mid-Holocene emergence proposed for Zone V comes from a number of studies, though there is some suggestion that it could have been a little later in date than predicted. On Enewetak, in the Marshall Islands, Buddemeier *et al.* (1975) record the highest sea level as being over 1 metre between 3 and 2000 BP. Schofield (1977) suggests higher than present sea levels attained during the last 4000 years, with a high stand at 2760 BP reaching +2.4 m. From Fiji, Nunn (1990a) has dated the Holocene sea level maximum, which he put at 1-2 metres above present, to between 3 and 2000 BP. Nunn (1991) has data from Western Samoa placing this episode at about 1000 BP with the high stand being at about 1 metre. In the Tuamotu Islands, Pirazzoli and Montaggioni (1988) dated the sea level maximum (0.8 m above present) to between 5500 and 1,200 BP. For French Polynesia in general, the same authors dated the sea level maximum (around 1 metre above present) to between 2000 and 1,500 BP. Problems were encountered with atolls because the sea level maximum probably transgressed their highest points, thus leaving no physical legacy. The mid-Holocene high stand is placed at 0.8 m about 3450 BP on Mopelia, in the Society Islands (Guilcher *et al.* 1969). Stoddart *et al.* (1985) place this high stand at 1.8 m, 3410 years ago on Mangaia, which has been revised to 1.7 m between 4000 and 3400 BP by Yonekura *et al.* (1988).

Yonekura *et al.* (1988) have suggested on the basis of the results of dating that the timing of the hypothesised mid-Holocene high stand was a little later than estimated by Clark *et al.* (1978) and Clark and Lingle (1979). Schofield (1970) claims dates for the Aroa Sands of between 3500 and 1200 BP, but these have been disputed by Yonekura *et al.* (1988), as most of the corals dated were not in growth position and thus likely to be secondary in character. Yonekura *et al.*

(1988) also suggest that no convincing evidence exists for a higher sea level on Rarotonga or Aitutaki. However, Schofield (1970) does have some evidence in a primary context on Rarotonga: a raised fossil coral outcrop at Avarua, 1 metre a.s.l. dated to 2,030 ±60 BP, though recrystallisation may mean the date should be placed earlier.

Tectonic movements can complicate sea level data by means of uplift or subsidence. In the south Pacific Ocean, tectonism is particularly important along the plate boundaries by the following island arcs: Solomon Islands-Vanuatu and Tonga- Kermadec-New Zealand (Nunn 1991). In the eastern Pacific Ocean away from the plate margins, tectonism has not been as significant factor, being controlled by `hotspot' effects (see Introduction 1.4.1) and subsidence is generally more common. Over the kind of timescale in question, however, these effects are not too much of a complicating problem.

Green argued that models of a higher sea-level stand during the Holocene could be significant for archaeology (Green and Richards 1975; Green 1979). Lapita sites were found in situations from which the sea had recently withdrawn, such as marine terraces and raised coral platforms. Though the general trend was eustatic fluctuation, a few situations could be explained in terms of tectonism (Green 1979).

Kirch and Hunt (1988) proposed a model of tectonic change with islands to the west of the Andesite Line experiencing uplift whilst those to the east underwent subsidence, such as Huahine, where a water-logged site was investigated by Sinoto (Sinoto and McCoy 1975). This helped to explain the lack of Lapita sites to the east of the Line that have come to light compared to the west.

Clark (1989) points out that frequently archaeologists have attributed the visible effects of the mid-Holocene highstand in sea level to local tectonism. Clark lists the mounting evidence from Southeast Asia to central Polynesia for this late drop in sea-level, and argues that a hypothesis suggesting regional uplift is severely weakened by such widespread concurrence. Also islands unaffected by tectonism still show signs of a higher sea level. The only island east of the Andesite Line to have possible evidence of subduction is `Upolu, so that only rare local effects can confound the situation, such as at Huahine. Even in Fiji, where there has been tectonic activity in more recent Holocene times, once the tectonism is allowed for and compared with stable areas of Fiji, a mid-Holocene highstand is still apparent (Nunn 1990a).

3.2.2 *Extinctions*

The mechanisms and timing of extinction are important in assigning cause. The research into extinction is critically reviewed, and alternative explanations proposed.

In New Zealand, the fact of the extinction of a number of creatures had long been recognised both in the Maori oral tradition and in the Pakeha writings of the 19th century (Davidson 1984: 5). Indeed, much skeletal evidence came to light of a spectacular sort: bones of large ratites, the moa, attracted a great deal of attention, some of it scholarly. The size of these birds no doubt meant that an awareness of the extinctions issue in the archaeological debate came well in advance of anywhere else in Polynesia. Duff's periodisation of New Zealand archaeology included a `Moa-hunter Period' (1956).

The size of the moa ranged from that of a bushturkey to a little over 3 metres tall (Anderson 1989b; Cassels 1984). Climatic change and human induced factors such as deforestation and hunting have been suggested as causes of extinction (Anderson 1989a; 1989b; Davidson 1984; Millener 1981). Eleven species of moa and 21 other bird species have been ascribed to pre-European human induced extinction, whereas 9 species are known to have become extinct since European arrival (Gill and Martinson 1991). Not only birds, but other animals were found to have been affected (Davidson 1984). Exploitation even affected shellfish in some areas (Anderson 1981).

Kirch and Yen (1982) noted the presence of an extinct megapode, declining numbers of turtle, fish and shellfish, and the eradication of certain large types of shellfish from archaeological deposits on Tikopia, a Polynesian Outlier.

Olson and James (1982) collated evidence that twice as many endemic species existed in the Hawaiian Islands as is recorded in the historic literature when fossil birds are taken into consideration. Three percent of nonpasserine birds survived into the historic period, 62% of passerines, and only one raptorial bird out of six originally existing. The finding of some of the extinct species' remains on archaeological sites confirms the contemporaneity of Polynesian settlement and these extinct birds and the fact that the birds were hunted (Olson and James 1984; Olson and James 1982). This does not, however, necessarily imply extinction before European contact. One must again remember the limited nature of the documentation for the first century, and especially the first decades, of European contact.

Kirch (1982) proposes that clearance of lowland forest and hunting would have been the major causes of faunal extinctions in the Hawaiian Islands. Christensen and Kirch's (1981) work on the terrestrial mollusc fauna from Barber's Point, O`ahu, indicated that there had formerly been open-canopy dry-forest and grassland. Some species cease to appear (extinction?) and exotic introductions, including those introduced during the period of European contact, materialise all in the top layer. It is difficult to establish from this what occurred prior to European contact and what thereafter. One interpretation from Christensen and Kirch (1981) might be that grasslands were already an important component of the lowland vegetation before human arrival, and thus, the intensity of cultivation rather than clearance should be the crucial factor in the elimination of endemic species of molluscs.

Steadman and Olson (1985) analysed bird bones from an archaeological site on Henderson Island in the Pitcairn group. Twelve species of bird were identified, 3 of which do not occur on Henderson island today, and 2 of which visit but do not breed there today. They argued that modern distribution patterns can give rise to erroneous views of the relationships and evolutionary history of organisms, and that the distributions of many species and genera today are not necessarily their full natural distribution. Diversity of many islands would have been much greater than at present. A second study (Schubel and Steadman 1989) with a larger sample of bones revealed the former presence of a *Gallicolumba* species, the most easterly representative of the genus so far discovered.

However, they assume that midden deposits (Sinoto 1983) faithfully represent the surrounding fauna, because the island appears to be so distant from others. An alternative explanation is that Henderson Island was visited by humans on a temporary basis[19] (rather than permanently settled), and these bird remains represent the consumption of remaining supplies from the inward journey, before the collection of new supplies for the outward journey. The archaeological sites (*cf.* Schubel and Steadman 1989; Sinoto 1983) could represent a series of temporary occupations. In such a case, the bird bones could represent birds from other islands. Voyaging experiments using traditional technology show that large distances on the map are relatively short in terms of voyaging time (Babayan *et al.* 1987; Finney *et al.* 1989; Lewis 1966).

Diamond and Case (1986) reviewing animal extinctions, especially on islands, re-iterated the view that human expansion has been responsible for the disappearance of many species during the course of the Holocene, and much of it before European expansion. This was taken up in more depth by Keegan and Diamond (1987), and analysed in terms of biogeographical theory.

Steadman's (1986) investigation of caves from Mangaia, in the southern Cook Islands, produced the bones of two extinct species of rail, which he suggests were made extinct by Polynesian settlers. As he points out, rails need little area, elevation or habitat diversity to survive. By comparison with the case histories of Laysan and Wake islands, they are vulnerable to human presence. In the absence of documentation from the period of European contact, it is not possible to confirm his suggestion that pre-European contact Polynesians were responsible for the demise of these rails.

This was expanded upon by Kirch *et al.* (1991; 1992), who advanced the idea that Mangaia's central volcanic interior was once forested, and that through swiddening activities, this was reduced in a matter of centuries to fernland. The indigenous and endemic fauna persisted in refugia in the makatea, until finally hunted out there. Steadman's analyses (Kirch *et al.* 1991; Kirch *et al.* 1992; Steadman and Kirch 1990) demonstrate the former presence of a number of sea and land birds and that they were hunted (because they were found in archaeological deposits). Their replacement by domesticated animals as the major animal food, however, might be interpreted as economic change rather than as total extinction as proposed in Steadman and Kirch (1990) and Kirch *et al.* (1991; 1992).

Olson (1986) analysed the information from the manuscript of Andrew Bloxham, who visited Ma`uke briefly in 1825 aboard HMS *Blonde*, and made a few notes on the biota. A "mysterious starling" collected by him still exists in the British Museum, and is a valid species, now extinct. A fruit dove, *Ptilinopus rarotongensis* cf. *goodwini* mentioned is probably extinct, and a petrel and a hawk are also mentioned, but are less probable.

Hawks may well have been more widely distributed. At the present time, they are restricted to West Polynesia (Watling 1982), though in the past, they were also found in the Hawaiian Islands before the advent of humans (Olson and James 1982). If identified by Bloxham correctly, Norway rats were already on Ma`uke in 1825 and this may have accelerated avian decline. Olson (1986) suggests that other birds would once have been present on the basis of comparisons with other islands, but had been destroyed by Polynesians prior to European contact. He further suggested that the remaining extinctions were just part of the continuum. One might wonder whether such extinctions would not have been assigned to the pre-European past if HMS *Blonde* had not passed by, and bones of these birds were found in archaeological deposits[20].

More evidence of avian extinction comes from the Marquesas Islands in the form of 2 species of parrot and 1 species of rail (Steadman 1987; Steadman and Zarriello 1987). These were found on pre-European archaeological sites.

Postulating that the distribution of many bird genera was once more extensive than today, Steadman (1989a) illustrated his view by describing a new species of starling (*Aplonis*) from Huahine, mentioning that another species from Ra`iatea was painted by Georg Forster in 1774 on Captain Cook's second voyage and yet another once existed on Ma`uke (Olson 1986), and by pointing out that an extant species still exists on Rarotonga.

Steadman (1989b) reviewed all the existing information on extinction in East Polynesia, noting that the worst affected seabirds were petrels and shearwaters, which nest colonially in burrows on the ground, and the worst affected landbirds were rails and ground doves, because many were flightless species confined to single islands. By comparing East

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19 Pitcairn Islanders frequently visit Henderson today, and set up temporary camps (Schubel and Steadman 1989: 3).

20 Even today, researchers have problems establishing whether a species is extinct or not: for example, the *Kakerori* was only rediscovered in recent times after decades of being unobserved (McCormack and Künzle 1990), and it is a matter of dispute whether the Barred-winged Rail and the Grass Owl are extinct on Fiji (Watling 1982).

Polynesia to the Galapagos Islands, which have experienced fewer extinctions of their avian populations (often extinctions have been only of a more local nature rather than total), Steadman (1989b) made a number of observations:

1) There had been a shorter period of human occupation of the Galapagos Islands.
2) The human population was smaller because of the unsuitable conditions.
3) Galapagos Islands birds were never a major source of food for humans.
4) For the last 3 decades there has been legal protection for the birds.
5) Introduced birds are absent on most islands.
6) Introduced mammals and plants are scarce or absent on many islands.

In fact, most extinctions on the Galapagos islands had been where human disturbance has been greatest.

Steadman's work at the Urei`a site on Aitutaki produced 19 bones (Allen and Steadman 1990), all but one of which were of the rail *Porzana tabuensis*, the remaining one being of an undescribed whistling duck (*cf. Dendrocygna*). He suggests that this is because the site does not represent the earliest period of human settlement and that the fauna has already been depauperated by human impact. Moturakau lagoon islet, on Aitutaki, has also produced a bone of the above rail (Allen and Schubel 1990). However, he mentions that 3 more land birds exist today and 2 others were extant until the 1940's or 1950's. None of these were in the archaeological deposits[21].

The demise of the pigeons and doves on Aitutaki, Steadman attributes to the construction of an airport during the Second World War, which replaced a large tract of forest (Allen and Steadman 1990). He implies that the birds in the archaeological deposits, in addition to putative birds driven to extinction, were lost due to habitat removal and predation from humans, dogs, pigs and rats.

Steadman (1991) reviewed the work on Aitutaki together with new material from Atiu. Of 15 birds represented in the fossil record from Aitutaki, 5 no longer exist today: these were a petrel, a booby, an extinct whistling duck, a rail and a lorikeet; of 6 birds represented in the fossil record from Atiu, 3 no longer exist: a ground dove, a pigeon and a lorikeet. Human overkill was once more implied.

Steadman and Pahlavan (1992) analysed the bird remains from a site on Huahine, in the Society islands, excavated by Sinoto and McCoy (Sinoto and McCoy 1975) which included both land and sea birds, some of which no longer occur on Huahine. This extended the known range of birds like *Gallirallus*, *Gallicolumba* and *Macropygia*. In addition, they noted that blood-borne protozoan infections were rare in the indigenous avifauna of the Cook Islands and were likely to be so in the Society Islands too. Isolation had protected them from such infection.

Steadman (1993) analysed bird bones from the To`aga site (As-13-1) on Ofu, in the Manu`a Islands of American Samoa. Five of the ten seabirds identified from the site were no longer present on Ofu, and one of the three landbirds. In addition, at least two of the species are now endangered. Steadman suggests that a chiefly tabu on megapodes in Tonga indicates a knowledge that overexploitation would lead to extinction, or alternatively, that they were a prestigious trade item. The awareness that overexploitation might eliminate the resource is claimed to be through past experience. The only appearance of *Megapodius* from To`aga is in the deepest cultural stratum, and so extirpation is alleged for the initial human colonization of the island; all from two fragmentary pieces of bone in a cultural deposit.

Such evidence for the extinction of *Megapodius* on Ofu could be produced through a luxury trade in the birds from elsewhere. This is ethnographically attested for elsewhere in the West Polynesia/Fiji area (Steadman 1993: 223). The fact that *Gallicolumba stairii*, a ground dove, still survives, albeit in a small threatened population, might suggest that shy ground dwelling birds were not automatic candidates for overexploitation and extinction. The fact that the present day population exists at all implies the bird survived over three and a half millennia of human occupation, but does not imply that it has always been endangered: that could easily be due to more recent conditions.

Finally, Steadman *et al.* (1994: 92) have found that nonchicken (native) bird bones from Ahu Naunau, Easter Island, were consistently fourth in rank among vertebrate categories through time, unlike in other East Polynesian sites investigated till now. This may have been due to the short time interval represented, though it is implied that the bird extinctions were a relatively gradual process on Easter Island. Unfortunately, except for a *Porzana* rail, none of the landbirds could be identified beyond the family level.

Alternatively, the fact that later assemblages have fewer native birds and there is relatively little change in this earlier assemblage through time, might support the idea expressed in the model proposed in section 9.2 that fresh extinctions occur when environmental thresholds were crossed (like large scale expansion into the interior of islands). It may be that other assemblages with either less time control or more compressed sequences mask such subtleties.

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21 Archaeological sites are by their nature artefacts. One might note that extant birds are not represented when they clearly must have existed there at the time. Other, now extinct, birds may have been present too. This could be the result of human selection in the past or of choice of where to excavate.

3.2.3 *Pre-human plant dispersal*

Arguments over the pre-human distribution of organisms, with the present scarcity of fossil data, concentrate around innate dispersability and modern distributions. This is important in the argument about what species could have been transported by natural means and what by humans, either deliberately in the case of cultigens or inadvertently in the case of ruderal weeds. It is also necessary to consider how plant communities functioned before human arrival and how humans may have disrupted the natural dynamics of island plant communities by their presence.

Carlquist (1967) investigated the dispersal of the flora of the Pacific Islands by noting the known dispersal methods of individual plants. The ecology of an island was found to be more important than distance in predicting whether a plant could establish itself there or not. Internal transport in birds was the most important vector for establishment on high islands, and oceanic drift for atolls. Other methods were rafting (infrequent drift), air flotation, barbs and bristles adhering to birds feathers, viscid fruits and seeds attaching to birds feathers, and seeds trapped in mud on birds feet. To Rarotonga, the two most important factors were: frequent drift (35.5%) and internal transport by birds (31.8%). Avian transport of one form or another accounted for 52.3% of the dispersal processes on the same island.

A study of plant propagules found on beaches on Viti Levu, Fiji (Smith, J.M.B. 1990) found that 73% were shore species, though there were other species, including those of freshwater habitats. The most abundant species was *Cocos nucifera*, including frequent examples of sprouting nuts. Amongst the other species were *Hibiscus tiliaceus*, *Inocarpus edulis*, *Pandanus tectorius* and *Terminalia catappa*. Coconuts, in particular, have attracted academic attention (Maloney 1993) as regards their dispersion both naturally and as a cultigen (possibly from 3000 or more years ago in India, though the evidence from Thailand suggests a very late domestication).

Van Balgooy (1971) investigated the methods of plant dispersal in the Pacific Ocean, and found that:

1) Wind was not an important dispersant, and transport is usually not far from source areas
2) Genera with diaspores suitable for water transport were generally well represented throughout the Pacific Ocean, especially on low isolated islands
3) On most islands, the best represented group were those species brought by internal bat or bird transport
4) Those genera which can attach themselves to animals externally were not so common, though they were better represented on high islands
5) Those brought by several different means are few in number, and increase proportional with distance for source regions
6) Genera with small non-specialised diaspores are frequent and increase with relative isolation and height of island
7) Genera with large heavy diaspores are also numerous, but decrease gradually east of the Andesite Line.

With regard to the Rarotonga, Van Balgooy (1971) considered it to be floristically allied more with the Society Islands than Tonga. It is not as diverse as the Society Islands or Tonga, Niue and Samoa, and the percentage of genera with world-wide and trans-Pacific distributions is greater than these neighbouring groups. This is presumably due to its increased distance from source locations - as compared to Tonga, Niue and Samoa - and the small, scattered nature of the Cook Islands - as compared to the Society Islands. This might suggest that some caution is necessary when comparing the diversity of Rarotonga today with models of diversity based on evidence from neighbouring island groups.

3.3 Environmental Present

Some ideas of how humans may have affected the biota of islands in the past can be gained through modern studies. A number of theoretical approaches have been taken, as well as studies of individual factors.

MacArthur and Wilson (1963; 1967) developed the equilibrium theory of island biogeography. The equilibrium is between immigration and extinction rates. The rate of immigration is inversely proportional to isolation from a colonizing source, whilst the rate of extinction is directly proportional to isolation and inversely proportional to population size. Simberloff (1974) demonstrated that this equilibrium, which is dynamic due to frequent extinction and immigration, is a multi-levelled process, involving evolution at a higher level and ecological change at a lower level. This has been challenged as being oversimplistic, overemphasising the species-area relationship, at the expense of factors such as habitat diversity, threats from introduced predators and minimum population requirements (e.g Reed 1985). Diamond (1969) points out that small islands with high habitat diversity can harbour as many species as large islands with poor diversity.

Diamond (1984b) shows that the dispersal ability of species, particularly in crossing water, significantly alters their chances of survival. Island area and population density are also vital factors. Habitat requirements can involve a relationship with another species that may itself be threatened (Diamond 1984b; Diamond *et al.* 1987). Indeed, the degree of endemism tends to increase the area requirement of species and their dependence on indigenous forest (East and Williams 1984). Lack of former habitat diversity seemed to be the main factor involved in extinctions studied on Barro Colorado Island (an island created in recent times through raised water levels) by Karr (1982).

Dispersal ability decreases as one approaches the equator (Diamond 1985), the reason being the more frequent occurrence of stable habitats. If habitats are stable, with no decrease in areas of suitable habitat and no increase in areas becoming suitable, like for example large tracts of rainforest, then there is no advantage in dispersing and there may even be a risk in doing so. In this case, species become sedentary.

Intrinsic rate of increase and generation lifetime of individual species are important factors controlling populations (Diamond 1984a). Individual species also have their own particular requirements regarding area and range of habitat (Diamond *et al.* 1987).

Islands may not always be characterised by a marked turnover of species, such as proposed by MacArthur and Wilson (1967), if they are not modified frequently, and especially if propagules from other islands are scarce and limited in range (Williams, G.R. 1981). In such cases, habitats and niches may remain unfilled. For example, introduced harriers on Tahiti have successfully filled the otherwise unoccupied niche of large carnivorous landbird (Bruner 1972).

However, studies by Zimmerman and Bierregaard (1986) on frogs in the Amazon rainforest indicate that far from the static situation that is being proposed as appropriate for island reserves, islands or isolated habitats are characterised by rapid turnover due to a high degree of speciation and the occasional arrival of exotic species. In other words, islands are dynamic places.

Decreasing land area due to rising sea levels can lead to a lowering of species diversity (Diamond 1984a). This response to diminishing area, and sometimes habitat diversity at the same time, may be delayed so that an island may carry more species than the island can sustain in the long term. Other changes brought about by climatic change may also divide up populations and restrict their range, as for example, vegetation communities may shift up and down mountains as the climate warms or cools (Brown 1971; Patterson 1984). This, of course, does not account for the majority of Holocene extinctions, but it can be a contributing factor. Watling (1982) points out that oceanic islands are characteristically low in diversity compared to continents, though endemism is generally high.

The fragmentation of once continuous tracts of forest can be even more threatening to species diversity than the simple reduction of such forest (Diamond 1972; Diamond *et al.* 1987). Significantly large areas of uninhabitable territory prevent organisms forming large enough populations, obtaining sufficient nutrients and recolonizing unpopulated areas. Once an area undergoes fragmentation, although it may initially contain a high diversity of species after a given `relaxation time' it will decline to a level more appropriate to its size and ecological variety (Diamond 1975; 1976).

Diamond (1975; 1976) has listed a series of design principles in the construction of preserves in order to maintain the greatest possible degree of diversity:

1) Larger preserves are better than small ones
2) The least division of the preserve the better
3) If unavoidable, then these fragments should be as close as possible to each other
4) Also these fragments should be arranged equidistant to one another and not linearly
5) The effectiveness of these fragments may be significantly improved by connecting them with narrow strips of protected habitat
6) Ideally, preserves should be as nearly circular in shape as possible in order to minimise dispersal distances within the preserve

It is interesting to note that this last principle covers most high islands in the tropical southeast Pacific Ocean as they were in their natural state. Colonization of radial valleys would instantly partition the circle, though connections would still persist through the central pinnacles. For some species this might mean traversing a hostile climatic or vegetation zone, with the result that for such a species the partition would be very effective.

As far as plants are concerned, the genetic barriers are not as severe as for animals because of the possibilities of hybridisation (Koopowitz and Kaye 1990). What is more crucial is the absence or presence of pollinators in the case of zoophilous cross-pollinators, threats from grazing animals and the alteration of plant communities, such as in the case of exotic invaders and deforestation (Koopowitz and Kaye 1990). Such alteration of plant communities can occur through natural environmental change or human agency.

King (1985) identifies special problems for islands since 93 % of the world's land and freshwater bird species and subspecies that have become extinct since 1600 have occurred on islands. The major cause, he proposes, was the introduction of alien predators, including diseases. The restricted amount of space on islands is the main reason for the vulnerability of insular ecologies.

Atkinson's (1985) study of the effects of commensal species of rats on the avifauna investigates the differential effects of the three rat species: *Rattus exulans* (Polynesian rat), *R. rattus* (ship or black rat) and *R. norvegicus* (Norway or brown rat). The first is the smallest species and preys on fewer species than the others, though it can prey on larger birds than the others. The second is the largest species tends to prey on ground-nesting birds. Finally, the third species is a dangerous predator to tree-nesting birds and is the best climber of the three. For example, recent research indicates the crucial role of *R. rattus* in threatening the ultimate extinction of the *kakerori* on Rarotonga at the present time (McCormack and Künzle 1990), though most of its decline predates the introduction of *R. rattus* and is attributable to the introduction of cats and fire-arms (Atkinson 1985; Gill, W.W. 1885).

However, it is noteworthy that in the tropical and subtropical zones the introduction of rats has had much less effect, because of the presence of land crabs (Atkinson 1985), especially *Birgus latro*, the robber or coconut crab (Burggren and McMahon 1988). Previous selective forces have thus immunised the avian populations to some extent against the predation of rats, though perhaps less so against *R. rattus*, which is a very agile climber.

Nunn (1991) points out that studies of feral pig populations show their destructive capabilities: for example, reducing the understorey of a beech forest from 80-100% to 2-15%. Rats, although they do not affect plant communities very much directly, can bring about ecological disequilibrium through predation of other animals.

Introduced birds are sometimes accused of harming indigenous species. This is, however, not thought to be a major contributor to elimination of species. McCormack and Künzle (1990) dismiss the idea that the introduced mynah bird or the long-tailed cuckoo might pose a threat to the endangered *kakerori* on the basis of studies done so far. Watling (1982) observes for Fiji, Tonga and Samoa that it is not threats from exotic species, but rather the inability of indigenous species to colonize habitats modified by humans that is at the root of the problem.

The above research is necessary when considering the various contributing factors to the alteration of the natural environment when human presence took place. This research is helpful when posing questions needed to be asked of the data presented in this thesis, such as: what the amount of area altered was? which areas were involved? were all habitats or microenvironments still represented? what the shape of the remaining undisturbed habitat was? to what degree the habitat was altered? were all remaining natural habitats still connected to each other? were any harmful exotic organisms released into the environment and what was their effect?

3.4 Résumé

Firstly, the questions dealt with in archaeology were the date, nature and economy of first settlement of different Polynesian islands and island groups, and then the nature and economy of settlement in later periods. Secondly, past environments in Polynesia have raised a number of issues, including those of sea-level change, extinctions of various organisms and the nature of the past flora seen from the point of view of natural dispersal mechanisms. Thirdly, questions and research, especially from biogeography, prompted by present day environments were outlined in order to understand the dynamics of natural communities and how they might be affected by, in particular, by human interference. In the next chapter, attention is focused on the southern Cook Islands, principally Rarotonga.

CHAPTER 4 PREVIOUS RESEARCH IN THE SOUTHERN COOK ISLANDS, IN PARTICULAR RAROTONGA

Selected research concerning the southern Cook Islands, principally Rarotonga, is presented here to show how the issues discussed in the previous chapter refer specifically to this smaller study area: that is those relating to the archaeology, environmental past and environmental present. Also more local questions and problems are raised.

4.1 Archaeology

Investigation in to the physical remains of the past in the Cook Islands began in a limited way with Buck (Te Rangi Hiroa), who noted the presence of up-standing monuments and a few details about them, though he did not carry out formal surveys and excavations. He did, however, describe numerous portable artefacts from the past, no longer in use (1927; 1932a; 1932b; 1934; 1944). Serious site surveys did not begin until 1962, when the Canterbury Museum team led by Duff started the first in a series of archaeological expeditions to the Cook Islands (see Figure 4.1). Canterbury Museum expeditions to Rarotonga took place during the summer of 1962-1963 (Duff 1965; Trotter 1974) and latter part of 1964 (Duff 1965; Duff 1968; Trotter 1974), and a Royal Society of New Zealand team led by Trotter and Duff undertook an expedition to Atiu in 1969 to commemorate the bicentenary of the visit of Captain Cook to New Zealand (Duff 1971; Trotter 1974: 87-119). On the 1964 expedition, Aitutaki was visited and monuments there were described though not formally surveyed (Duff 1968).

At the time of Buck's investigations it was thought that subsurface archaeology would not be a useful investigative tool as the time depth would be too short. Buck calculated the period of settlement as beginning in the 12^{th}-13^{th} centuries on the basis of generations from the genealogies (Buck 1944). The introduction of radiocarbon dating into

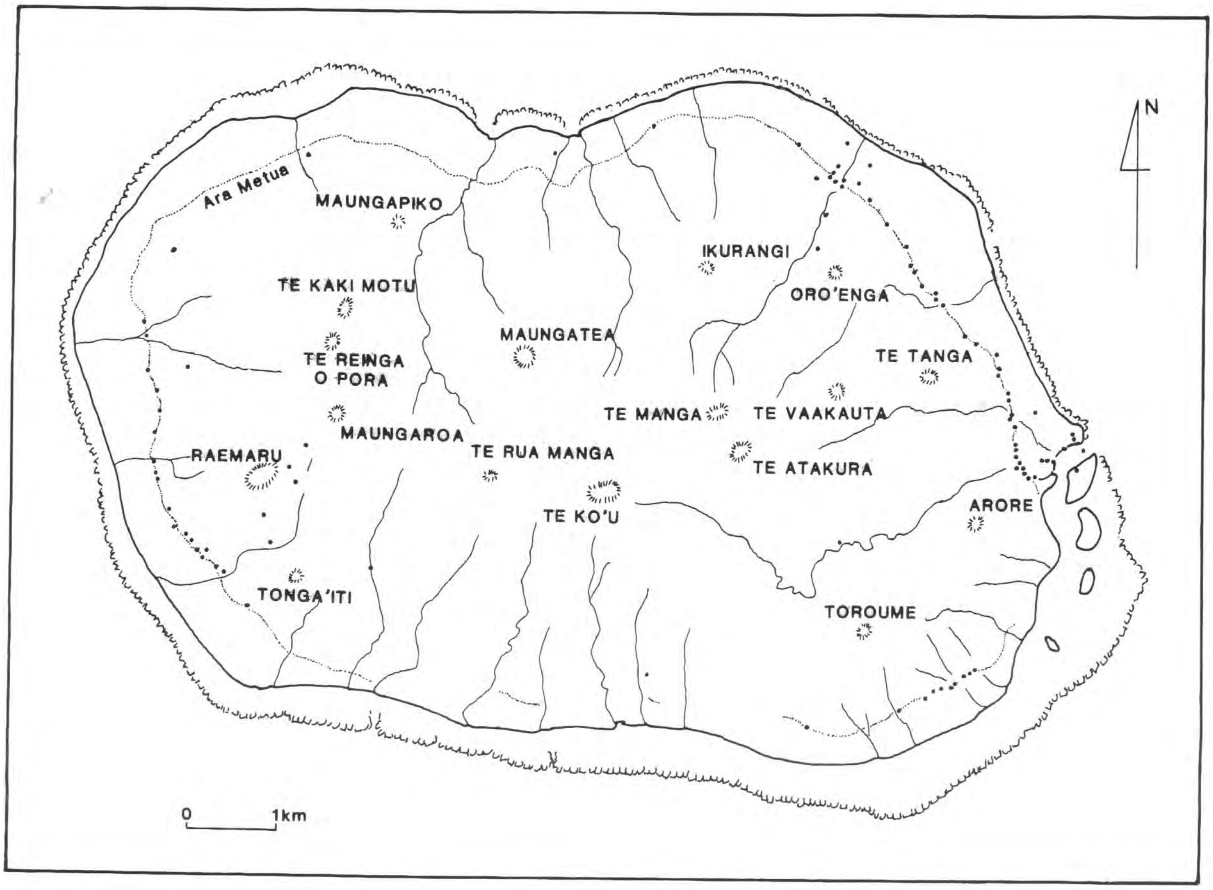

Figure 4.1 Map of Rarotonga, showing archaeological sites.

Pacific archaeology stimulated a new look at the chronology of Polynesian colonization. With its pivotal position between East and West Polynesia, the Cook Islands was an obvious early choice for the application of the technique. The earliest date from the expeditions of the Canterbury Museum and the Royal Society of New Zealand was 650 $\pm$50 BP, which correlated with Buck's chronology.

It was assumed that the earliest settlement sites on Rarotonga would take the form of middens in beach, cave and rock shelter deposits (Duff 1974a: 10), presumably inspired by such finding in the Hawaiian Islands (Emory and Sinoto 1961; Kirch 1985), New Zealand (Duff 1956) and the Marquesas Islands (Suggs 1961). The expeditions to Rarotonga failed to locate such sites, and therefore, turned their attention to the surviving upstanding monuments, about which some oral tradition was collected. Duff believed that early coastal sites had been destroyed by later cultivation. The following types of sites were investigated: the *Ara Metua*, *marae*, *koutu*, T-shaped *paepae* and the *paepae `are*. A total of 103 sites was noted, and a small selection of these were excavated and/or surveyed.

In Tupapa, the *koutu* Arai te Tonga and the T-Shaped *paepae*, Te Maru o te Ta`iti, were surveyed. In the same *tapere*, the T-Shaped *paepae* `Arerangi and Pokata, the `Are Kariei and the marae Marae Manuka and Marae Pureora were surveyed and partially excavated. Elsewhere, *paepae `are* were surveyed and excavated at Vaiakura and Avana, terraced marae, *paepae `are* and *`are kai* were surveyed and excavated on the Maungaroa, and the *Ara Metua* was surveyed.

In 1969, the expedition to Atiu (Duff 1971; Trotter 1974) sought to locate and record house sites and marae on the inner side of the makatea, belonging to the immediate pre-European contact period. Time limits meant that only traditional and obvious structures could be investigated, and no attempt was made to locate putative early coastal sites. Thirty-two sites were noted, a few of these were surveyed and only one, an *umu*, was excavated. The sites investigated included burial caves, marae and house structures. One burial cave, Vaiari, a basalt stone seat with stalactite backrest at Arangirea, the marae Marae Vairakaia and Marae Orongo, the Missionary Period tomb at Paikea and a ceremonial complex at Marau were all surveyed, and an *umu* on the central volcanic hill in the *vaka tangata* Te Enui was excavated.

Bellwood (1978), heading an Auckland University team, carried out a program of fieldwork in the Cook Islands in three campaigns: December 1968-February 1969, December 1969-February 1970 and May-August 1972 (see Figure 4.1). He excavated the Ngati-Tiare site (RAR. 40), noted by Duff as being associated with a cache of stone adzes, in 1968, 1969/70 and 1972 (Duff 1974b; Bellwood 1978). Bellwood also excavated the Urei`a (AIT. 10) and `Are Karioi (AIT. 3) sites on Aitutaki, as well as site surveying on Aitutaki and Mangaia (fieldwork was also carried out on Tongareva in the northern Cook Islands). There was more extensive survey and excavation of the structures on the Maungaroa (Bellwood 1978: 10-53), as well as a series of site surveys in the Rutaki and Turangi valleys, with a survey of the Avana valley taro pondfield terraces.

Bellwood (1971; 1978) believed that settlement had always been primarily coastal, and because of the continued use of the coast for settlement, remains had been destroyed. Thus, he felt compelled to concentrate on the inland valleys, where upstanding surface remains are still to be seen. The Maungaroa settlements were regarded by Bellwood (1969) as being atypical of the island as a whole, Tinomana and his people having being trapped up there for many generations, due to failure in warfare. He cited John Williams (1843: 172) and William Gill (1856: 39) as evidence of this. The settlement therefore was an adaptation to difficult terrain, making use of the meagre flat land available for cultivation and settlement.

In 1984, Chikamori (1987) excavated burial sites on Pukapuka, in the northern Cook Islands. Although culturally different from the rest of the Cook Islands, being a West Polynesian culture (Beaglehole and Beaglehole 1938), this had ramifications for the southern Cook Islands as well in that both groups occupy a middle ground between East and West Polynesia, and were thus expected to yield the earliest dates east of Tonga and Samoa. Chikamori's earliest date (when corrected for the Ocean Reservoir effect) put the settlement of Pukapuka at 2,310 BP.

Katayama (1986; 1987) analysed the evidence of skeletal material from Mangaia, Rarotonga and Miti`aro as well as physical characteristics of modern Cook Islanders to ascertain their biological affinities with neighbouring island populations. He concluded early settlers colonizing East Polynesia passed through the southern Cook Islands, some remaining, or that there was considerable contact between the southern Cook Islands and West Polynesia in the late prehistoric period. Katayama and Tagaya (1988) presented a report of physical and linguistic research in the Cook Islands, which provided information on the physical and linguistic relationship of Cook Islanders to neighbouring peoples. It identified present-day Pukapuka and Mangaian *populations as being most representative of pre-European populations of the Cook Islands.*

Walter (1990; 1991; 1993; **in press**) excavated a coastal village site at Anai`o on Ma`uke, with an assemblage correlating to the `Archaic East Polynesian Culture' of Sinoto (1970; 1983). Two sherds of Polynesian Plain Ware were also found (Walter 1990; Walter and Dickinson 1989). Also, Sinoto (1988) had previously discovered a sherd of possibly Melanesian origin at Varakaia on Ma`uke. Walter suggested that early sites in the southern Cook Islands, including Rarotonga, were beginning to reveal a pattern of coastal settlement by reef passages, which may have been chosen to control important landing sites at a time when there was regular offshore voyaging. Separate areas of the site were found to have been utilised for cooking, fishhook production and stone tool making.

Evidence of inshore fishing and collection of lagoonal resources was found, and Walter believed this to have been a significant part of the economy of the site (Walter 1991). The presence of pearlshell in the earlier levels suggested that there were formerly wider trade links, including lithic material imported from Aitutaki or Rarotonga for making adzes. These ended with an increasing population abandoning nucleated coastal settlements to occupy the available land directly in order to claim ownership. This gave rise to a dispersed pattern of settlement that continued into the post-European contact period.

In 1987, Allen and Schubel (1990) carried out excavations at Moturakau Rockshelter (MR. 1), on the *motu*, Moturakau, of Aitutaki. Again seafood, fish in particular, was important to the site economy. Some limited fowling was practised, which suggested to Allen and Steadman (1990) that the site was not of the earliest period. They suggested the site was used as a basalt quarry, possibly for export to other islands, such as Ma`uke. However, its use as a quarry site is disputed (P.J. Sheppard pers. comm. 1993).

In 1990, Kirch excavated the Tangata Tau Rockshelter on the makatea of Mangaia (Kirch *et al.* 1991; Kirch *et al.* 1992). There was evidence of seafood being important, with a number of extinct landbirds and seabirds and numbers of fruit bats. Alleged deforestation of the volcanic interior by humans was put at 1600 BP, and the use of the rockshelter was dated to from 1000 BP onwards. An assemblage of basalt adzes, other basalt tools, fishhooks, abrading tools, tattooing needles among other things was found. The fishhooks were made from pearlshell at first and were later replaced by *Turbo* shell. Since pearlshell would have had to have been imported, for example, from Aitutaki, this was thought to imply that there had been wide trade links in the past which were gradually reduced due to increasing social isolation resulting from spiralling warfare (Kirch *et al.* 1992: 175).

Also in 1990, Kurashina, Stevenson and Sinoto carried out surveys of marae, including some excavation, on Rarotonga, Atiu and Miti`aro (Allen and Schubel 1990).

In 1991, Chikamori investigated three metres of cultural deposits, as yet undated, 6 m a.s.l. in the Avana Valley (cf. Sutton *et al.* **in press**).

In 1992, excavations were being undertaken on house sites in Mangaia, on the lower slopes of the volcanic hills above the taro swamps by J. Endicott (Endicott pers. comm. 1992).

4.2 Pre-European Contact Environmental Past

Research into the environmental past of the southern Cook Islands only began fairly recently. Steadman (1986) recorded two previously unpublished species of rail, one and probably both of which are now extinct. He attributed their demise to pre-European contact Polynesian overexploitation. Later, he (Allen and Steadman 1990; Kirch *et al.* 1991; Kirch *et al.* 1992) analysed the sub-fossil remains of more such avian extinctions from Aitutaki and Mangaia.

Parkes investigated the pollen record for Lake Te Roto on Atiu in order to determine whether humans may have had an influence on past vegetation changes (Parkes *et al.* 1987). She attributes the growth of open scrub and fernlands to human activities around 1420 $\pm$45 BP on the basis of her analyses (Flenley pers. comm. 1992). She suggests that *Casuarina equisetifolia* was a Polynesian introduction because it appears in the pollen record about this time.

Lamont (1990) carried out similar analyses for Lake Tiriara on Mangaia, and Dawson (1990) undertook chemical and mineralogical analyses for the same site. The results were combined for wider interpretation (Kirch *et al.* 1991; 1992). The period from around 1600 BP was construed in terms of sustained human disturbance, causing erosion and permanent deforestation. More recent work based on pollen cores from nearby swamps has been used to re-interpret the date, so that the first human disturbance of the vegetation has been put at 2500 BP (Ellison **in press**).

Allen and Schubel (1990) analysed fish and seafood remains from Moturakau, on Aitutaki. The results indicated a preponderence of reef and inshore fish were taken. Pearlshell was also found, and since it does not exist there anymore, it was proposed that there was overexploitation of that resource. Melinda Allen (1992) proposed that erosion due to clearance of forest and agricultural activities caused soil run-off to accumulate in the lagoon, causing changes in habitat that led to the local extinction of pearlshell.

Allen (1992: 191) also draws on the paucity of primary native forest in charcoal remains, except for *Calophylum*, the extinction of native landbirds and the apparent replacement of the native *Partula* landmolluscs by adventives in the occupation levels on Aitutaki.

Some environmental changes have been more exclusively natural. The sea-level debate, in particular, is important to the understanding of former environmental conditions in the southern Cook Islands.

Schofield (1970) puts forward the possibility of a 1-2 metre high stand of sea level. His evidence consists of a raised fossil coral outcrop 1 metre above present sea-level dated to 2,030 $\pm$60 BP, though this may well be earlier due to recrystallisation, and the coral rubble ridge - the `Aroa Sands' of Wood and Hay (1970) - (below the A-horizon at the highest points) dated at Kavera to 3,510 $\pm$50, at Matavera to 2,470 $\pm$63 BP, and at the Black Rock (Tuoro) to 1,235 $\pm$57. This is supported by research elsewhere in the Cook islands - Scoffin *et al.* (1985) on Suwarrow and Yonekura *et al.* (1988) on Mangaia. On Mangaia, emerged microatolls on the emerged shore were dated, and the results implied a maximum sea level of +1.7 m between 4 and 3000 years ago.

There has been some suggestion of tectonism in the southern Cook Islands. McNutt and Menard (1978) proposed that the growth of Rarotonga and Aitutaki caused the uplift of Mangaia, Atiu, Ma`uke and Miti`aro due to lithospheric arching. However, this has not been generally accepted due to disagreement on the extent and synchroneity of these events between the islands in question (Jarrard and Turner 1979; Spencer *et al.* 1987).

4.3 Post-European Contact Environmental Past and Present

European records of the environment of the southern Cook Islands began with Captain Cook in 1777 who visited Mangaia, Atiu, Takutea, Manuae, Aitutaki and Palmerston (Beaglehole 1967). Rarotonga, however, was not generally known to the Europeans until the arrival of the missionaries, who recorded little detailed information on the natural history of the southern Cook Islands, with the exception of William Wyatt Gill (1885).

Flora

Captain Cook recorded that Mangaia had a forested makatea, with the hill in the interior having fernlands with the summit having *Casuarina* woodland (Beaglehole 1967). Later, William Wyatt Gill (1885) made notes on some of the cultivated and wild species of plant on Rarotonga.

The first flora of Rarotonga was compiled by Cheeseman from a visit in 1899 (Cheeseman 1903). Cheeseman divided the flora in to three groups: indigenous, pre-European and post European introductions. These distinctions have been continued by later authors (e.g. Sykes 1983; Merlin 1985). He noted that the upland vegetation was almost exclusively composed of natives, whilst the lowlands, in contrast, was predominantly comprised of exotics. *Hibiscus tiliaceus* and *Aleurites moluccana* were recorded as being common in the valleys and occurring up to at least `800 ft' (264 m). He also claimed that these formed `the major portion of the forest', which was later rejected by Merlin (1985). Cheeseman mentions that in the late 19th century *Fagraea berteriana* was common in the uplands, and occasionally even planted as an ornamental on the lowlands in the villages.

In 1925, 1927, 1929, Wilder visited Rarotonga, and published a new flora (Wilder 1931). This unfortunately contains a number of inaccuracies, both botanical and in terms of the Maori nomenclature (Sykes 1980). He recorded the presence, albeit uncommon, of *Cecropia palmata*, which is now widely distributed, though not common (Merlin 1985), *Coccoloba uvifera*, and *Elephantopus scaber*, which is now present from the lowlands up to the peaks (Philipson 1971): none of these having been observed by Cheeseman in 1899. *Argusia argentea* is listed as common on the shore by Wilder and later by Philipson (1971), though only as a few clumps on the east coast by Cheeseman (1903).

Copeland (1931) presented a report on a fern collection made by H.E. and S. Thew Parks, which was less extensive than those by Cheeseman and Wilder.

Philipson (1971) collected vascular plants from Rarotonga in 1969, and presented a brief discussion of the floristics, in particular, the phytogeographical relations of the Rarotongan flora.

Brownlie and Philipson (1971) investigated the pteridophytes of the southern Cook Islands, and collated all previously existing research. The total of 80 species listed were all either found outside the Cook Islands or closely related to species found elsewhere.

Stoddart (1972) described the environment of the *motu* of Rarotonga, including brief descriptions of the vegetation cover. In the same volume, Fosberg (1972) listed the vascular flora of these same islands, along with distribution maps of vegetation types for the three largest of them. Later, Fosberg presented a similar study for Aitutaki (1975).

Sykes (1980), noting the lack of floristic research in the Cook Islands, began a programme of detailed investigation of the flora, not just of Rarotonga, but the other islands as well (Sykes 1980; 1983; 1992).

On Rarotonga, Sykes (1983) divided the vegetation into three zones: coastal, lowland and upland. The greater part of the coastal zone was found to be much altered by human interference. The indigenous vegetation of the coast which survives is typical of other islands in the tropical South Pacific. The lowland zone comprises, not only the coastal plain, but also the lower gently sloping valley bottoms. The native vegetation of this zone, despite the richest soils, is overshadowed by exotic invaders and cultivated plantations. Finally, the upland zone includes everything above about 50 m a.s.l., and is almost exclusively covered in indigenous species.

Merlin (1985) undertook surveys of Sykes' upland zone (Sykes 1983), and subdivided it into three plant associations on the basis of dendrogram analyses: *Homalium* montane forest, *Fagraea-Fitchia* ridge forest, and *Metrosideros* cloud forest. He also described the *Dicranopteris*-dominated fernlands, and attributed them, like Sykes (1983) to past human activities. Merlin challenged the belief that the uplands had been largely immune to incursions of exotic plants, though accepted that they are still predominantly composed of the native flora. He suggested that this was due to the lack of prolonged human disturbance, though low levels of disturbance were noted, like hunting for birds and collecting plantains.

Merlin (1991) then investigated Mangaia's makatea vegetation, using vegetation surveys and dendrogram analyses and identified a number of plant associations. Sykes (1992) presented a report on the floristics of Atiu.

Animals

Research into the avifauna began with the visit of Captain Cook to Palmerston Island in 1771, when large colonies of seabirds were recorded (Beaglehole 1967). Later, Captain Byron on H.M.S. Blonde to Ma`uke in 1824, when members of the crew made notes and illustrations and took some dead specimens (Holyoak 1974; 1980). The information was not well recorded, but it is interesting to note the absence of one or two species mentioned which are not seen today.

Thomas Nightingale (1835) visited Rarotonga briefly in 1834, and noted a lack of birds (though his description of his visit only really includes episodes on the coastal plain). He says that a certain bird, dwelling in the mountains with feathers that were used in chiefly headdresses, had been hunted to extinction. From Buck's (1944) descriptions of Rarotongan headdresses, this would either be a red-tailed tropic bird or a red lorikeet. The first still exists in Rarotonga (Holyoak 1980), and the second is restricted to the coastal plain or the low-lying valleys, and feeds primarily on coconut nectar (Bruner 1972). It could be that he confused two stories. The fact that he referred to one of the missionaries he was staying with as `Simpson' instead of `Pitman' might suggest that he did not take careful notes (Nightingale 1835). One should also bear in mind that some birds such as lorikeets may have been brought to islands where they did not previously exist because of their economic value[22].

Later, Hartlaub and Finsch (1871) produced a list of Rarotongan birds, including the grey duck, which became extinct on Rarotonga in the 1920's (McCormack and Künzle 1991). William Wyatt Gill (1885) noted that the *kakerori* (*Pomarea dimidiata*) was less frequent than in previous times in the valleys where it served to cut down the number of insect pests on taro. He suggested that this could be due to either the introduction of new predators, especially the cat, and the use of

22 For example, Watling (1982) points out that the Red-breasted Musk Parrot was introduced to Tongatapu and `Eua by the Tongans from Fiji for this very reason.

firearms in hunting. In addition, he thought that cyclones could have contributed: `Consequently the `kakirori', two species of which were once common, especially in the neighbourhood of the sea, was (it was believed) exterminated' (Gill, W.W. 1885: 127-128).

In fact, William Wyatt Gill (1885: 127) states that:

> The woods of Rarotonga, when I first knew the island some thirty-two years ago, were everywhere vocal with the song of birds...I have more than once ridden round the island without hearing the cry of any but sea-birds. The stillness of the forest would be intolerable but for the pleasing hum of insects as the sun declines.

Also, he quotes from an *ariki*:

> the chief justice Vakatini (about seventy-five years of age) spoke as follows: `Let me remind the young of our ancient methods of catching birds before the introduction of fire-arms. Landbirds were then plentiful. [Gill, W.W. 1885: 78].

Not much detailed attention was given to the southern Cook Islands until recent times, apart from a list of birds from Mangaia published by Christian (1920). In the 1970's, a series of small articles appeared including Holyoak (1974; 1976) and Turbott (1977), but it was not until 1980 that Holyoak produced the first comprehensive survey of the avifauna (Holyoak 1980). McCormack and Künzle (1990; 1991) provide some useful additional information.

The landbirds were responsible for the spreading of fruiting plants, for example, pigeons on Rarotonga fed on mistletoe (*Loranthus*) berries, and thus spread the mistletoe seed to other host trees on which it is parasitic (Gill, W.W. 1885: 84). The *Rupe* (*Ducula pacifica*) fed on berries of the banyan tree (*Ficus prolixa*), the *Koka* (*Bishofia javanica*) and the *Karaka* (*Elaeocarpus tonganus*) - Gill, W.W. 1885: 78). *Rupe* sipped the nectar from *Neinei* (*Fitchia speciosa*) flowers (Gill, W.W. 1885: 79), thus presumably pollinating them. *`I`oi* (*Aplonis cinerascens*) did the same with coral trees or *Ngatae* (*Erythrina variegata*) - Gill, W.W. 1885: 78. This is a lowland ornamental tree, and according to this same account, traps were set for the *`i`oi* near the flowers at mid-day while they were asleep in the forest.

Research on other animals is less advanced. William Wyatt Gill (1885) made notes on some marine and lagoon animals, as well as a species of wasp, two varieties of grasshopper, a phasma or spectre insect, various types of land mollusc and some introduced insects. Crombie and Steadman (1986) composed the first overview of the lizards of Rarotonga and Mangaia. Wilson and Taylor (1967) produced the first investigation into Cook Islands ants, listing 17 species. Taylor (1967) added 3 more ant species to the list. Since the ant species were composed of a very small selection of the Indo-Australian fauna and none amongst them were definite endemics, it was concluded in both articles that all were human introductions: some Polynesian introductions and some later European introductions. Wise (1971) made a preliminary list of all types of terrestrial invertebrates in the Cook Islands. Some additional information on the non-avian side of the fauna is presented in McCormack and Künzle (1991).

It is possible that the decline in the *kakerori* led to an increase in insects. William Wyatt Gill (1885) records that insect pests on taro increased on the valley plots, after *kakerori* numbers fell. Perhaps the insects were also infesting forest plants too. In the same book, Gill mentions without the noise of song birds, the `pleasing hum of insects' was all that could be heard in the forest (Gill, W.W. 1885: 127 - see above). This may be more significant than first appears. Some insects, though, may have been predatory on the other insects, creating some natural balance.

4.4 Résumé

The archaeology undertaken in the southern Cook Islands was described and its ramifications discussed. Issues regarding the past and present environments were investigated and the evidence so far amassed was presented.

The next four chapters look at the research undertaken in this project, commencing with an outline of the aims and techniques of the fieldwork.

CHAPTER 5 FIELDWORK

The aims of the fieldwork, conducted by the author on Rarotonga, are discussed as a whole, and then those of the three separate periods of fieldwork are described in more detail. Some general aspects of the methodology employed in this work is indicated, as well as specialist techniques used which are not covered in succeeding chapters. Finally, the achievements of the fieldwork are outlined.

5.1 Aims

5.1.1 *Overall Aims*

Fieldwork was undertaken to locate polliniferous deposits dating back long enough to cover comfortably the period before which as well as during which humans had lived on Rarotonga, and to sample these deposits. Modern vegetation studies, as noted above (Chapter 2), were carried out to establish the current state of the vegetation and together with modern pollen rain studies these were to provide comparisons for the fossil evidence. Reference pollen samples, including voucher specimens of the plants the pollen came from, were to be collected. Topography and location, where they could have a bearing on site formation processes, were to be carefully noted. Oral tradition and local information were gathered where time allowed.

5.1.2 Fieldwork February 1990

Flenley, Barker and Sutton carried out the first phase of fieldwork on Rarotonga in the period February 3-15th 1990 (Sutton *et al.* 1991). It was thought that perhaps the coastal platform was recent, having been formed possibly only since human settlement, with the present-day swamps being remnants of a former lagoon. The swamps were to be examined for depth, age, modes of origin and scientific potential.

The swamps selected were to be assessed in terms of general levels of preservation of organic materials in order to gauge their viability for palynological work. Radio-carbon samples were to be obtained from the cores taken.

Site Locations (Figures 5.1)

Six sites were initially cored by Sutton *et al.* (1991) in February 1990, though many more were visited (Ibid: 12). The topographical map of Rarotonga (Lands and Survey 149, 4":1 mile, 50' contour) was searched for interfluvial swamps, as Flenley had hypothesized that those swamps at the maximum distances from rivers, where sediments from the island core would be thinnest, would be the best to study. These swamps and some others shown on the Land Use Map of Rarotonga (Lands and Survey 146/1&2) were investigated.

The swamps selected for coring were assessed to be adequate for the preservation of pollen. Radiocarbon samples were extracted from the cores taken and they showed fairly late dates except for two. One in particular, a large swamp called Karekare swamp (formerly labelled as `Matavera swamp'), in the north-east of Rarotonga, was later identified from radiocarbon samples as having sediments dating at least to the eighth millennium BP (the date was taken from about a metre above the base). This was thus judged to extend well back before the period of human settlement in the eastern tropical Pacific and more besides. The following descriptions (5.1.2.1 to 5.1.2.6) are after Sutton *et al.* (1991: 12-13).

5.1.2.1 Atupa

This is the largest area of swamp on Rarotonga. The construction of the International Airport in the early 1970's reduced its area, though the greater part of the swamp remains. It is at present cultivated, with some areas left fallow. It was cored at five places along a transect through the swamp from a point on the *Ara Metua*, approximately 500 metres west of the Avatiu Valley *Ara Noa*. The deepest deposit along that transect was located, and is referred to as AT1 in Table 1. The deposit there was sampled at 10 cm intervals down to 3.50 m.

5.1.2.2 The Latter Day Church Site, Arorangi

This site is just inland from the Latter Day Saints church south of Arorangi. It is a narrow swamp, only 20 metres wide, which parallels the coastline. This swamp is shown on the topographical map as a food swamp passing through an area of coconut plantation and bush which crosses the *tapere* boundary between Akaoa and Vaikura.

Sutton, Flenley and Barker cored at three locations within the swamp and found the deepest spot (ARM1) which was sampled (as above), using the Feek corer, to a depth of 4.50 m.

5.1.2.3 Aro`a Taro swamp

The site sampled is located on a broad band of swamp near the Aroa Radio Station, 600 metres north of the Rarotonga Hotel. The swamp is intensively used, and stretches from the back of the coastal ridge of coral sand, to approximately 80 metres inland, where there is a high bank which may be an old shoreline. It was cored at 4 spots along a transect approximately perpendicular to the coastline, and the deepest spot (AO1) was traced to the inland edge of the swamp. Then it was sampled (as above) using the Thomas corer to a depth of 3 m.

5.1.2.4 Karekare swamp (originally labelled Matavera swamp - MR)

In February 1990, after exploratory cores, and improvisation of an additional 7.6 m of rods, a continuous 11.5 metres was sampled (as above) into the swamp deposits at a location, KK4 (MR1), just east or seaward of the land islet located at the inland end of Karekare swamp (Figures 5.1, 5.2, 5.3).

When cored, the base of the column proved to be an orange clay similar to those formed by the weathering of the Rarotongan basalts. No coral sand was encountered, although the base was apparently below current sea level.

Subsequently, the swamp was cored to 7.5 metres at two locations north of an islet of dry and raised land (in the swamp) and closer to the inland edge of the swamp in order to record the swamp margin stratigraphy.

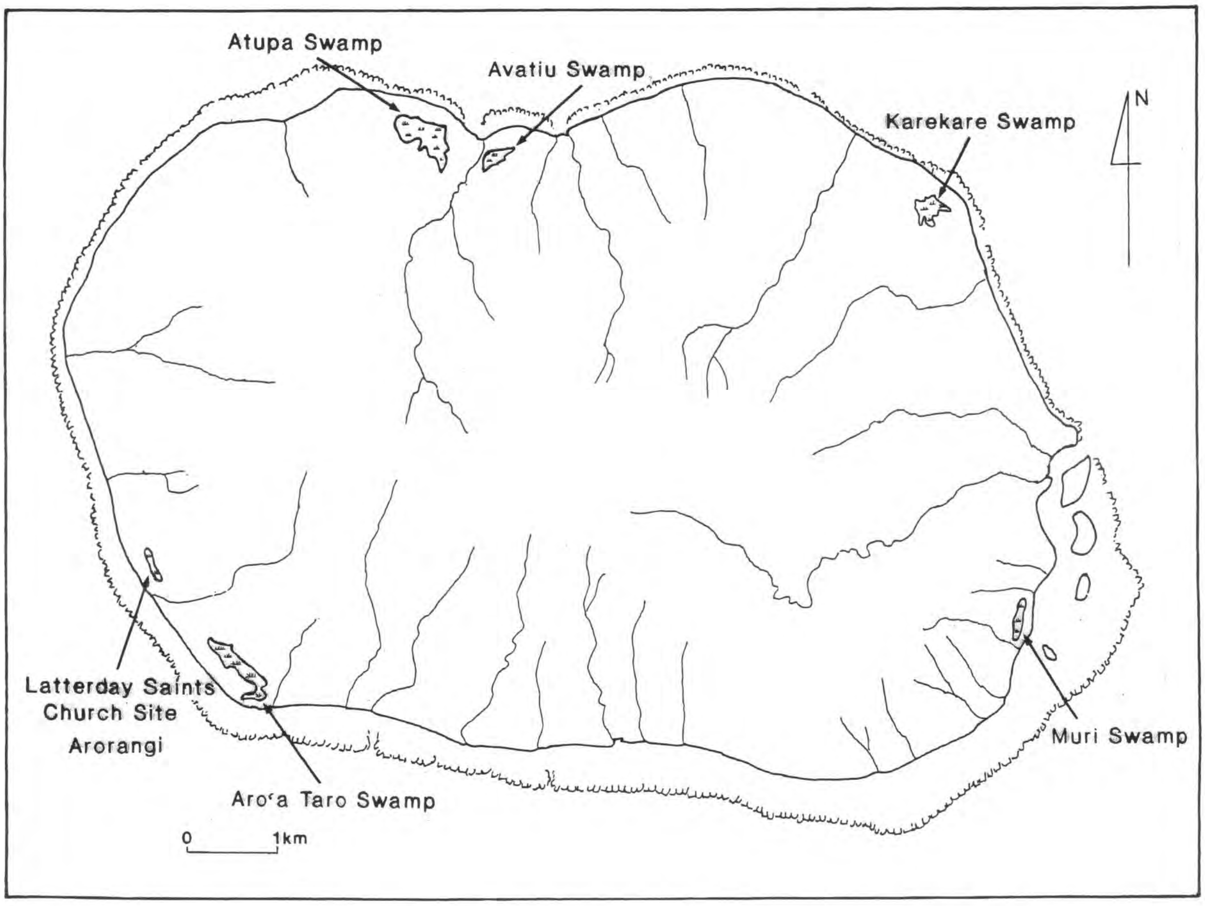

Figure 5.1 Map of Rarotonga, showing the location of swamps cored.

5.1.2.5 Muri

Flenley and Barker cored along a transect of the Muri swamp, in Aremango *tapere*. Two buried soils overlying a basal coral sand, 1 metre below the surface, were sampled for radiocarbon dating but no pollen was collected due to the unsuitable nature of the deposit.

5.1.2.6 Avatiu

The Avatiu swamp was cored at a number of locations in order to ascertain the depths. These were: immediately west of the road to Avatiu from the *Ara Metua*, and north of the inner road opposite the Ruatonga Stream. A coral sand or gravel base was found a short distance beneath the surface throughout this area. The intervening deposit was composed predominantly of soils with a high inorganic content, unsuitable for the preservation of pollen.

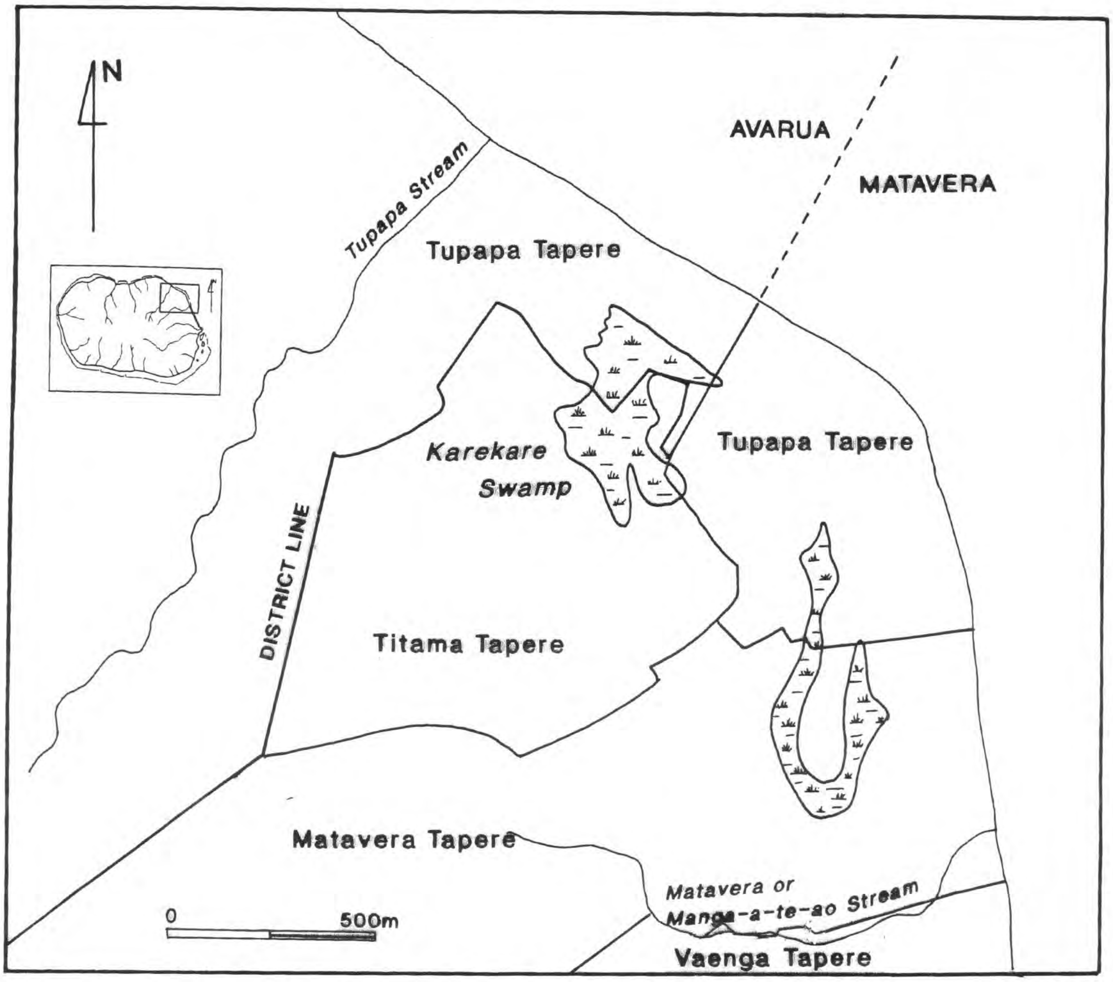

Figure 5.2 Detailed map of the Tupapa, Titama and Matavera *tapere*, showing the location of Karekare swamp.

5.1.3 Fieldwork November/December 1990

Karekare swamp was selected for further investigation in the November/ December 1990 season of fieldwork, after initial pollen analysis showed it to be promising and a date of 8373 BP (calibrated) was obtained from sediment at a depth of 9.5 m. Other swamps sampled on the previous trip were not researched any further as they were felt to offer inadequate material for study.

Swamp stratigraphy would be clarified by cores from the landward side to the seaward side. In the end, time limits meant that cores were taken from the landward side to the centre. This was the more important part of the swamp since that would have been where any erosion would have come from.

A core was taken by Feek and Peters from the centre of the swamp in order to sample what would be likely to be pollen rain from a wider area (*cf.* Moore and Webb 1978; Moore *et al.* 1991), and to get a deeper core sample. Coral sand and weathered basalt were found at the bottom. Two other cores were taken from closer to the swamp margin.

Other work undertaken included modern pollen sampling to broaden the reference collection, electrical resistivity survey, within time constraints and the noting of topographical features and sediment exposures time permitting.

5.1.4 Fieldwork August 1992

The fieldwork season lasted from the 4/08/92 to the 2/08/92.

The tasks to be undertaken were vegetation surveys of the important vegetation types, the gathering of modern pollen rain samples from the vegetation plots, the sampling of wood from different tree and shrub species for a reference collection and the collection of voucher specimens for the identifications made and for the wood samples. Where possible and time allowed, oral tradition and recollections from the living memory of Cook Islanders were noted.

Also, investigated at this time were the questions of the features found on the islet, especially the apparent earthen wall around its edge and the mound at one end.

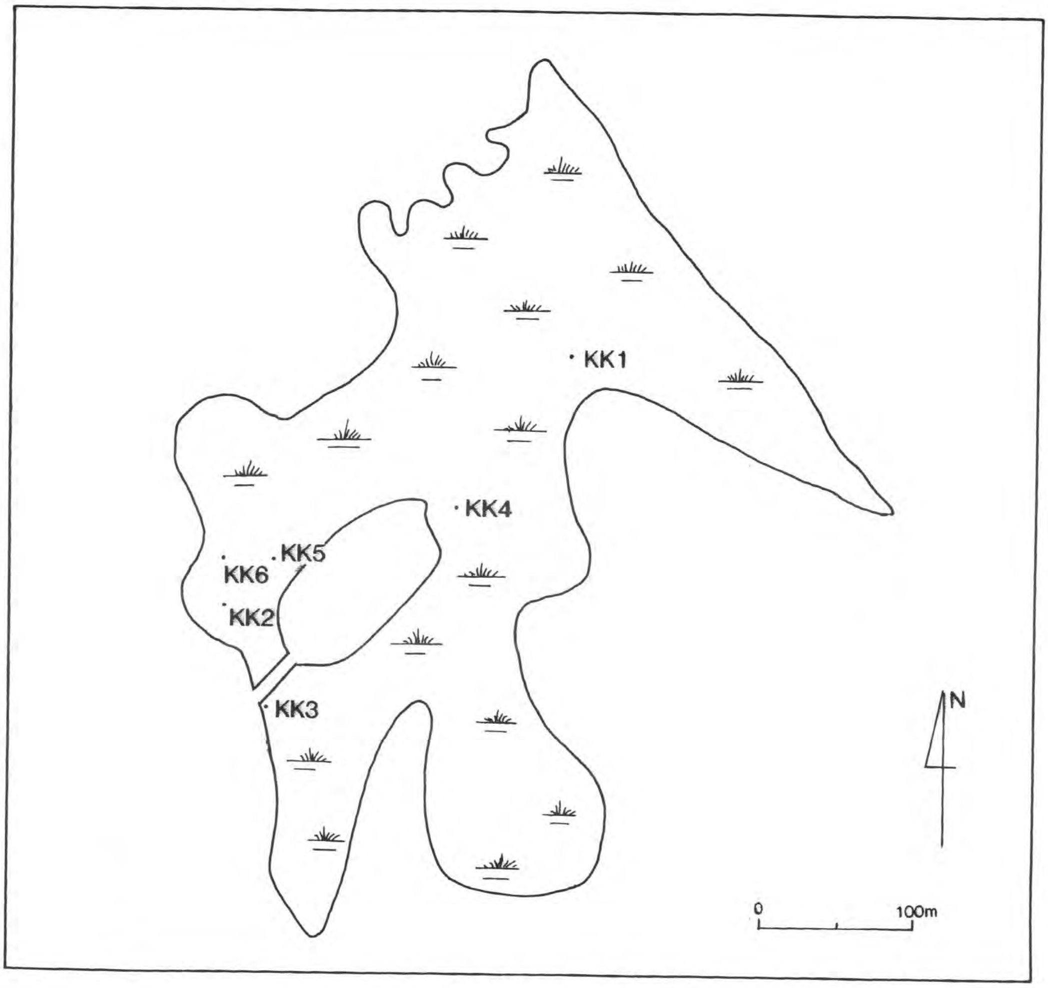

Figure 5.3 Map of Karekare swamp, showing the location of the core samples.

5.2 Methodology

The methodology, as stated here, applies to all fieldwork reviewed here. The methods used included electrical resistivity, swamp coring (see section 7.11), photography, pH tests (see section 7.31), preservation of plant and pollen specimens in alcohol or bioquat (all-purpose biocide), and vegetation survey (see section 2.1).

5.2.1 *Electrical Resistivity Methodology*

A Wenner Array with a spacing of 1 metre between probes was used over Karekare swamp (Coles 1972). Due to the water-logged nature of the terrain, it was clear that the underlying hard geology would not be detected directly. It was hoped, however, that the top layers would follow any pattern of sagging or bulging in the lower levels, albeit in a less marked way.

5.2.2 *Collection and Preservation of Modern Plant Specimens*

Specimens were taken of unopened mature flowers (for pollen), plus samples of leaf and twig. Voucher specimens were also selected in order to confirm identifications in the vegetation surveys. These were then soaked in methylated spirits or bioquat (all-purpose biocide) for preservation. They were then sealed in plastic bags and labelled.

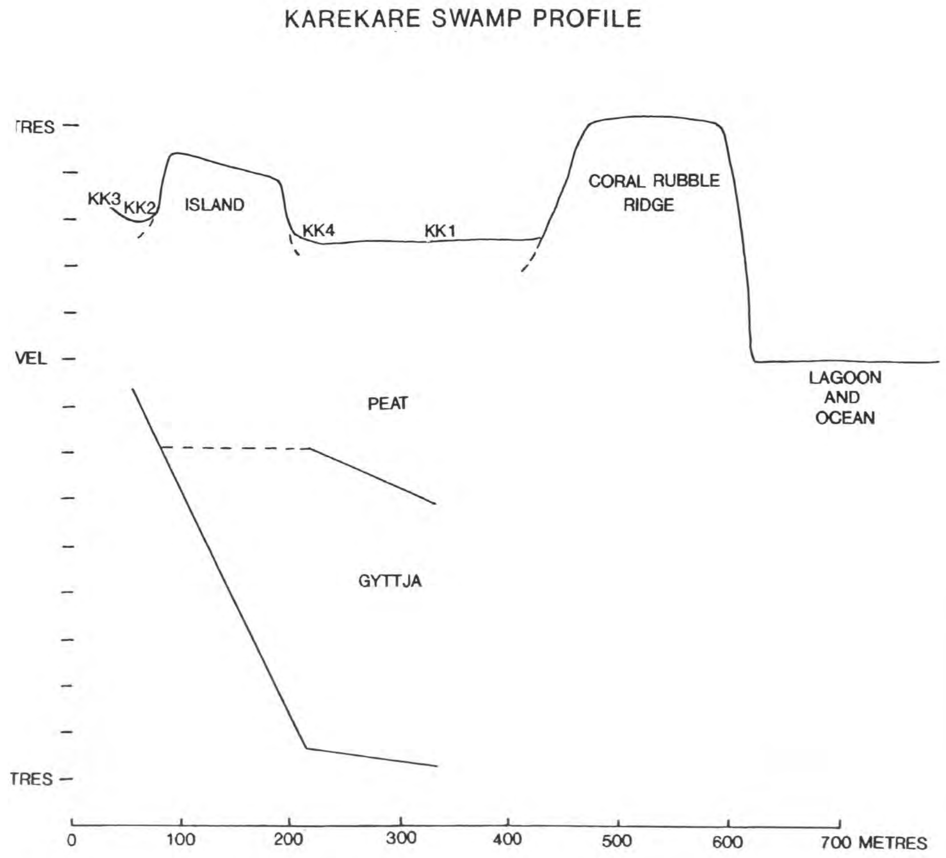

Figure 5.4 Profile through Karekare swamp, including information from the cores.

On the return to Auckland University, all these specimens were dried out at 50 °C over a few days in presses, until ready, in the Botany Department drying ovens. While needed for study, they were kept in freezers in the Anthropology Department. They are now in the herbarium of the Auckland War Memorial Museum.

Identifications were made or confirmed by W.R. Sykes of Manaaki Whenua/Landcare Research NZ Ltd., Lincoln and G. McCormack of the Cook Islands Natural Heritage Project, Rarotonga.

5.2.3 *Photographic Methodology*

On the fieldwork seasons of November/December 1990 and August 1992, a Pentax K1000 was used. For each core sample, both colour and black and white exposures were taken. Black and white film was used to bring out contrasts more clearly. Photographs were also made of sample context and general location.

5.3 Results of Fieldwork

5.3.1 *Fieldwork February 1990*

From Karekare swamp, three cores were obtained KK4, KK5 and KK6. KK4 was the deepest which produced the aforementioned 8373 BP date, and was a few metres seaward of the land islet in the swamp. Core samples and core descriptions were also obtained from five other swamp sites, though with no calibrated dates earlier than 1415 at 2s (Appendix A.6) and with much shallower deposits than Karekare swamp.

5.3.2 *Fieldwork November/December 1990*

The fieldwork consisted of three parts:

1) Investigation of the swamp, including an electrical resistivity survey, a conventional survey, a photographic record of the swamp, and a number of cores through the swamp at different points to sample the stratigraphy.

2) Collection of modern specimens to improve the present reference collection (of pollen) together with herbarium specimens consisting of twigs, leaves and flowers. Time was also used to familiarise myself with the vegetation, and with the present-day plant communities.
3) A study of the surrounding topography, including existing sections through natural deposits, in order to place the swamps into context and try to explain their formation processes.

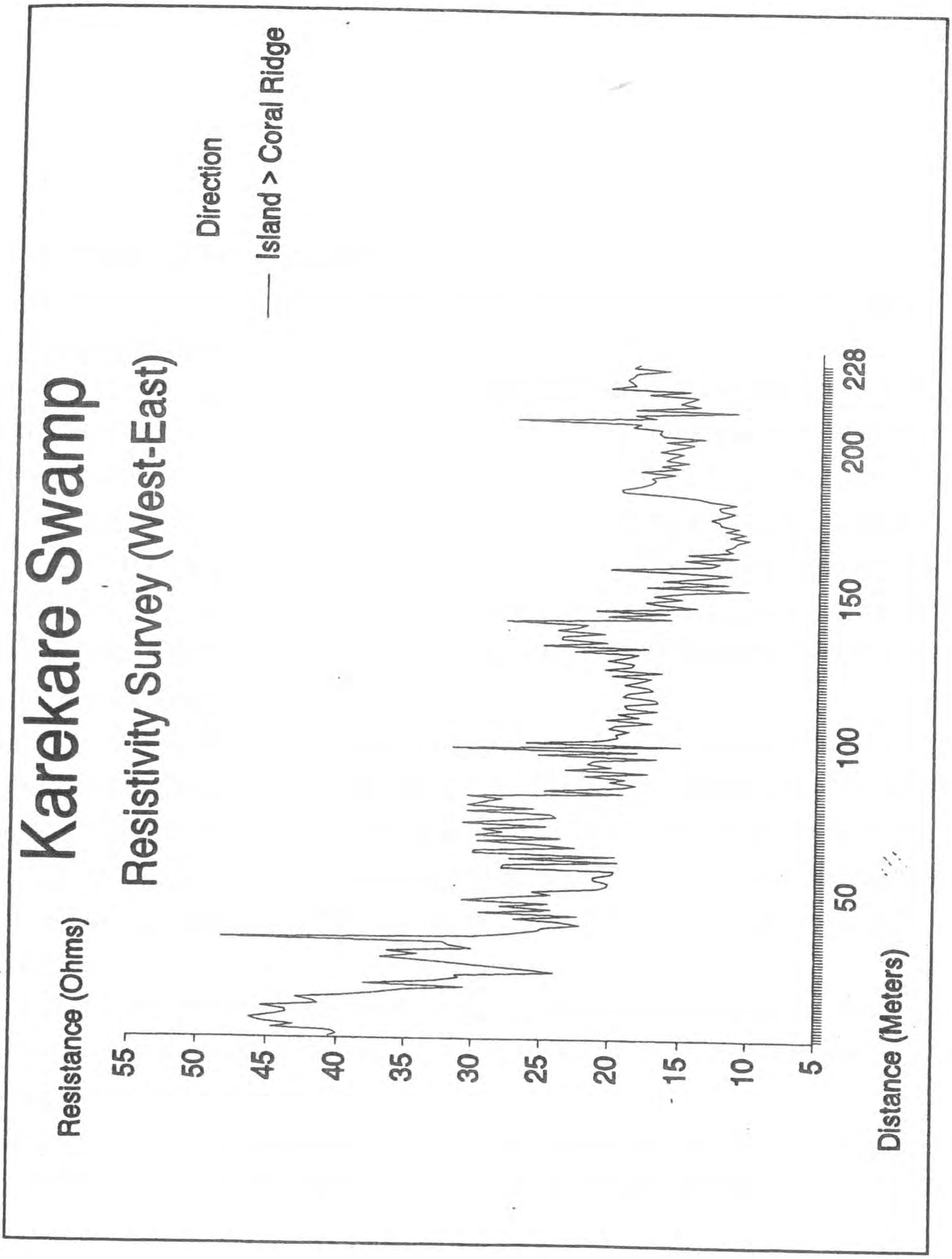

Figure 5.5 Electrical Resistivity Survey across Karekare Swamp, from the island to the coral rubble ridge (West-East).

1) Investigation of Karekare swamp (Figures 5.1, 5.2, 5.3 and 5.4):
A Martin-Clark Resistivity Meter, was used to obtain an estimate of the underlying topography of the swamp (*cf.* Darwin *et al.* 1990 for similar sub-surface topographical survey). A transect was chosen, oriented north-south, to the landward side of the islet. This was very irregular due to the surface background provided by the alternation of taro bed and drainage ditch. Little change is represented by the resulting figures when the background is accounted for. This was not a very reliable set of results, and is not presented here.

Next, a line was investigated from the seaward end of the islet to the storm beach, following the line of the drainage ditch, a distance of about 230 m. This produced much more satisfactory results, demonstrating a gradual slope towards the sea, finally rising again slightly over the last 70 m to the storm beach (Figure 5.5).

At a deep point near the centre of the swamp, the first core was taken (KK 1) and descended almost 11 m. Layers of worked humic detritus gave way to peat and thence to gyttja, as occurred in the core taken in February 1990 (KK4 [MR1]).

Each sample (50 cm) from the core hole was photographed, recorded with a description, including a Standard Color Identification Chart (Fujihira Industry Co.Ltd., 6th ed. 1965) definition, and occasionally - where of interest - tested for pH by means of universal indicator (this was to assess the role of sea water in the formation of swamp). The result of the pH testing was that the swamp was weakly acidic during most of its existence and at some periods neutral. This is, of course, assuming little or no interplay between layers. The meaning of this result would seem to be that some small degree of interference from the sea occurred throughout the life of the swamp, albeit a rather secondary force in the formation processes.

Another core (KK2) was taken from the north-west part of the swamp halfway between the coral rubble causeway to the islet and the northern shore of the swamp. This produced a substantial thickness of wood peat before reaching the bottom at 3.5 m.

A final core (KK3) was made close to the landward shore of the swamp. After passing through a layer of humic loam, the auger started to take in a very compact and fine blue-grey clay at about 2 m, which proved impossible to penetrate without damaging the equipment.

A conventional survey was undertaken in order to pinpoint the exact positions of the cores taken (Figure 5.3). The government benchmarks are situated along the coastal road (the *Ara tapu*), which passes over the storm beach. I used the opportunity to undertake a profile (Figure 5.4) from the crest of the storm beach to the back of the swamp, taking in the cores and the government trig points. This demonstrated that the storm beach was about 4 m above sea level, and the swamp surface, excluding the area around the islet, about 2.2 m. The swamp depth is thus about 8.7 m. Finally, the swamp surface around the islet is about 3.5 m a.s.l..

This raised part of the swamp around the islet was wet woodland before the 1940's, according to the owners of the portion of the swamp immediately southwest of the islet. Coconut and *puraka* (*Cyrtosperma chamissonis*) were collected from it as an additional food source. This tallies very well with the evidence of the odd tree stump and the wood peat from the core samples. In the 1940's, the ground was cleared for cultivation of taro, and, thus, taro beds and drainage ditches were created from scratch (see 6.5.2).

Photographs were taken from different positions all around the swamp to create a clear visual record of the location of the fieldwork. Location shots were made for the cores as well.

2) Collection of Modern Specimens
Time was spent for the author to familiarise himself with the various vegetational communities: on the islets in the lagoon near Muri; along the shoreline; around and on the swamp; on the alluvium of the coastal plain - cultivated and non-cultivated areas; up the mountain valleys of Tupapa, Avana, Avatiu, Vaima`anga and Maungaroa -cultivated and non-cultivated areas; along the fern-covered ridges; and finally, the cloud forest.

It was noted that much of the vegetation up the mountain valleys and on the ridges was of a secondary character. On many ridges, there was dense fernland or open *Toa* (*Casuarina equisetifolia*) woodland, and in the valleys, there was *`Au* (*Hibiscus tiliaceus*) thicket with various other pioneer plants as minor components. This gives the impression that much of the upland region of Rarotonga was once cleared. David Todd (pers. comm. 1990), a contract zoologist, then visiting Rarotonga, pointed out that, in some valleys, the *Homalium acuminatum* trees have two trunks, possibly due to coppicing in the past.

3) A Study of the Surrounding Topography:
A number of problems presented themselves in considering the situation of Karekare swamp which could assist in the interpretation of the core samples. Firstly, it is on the only stretch of coastline that has a high storm ridge composed of coral rubble instead of the usual low flat ridge of fine coral sand. Secondly, it has the narrowest stretch of lagoon on the

island with the reef only a few metres away from the beach. Thirdly, the coastal plain is at its widest in the area of Karekare swamp. Another interesting point is that the mountains are at their highest in this northeastern quarter of the island.

5.3.3 *Fieldwork August 1992*

The tasks undertaken were:

1) Vegetation surveys of the important vegetation types (see Chapter 2).
2) The collection of moss, leaf litter and soil samples from the vegetation plots surveyed for evidence of the modern pollen rain (see section 2.2).
3) The collection of samples of wood from different tree and shrub species for the reference collection of the Anthropology Dept. at the University of Auckland, under the care of Dr R.T. Wallace (see Chapter 8).
4) The collection of voucher specimens for identifications made and for the wood samples.
5) Where the opportunity arose, oral tradition and recollections from living memory were noted (see Chapter 6).

5.4 Résumé

The aims of the fieldwork were: to locate and sample polliniferous deposits extending back to before human settlement on Rarotonga; to carry out modern vegetation studies in order to assess the state of the vegetation with modern pollen rain studies to provide comparisons for the fossil data; to collect reference pollen and voucher specimens of the plants the pollen came from; to note topography and location; and to gather oral tradition and local information. Three trips were made to Rarotonga from 1990 to 1992 for the purpose of fieldwork, and these have been described.

CHAPTER 6 DOCUMENTARY WORK

This chapter looks at evidence from historic documents, oral tradition, living memory (of Cook Islanders) and ethnographic literature and extracts information and ideas therefrom about the former ecology, economy and human settlement of Rarotonga at different periods in order to take account of human-environmental changes in later periods of human settlement. A section on pictorial and photographic evidence compares the relatively late images of Rarotonga's landscape with the landscape of other East Polynesian islands (Mangaia and the Society Islands) at the time of Cook's voyages and notes a number of common themes.

6.1 History

In Chapter 1, an outline of Rarotongan history was given. The following section looks firstly at the documentary evidence, then oral tradition in order to ascertain the state of the Rarotongan landscape during the initial period of European contact and if possible prior to European arrival. This not only completes the history of human-environment relations, but also helps to allow for changes which may be recent in origin.

6.1.1 *Documentary accounts*

The earliest documentary accounts are mainly those of missionaries of the London Missionary Society, who evangelised the island from 1823 onwards.

These accounts tend to agree that the central mountainous core of the island was forested, though there is a degree of uncertainty regarding the state of the lowlands. Much of this is due to overstatement by the missionaries (see below), possibly in order to impress audiences back in Britain. Relating missionary success in converting Pacific Islanders was the main purpose of such reports.

Compare the following depictions of Rarotonga. The first is that of 1830 by the Reverends John Williams and Charles Barff:

> June 3. Saw the fine island of Rarotonga early in the morning. It had a fine romantick appearance from the vessel, the lofty mountains separated by deep ravines and all covered with a beautiful foliage, formed a

majestick landscape.....The extent of Cultivation was to us a novel sight, almost every Individual having his kaina/kainga or small farm cultivated with plantains, ti, taro, yams, etc., so that the whole settlement appeared one extensive garden. [Williams and Barff 1830: 5].

The second is that of Aaron Buzacott, the missionary stationed at Avarua, Rarotonga:

> The "Industry" reached Rarotonga on 16th February, 1828. The island presented a most romantic ppearance. Range upon range of mountains towered above each other, forming to the eye a gigantic ladder, by which the Titans might ascend far above the clouds, and hold intercourse with the immortals. The low-lands revealed cultivated spots amid stately trees and forests. The very hills and mountains, from base to summit, were covered with dense wood of varied growth and colour. Mountain torrents leapt from crag to crag - forming the most lovely cascades and miniature water falls, and breathing a grateful coolness through the hot atmosphere. A vegetation of wondrous luxuriance grew down to the sea shore, and seemed to contend with the ocean for every inch of ground. The battlefield of this bloodless war was a narrow strip of white sand which fringed the whole island. [Sunderland and Buzacott eds. 1866: 25].

Both are descriptions of the island as seen from an approaching ship, and both indicate a forested interior, but differing on the level of cultivation. However, the former does limit it to the `settlement', which suggests that this concerns the post-contact settlement pattern of villages or *oire*, rather than more scattered dwellings amongst the cultivations (*cf.* Crocombe, R.G. 1961). The latter description suggests that cultivated areas were separated by stretches of forest, and that the cultivated spots were broken up by trees. Some of these trees would no doubt have been crop trees. Forest or woodland appears to have extended right to the shore from the second description.

William Gill (1856), the missionary stationed at Arorangi, Rarotonga[23], mentioned that the staple diet of Rarotongans consisted of vegetables and fish, with pigs and poultry being consumed at feasts.

An explanation for this lack of extensive gardening is to be found in John Williams' missionary memoirs:

> Between each district was left a space of uncultivated land, generally about half a mile in width. On these wastes their battles were most frequently fought; for the inhabitants of each district invariably used every exertion to prevent their opponents from making encroachments upon their kaingas or cultivated lands, and therefore disputed, with greatest pertinacity, every inch of uncultivated waste; nor did they, until entirely driven off, yield their possessions to the hands of the spoiler. But since the introduction of Christianity, many of these wastes have been cultivated. [Williams, J. 1843: 210].

Warfare and disputes, therefore, had created bounds to the potential exploitable land. Other examples of such `no man's land' areas in Polynesia include Tongareva (Buck 1932b) and the Marquesas Islands (Melville 1847; Robarts 1974).

William Gill of Arorangi records the presence of woodland before the construction of the church and village, which he attributes to the warfare which prevented its use for settlement, though a reading of the memoirs of Maretu (1983), a Rarotongan who became a missionary, provides a balance to the idea that this had been going on for `many generations':

> The site fixed on for their settlement is about 6 miles from Avarua, a level piece of ground two miles long, at the base of a noble range of mountains, and facing due west. It involved no little difficulty and labour to clear this land, for it was covered with trees and brushwood, the growth of many generations. [Gill, W. 1856: 39-40].

William Wyatt Gill, missionary first on Mangaia and later at Avarua, on Rarotonga, also provides evidence of what was occurring:

> The outward condition of these islanders has been marvellously improved since the introduction of hristianity. The soil is better cultivated, waste lands have been reclaimed, numerous places once sacred to the gods are now planted for the good of mortals... [Gill, W.W. 1876a: 15]

This supports the oral evidence given below that once there were uncultivated wooded areas between settlements, although these were cultivated under missionary influence. In addition, some areas once considered *tapu* were no longer held in awe and were thus exploitable. However, oral tradition suggests this may have been a very gradual process (see below).

Many scholars have quoted John Williams' extravagant portrait of the agrarian landscape of Rarotonga without looking at the context of the quote. Firstly, Williams was describing one particular scene and not the entire island as is often taken to be the case - he was merely stating that the island was `in a high state of cultivation' and gave an example:

> One valuable peculiarity of this lovely island is, the extent of its low land. In many of the Islands, the mountains approach so near to the sea as to leave but little arable land; but this is not, to my recollection, the case in any part of Rarotonga. Its soil also must be exceedingly rich, or the climate peculiarly adapted to the fruits which grow there; for on our arrival, we were astonished to see the *taro* and *kape*, the *ti* and sugar cane growing luxuriantly nearly down to the edge of the sea. The whole island was also in a high state of cultivation, and I do not recollect having witnessed any thing more beautiful than the scene presented to me, when standing on the side of one of the hills, and looking towards the sea shore. [Williams, J. 1843: 205-206].

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23 Not to be confused with William Wyatt Gill (see below).

It is the scene from a hill behind that forms the basis for the well-known quote. Food swamps on Rarotonga stretch from near the mountainside to a coastal ridge of coral rubble or sand, hence gardens could stretch right to the coast. A `high state of cultivation' is not a precise description, and could be interpreted differently from how it has commonly been interpreted.

> In the first place, there are rows of superb chestnut trees, *inocarpus*, planted at equal distances, and stretching from the mountain's base to the sea, with a space between each row of about half a mile wide. This space is divided into small taro beds, which are dug four feet deep, and can be irrigated at pleasure. These average about half an acre each. The embankments round each bed are thrown up with a slope, leaving a flat surface upon the top of six or eight feet in width. The lowest parts are planted with taro, and the sides of the embankment with *kape* or gigantic taro, while on the top are placed, at regular intervals, small beautifully shaped bread-fruit-trees. The pea-green leaves of the taro, the extraordinary size and dark colour of the kape lining the sloping embankment, together with the stately bread-fruit trees on the top, present a contrast which produces the most pleasing effect. [Williams, J. 1843: 206-207].

The spacing of the rows of *Inocarpus* do not fit in with the scale of the swamp gardens today. Nor has any swamp on Rarotonga ever been large enough to take more than three rows even if the sides of the swamp were included as two rows. Clearly the description was written far away in time and space from the reality. One should not therefore take the measurements and details too literally. From the oral tradition mentioned below, taro was not necessarily grown every where on the lowlands. The context of this quote shows he is remembering one particular spot, no doubt the main station at Avarua. It does, however, give a broad impression of economy of space, cultivating as many different items in one area as possible.

Cultivation on the coastal plain presented a number of difficulties: lack of running water, drought, cyclones, flooding and tidal waves (Afsenius 1988a; 1988b; 1988c). For example, Buzacott describes the cyclone of December 1831 thus: `All the way inland was one sheet of water to the foot of the mountains' (Sunderland and Buzacott 1866: 86). Buzacott then explains the resulting problems:

> In a few days it was certain that not a breadfruit, or banana, or taro (wild arum) could be obtained by rich or poor, at any price...The taro, washed by salt water, began to wither and rot. Some few patches had been drenched by rain floods, and these remained, and became more precious than gold. [Sunderland and Buzacott 1866: 89].

The crops were badly affected by such conditions especially the taro, so it is not surprising that oral tradition (as presented below) stresses the importance of the valleys. That the valleys were cultivated is indicated by William Wyatt Gill who mentions the chestnut trees (*Inocarpus edulis*) at the top of the valleys:

> The whole island is clad with rich tropical verdure...primeval forest, with its many shades of green; immense chestnut trees, laden with fragrant blossoms, marking off the actual domain of man... [Gill, W.W. 1876a: 11].

On should note also the order of the crops mentioned by Buzacott above: breadfruit and banana before taro. William Wyatt Gill stated:

> The staple diet of the Rarotongans consists of bread-fruit (*Artocarpus incisa*[24]) and plantains. The bread-fruit harvest marks the arrival of summer, so that its name is a synonym for plenty. These islanders speak of `bread-fruit and winter', *i.e.* summer and winter. Plantains mostly grow in distant and almost inaccessible valleys whilst bread-fruit groves often surround their dwellings. When in season and no untoward gale has destroyed the young crop, an air of contentment rests upon the countenances of the islanders...Seven varieties of breadfruit are indigenous to Rarotonga...At Rarotonga the trees bear only once a year; at Aitutaki and some other islands twice or even thrice. [Gill, W.W. 1885: 175-176].

This is supported by a letter written by Charles Pitman, the missionary stationed at NgaTangi`ia, Rarotonga, in 1832 to the LMS:

> a most dreadful hurricane....destroyed also, nearly the whole of their breadfruit, + other trees on which they chiefly subsisted. Since which period the Natives have been obliged to seek their food in the mountains, + are forced to feed upon the roots of the Banana + ti trees. [Pitman 1832: 3-4].

Thompson (1900), a missionary who made a tour of LMS missionary stations in the Pacific Ocean, records that whereas Mangaia is famous for its taro and Aitutaki for its breadfruit, Rarotonga had always been noted for its plantains. Williams and Barff mention that

> August 20th. Early in the morning took our leave of the People at Natagnia but they were at Arorangi on the 19th, and travelled in land to Avarua, Mr Buzacott's Station. The Distance between the two stations we

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24 Known as *Artocarpus altilis* today.

supposed to be about eight miles through a countryside under cultivation almost all the way with Bananas, Mountain Plantains, & c. The soil appeared a fine rich clay all the way. [Williams and Barff 1830: 31].

On the other hand, sweet potatoes or kumara do not appear to have been cultivated according to Buzacott, though archaeological evidence from Mangaia suggests otherwise (Hather and Kirch 1991).

Mr. Buzacott found great difficulty from the strong prejudices of the people. Having procured at no small trouble, a quantity of sweet potatoes for planting, the natives refused to accept them and to plant them, declaring in true old tory fashion, that their fathers had managed to live without them, why could not they? [Sunderland and Buzacott 1866: 90].

Cultivation on the coastal plain appears to have taken place in the swamplands and along the *Ara Metua*

There is a good road round the island, which the natives call *ara medua*, or the parent path, both sides of which are lined with bananas and mountain plantains; and these, with the Barringtonia chestnut and other trees of wide spreading foliage, protect you from the rays of the tropical sun, and afford even in mid-day the luxury of cool, shady walks of several miles in length. The houses of the inhabitants were situated from ten to thirty yards or more from this pathway, and some of them were exceedingly pretty. The path leading up to the house was invariably strewed with white and black pebbles; and on either side were planted the tufted top *ti* tree or *dracaena*, which bears a chaste and beautiful blossom, interspersed alter-nately with the gigantic taro. Six or eight stone seats were ranged in front of the premises, by the side of the "parent pathway". [Williams, John 1843: p.207].

Also, together with Barff in 1830, he records that the stretch of road between Avarua and NgaTangi`ia was cultivated on both sides:

June 4 th. Visited, in company with Mr. Buzacott, Mr. Pitman's Station. The distance from one station to the other is about seven miles. The road is a tolerable good one in most Places and shaded from the sun by the branches of the spreading trees. The land on each side of the road was cultivated all the way. [Williams and Barff 1830: 5-6].

It could be that he is generalising from this area, as this is from archaeological evidence and oral tradition (see below) the more populous side of the island. Note `the branches of the spreading trees': this was not an open landscape.

However, this should not be taken to imply that the whole of this area, let alone the whole of the coastal plain, was continually under cultivation. Firstly, there were the contested areas between lineages; secondly, the swamp-lands are not as extensive as Williams claims, even allowing that the construction of the airport in the area of Nikao to Atupa in the 1970's reduced the size of the swampland in the area; and thirdly, between the area neighbouring the road and the coast, there is documentary evidence of coastal forest before the building of the *Ara Tapu*, the `Holy Road' of the missionaries, the main road used today.

at the end of the year the missionary Gill[25] arrived and shifted Matavera village to the coast because there was too much mud on the inland road. The sites for the houses were cleared together with the village road. The people of Avarua cleared [their section of the coastal road] until they reached Pue where they stopped .....Ta stopped us because he wanted it[26] left as shelter for his home. So we came back here to Ngatangiia. Pa said "Let's clear our area until it is in line with Matavera." *The east coast had been completed, but*[27] there was still Ta's [to be cleared] and Matavera still had to join on to Avarua, who had stopped at Pue. [Maretu 1983: 192].

So before 1857, there was no *Ara Tapu*, and there was clearly coastal forest in abundance. The road was then completed by William Wyatt Gill, missionary at Avarua, Rarotonga, formerly stationed on Mangaia, after 1860:

Wyatt Gill and some other missionaries had come. George Gill and some friends [Cook Islands missionaries] had sailed for the heathen lands[28]....Wyatt Gill then completed the new road, clearing from Pue to Matavera. He then went to see Ta to ask his permission. Ta thereupon cleared his section. [Maretu 1983: 192-193].

This does not include from NgaTangi`ia to Avarua via Arorangi, which must have been even later therefore. The fact that Maretu does not discuss this may reflect his greater personal interest in the eastern side, though it may also reflect the lower population and thus interest paid generally in the western side. William Wyatt Gill (1876b: 138) mentions in recording the story of the origins of pigs on Rarotonga a `dense ironwood forest, not far from the beautiful white sandy beach of Nikao', which supports the idea of the existence of such coastal forest on the eastern side of Rarotonga too.

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25 George Gill, was the missionary at Avarua between 1857 and 1860. From Maretu's narrative, this appears to be late 1857.

26 I.e., the bush.

27 Connecting italics inserted by author (C.Peters).

28 This would put the date at 1860.

The population of Rarotonga was put at between 6 and 7000 people by Williams (1843), which is obviously an estimation having such a wide margin of potential error. The first figure that appears to have a more accurate basis is that of December 1843, when the population was 3,300 (William Gill 1856: 72). This was after diseases had reduced the population, so the population when the missionaries arrived would have been greater. However, it should be borne in mind that despite Williams' claim to have converted the entire population (1843), the missio-naries may well have brought in some degree of guess-work into their figures as some sections of the population were not converted (*cf.* Pitman 1827-842; Utanga pers. comm. 1992). The round figure of 3,300 might suggest this too. Estimates erring on the generous side would have been more impressive for the LMS board of directors back in London.

Williams' figure of 6 or 7,000 may be rather large, especially when one considers the hyperbole used in his description of the size of the taro swamps (Williams, J. 1843: 205-207). Williams was writing to impress and persuade not to provide an accurate scientific account. His idea, that `the richest soil on the island would have been found on the Arorangi to Avarua side' (Williams and Barff 1830: 31), shows that his knowledge of the island was also not good (*cf.* Leslie 1980 for information on soils).

The idea that Polynesian rats (*Rattus exulans)* may have been a factor in altering the ecology of the island (because in significant numbers they can extirpate other animals and consume plant seeds and seedlings) certainly receives support from missionary accounts - for example:

> When we arrived on the island, it was literally filled with rats. Often have we counted droves of fifty at a time come into our room while at meals. [Pitman 1833: 3].

William Gill (1856) states that pigs and poultry were eaten on festive occasions. Williams (1843) believed that pigs were not that common, but it is apparent from Maretu (1983) that the Rarotongans had hidden them in case the missiona ries wished take them away, because the Tahitian pastors had led them to believe that as part of a ploy to hold on to more power. Some animals were even more restricted with regard to who was entitled to eat them:

> All turtle were formerly sacred, being eaten only by kings and priests. It is quite otherwise now (except at Rarotonga, &c.). [William Wyatt Gill 1885: 128].

Cash crops or at least barter crops were started early under missionary influence. Buzacott (Sunderland and Buzacott 1866) claimed to have introduced the kumara as a crop for trade (probably new varieties). William Gill (1856) describes how cotton was grown from the 1830's onwards and coffee was established at least by 1852. William Wyatt Gill (1876a) mentions the growing of coffee `plantations' under the shade of coconut trees.

Europeans had already introduced several other crops by the 1830's. Daniel Wheeler, a Quaker minister who visited Rarotonga in 1836, described the lowlands of Rarotonga thus:

> These districts team with bread-fruit, plantains, bananas, citrons, limes, vis, papaws [*sic*], taro, sweet potatoe [*sic*], sugar-cane, cocoanuts, palms, and many other tropical productions of majestic growth. [Wheeler 1842: 776].

Wheeler (1842: 544) also mentioned that Alexander Cunningham, a trader, had set up a sugar cane plantation on Rarotonga by 1836, so capitalism had taken root relatively rapidly.

6.1.2 *Oral Tradition, Living Memory and later documentary records*

Recorded oral tradition and living memory provides evidence as to the former landscape, some of it reinforcing the missionary records. The following discussion deals with each part of the landscape separately: valleys, coastal plain, coast, marine and lagoon resources.

List of informants:

Kiriau Maoate (Turepu), Totoko`itu Research Station, and also a *Mata`iapo* of Takitumu.
George Cowan, Minister of Public Works, Rarotonga.
George Tara`are, Dept. of Agriculture, Rarotonga, and also a *Tumu Korero* for Matavera.
William Hosking, Minister of Agriculture, Rarotonga.
Anthony Utanga, Dept. of Marine Resources, Rarotonga.
Alamein Vakapora, a *Mata`iapo* of Tupapa, Rarotonga.
Teariki Rongo, Minister of Conservation, Rarotonga.
Ngatoko Ngatoko, Dept. of Agriculture, Rarotonga.
Gerald McCormack, Cook Islands Heritage Trust, Primeminister's office, Rarotonga.
Stuart Kingan, resident of Tupapa, and former civilservant.
Sir Thomas Davis, former Primeminister of the Cook Islands and writer, Rarotonga.
Rangi Moeka`a, Dept. of Education, Rarotonga.
Inatio `Akaruru, Deputy Primeminister of the Cook Islands, Rarotonga.

Valleys:

The settlement of the valleys is evidenced in the ancient chants, which refer to the valleys being full of "sounds and noises" - i.e. human activity. The tracks up to the mountains were also ancient to post look-outs to watch out for raiders coming over the ridges from other areas (Moeka`a pers. comm. 31/08/92). Some archaeological structures on Raemaru and the upper Maungaroa Valley have been suggested as look-outs (Bellwood 1978: 38 and 40 respectively).

The valleys were used up until fairly recent times on a much greater scale than is now seen. There were the banana plantations, though, through the influence of European traders, these were used for cash cropping. Scott (1991: 41) and Gilson (1980: 39-40, 52-53, 79-80) discuss the early export industry in produce in the 19th century and early 20th century to Auckland, Tahiti, California and Samoa. Some European merchants regarded the islands in the Cook group as their own personal empires (Scott 1991).

Johnston (1959) suggested that the inland forest had had larger trees removed for building material and boxwood, and many spurs supported only low fernland due to continued burning and accelerated soil wash. According to Johnston, until a decade before his article, the gentler slopes on the sides of the inland valleys were major banana-producing areas.

Banana leaves were also important (though *Musa paradisica* or the `Cavendish Banana' was a missionary introduction - see below). *Rau meika*, the green banana leaf, made useful platters if passed over a fire as this process prevented the leaf splitting. *Rau uru*, the dry dead leaf of the banana, was used as mulch in the food swamps (Cowan pers. comm. 30/08/92).

Huge orange trees used to be found up in the valleys. As a boy Utanga was sent to pick the fruit from them (Utanga pers. comm. 10/08/92). Maretu (1983) related that the Bounty brought them. Wild oranges occurred on Rarotonga, Miti`aro, Mangaia, Atiu and Ma`uke. In the 1960's, terraces were created at Muri for attempts at producing pineapples (Hosking pers. comm. 6/08/92).

Kava also was still planted up the valleys this century for medicinal purposes, right up the top of the stream valleys among the boulders and the *`au* thickets. Utanga recalled that as a boy, he was sent to harvest the kava (perhaps because the missionaries had disapproved (*cf.* Gilson 1980), people used this as a device to hide it - author's suggestion). It is planted today as well, though not up in that locality any more - i.e. the valleys (Utanga pers. comm. 10/08/92).

One introduction was not so useful: the mile-a-minute vine, introduced by the American troops during the Second World War, has proved a pest (Hosking pers. comm. 6/08/92).

Trackways, now used by tourists wishing to observe Rarotonga's natural scenery, were and are important to Rarotongans, themselves. The Cross-Island Track, the most well-known of these routes, was an ancient trackway, though the original route is not exactly the same track as used today (this was created in the 1970's). The original track went up the Avatiu Valley as at present, but instead of heading up the left-hand ridge after the village at the back of the valley and going down the Papua Valley, one had to take the right-hand ridge and cross over to the Rutaki Valley, passing Te Rua Manga on the left (Utanga pers. comm. 31/08/92; Rongo pers. comm. 31/08/92).

Savage (1962), who used Te Ariki Tara`are as his source, records that people used to climb up Oro`enga, the small mountain by Karekare swamp, to collect the feathers of certain birds, which nest there, to adorn chiefly headdresses. The descendant of Te Ariki Tara`are, George Tara`are (pers. comm. 7/08/92), informed the author that *rakoa* (*Phaethon lepturus*) and *tavake* (*Phaethon rubricauda*) nested on Oro`enga in small holes in the rock.

Evidence for any clearance of mountain forest is lacking (*cf.* Ch4). The forest appears to be primary on the mountains themselves, but not in the valleys, because, for example, there is the presence of *`au* (*Hibiscus tiliaceus*) thickets and coconut trees planted at the end of the valleys sometimes (McCormack pers. comm. 1992). Also, one can observe abandoned taro pondfields at the back of some valleys like the Tupapa Valley, just below the zone with *Inocarpus edulis* trees and *Alocasia macrorrhiza* (Afsenius 1988c and personal observation). The theory of David Todd, a contract botanist, is that the *Homalium* were coppiced. There is evidence according to Todd at one place where a *Homalium* patch is divided by a fence: on one side all the *Homalium* have a single trunk, and on the other they have several trunks (McCormack pers. comm. 1992).

On some of the lower ridges of the mountains there are fernlands. Fernlands have a long history, for instance, there is Cook's description of Mangaia with ferns and *Casuarina* (Beaglehole 1967).

The slope immediately behind Karekare swamp was planted (see below) - Tara`are pers. comm. 7/08/92 - so some lower slopes may have been utilised.

On the south side of the island, there is the long gentle slope of the terrace, composed of lateritic soil, from the base of the mountain to the thin strip of swamp, which is only partially utilised. On the other side of the swamp is a well-sorted coral sand zone which extends to the beach (Author's field notes 9/08/92).

Coastal plain:

The *Taura `oire* led people to move from valleys to the coast. Some people were without land on the coast, so the law made provision for all to have access to a house site on the coast (Crocombe 1961; Gilson 1980). The laws of 1906/7 and

1915 governing the operation of the land court encouraged the further development of the coastal plain for agriculture (Crocombe 1961; Gilson 1980).

Not all areas were even then cultivated. The area around Tuoro (Black Rock) was avoided by the generation before Moeka`a because of fears engendered by its association in the pre-Christian religion with the departure of the spirits of the deceased for `Avaiki (the land of the ancestors) from a *Pu Pua* tree (*Fagraea berteriana*) that grew there. Other areas included the Paringaru stream, Tikioki, and Mimiti o Apara[29] (an area extending from the bend in the *Ara Tapu* south of the Education Department to Matavera - this included Karekare). These were wild tracts between the cultivated and settled village lands. Until about 20-30 years ago, there were still clear boundaries between the villages which have now largely disappeared under expanded settlement. In the south, there were larger boundaries between the settlements (Moeka`a pers. comm. 10/08/92).

It could be argued that this was due to later regeneration of the vegetation after the population decline during the nineteenth century, but the accounts of the missionaries mentioned above (pp.130-131 and 134-135) suggest that such wild tracts existed at the time of initial European contacts too.

There was less settlement on the south coast between Arorangi and Titikaveka, because the *tapere* in between were disputed territory between the *vaka* and they might be lost through warfare (*cf.* Crocombe 1961; Maoate pers. comm. 31/08/93; *cf.* Maretu 1983). There are less attractive marine resources in the area too (Maoate pers. comm. 31/08/93). The idea of a lack of settlement between Titikaveka and Arorangi may also in part be due to the fact that that is where the European growers had their plantations - for example, Hosking, McKegg, Wigmore and Smith (Cowan pers. comm. 30/08/92; Scott 1991).

Another area with a lack of settlement was the area around Karekare swamp. People considered the Karekare area to be haunted by ghosts up until the 1970's. It was still covered in bush until the 1970's and 1980's (Utanga pers. comm. 5/08/92).

Coastal swamps were used as food gardens, though there a number of problems connected with coastal agriculture. The flooding and hurricanes on the coastal plain, which would have put people off settling there in the first place (Cowan pers. comm. 30/08/92), were a hazard for crops too. Examples of this are the tidal waves of 1835 and the 1840's mentioned by the missionary Buzacott (Sunderland and Buzacott 1866).

Karekare swamp had problems with freshwater flooding and saltwater tidal waves not draining away for months, which made it difficult to grow taro. Atoll taro or *puraka* was grown as the main crop instead (Tara`are pers. comm. 30/08/92). Other areas have similar problems, for example, Puaikura has had drainage difficulties associated with lowlying areas affected by flooding (Jonassen 1979)

Other useful plants could be grown on swamps too. *Mata* (*Paspalum orbiculare*) grew naturally on swampland in uncultivated areas. Areas were set aside to permit its growth. *Mata* was used to cover the *kirikiri* flooring in houses to provide a soft surface. Later, it was used to stuff mattresses. It was replaced by the introduction of kapok/*mamau*, which in turn was replaced by artificial foam mattresses purchased in the shops. People used to mulch the taro patches with *mata* as well (Cowan pers. comm. 30/08/92).

Mauku (*Mariscus javanicus*[30]), a sedge, was used as a coconut strainer. Its stalks were scraped and beaten out in order to extract the white fibres. *Puru* (coconut husk) was used only in the bush as a makeshift alternative, because it stains the coconut cream a brownish grey. Cook Islanders preferred the *mauku* because it was cleaner. It was used to strain juices out of other plants - for making *vairakau* or traditional medicines in particular. It has been replaced in more recent times with store-bought muslin cloth. *Mauku* was also permitted to grow on the swamps. Both *mata* and *mauku* are still used on the outer islands, but on Rarotonga, only the old people still remember (Cowan pers. comm. 30/08/92).

*I`i*/Tahitian chestnut (*Inocarpus edulis*), *ava*/banyan (*Ficus prolixa*), and *kuru*/breadfruit (*Artocarpus altilis*) were all planted as boundary markers and wind-breaks (Crocombe 1961; Moeka`a pers. comm. 10/08/93).

Plantations of coconut were also useful. Some coconut trees grew at the back of Karekare swamp up to the 1940's (see below). *Kkau* or coconut leaf was a major source of raw material for thatching and basketry (Cowan pers. comm. 30/08/92; Buck 1944).

Much land was in the hands of the European growers (though not through outright ownership, but via long-term leases). Supplies of tropical fruit (and cotton up to the 1890's) were exported to Sydney and Auckland. Wood was also need for the fires to prepare whale oil and blubber, and food was required to feed the whalers and merchants that passed through (*cf.* Gilson 1980; *cf.* Scott 1991). Rarotonga also had a thriving citrus industry until the mid 1970's (Cowan pers. comm. 30/08/92).

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29 The original boundaries of Takitumu stretched from the Paradise Inn to the Sheraton. Takitumu was envisaged like a fish with its head (Mimiti o Apara) between the Paradise Inn and Matavera, its stomach at NgaTangi`ia and its tail between Titikaveka and the Sheraton (Moeka`a pers. comm. 10/08/92). Alternatively, it was seen as a canoe (`Te Vaka Ta`unga' – Crocombe, M.T. 1979).

30 See Whistler (1990) and list in Appendix A.5.

A certain number of the alterations to Rarotonga's natural landscape are recent and not ancient ones. Jim Allinson (1991) showed that the greatest threat to the conservation of Rarotonga's natural resources has been and is urban development as population increases, not so much from internal growth as from returners from New Zealand and Australia, and to a lesser extent from immigration of Outer Islanders (Cook Islanders not from Rarotonga). As a side effect of this escalated population, there has been and is more pressure to use up land so that the new-comers can earn a living. However, a large proportion of the community were employed by the government and the tourist industry, and many people consumed imported foods, so housing was the most extreme threat (Allinson 1991).

Population figures given by the missionaries for the time of their first contact with Rarotonga may well be flawed. John Williams would not necessarily have had access to all the population from which to make his estimate. There were probably still significant portions of the population who were still heathen, even though Williams claims to have converted the whole population (Williams 1843). For example, Utanga's great grandfather died in the early years of this century still a heathen. This was apparently not an isolated example (Utanga pers. comm. 31/08/92). Missionary figures are therefore likely to be estimates, not precise numbers. Indeed, Williams states the population to have been 6 or 7,000 (Williams 1843). If Williams' descriptions of cultivation are anything to go by, he probably was extrapolating from the richest areas of the island where he spent most of his time, and was not including areas like the southernmost *tapere* which appear to have been occupied by heathens (see above).

Another more recent problem, has been the introduction of pests like the Mile-a-minute vine introduced by the American troops during the Second World War (Hosking pers. comm. 7/08/92).

Davis does not believe the *Manu kura* (*Vini kuhlii*) - see section 4.3 - to have become extinct until it ceased to be *tapu*. *Tapu* and *ra`ui* were tools of chiefly resource management. Red lorikeet feathers were used for chiefly costumes (*cf.* Buck 1944; Davis 1992), and their over-exploitation may have been prevented by chiefs placing a *tapu* on them. Any trade in feathers would not have overly affected them as the feathers could only be used by chiefs, the chiefs also would be the only people likely to be able to afford to travel. Once *tapu* was removed, the bird would not have lasted long (Davis pers. comm. 29/08/92).

On Mangaia, there has been the question of how ancient the problem of erosion off the central volcanic hills into the taro swamps has been and whether there had been any local attempt at conservation (Kirch *et al.* 1991; 1992). Rongo noticed that stakes of coconut wood were placed on the side of the hills as silt traps. This was also the case in the streams. Local people told him that this was traditional practice, but that it was no longer as effective as it had been in the past, because of slope cultivation for the pineapples. The siltation has started to block the water outlets through the makatea to the sea, and has made the swamp land closest to the makatea unusable (Rongo pers. comm. 10/08/92).

Coast:

The coastal vegetation used to be, until recent times, mostly *`utu* (*Barringtonia*), *puka* (*Hernandia nymphaeifolia*) and *`oronga* (*Pipturus*), with some *`ara ta`a tai* (*Pandanus*) areas. A great expansion in building has also contributed a substantial amount to the disappearance of much of this vegetation (Cowan pers. comm. 30/08/92).

50 years ago, *`ara ta`a tai* (*Pandanus*) was a common shoreline plant, but then a blight affected them (`Akaruru pers. comm. 6/08/92). The *Pandanus* problem was confirmed by Cowan (pers. comm. 10/08/92).

Pandanus stands were affected by a white mealy bug about 50 years ago. Before then, it was a common shore plant (Tara`are pers. comm. 7/08/92). In the early 1940's, the *Pandanus* had already been hit badly by the blight, although there were still plenty between Avatiu and Arorangi. In the earlier part of this century, there used to be inland plantations of *Pandanus*. About 10-15 years ago, there was still the odd patch left. There were some patches in the area of the present Education and Conservation departments. Coconut crabs were much more common then, as the *Pandanus* scrub was where they lived - underneath the aerial roots (Moeka`a pers. comm. 10/08/92).

Documentary sources provided to me by McCormack contributed some additional data for elucidating the story. The mealy bug - *Pseudococcus pandanii* - was preyed upon by a ladybird, so did not present a problem in 1913 (Reid 1914). However, Dumbelton reported a problem occurring in the period 1926-1930, caused by a *Pseudococcus* species (Dumbelton 1950).

The *Pandanus* grew on either side of the *Ara Tapu*, not just on the shore. For example, at Kingan's house in Tupapa (on the coral rubble ridge at the edge of Karekare swamp), there were many *Pandanus* growing on the shore, and at Kiikii, there were *Pandanus* thickets on either side of the road (Utanga pers. comm. 10/08/92).

Pandanus posts were used for temporary dwellings associated with fishing on the shore. The thatching was made from *k kau* (coconut leaf). The coast was bushy, and was reached by means of paths coming down from the *Ara Metua* (Tara`are pers. comm. 7/08/92).

A *Barringtonia* canopy used to exist along the roadside, with trees planted on either side of the road for shade and as wind-breaks. This was because long journeys were made on foot in the full glare of the sun before the advent of the car -

see Thompson (1900) for confirmation of this. In more recent times, there has been a tendency to cut these trees back on both sides of the road (Moeka`a pers. comm. 10/08/92).

There was a trend from the 1960's, following the New Zealand thinking at the time, to fit the landscape to match the architect's plans for the development whether it be a road or a building. Also, as part of the trend, sea-views were always attempted. Cowan tried to make allowances for the trees, but there was a great deal of pressure for the Ministry of Works to remove `obstacles' like trees to avoid kinks in its road-improvements schemes. People chopped down trees on both sides of the road in order to achieve a sea-view emulating the New Zealand fashion (Cowan pers. comm. 30/08/92).

The beach rock at Edgewater Resort has been exposed in more recent times through people overexploiting the beach for aggregates. In the past the requirements were much smaller relatively speaking: baskets were filled to transport to the paepae, in order to beautify them with fresh clean *kirikiri* (coral gravel) - Cowan pers. comm. 30/08/92.

Marine and Lagoon resources:

Marine resources were gradually exhausted from the privations of the 1930's depression (Scott 1991) and through the hardships of the Second World War, and continually increasing thereafter with a burgeoning population and more and more efficient technology (Utanga pers. comm. 10/08/92). There were depletions in marine resources this century due to overuse. *Karikau* (a cone shell) and *ari`i* shells have been collected for ornaments (Cowan pers. comm. 30/08/92).

Green turtle has been known to nest even in recent times - in the last 10 years at least twice (McCormack, pers. comm. 1992):

1) Near the Education Department at Tupapa in February 1985, there was a nest containing 40 eggs.
2) At the Edgewater Resort Hotel in Tokerau *tapere* in August 1986, a hatchling turtle was found.

William Wyatt Gill (1885: 130) mentions a Rarotongan proverb concerning the way mother turtles desert their young after preparing the nest, which suggests that they were common enough to people to observe their behaviour. However, turtles are generally much more common on atolls than high islands, so one should not imagine that Rarotonga possessed as many turtles as say Rakahanga, in the northern Cook Islands.

Whaling used to occur in the area, and blubber and oil were prepared on shore on Rarotonga (Gilson 1980; Scott 1991; Utanga pers. comm. 10/08/92). Seasonal visit of humpback whales occur in August and September (Rongo pers. comm. 31/08/92). However, whaling may not have been quite so rife here. There was a small business located on Rarotonga, but this folded before the advent of the First World War. Most whalers were practising in the area of Fiji and Tonga (Howe 1984; McCormack pers. comm. 1992).

6.2 Site Historical

Karekare swamp (`te tua repo o Karekare') is mentioned in oral tradition recorded earlier this century as the subject of a dispute, many generations ago (Vakapora 1911). Unfortunately, no specific details are given about its usage in this account. Present day oral tradition and living memory were therefore used.

Puraka (*Cyrtosperma chamissonis*)[31] was used as a boundary plant as well as being the main crop in the swamp at Karekare. [The stems of the *puraka* were used to weave hats from - Utanga pers. comm. 5/08/92]. *Puraka* can survive hurricanes and freshwater flooding from the mountains. The sea tides that accompanied the hurricanes could be damaging to taro, but the hardier *puraka* could resist the deep and salty water. The combination of the freshwater and the sea water floods in an area where the drainage was blocked by the coral rubble ridge, and was consequently very slow, meant that the swamp was deep open water for several months each year [i.e. it was in fact a marsh, not a swamp]. The water level used to reach waist height for most people. In the dry season, taro was also grown at Karekare free from these hazards. Drainage channels were put through to the reef between 1963 and 1965 (Cowan pers. comm. 17/08/93).

Cowan confirmed the use of Karekare swamp for growing *puraka* (Cowan pers. comm. 30/08/92). In the dry season, taro was also grown at Karekare, free from the hazards of freshwater flooding and saltwater tidal wave -in the sense of storm surge - (Tara`are pers. comm. 7/08/92). Utanga also confirmed that when the swamp was cultivated with *puraka*, taro was grown along the side, during the dry season, as it does not like salt water (Utanga pers. comm. 10/08/92). A passage was dug through to the sea in the 1960's (Tara`are pers. comm. 7/08/92).

Even before the drainage of Karekare swamp, if a taro patch was left long enough, *`au* trees would grow there. *Paku`au* (*`au* roots) could grow, even in a deep swamp such as Karekare - Karekare was the deepest on Rarotonga. As for the problem of salt water, on Aitutaki, the *`au* has its roots constantly exposed to sea water by the shore (Tara`are pers. comm. 7/08/92).

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31 *Puraka* is recorded by Buck (1944: 17) as being a traditional crop of Aitutaki. However, linguistic evidence from Geraghty (1990) might lead one to suspect its antiquity in the southern Cook Islands. Further investigation is required to resolve the dichotomy between these conflicting sources.

The island in the swamp at Karekare has a mound at one end and a depression at the other. At the depression end there is what looks like a bank around the edge. Vakapora (pers. comm. 2/09/92) explained this formation as being the result of rich volcanic soil being extracted from the depression end to mulch the taro patches with.

The slope immediately behind Karekare swamp was planted with root crops (like arrowroot, taro tarua, and kumara), bananas, coconut trees and oranges (Tara`are pers. comm. 7/08/92). Some crops are Polynesian introductions, so this could well be ancient practice.

Some coconut trees grew at the back of Karekare swamp up to the 1940's, with *puraka* in between according to landowners of taro patches behind the island in the swamp (pers. comm. 1990).

Not all areas were cultivated. Among these areas was Mimiti o Apara (an area extending from the bend in the *Ara Tapu* south of the Education Department to Matavera - this included Karekare) - see 6.1.2 above.

People considered the Karekare area to be haunted by ghosts up until 1970's. There is also a concentration of marae in the area, such as Vakapora's marae and the Arai te Tonga koutu, which may have added to people's misgivings about settling the place. Missionaries may have had some part in creating this feeling (Utanga pers. comm. 5/08/92).

The area around Karekare was bush until the 1970's and 1980's (Utanga pers. comm. 5/08/92). Kingan was the first to build a house there [in 1971 - Kingan pers. comm. 1992]. People feared the ghosts until they saw that *papa`a*[32] like Kingan could build and live there with apparent impunity. The stories of ghosts were possibly spread by potential landowners to prevent rival claimants preempting them. Also, there were the problems of thick *Barringtonia* trees being costly to remove in terms of time and effort, and the presence of marae in the area (Ngatoko pers. comm. 7/08/92).

At Kingan's house in Tupapa (on the coral rubble ridge at the edge of Karekare swamp), there were many *Pandanus* growing on the shore (Utanga pers. comm. 10/08/92).

6.3 Ethnography

At the time of first European contacts, Polynesia had a variety of societies based on differing social, economic, technological and environmental conditions. After European contact, these societies went through many changes in each these aspects. It is important to consider the differences in space and time (including any possible changes before European contact), and then review them with regard to their effect on the human-environment relationship. For example, it is not adequate to assume a homogeneity and continuity, particularly in the transition to capitalist economies, under European influence. Some analyses suffer from distinguishing between Polynesian and European, rather than between economies based on kinship relationships (including those verging on a more tributary style economy) and those based on Capitalism, regardless of "race" or ethnic group (*cf.* Wolf 1982). In New Zealand, some writers tend to distinguish between Maori New Zealand before 1840 and the British colony after 1840, instead of non-capitalist New Zealand of the 18th century and capitalist New Zealand, at least in some parts, at the turn of the century, especially from the 1820's on: a subtle but important distinction.

Societies within Polynesia differed in the degree of social stratification. Some societies like that of Pukapuka, in the northern Cook Islands, though it had chiefs, had no distinct chiefly class (Beaglehole and Beaglehole 1938), while at the other end of the scale, Hawai`i had very distinct chiefly classes that were moving away from family links with the common people (Kirch 1985). These differences in stratification can affect the treatment of the environment and the economy. Whilst the local environment might have influenced the degree of social stratification, it cannot be the only cause. Few circumstances have a single cause: even if other factors have not changed, the fact that they have not changed is in itself a cause. For example, Easter Island is not one of the richest environments in Polynesia, yet there was apparently a period of increasing social stratification from the evidence of oral tradition and from the upstanding archaeological remains (Bahn and Flenley 1992; Heyerdahl 1961).

The economies of different islands varied too, with larger high islands being capable of greater production, more varied production, and higher populations, whereas at the other extreme, small atolls being low in production with little range in the type of plants that can grow on them and insufficient production to allow the raising of animals, especially pigs (Bay-Petersen 1983). For instance, the Paper Mulberry *(Broussonetia papyrifera)* does not grow successfully on atolls, so tapa cloth is not often produced on them (Buck 1932a; Buck 1932b).

The natural production in terms of wild resources also varies enormously from island type to island type. For example, high islands not only have greater space and larger resources but a variety of different types of habitat. The size of habitat is not the only variable in biological diversity (*eg.* Diamond 1969). How the topography effects the human exploitation of an island can influence the magnitude of such effects: for example, if the habitat is divided by zones of exploitation and if such zones create elongated or peninsula-like areas of natural habitat, then extinction rates are likely to be more pronounced (*cf.* Diamond 1976).

32 People of European origin (Savage 1962).

Technology is partly affected by available resources, and partly by more cultural differences. The lack of available resources may be offset by gift exchange, though usually alternative materials could be found. In the case of one-piece fishhooks, pearlshell was replaced by *Turbo* in the southern Cook Islands once trade links declined (Walter 1990: 314). Pearlshell in the tropical Pacific for use as inset material in carvings (Davidson 1984: 217) or for pendant manufacture (Ibid: 82-83) was replaced by paua shell in Aotearoa.

Environmental variation occurs not just in terms of the type of island and its size, but also in terms of the climatic zone it occurs in and the closeness of other islands. It is important to be aware of certain environmental changes over time, such as sea level change and fluctuation in weather patterns.

The concept of sensitivity to environmental problems is probably (at least in approach) a modern one, not shared by ancient Polynesian societies. However, the question of resource management clearly was[33], as is evidenced by the existence of prohibition terminology, such as *ra'ui* in the southern Cook Islands. The term *ra'ui* means that if a type of food, whether wild like fish or domesticated like taro, is running low and stocks need to be allowed to recover then a *ra'ui* is issued making it taboo to use those resources whilst that *ra'ui* is in force. Such a *ra'ui* can also be used to build up resources in preparation, say, for a feast.

Central Polynesia, in particular, has the problem of small islands with limited space and limited resources, so that such resource management must have been important to maintaining a reasonable standard of living.

Another restriction on use of land was the system of swidden or 'slash-and-burn' cultivation, which involved crop rotation with plots lying fallow in between periods of use. This means that certain areas were returned to a semi-wild state temporarily and probably contributed significantly to the local ecology.

Some areas were more long-term out of production: those areas that formed the boundary between lineages, those areas under dispute and those areas owned by lineages driven off their land (Gill, W. 1856: 39-40; Williams 1843: 210).

Other factors could be spiritual and psychological controls on the exploitation of the landscape. For example, certain animals were not allowed to be eaten by particular lineages (Mokoroa 1981; Kauraka 1983), and certain trees like the *tamanu* (*Calophylum inophylum*) and the *kauriki* (*Terminalia catappa*) on Rarotonga were the domain of the gods and had to be treated with respect, hence the fierce reaction to felling these trees on the conversion of Rarotonga to Christianity (Savage 1962). Radical alteration of any landscape may meet resistance from those who have grown up in it and who may find some security in its stability. Aesthetic reasons can sometimes play a part as to whether this part or that part of a landscape is altered.

A more specific look needs to be taken at the exact use of certain plants and animals, both wild and domesticated, in order to assess the relative importance of these and consequently the relative effect that their exploitation would have on the environment.

Equally, a careful analysis is required of what sort of areas on islands were influenced by human presence and in what way were these areas influenced and to what extent. A study of the early pictorial evidence together with the written accounts of European explorers, archaeology and oral tradition can be very enlightening. For example, the traditional management of the landscape of Mangaia as noted by Buck (1934) is confirmed by the illustration from Captain Cook's second voyage (Joppien and Smith 1987b: 290). This shows that the central volcanic plateau or *Maunga*, Rangimotia, was not under any sort of cultivation and was covered in trees; the slopes going down to the *puna* or swamplands were free of trees, so could well be covered in *tuanu'e* or False Staghorn Fern (*Dicranopteris linearis*) as described by Buck (1934); and finally, the *makatea* is shown as covered in forest, the coconut palm predominating.

It is important to work out where exactly people were living, where they were carrying out their worship, where they were disposing of their dead and where they were cultivating their crops and letting their livestock loose.

Having established these details, it should also be borne in mind that ancient Polynesians were not necessarily passive victims of exponential population growth, but rather they did have some control over the course of their own population development. For example, in Tikopia, one of the Polynesian outliers, celibacy for younger males, *coitus interruptus*, infanticide, abortion, warfare, exile and possibly a weighting of the male/female ratio more towards the male were ways in which population growth could be controlled (Firth 1936: 373-374; Kirch 1984: 116-120). Robarts (1974), an early nineteenth century beachcomber in the Marquesas Islands, records voluntary exile as a means of reducing population during periods of extreme famine. Mead (1929) records in Samoa the use, albeit seldom, of over-consumption of kava or heavy massage to induce an abortion. However, Brewis (1990) has suggested that abortion was largely a post-Contact phenomenon.

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33 In fact, environmental concern and resource management are probably one and the same thing. People who are concerned about the environment, are concerned because of a fear that the World's natural resources are threatened, and therefore they are threatened. Environment is not a physical entity, but an abstract concept denoting changing conditions in world around us. Just like other abstract concepts such as weather, it cannot be created or destroyed.

Ethnological studies are also needed to review the relationship with the landscape in a more holistic way. The boundary between wild and domesticated landscapes is to a certain extent artificial as both are necessary to and are in fact utilised by humans in any society, and the degree of utilisation and manipulation varies in degree and spatial patterning.

6.4 Ethnobotany and Ethnozoology

The missionary William Gill (1856) stated that vegetables and fish formed the staple diet of Rarotongans, and that pigs and poultry were eaten only on festive occasions. A detailed discussion of fish is outside the limits of this thesis, though one should bear in mind that the vegetation part of the economy dealt with here was supplemented to a significant degree by marine resources. Fish as part of the marine produce consumed may have been overemphasised in the past due to a male bias, because shellfish collection has been considered to have been, to a large degree, women's work (Parslow 1993).

Cultivated food plants (Buck 1944), prior to European contact, included the coconut, the breadfruit, the banana, the plantain, taro, giant taro, atoll taro[34], yam, arrowroot (*pia*), ti, pandanus, tahitian chestnut (*i`i*), kava and a little turmeric (*renga*).

In times of famine, certain wild foods were consumed (*kai o te onge*), such as the cooked pith of the tree fern (*`eki* - *Cyathea decurrens* and *parksiae* - Whistler 1990), the cooked corm of the horseshoe fern, raw or cooked *nono* fruit, the wild yams (*u`i purai* and *pirita*), *poroporo* and *poro`iti* berries, *poro`iti* leaves and wild arrowroot (*teve*). Also, the fleshy rhizome of *`Ana`e* (*Angiopteris longifolia*), *ka`ika* (*Syzygium malaccense*) fruit and the aerial roots and terminal buds of Pandanus were eaten as famine food (Whistler 1990). *`Itoa* (Miti`aro only) fruits were eaten by children. Some of these plants, while not necessarily cultivated as such, may nevertheless have been introduced by Polynesians before European contact and have been deliberately planted as a resource. Famine was also dealt with by means of cultigens at the back of the valleys like the mountain plantain, *ti*, *kape*, and *i`i*, and stored foods such as *ma`i* or breadfruit paste.

Domesticated animals introduced to Rarotonga by Polynesians, before European contact, included the pig, the dog[35] and the fowl, though elsewhere in the southern Cook Islands their distribution was varied and not so well-recorded (Buck 1944). Wild birds, turtles, shellfish and fish were also important elements in the flesh part of the diet. Rats have been recorded as a food only on Mangaia (Buck 1934), though the widespread usage of rats for food in Polynesia (for instance, in Tonga - *cf.* Martin 1817) could imply that they were at one time also eaten on Rarotonga. Cannibalism did occur, though for reasons other than satiating hunger (*cf.* Barber 1992; Kirch 1984: 159).

As demonstrated at the beginning of this chapter, the most important crops of Rarotonga were breadfruit, coconut and various varieties of banana or plantain (followed by taro). This makes the Rarotongan economy quite similar to that of Tahiti (see Beaglehole 1950: 120; Bougainville 1771: 249; Massal and Barrau 1956: 20; Oliver 1974: 220-253). Some further explanation of the nature of these crops is needed.

Breadfruit generally has two seasons corresponding with the equinoxes. On islands closer to the equator, the harvests associated with the equinoxes are about equal, but the further polarward the islands, the more the summer equinox harvest becomes dominant, with the winter equinox harvest gradually eclipsing (Afsenius 1988b). On Rarotonga, the crop is near its southern limit, so there only is a peak in production in the summer, with insignificant yields at other times of the year. The main peak in Rarotonga is in April with a minor peak in November (Afsenius 1988b).

The number of fruit produced is the cumulative effect of conditions attaining during the previous year, though the effects of drought and storm at flowering and fruiting time can influence the final production. Radiation is a key factor in promoting fructification, so, that even branches on the same tree can have different seasons due to differential radiation received owing to seasonal change in the direction and intensity of the sunlight. This factor means that especially on a high island like Rarotonga seasons can be staggered by means of trees being located at different points on the island and at different altitudes up the valleys. Early and late varieties of breadfruit also help spread the harvest season.

The problem of the breadfruit harvest being so seasonally concentrated can also be overcome by preservation techniques, in particular that of fermentation in pits in the form of a paste (Massal and Barrau 1956), called *ma`i* in the Rarotongan language (Savage 1962). As mentioned by William Wyatt Gill (1885), breadfruit trees were planted around the dwellings, and the word for breadfruit, *kuru*, was also the word for summer and indicated plenty. Plantains, on the other hand, were grown in the valleys, and, from other missionary evidence, along the *Ara Metua*, the ancient roadway.

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[34] Buck (1944: 17) records it ethnographically from Aitutaki, and Whistler says: 'the aboriginally introduced giant swamp taro, uncommon in cultivation on the volcanic islands but common on the atolls where the real taro will not grow. The large starchy rhizome is eaten but is considered much inferior in taste to taro'.[Whistler 1990:395].

[35] Possibly. Buck mentions the dog as being among the domesticated animals possessed by the southern Cook Islanders, including Rarotongans, though does not state his source. Williams (1843) does not mention the dog in his list of missionary introductions, but mentions it in a list of curious names given by the Rarotongans to various animals, including the introduced cat and the introduced horse. Archaeological sites record the presence of pig, domestic fowl (Bellwood 1978; Trotter 1974) and dog (Walter 1990: 287).

Musa paradisiaca, *Musa sapientum* and *Musa nana* cultivars are probably derived from two original strains *acuminata* and *balbisiana* (Afsenius 1988a; Barrau 1961). The modern commercial varieties of *Musa nana* and *Musa sapientum*, derived from the first strain, including the Cavendish Banana brought to Polynesia by John Williams of the LMS (Massal and Barrau 1956), are heavy yielders and being short, less prone to cyclone damage, though they are susceptible to droughts. The varieties of *Musa sapientum* and especially *Musa paradisiaca* grown in Polynesia before the advent of Europeans contained at least some genes of the second strain making them more drought-resistant, though starchier, and therefore requiring cooking before eating (Afsenius 1988a).

Bananas and plantains are good all the year round producers, though with a summer peak in production when further away from the equator as on Rarotonga. This means that problems of storage or an overreliance on one season are not encountered. The main problem is that of water supply and protection from strong winds. Tempera-ture, soil conditions and radiation can also be controlling factors (Afsenius 1988a).

Musa troglodytarum or mountain plantains are also all the year round producers. They have heavier moisture require-ments than other plantains and bananas, though their temperature requirements are less. Mountain plantains tend to be grown on the talus slopes at the back of the inland valleys. They are especially useful as a reliable food source, including at times of famine (Afsenius 1988a; Tara`are pers. comm. 1992). The fruit of mountain plantains must be cooked before consumption (Barrau 1961). Stands of these are still found in the Takuva`ine, Tapapa and Pue valleys (Afsenius 1988a)

Taro (*Colocasia esculenta*) is more seasonally affected the more polarward it is found. Because production is related to the cumulative results of the past 12 months in the varieties with a 10-15 month growth period, it does not matter so much what season it is planted in, but what kind of year it has been generally. It is thus advantageous to plant and harvest continuously throughout the year in order to maintain a constant supply, with perhaps an increased planting rate during the winter. With the varieties requiring only a 6-8 month growth period, production can be much more variable according to season (Afsenius 1988c). Storage of taro can be achieved simply by leaving it in the ground for several months after maturity of the tuber has been reached. Important factors controlling production are water supply, temperature and soil conditions.

Although taro is recorded largely from the swamps on the coastal plain on Rarotonga (*cf.* Barrau 1961: 26; Williams 1843: 205), it is clear that there were taro gardens up the valleys. For example, Bellwood (1978:) found physical remains of such gardens in the Turangi valley, and Afsenius (1988c) and the author have noticed remains of deserted pondfields in the Tupapa valley. No dates exist for these structures, so it is not possible to assign them to the period before European contact with any certainty. The installation of water-intakes may have caused the taro gardens to be abandoned (Afsenius 1988c).

The taro gardens up the valleys may have been more important from the point of view of reliability: water is still plentiful up the valleys even when there is a drought on the coastal plain, because coastal swamps are further away from the water supply (Afsenius 1988c); the valley gardens were more easily protected during periods of strife and famine; and the coastal gardens were subject to freshwater flooding and saltwater storm surge. This last problem was ameliorated by simply planting taro during the dry or winter season, no doubt with 6-8 month varieties. Just because there were these problems with cultivation of taro on the coastal plain, does not mean to say that taro was not grown there, because, for example, on Pukapuka, an atoll in the northern Cook Islands with similar or worse problems of storm surge, people still grew taro before European contact (Beaglehole and Beaglehole 1938).

However, unlike Pukapukans, they had alternative, more reliable places to grow taro, and so taro, when and where it was grown on the coastal plain, may have been an attempt to increase production where possible in a marginal environment, not the main basis of the food supply. On Pukapuka, this is also the case (Beaglehole and Beaglehole 1938; Mary Salisbury pers. comm. 1993). It is interesting to note in this regard that Tara`are (pers. comm. 1992) listed it in the form of po`i as a famine food. Supplies of food of whatever variety that could be grown in upper valleys no doubt were kept till last for such eventualities.

Kumara is listed both by John Williams (1843) and Aaron Buzacott (Sunderland and Buzacott 1866) as a missionary introduction. Buzacott even mentions how it happened and claims to have been the introducer. Yen (1974: 11) regards such claims as being the result of European cultivars replacing older Polynesian ones, and that there was an exchange of cultivars throughout Polynesia. He quotes among others, Wilder's (1931) list for Rarotonga as evidence for this. Buck (1934) mentions that Mangaians cultivated kumara in patches in the makatea where there was enough soil to be had, which might suggest that it was at least present in the southern Cook Islands. Hather and Kirch (1991) record it archaeo-logically from at least 1409 AD.

However, the fact that Buzacott thought that he had introduced the kumara might indicate that it was at least not especially common and was not, therefore, very significant in the economy of Rarotonga. The resistance he met in trying to introduce it is also worth noting. It is also worth noting that if Buzacott was unaware of the existence of kumara, the absence of other crops in missionary records, including atoll taro, would not necessarily be an indication that the crop was unknown and unused[36].

In Appendix A.5, there is a list of all the useful plants, with additional information on animals and minerals exploited, according to the zone(s) in which they are found. Then by the entry for each plant are listed the various uses of that plant. The sources for this are Buck (1927; 1944) and Whistler (1990). Its purpose is to assess the extent and nature of traditional human exploitation of each zone. Relative importance of plant types, especially in terms of quantity of material used, should be always be considered. Some plants occur in more than one zone. In this case, one has to consider where the plants are most common or most convenient for humans to gather them.

This list shows that there was a concentration on the resources of the coastal plain and the shore. There were more types of plant used in these areas, with more uses per plant type, and there were more plants which had more regular and vital roles. The soils of the upland areas are not suitable for horticulture (due to extreme limitations due to steepness of slope, high erosion risk and low nutrient levels), both those under woodland as well as those under fern (Leslie 1980), though some famine foods and medicines could be obtained therefrom. Some trees were important sources of timber for certain items which would also have contributed to encouraging its maintenance as forest. The uses of wood from trees in this zone were less frequent uses than those in the lower lying areas. The precipitous nature of much of the terrain would, in addition, not have recommended its exploitation. It is interesting to note that none of the recorded plant resources of the upland zone comprised exclusively cloud forest species, including the fairly common *rata* or *Metrosideros collina*.

The coastal plain and valley plants form the longest list and include many species probably introduced by Polynesians before European contact. A number of species are away from their natural habitat like the coconut and the pandanus. There is a larger number of herbaceous species in this zone accounting for about half the species, thus this would have been the most open and disturbed zone. The trees and shrubs, however, still account for the greater number of uses and greater quantity needed. The wood from this zone is often for routine uses. Many plants are noted as being medicines, and some famine foods occur too. Some species typical of disturbed areas, or of regrowth after human usage, were of great importance and must thus be seen as something deliberate rather than accidental. Examples of this are *mata* (*Paspalum orbiculare*) used for instance as floor covering for houses, and the *`au* (*Hibiscus tiliaceus*) used for binding and weaving material. As suggested by Cowan (pers. comm. 1992), these would been incorporated into a system of crop rotation with fallow periods, so that the land would have still delivered a product of some value to the landusers.

The clear majority of shore plants listed are trees and shrubs. Thus it would have been in the interests of people to have maintained this zone as forest, because the land is not very suitable for horticulture at least without modern fertilisers (Leslie 1980) and because the trees there had such an important role in the economy. Some manipulation of the vegetation might, however, be expected like the deliberate extension of stands of coconut and the planting of cultivated varieties of coconut too, though not to the extent of the cash crop plantations of the 19th and 20th centuries. Large plantations of coconut trees would necessarily involve depletion of other useful shore trees, and coconut trees could be grown in the valleys and on the coastal plain as indeed they were (*cf.* Williams 1843). Many of the trees in this zone serve for frequent uses. Few shore species are noted as famine foods, though there are many uses of them as medicines.

Mineral resources are available in all zones, though only the shore zone possesses both coral and basalt, which are the most important. Outcrops like Tuoro, the Black Rock, and Ta`akoka *motu* are potential sources of basalt in the shore zone. Clay and ochre which were of much lesser importance were available in the coastal plain and valley zone as well as the mountainous uplands.

Animals were available in all zones too. William Gill (1856) makes it clear that fish were a major staple, so obviously the lagoon and ocean zone would have been the most important zone. Allen (1992) and Walter (1991) note the importance of shellfish and other lagoon resources to the diet of Cook Islanders in the past. The adjacent shore would have been useful for obtaining sea birds too.

Domestic animals were available in the coastal plain and valley zone, though feral populations of domestic fowls could have been available in the uplands too before European contact (Holyoak 1980). Domestic animals were consumed at feasts rather than daily. Wild land birds and some sea birds, like the herald petrel and the red-tailed tropic bird, were obtainable from the mountains too, and were no doubt supplementary food in Rarotonga. The *kakerori* or Rarotongan flycatcher was known to reduce the pest density on taro (Gill, W.W. 1885), and so may have been exploited less than say the *kukupa* or Rarotongan fruit dove.

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36 In this respect, it should be noted that the genus *Cyrtosperma* was not identified until 1851, and the edible species, *chamissonis*, not until 1861 (Jackson 1895: 705). The missionaries may have regarded it as just a variety of *Colocasia esculenta* before this information became widely known.

6.5 Pictorial and Photographic Work

This section attempts a visual idea of the landscape at initial European contact to provide a reference point for the later end of the environmental sequence, and not to suggested as a model in itself for the landscape during earlier periods. Comparative material is taken from islands with the closest cultural (Bellwood 1987: 85; Biggs **in press**) and vegetational connections (Van Balgooy 1971: 109-110) and where similar geology occurs (except the *makatea* on Mangaia) to reduce local variation problems as much as possible. Some authors (like Kirch 1984; Enright and Gosden 1992; Nunn 1990b; 1991) have compared human-environment relations all over Polynesia and other Pacific Islands to identify trends: here this is done over a more limited area. No claim is made that the Rarotongan landscape was exactly the same as say the Tahitian or Mangaian ones at European contact. Instead, trends are suggested, such as wooded shorelines (though with economically useful trees).

The evidence of old photographs could be of use in assessing change within the last century. A photograph by Josiah Martin, taken in the 1890's (Plate 6.3), indicates that at least the Avana Valley was not clear of woody vegetation at this time (though this does not necessarily imply that the vegetation was in a primary state). From another photograph of Martin's (Plate 6.4) and one from the New Zealand parliamentary papers (Plate 6.1), the coastal plain appears to be given over at least in some parts to the intensive almost monoculture of coconuts. One picture of rutted road (Plate 6.2), identified as possibly the *Ara Metua* by Scott (1991), with coconuts towering overhead, dates to 1903 and shows that a continuous canopy may well have existed in some places from the mountains to the shore despite the interruption of the roads, in particular the *Ara Metua*.

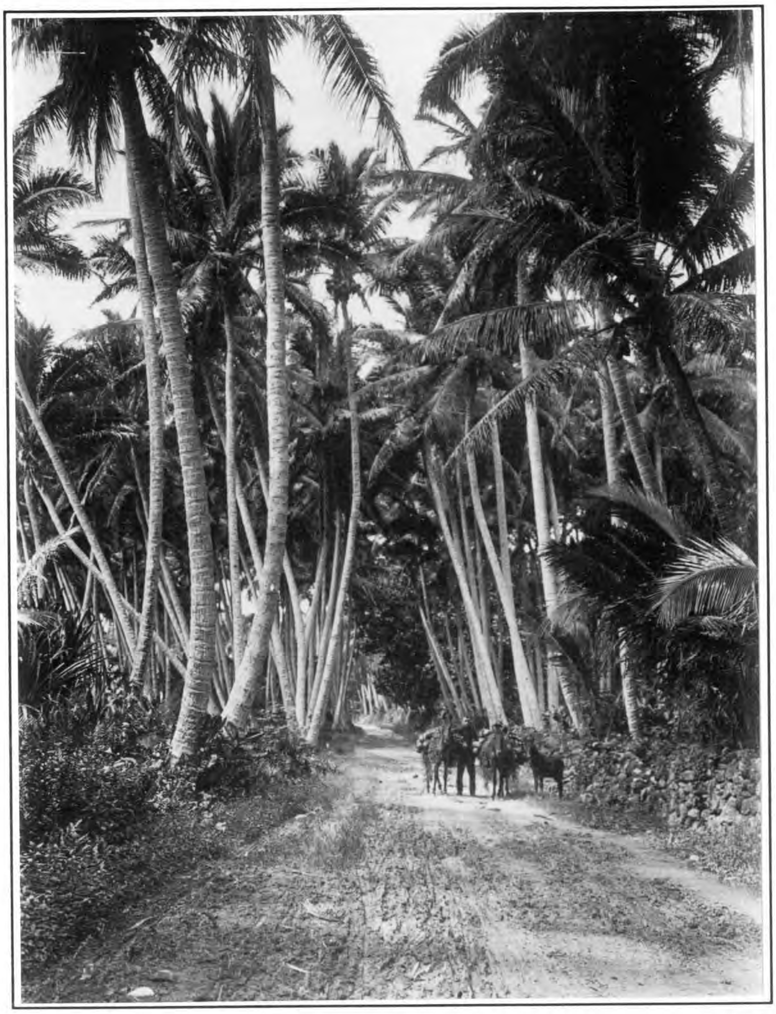
Plate 6.1 The wharves at Avarua, Rarotonga, 1911. Appendices to Journals, New Zealand House of Representatives 1911.

Pictorial evidence from Rarotonga is very sparse from the period of initial European contact. The illustrations from missionary accounts include artefacts and images of gods, while landscapes are restricted to broad outlines behind mission buildings. A picture in William Wyatt Gill (1885) shows the village at NgaTangi`ia with a thickly wooded coastline with many coconut trees among other trees (Plate 6.5). Apart from this, one is forced back on the written evidence.

This pictorial and photographic evidence from Rarotonga might be questioned on the basis that it is late in date, and represents a situation where there has been a dramatic downturn in population, and where European influences have begun to intrude, such as the wharves at Avarua and the village at NgaTangi`ia. However, when compared with the pictures made during Captain Cook's voyages from other islands, it becomes clear that there is significant correspondence between these sources, even though separated by a century.

Elsewhere in the Cook Islands: Mangaia, Atiu, Manuae, and Palmerston Island were illustrated by artists on Captain Cook's second voyage (David *et al.* 1988; Joppien and Smith 1985a; 1985b; 1987a; 1987b). More comparable islands to Rarotonga from the Society Islands group were also painted by artists on Cook's expeditions (David *et al.* 1988; Joppien and Smith 1985a; 1985b; 1987a; 1987b) and by George Tobin on Captain Bligh's second voyage to Tahiti in 1792 (Oliver 1988).

As mentioned above, Tahiti had a similar economy to Rarotonga in that it is a high island, where the main food crops were coconuts, breadfruit and plantains (Massal and Barrau 1956). There are important differences though, in that Tahiti is a much larger island than Rarotonga, closer to the equator, with warmer weather and a higher frequency of storms, and was probably more hierarchical than Rarotonga according to the marae structure (Eddowes 1991). Nevertheless, a comparison, bearing in mind the differences, may be useful.



Visual representations of islands made on Captain Cook's voyages have a number of problems associated with them (Smith, B. 1988). The paintings of John Webber (Plate 6.6), William Hodges (Plate 6.7) and William Ellis (Plate 6.8) of Vaitepiha, on Tahiti Iti (Taiarapu peninsula), though they involve different styles do seem to agree on a coastline here arboriculture was predominant. The surrounding hillsides appear to be woody too. The trees on the shore are not simply coconut, but a mixture of species. It should be noted that there is also a lack of concentrated settlement.

The following pages will compare written descriptions and visual representations of Tahiti, and some other islands from the Society Islands and southern Cook Islands groups.

Hodges (Plate 6.7) and Ellis (Plate 6.8) show the mountains in the interior to be wooded of their illustrations of Vaitepiha Bay and Valley, Tahiti Iti (Taiarapu peninsula). The lower mountains, closer to the coast are more patchily vegetated, with areas of herbaceous growth and areas of bush. The shore and river estuary areas have coconut trees, breadfruit trees, pandanus trees, plus some other less distinguishable trees in Webber's and Ellis' paintings.Dwellings, but at low density, are seen in the paintings of Webber and Hodges. Small areas around these buildings are free of large vegetation.

Plate 6.2 Rutted road, possibly the *Ara Metua* 1903. Auckland Institute and Museum Library Winckelmann photo.

One should bear in mind that the conventions of the time were to depict human beings in their landscape with various aspects of their material culture in a compact fashion in order to present the information succinctly (Joppien and Smith 1985a; 1985b; 1987a; 1987b). No marked coastal ridge is visible as in Rarotonga.

William Ellis' description of the bay of Vaitepiha and the valley behind it support this, though adds the idea that up the valley along the stream more definite plantations of these fruit trees existed:

> On each side of the stream are placed the houses of the natives, interspersed with plantations of bananas, coco nuts, breadfruit and a kind of apple-tree; the lofty hills on each side, whose tops reach beyond the clouds, the variety of birds, which are continually flying from place to place, and the noise of the falling water, re-echoed by the surrounding hills afford a scene striking beyond description. [Ellis 1782: 128-9, quoted in Joppien and Smith 1987b: 343].

Lt. George Tobin, in Captain Bligh's crew on his second voyage to Tahiti in 1792, presents even more detail about the valley of Matavai Bay (see Webber's painting - Plate 6.9) thus:

> ...we entered a valley about half a mile across the hills rising gently on each side richly clothed above half way to their summits, with bread fruit, cocoa nut, Avees [vi; *Spondias dulcis*, native `mango'], Eratta (a large kind of chestnut) [i.e, *rata*, also *mape*; *Inocarpus edulis*, Tahitian chestnut] and many other trees ...We passed many houses...Advancing up the stream breadfruit and cocoa nuts became scarce , and the valley more confined...the country soon became more wild and picturesque...Breadfruit and cocoa nuts were no more to be seen, but there were plantains the whole of our walk, and the soil, where free from rocks, productive...On either side beautiful cataracts from a great height suddenly caught the eye...At this distance no more habitations were observed. [Oliver 1988: 96-97].

Though there is a certain amount of romanticism about this passage, it lists the important crops which are trees, and informs us that there were wild birds to be found, despite the presence of human horticultural activity. If the paintings are anything to go by, then the word `plantation' is not being used in the regulated and intensive way that one might imagine. Possibly, the plantation aspect of the valley may have been played down by the influence of romanticism.

Plate 6.3. View up the Avana Valley by Josiah Martin, 1890's. Alexander Turnbull Library, Wellington. Ref. No. F 144851 ½

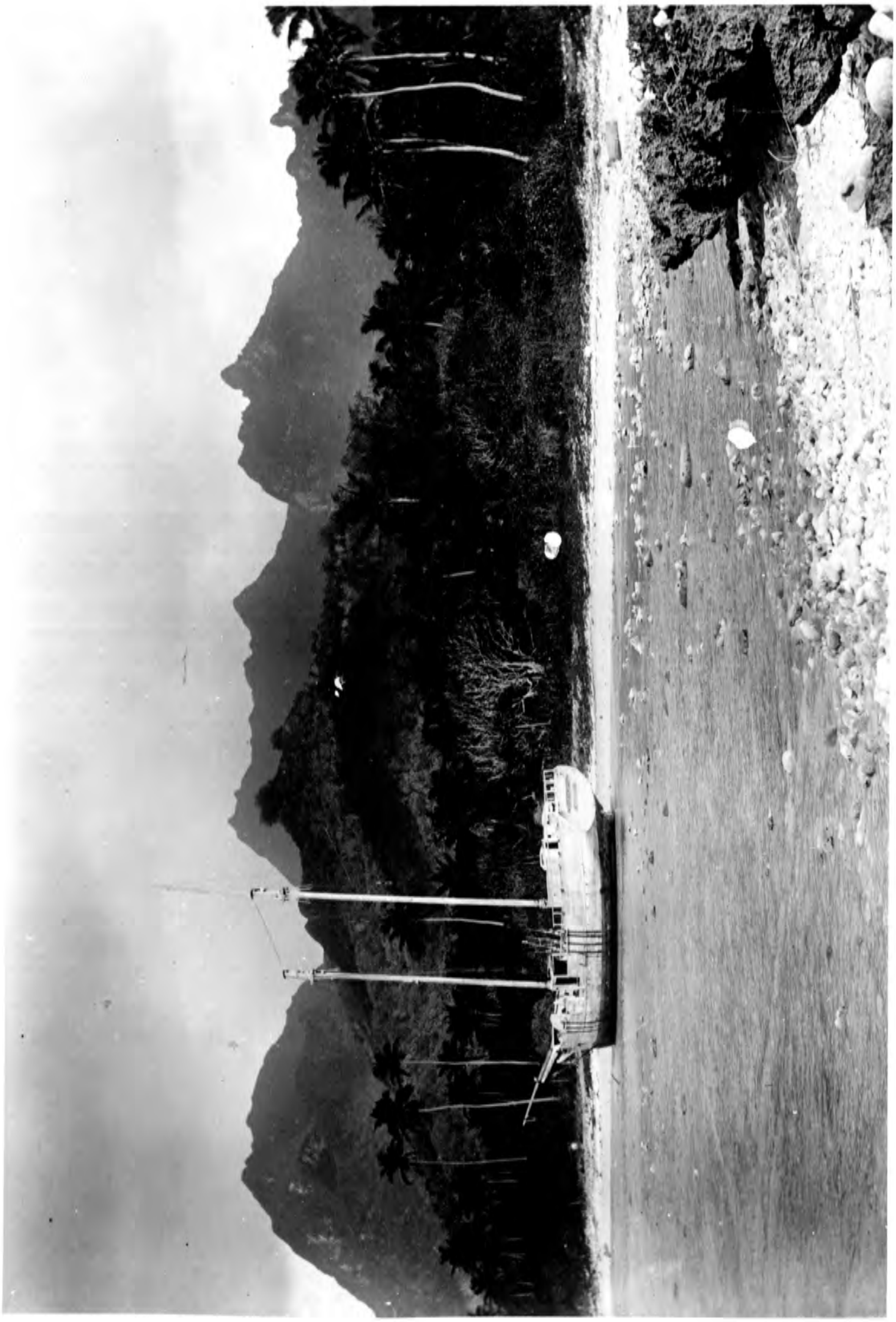


Plate 6.4 NgaTangi'ia, by Josiah Martin, 1980's. Alexander Turnbell Library, Wellington. Ref. No. F 144852 ½ .

Plate 6.5 A *Rarotonga Village*, from William Wyatt Gill (1885:72).

However, B. Smith (1988) suggests that the painters on Captain Cook's expeditions were still bound to record information reasonably accurately. Unlike other landscape painters in Europe, they were part of a scientific research project. In this way, there was a limit to the fantasy content of such painting, especially for Webber and Ellis, because Captain Cook was particularly concerned on his third voyage that the artists record accurately what was needed (Joppien and Smith 1987a). Hodges' depiction of Matavai Bay (Plate 6.10) has the mountains forested, except in small patches, including the craggy parts. Webber's version (Plate 6.11) indicates that the mountainsides are fairly steep and rugged, and no doubt as a consequence are poorly covered by arborescent growth. What looks like a boulder and gravel stream bed running through the middle of Webber's (Plate 6.9) painting is also fairly plant free. Such stream beds are active formations so this is to be expected. Fruit trees are illustrated in both paintings: coconut trees, pandanus trees and plantains are present, though not in a very ordered and rigorous plantation manner, in Webber's painting; in Hodges' painting, many coconut trees are visible amongst the coastal woodland, and plantains are implied by the presence of plantain fruit on a canoe in the foreground. A few scattered huts are seen in Webber's illustration.

In Tobin's paintings of the coast at Tehaha-Fa`a`a, in Tahiti (Plate 6.11) and in Matavai Bay (Plate 12), one can see a closer, more detailed portrayal of the nature of the coastal vegetation; one that compares well with Plates 6.4 and 6.5 of Rarotonga above.

It is useful to compare the above paintings of Tahiti with the written accounts of Captain Cook and Bougainville. Firstly, their description of the landscape in general (though Bougainville only saw the east coast). Bougainville (1771) emphasised the woody nature of Tahiti:

> Quoique les montagnes y soient d'une grande hauteur, le rocher n'y montre nulle part son aride nudité : tout y est couvert de bois. A peine en crûmes-nous nos yeux, lorsque nous découvrîmes un pic chargé d'arbres jusqu'à sa cime isolée qui s'élevait au niveau des montagnes dans l'intérieur de la partie méridionale de l'île. Il ne paraissait pas avoir plus de trente toises de diamètre, et il diminuait de grosseur en montant ; on l'eût pris de loin pour une pyramide d'une hauteur immense que la main d'un décorateur habile aurait parée de guirlandes de feuillages. Les terrains moins élevés sont entrecoupés de prairies et de bosquets, et dans toute l'étendue de la côte il règne sur les bords de la mer, au pied du pays haut, une lisière de terre basse et unie, couverte de plantations. C'est là qu'au milieu des bananiers, des cocotiers et d'autres arbres chargés de fruits, nous apercevions les maisons des insulaires[37]. [Bougainville 1771: 223]

37 Though the mountains there are of a great height, the rock is in no way exposed in its arid bareness: all of it is covered in trees. We could hardly believe our eyes when we discovered a peak loaded with trees right up to its isolated pinnacle, which rose to the level of the mountains in the interior

Plate 6.6 John Webber, A *View in Vaitepiha Valley*, August 1777, British Library, London, Plate 51, p. 47 (Joppien and Smith 1987a)

Plate 6.7 William Hodges, *A View taken in the Bay of Otaheite Peha [Vaitepiha]*, c. 1775-6, national Trust, Angelsey Abbey, Cambridgeshire. Plate 53, p. 62 (Joppien and Smith 1985b)

of the southern part of the island. It did not appear to exceed 30 *toises* [58.47 metres] in diameter, and its thickness reduced as it ascended; from afar, one had taken it for a pyramid of an immense height that the hand of a skilled decorator had furnished with garlands of foliage. The lower lying regions were interspersed with prairies and copses, and all along the expanse of the coast on the margins of the sea, at the foot of the high land, there prevailed a lens of low and continuous land, covered in plantations. It was there in the middle of the banana trees, coconut trees and other trees laden with fruits, that we perceived the houses of the islanders. *Author's translation*

Plate 6.8 William Ellis *(A View in Vaitepiha Bay [August 1777]*, Mitchell Library, State Library of New South Wales, Sydney, Plate 3.82, p. 343 (Joppien and Smith 1987b).

Bougainville makes clear that the mountainous interior was thickly forested, though the lower slopes were divided up into areas of herbaceous growth (fernland, no doubt) and bush. The coastal strip was covered in plantations of banana trees, coconut trees and other fruit trees, with dwellings interspersed amongst them. He then relates that they were scattered with out any form of nucleation (as the paintings indicate too):

> Tout le plat pays, depuis les bords de la mer jusqu'aux montagnes, est consacré aux arbres fruitiers, sous lesquels, comme je l'ai déjà dit, sont bâties les maisons des Taitiens, dispersées sans aucun ordre et sans former jamais de village.[38] [Bougainville 1771: 249].

It is useful to compare these renditions of the Tahitian landscape with Captain Cook's description. Captain Cook commented on the quantity of fruit trees on the coast and the scattered settlement, though he mentioned that the tops of the most mountains and ridges were barren.

> Between the foot of the ridges and the sea is a border of low land surrounding the whole island, except in a few places where the ridges rise directly from the Sea, this low land is of various breadths but no where exceeds a mile and a half; the soil is rich and fertile being for the most part well stocked with fruit trees and small plantations and well water'd by a number of small rivulets of excellent water which come from the adjacent hills. It is upon this low land that the greatest part of the inhabitants live, not in towns or Villages but dispersed every where round the whole Island. The tops of most of the ridges and mountains are barren and as it were burnt up with the sun, yet many parts of some of them are not without their produce and many of the Vallies are fertile and inhabited. [Captain Cook in Beaglehole (1955: 120)].

Given that these two visits were not far apart, they were describing the situation at a similar time, though they may have been thinking of different parts of the island. The paintings presented here may help to elucidate the true circumstances. The ridges were probably the lower ones depicted by Bougainville. Bougainville stresses that Tahitians, for most every day purposes, were making use of cultivated wood, rather than that growing on the mountains, something which tallies well with the author's zonal comparison for Rarotonga (See above).

> Le bois propre à travailler croît dans les montagnes, et les insulaires en font peu d'usage. Ils ne l'emploient que pour leurs grandes pirogues, qu'ils construisent de bois de cèdre. Nous leur avons aussi vu des piques d'un bois noir, dur et pesant, qui ressemble au bois de fer. Ils se servent pour bâtir les pirogues ordinaires de l'arbre qui porte le fruit à pain.[39] [Bougainville 1771: 250].

[38] All the level ground, from the edge of the sea to the mountains, is consecrated to fruit trees, under which, as I have already said, the houses of the Tahitians are built, dispersed without any order and without ever forming a village. *Author's translation*

Table 6.9 John Webber, *A View in the Valley of Matavai Bay,* August-September 1777, British Library, London. Plate 70, p. 62 (Joppien and Smith 1987a)

Bougainville's assessment of the daily diet of Tahitians corresponds with William Gill's (1856) of that of the Rarotongans:

> Les végétaux et le poisson sont leur principale nourriture ; ils mangent rarement de la viande.[40] [Bougainville 1771: 252].

Cook and Bougainville's lists of the principal cultigens of Tahiti are fairly consistent with one another. Coconuts, breadfruit and bananas/plantains are the first recorded in both lists. Yams and sugar cane are also mentioned by both explorers.

> Les principales productions de l'île sont le coco, la banane, le fruit à pain, l'igname, le curassol, le giraumon et plusieurs autres racines et fruits particuliers au pays, beaucuop de canne à sucre qu'on ne cultive point, une espèce d'indigo sauvage, une très belle teinture rouge et une jaune.[41] [Bougainville 1771: 249].
>
> The produce of this island is Bread fruit, cocoa nuts, Bananoes, Plantains, a fruit like an apple, sweet potatoes, yams, a fruit by the name of Eag melloa and reckond most delicous, Sugar cane... [Captain Cook in Beaglehole (1955: 120)].

Domestic animals consisted of pigs, dogs and domestic fowls, and rats were numerous:

> Nous n'avons vu d'autres quadrupèdes que des cochons, des chiens d'un espèce petite, mais jolie, et des rats en grande quantité. Les habitants ont des poules domestiques absolument semblables aux nôtres.....Iles ne nourissent leurs cochons et leurs volailles qu'avec des bananes.[42] [Bougainville 1771: 250-251].

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39 The wood suitable for working on grew in the mountains, and the islanders made but little use of that. They only used it for their great canoes, which they constructed out of cedar wood. We have also seen some picks of a hard and heavy black wood, which resembles ironwood. These serve to build ordinary canoes made of the tree that bears the breadfruit. *Author's translation*

40 Vegetables and fish are their main source of nourishment; they rarely eat meat. *Author's translation*

41 The main produce of the island is coconut, banana, breadfruit, yam, *currasol* [polynesian plum: *Spondias dulcis*?], gourd and several other roots and fruits peculiar to the country, a lot of sugar cane, which one does not cultivate at all, a species of wild indigo, a very beautiful dye of red and one of yellow. *Author's translation*

42 Other than pigs, dogs of a small but pretty variety, and rats in great quantity, we did not see any quadrupeds. The inhabitants have domestic fowls absolutely comparable to our own....They feed their pigs and poultry on nothing but bananas. *Author's translation*

Table 6.10 W. Hodges *[The Resolution and Adventure in Matavai Bay, Tahiti]*, c. 1776, National Maritime Museum, London. Plate 54, p. 63, Joppien and Smith 1985b).

Table 6.11 George Tobin, *Scene of fishing, in Téhaha-Fa'a'a,* 1792 (Oliver 1988, Plate 20).

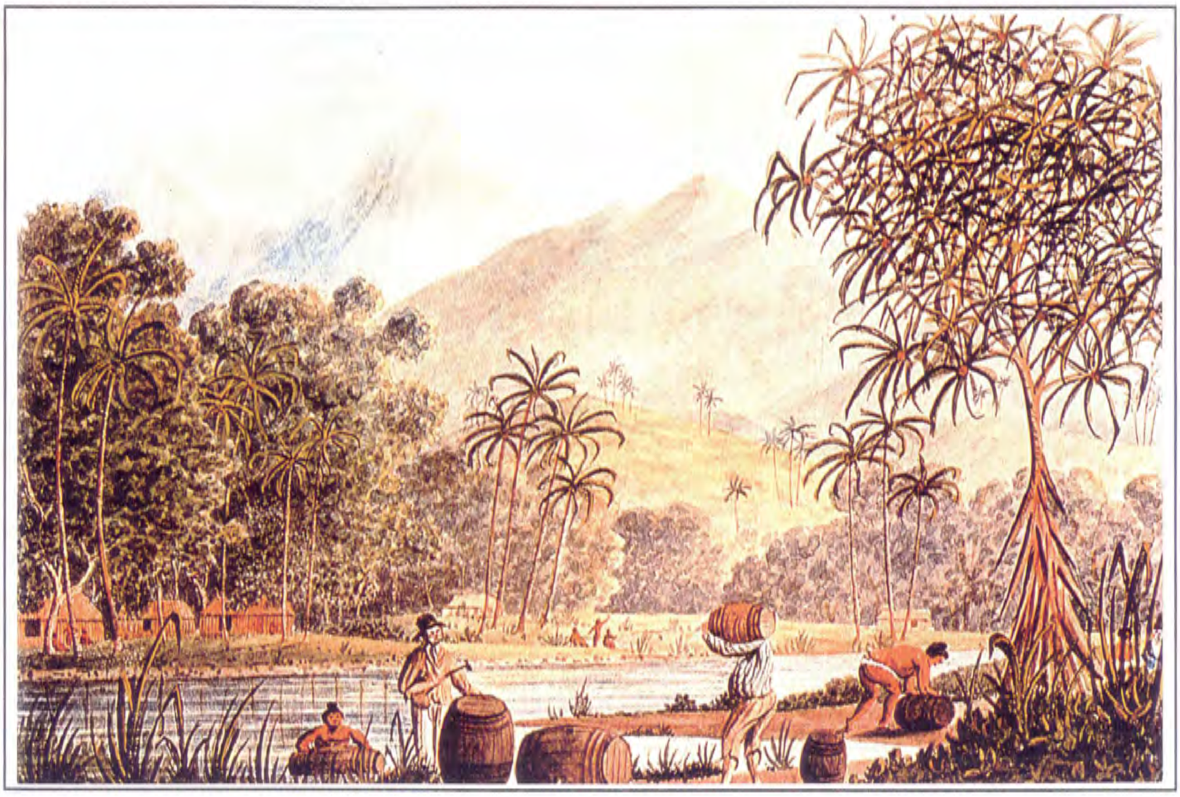

Table 6.12 George Tobin *The watering place, Matavai Bay,* 1792 (Oliver 1988, Plate 27).

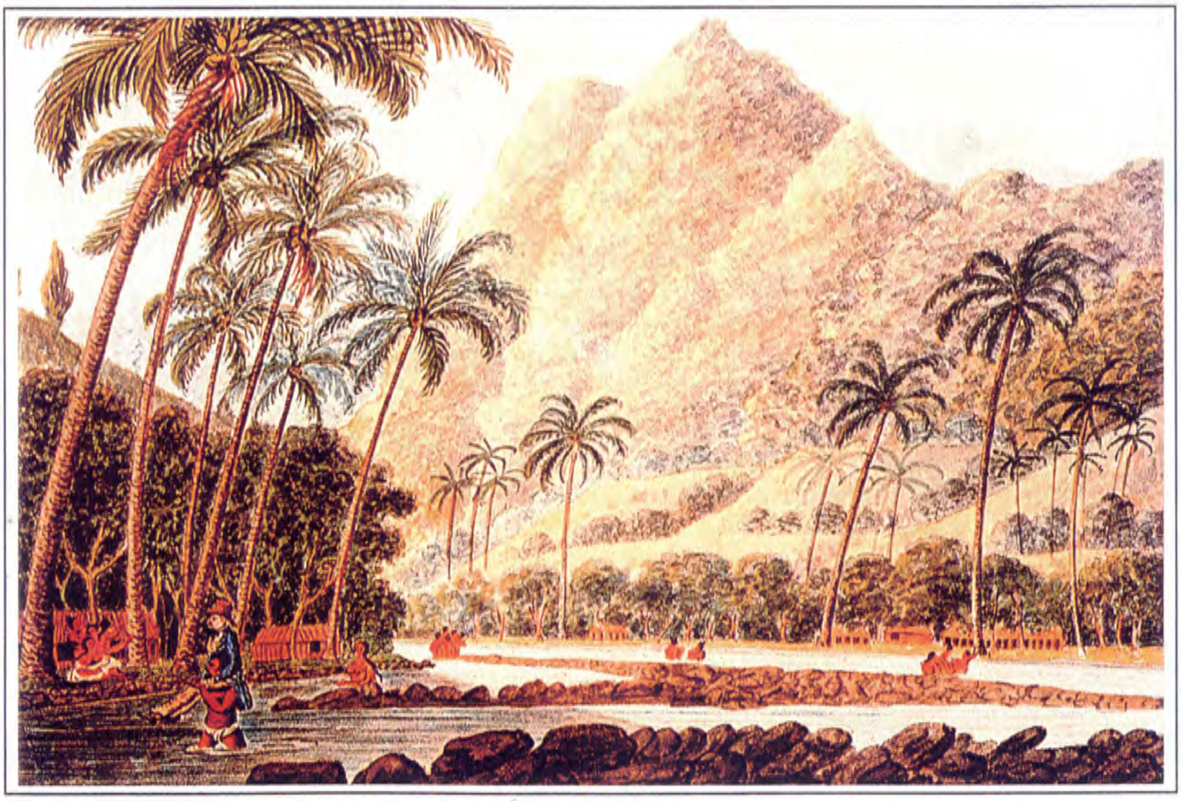

Table 6.13 George Tobin, *A view of Ha'apaino'o River*, 1792 (Oliver 1988, Plate 19).

Table 6.14 John Webber, *A View of Aimeo Harbour (Papetoai Bay)*, October 1777, British Library, London. Plate 74, p. 64 (Joppien and Smith 1987a).

Table 6.15 John Webber, *A View of Aimeo Harbour (Papetoai Bay)*, October 1777, British Library, London. Plate 75, p. 65 (Joppien and Smith 1987a).

The pigs and fowls were fed on bananas, so that they too form part of the horticultural produce, only indirectly. Seasons of scarcity were overcome with resort to produce and products therefrom deriving from humanly controlled resources:

> Contrary we found the season for that fruit wholy over & not one to be seen on the Trees & all other fruits & roots very scarce; the Natives live now on Sour paist which is made from bread fruit, & some bread-fruit & wild plantains that they get from the Mountains where the season is Later & on a Nut not unlike a Chess nut which are now in perfection... [Captain Cook and Sir Joseph Banks, Mitchell Library, Sydney, MS in Beaglehole (1955: 534)].

Other high islands in the Society Islands and Cook Islands were visited by Captain Cook, and a look at some of them might be useful for comparison. Firstly, there is Mo`orea, next to Tahiti.

Both pictures of Papetoai Bay, Aimeo (Mo`orea) by John Webber (Plates 6.14 and 6.15), depict mountains in the interior mostly forested, with the lower slopes approaching the coast being a patchwork of herbaceous an growth and bush. The shore is wooded, including with coconut trees, with the odd hut appearing between the trees. One should note the more open areas on the lower slopes. The open areas are also irregular and mostly limited to the lower slopes as on Tahiti and Rarotonga. The lack of dwellings and gardens is partly due to a devasting war prior to Captain Cook's visit. However, although much settlement in the `Opunohu Valley (behind the shore) is attested archaeologically, archaeological investigations there show only one marae with associated platforms, and no other structures, in all the hilly area under fern growth today (*cf.* Descantes 1990: 169). Settlement followed the rivers, and spread up the lower slopes (*cf.* Descantes 1990).

Gentler slopes were cultivated in many instances. Georg Forster, on Captain Cook's second voyage in 1777, remarked on such gardens thus:

> The next day we took a walk up one of the hills, which is every where planted with bread-trees, pepper [the shrub whose root was used for making kava] and mulberry-trees, yams and eddoes. The mulberry or cloth-trees were cultivated with particular attention; the ground between them was carefully weeded, and manured manured with broken decayed shells and coral, and the whole plantation surrounded with a deep furrow or channel, in order to drain it. In many places they had burnt away ferns and various shrubs, in order to prepare the ground for future plantations. [Oliver 1988: 112].

This is confirmed by an illustration of George Tobin, depicting what appear to be gardens at the mouth of the Ha`apaino`o Valley (Plate 6.13). Note the more ordered nature of these gardens to the patchwork of bush and fernland in the preceding plates (Plates 6.14 and 6.15) and the furrow mentioned by Forster.

Spöring shows the shoreline at Opua, Ra`iatea, to be thickly wooded including many coconut trees and a few scattered huts (Plate 6.16). Mangaia also has a thickly wooded shoreline, with a lower more hilly interior, sparsely vegetated. The lower slopes are again scantily wooded.

Ellis' illustration of Mangaia (Plate 6.17) demonstrates that the makatea was thickly wooded in the late 18th century. The lower slopes of the hill are lacking in trees, though the mountain tops and some ridges were wooded: this may be with *toa* (*Casuarina equisetifolia*) as today pertains. This is confirmed by his written description, which adds that the makatea forest included coconuts and plantains; undoubtedly, the result of human cultivation and manipulation.

> The interior parts rose in moderately high hills, upon the tops of which were trees of various kinds. The sides next the sea were very woody, and we could plainly distinguish coco nut and plantain trees in abundance. [Ellis 1782: 33, quoted in Joppien and Smith 1987b: 290].

Captain Cook provides a more detailed description adding the presence of breadfruit and *Cordyline terminalis*. The lower slopes of the mountain were covered in fern and the mountain tops were covered in open woodland.

> In the middle it rises into little hills from whence it descends gently to the shore...The descent here is coverd with trees of a deep green colour...which seem all of one sort unless nearest the shore, where there are great numbers of that species of Dracaena found in the woods of New Zealand...Farther up on the ascent of trees were of the deep green mention'd before, which some suppos'd to be the Rima[43] intermixd with some low Cocoa palms & a few of some other sorts...On the little hills were some of a taller sort thinly scatterd, but the other parts were either bare and of a reddish colour or cover'd with something like fern. [Captain Cook in Beaglehole (1967), Part 2: 828-829].

Oral tradition recorded by William Wyatt Gill (1894) in fact records the existence of the landscape described by the above European explorers generations before European contact.

Kirch (1982; 1983; 1984: 123-151) argues by comparison of evidence that includes vegetative associations, ethnographic, historical and archaeological data from all over Polynesia (and some other Pacific Islands) that people brought `transported landscapes' with them that included fern and grasslands, cultivation plots and reduced forest cover, especially in the lowlands, as well as erosion, alluviation and progradation.

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[43] Breadfruit tree.

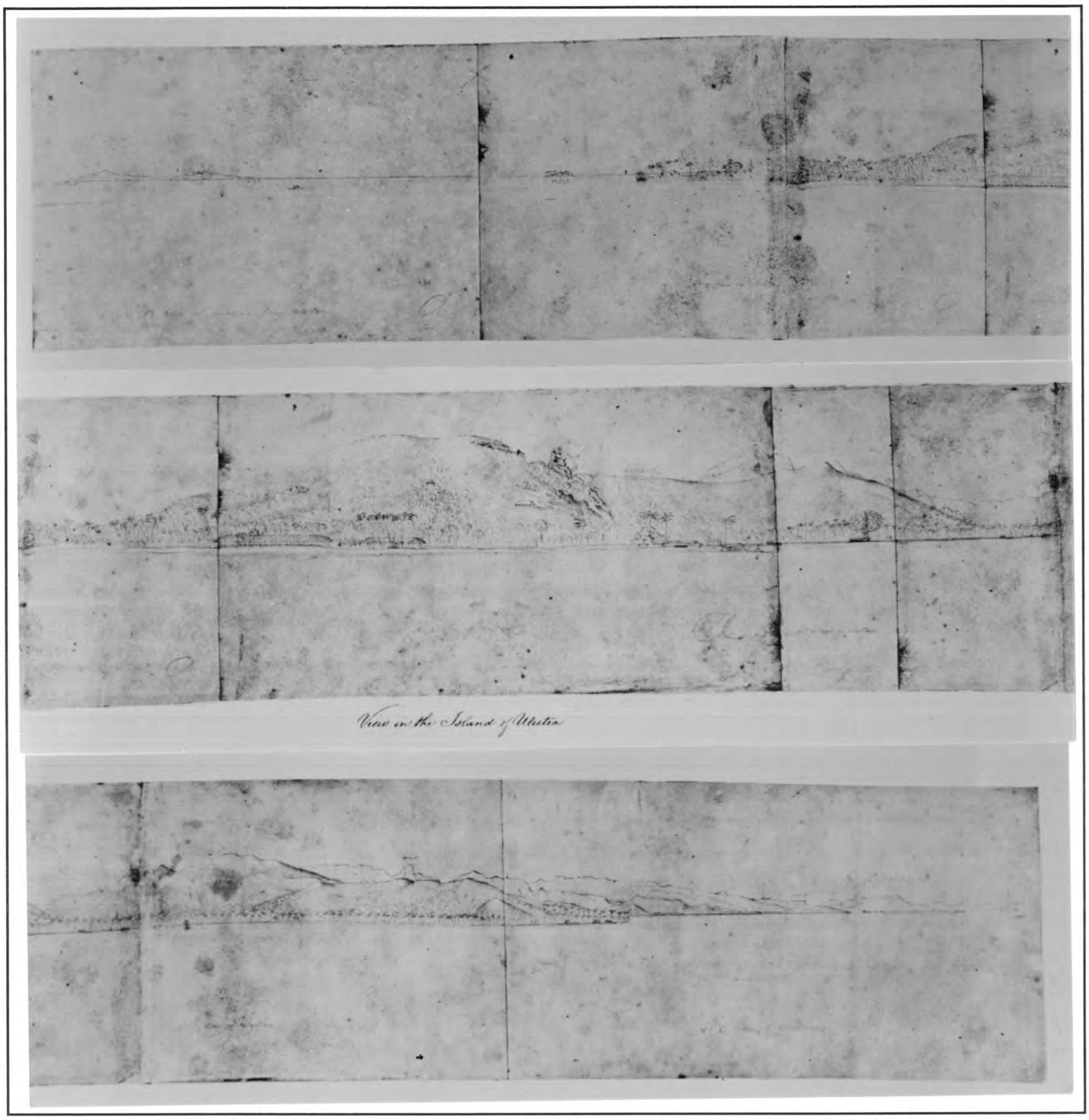


Plate 6.16 Spöring. *[View from the anchorage in Opua Harbour]*, Ra'iatea, 1769, British Library (David et al. 1988)

The main trends identified in the pictorial and photographic evidence here seem to be the existence of fernlands by the time the first Europeans arrived, shorelines wooded with economically useful trees and infrequent use of the uplands for timber, though some uplands were not wooded. Fernlands do not appear to be cultivated at this time at least. Pictoral evidence indicates inland valleys were cultivated with tree and shrub crops, though this cannot apply to all parts of Rarotongan valleys as some have structural evidence of pondfields (Bellwood 1978; personal observation; Trotter 1974). While the comparative evidence from other islands on its own is not significant, it can provide supportive evidence to early missionary writings, later photographic and pictorial material and ethnological and ethnobotanical studies from Rarotonga, for how the landscape is likely to have looked at European contact.

6.6 Conclusion

This chapter has dealt with evidence for the early period of European contact, in order to establish a firmer basis for the end part (that is from the period of European contact onwards) of the environmental sequence to be suggested for Rarotonga in Chapter 9. Any extension of any aspects of this later landscape back in time are merely suggestions, though one must explore possible mechanisms by which these aspects came about and, indeed, the chronology of when those various aspects arose.

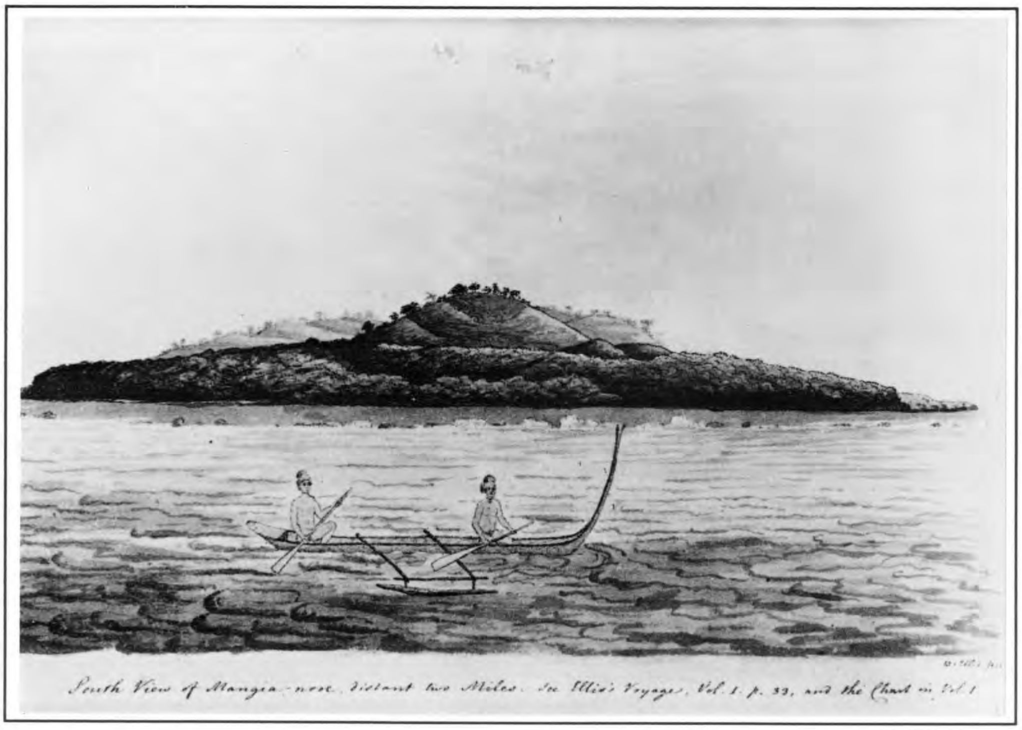


Plate 6.17 Ellis *[Two Men in a Canoe off Mangaia]*, March 1777, Turnball Library, Wellington. Plate 3.30, p. 290 (Joppien and Smith 1987b)

Rarotonga was an island where the main staple cultigens were plantains, breadfruit with coconut, *puraka* and taro as important supporting crops. The main areas settled and cultivated would have been the valleys and the coastal plain on either side of the *Ara Metua*. The later clearance of the *Ara Tapu*, which runs over the coastal ridge consisting of coral sand and rubble, suggests this ridge was not cultivated at least in the way other parts were, and at least not at the time of European Contact.

The reason is probably because the soils on the coral sands and rubble are drought-prone and not very rich in nutrients. The best usage of such land may have been to manipulate plants that could naturally survive there such as coconut trees and pandanus. The mountainous interior was steep, with poor soils (Leslie 1980), and was consequently not settled, though occasional uses were found for some of the trees and herbaceous plants there.

Food from the lagoon and sea must also be mentioned as it was clearly a very important and probably crucial part of the diet from the mention that it gets in ethnographies, such as Buck (1944) and the European explorers and missionaries. However, the role of lagoon resources may have been played down in such accounts because this was often labelled as women's work and downgraded as such (Parslow pers. comm. 1993, Parslow 1993).

In the cultivated areas, a system of crop rotation was practised, with some areas allowed to remain fallow. The pioneer species colonizing such areas were also utilised such as grasses and sedges. Space was used with economy, so that some crops were planted in the gaps between other crops (*cf.* Williams 1843). There was an intensive use of plants in the cultivated zone, especially of the cultigens, multiple uses being very common.

Not all utilisable areas were necessarily used: disputed boundary areas between tribes were left alone - see section 6.1.1 - as were areas associated with ghosts and spirits such as Tuoro (the Black Rock) - see section 6.1.2.

The comparative evidence from Tahiti, Ra`iatea, Mo`orea and Mangaia presented (see section 6.5) suggests that the fernlands on the lower slopes of mountains on high or raised islands are pre European contact features of the landscape. It has been claimed that such fernlands are the product of cultivation in the past, leaving the soils degraded (*cf.* Parkes and Flenley 1990). However, Leslie (1980) mentions that both the soils under the fernlands and under the forested areas are poor and unsuitable for agriculture. The steepness of some of the ground would also cause problems.

Lepofsky *et al.* (1992) argue that sedimentation from an alluvial flat in the `Opunohu Valley, Mo`orea starting from after AD 600 was caused by erosion from deforested hillslopes; the later establishment of fernlands finally stabilising the ground. However, the fact that the complete sequence of sedimentation was not taken, because of the water-table, means that there is no greater chronological depth in the sediments collected to allow a consideration of what more long-term natural sedimentation patterns may have been. Supportive evidence for the arguments of Lepofsky *et al.* (1992) comes from Parkes and Flenley (1990), Flenley and Parkes (1988) and Parkes (n.d.), whose study of pollen and sediments from Lac Temae, Mo`orea, argues for similar causes of erosional material, though the author is not entirely content with these conclusions (see section 9.3 below).

A look at the sequence from Aneityum (Spriggs 1981) shows greater rates of sedimentation occurring before the levels argued to have been influenced by people. Episodes of such a degree of sedimentation may be a natural phenomenon. In this respect, it is interesting to note firstly, the work of Grant (1985) in New Zealand showing that, over consecutive periods of erosion, the total deposition of sediments had actually decreased during the last *circa* one thousand years despite human presence, and secondly that of Athens *et al.* (1992) on O`ahu, in the Hawaiian Islands, also showing that the sedimentation rate was less during the period of human settlement than before. Nevertheless, given the evidence of Lepofsky *et al.* (1992) as it stands and the evidence of Parkes and Flenley (1990), Flenley and Parkes (1988) and Parkes (n.d.), human intervention in the creation of the fernlands remains a strong possibility.

It is noticeable that the fernlands are greater in extent in the north-west of Rarotonga were precipitation levels are lowest. Cowan (pers. comm. 1992) informed the author that burning of the fernlands is mentioned in some oral tradition in order to flush out fugitives heading for the forest. Slashing and burning the forest itself is not described. If humans were responsible for burning activities to flush out fugitives (Cowan pers. comm. 1992) or as a prank as suggested by one author (Johnston 1959), these might be reasons for the presence of such fernlands.

It has been suggested that the fernlands were created by swiddening. Judging for the evidence of Leslie (1980) that the soils of both the fernlands and forest of the lower slopes are very poor and susceptible to erosion, this seems unlikely at least in the long term: such cultivations would have to have been abandoned after a short while.

However, forest fires could achieve the same result naturally and probably did so in the past, and the concentration of fernlands in the leeward north-west of Rarotonga suggests that natural conditions might at least be influencing the extent of humanly started fires. This would fit in with evidence presented by Hughes *et al.* (1979) for Lakeba and their view that many such debates regarding `natural' *versus* `anthropic' origins of plant communities have subsequently been settled by demonstrating that people have `been responsible for extensions in range of these communities rather than their creation' (Ibid: 109). This is a view shared by Nunn (1991). Southern (1986) similarly regarded the *talasiga* on Viti Levu, Fiji, as being a natural phenomenon extended by human activities.

However, the existence of extensive fernlands in the `Opunohu Valley, on Mo`orea (see Plates 14 and 15), one of the Society Islands, may counter this idea as a general rule, as Mo`orea is a windward island (though the `Opunohu Valley is itself leeward - Villaret 1956: 70). Indeed, the majority of authors (though not all) support the notion of the fernlands being entirely the result of human intervention such as clearance of the former forest and repeated swiddening. In view of this, the author proposes the possibility that their existence was natural, and only their extent was artificial, but cautions that this remains, for the moment at least, a suggestion.

Now that the documentary evidence has been investigated, the physical and chemical evidence from Rarotonga will be analysed in the next chapter.

CHAPTER 7 LITHOSTRATIGRAPHY

Techniques concerned with the analysis of the mineral component of the core samples are considered here, as well as the dating of the samples. The techniques used were stratigraphy, loss-on-ignition tests, pH tests, x-radiography, charcoal counting, grain size analysis and chemical analysis. Charcoal counting is viewed in the lithostratigraphy as evidence of burning, rather than as a biological indicator. Finally, there is an analysis of the radiocarbon dates from the core samples.

7.1 Stratigraphy

7.1.1 *Methodology*

Cores as discussed in Chapter 5 were taken by sampler from swamps on the coastal plain of Rarotonga. Certain of these from Karekare swamp were analysed on the basis of both the lithostratigraphy and biostratigraphy. Others are more briefly described. The initial cores (from February 1990) were taken from a number of swamps to assess depth, formation processes, age (by means of radiocarbon dating) and what potential they would have for investigation of past environments - for instance, if they were polliniferous. They revealed the potential of the Karekare swamp and further sampling (in November 1990) took place there. It involved samples from the swamp edge as well as the middle in order to sample both local and regional pollen rain (Moore and Webb 1978).

Cores were taken with three different types of sampler: the Hiller Borer, the Russian or D-Section Sampler, and the Piston Sampler. The first is useful where the sediment is very compacted, the second because of its sharp blade where the sediment is fibrous, and the third only where the sediments are soft, not too fibrous, not too gritty and uncompacted. This last type, however, obtains a metre of undisturbed sample in a significantly better condition than the other two types.

In practice, the D-Section Sampler was almost exclusively used, bar a very few samples. After, the top sample, it was realised that the Piston Sampler, though the preferred type, was not tough enough for the grit and fibre in the sediments. Core KK2 was quite compacted and required greater use of the Hiller Borer.

As soon as the sampler was removed from the ground, each sample was cleaned of the contamination of muddy water received on its way out of the ground using a clean knife or trowel, and photographed with a scale beside it. A recording scheme was set up by Flenley on the February 1990 trip and followed, with additions (colour notation and pH), by the author. The details of changes in sediment content (the Troels-Smith notation is from Troels-Smith 1955), including pH and colour were noted down (using the Standard Soil Color Chart© - Fujihira Industry Co. Ltd. 1965), and the core samples were packaged in electrical conduit boxes (which fitted their dimensions very well, avoiding problems of movement in transport - Flenley pers. comm. 1992). On the occasion when it began to rain, samples were immediately packed and taken back to the motel, where the noting, pH tests and photographing were undertaken on arrival. On the February 1990 trip, Karekare swamp core KK4 and the samples from cores taken from the other swamps were placed in labelled plastic bags rather than electrical conduit boxes.

7.1.2 *Potential Sources of Experimental Error*

The rods used to extend the depth penetrated by the sampler, whilst relatively stiff and unbending on their own, when attached in a line of a few metres have the potential to tolerate a small degree of curvature which could deduct a centimetre or two from the correct depth. Although the rods can be controlled fairly accurately from the point of view of perpendicularity above the ground surface, below the ground surface, a slight deviation from the perpendicular increases in value the deeper the rods go.

The sampler can sample a great time depth, but areally, it samples very little. If deposits are reasonably uniform, the technique works well, but the less uniform they become, the less reliable such sampling becomes. This can be offset to a certain extent by comparison with a number of widely-spaced cores in the same swamp. By such means, it is easier to ascertain what is reliable and what is not.

In the process of sampling, water creeps into the hole left by the sampler between samples. This water is very cloudy with suspended particles leached off different levels in the sampler hole, and mixed up by the action of the sampler moving up and down the hole. This water seeps into the sample-holding component of the sampler, leaving a film of undifferentiated mud on the outside of the sample. This does not present so much of a problem as this can be scraped off, and material for testing such as pollen analysis and pH tests, can be taken from well within the uncontaminated part of the core sample. The ends of the core sample present more of a problem as they tend not to be as stable and compact as the rest of the sample, and more surface area is presented to the contaminated water. These factors, therefore, mean the contaminated water penetrates far more readily than normal. The ends of core samples were consequently avoided for testing.

Deposits that are soft and malleable, especially when interbedded with harder layers, are apt to undergo compaction or distension when removed from the sampler. This can lead to minor errors in measuring the depths of layers, though these are limited by the depth of the top and bottom of the core sample. Careful handling, and as little handling as possible before noting, testing and photographing, reduces these problems. When the sample-holder was opened, the investigation was carried out straight-away, and the sample was removed free of the sample holder for photographing.

Samples can undergo changes in pH on exposure to air, so the pH tests were done immediately after removal from the ground, and certainly not back in the laboratory in Auckland. Changes in colour and moisture are also a danger avoided by on the spot notes and photographs (Millar *et al.* 1965). Thus, error here is likely to be minimal.

7.1.3 *Results*

See Appendix A.3 Stratigraphy. The stratigraphy for Karekare swamp (up to 10.9 metres deep) consisted of a basal clay, followed by gyttja (with lenses of coral sand in the lower levels), followed by peat (starting between 4.4 and 5.6 m) and ending in peat with a high mineral component (from 1.3 m). The other shallower swamps consisted of clay and gyttja layers, with small amounts of peat or coral sand in places.

7.2 Loss-on-ignition Tests

7.2.1 *Methodology*

Loss-on-ignition tests were undertaken for 20 samples from KK4. The purpose was to detect changes in the organic content of the sediments, by burning off the biotic material. This can help to ascertain more precisely where layers begin and end, and to understand more fully the processes involved in deposition. The method is as used in Allen *et al.* (1974). Water content was first extracted using the method described in Allen *et al.* (1974), so loss-on-ignition tests were carried out on dry samples. Dried samples were placed in crucibles in a furnace, and then fired. They were weighed and this weight was subtracted from the weight before firing to give the amount burnt off. This figure was divided by the original weight before firing and multiplied by 100 to give the percentage loss-on-ignition. This is equivalent to the organic content of the sample.

7.2.2 *Potential Sources of Experimental Error*

The size of the samples could create problems if the layers from which they come are heterogenous as stated in 6.1.2, though because the samples are yet smaller the potential problems are greater. However, as this produces random errors rather than systematic, this would express itself in inconsistencies in overall trends, or in more extreme cases a lack of trend. The results being fairly consistent, therefore, do not appear to be too adversely affected by such problems.

Rounding off of figures to two decimal points creates small errors but not of a significant degree.

Finally, burning in a furnace can also drive off CO_2 from the sample, which could be significant given the possible influence of carbonate from the coral rubble ridge at the seaward end of the swamp. However, this would not seem to be too much of a problem as the pH levels from the core were not alkaline, except for the bottom levels of the swamp where some coral sand was deposited directly into the swamp.

7.2.3 *Results*

Results are presented in Figures 7.1. to 7.5 and Tables 7.1 to 7.5. These show that, in Karekare swamp, the organic content increased from the gyttja to the peat, and then decreased in the last 1.3 m of sediment. The results from the other swamps shows an increase in organic content in the upper deposits.

Table 7.1 ARORANGI MORMON CHURCH SITE (ARM1)

Depth (cm)	ARM1 0	ARM1 60	ARM1 100	ARM1 150	ARM1 210	ARM1 250	ARM1 300	ARM1 350
% Loss	51.96	4.69	8.75	9.43	3.74	4.72	3.77	4.10

Table 7.2 ARO`A SWAMP (A01)

Depth (cm)	AO1 0	AO1 50	AO1 100	AO1 150	AO1 200	AO1 250	AO1 290
% Loss	12,61	11,20	9,74	3,78	7,32	4,62	3,88

Table 7.3 ATUPA SWAMP (AT1)

Depth (cm)	AT1 0	AT1 50	AT1 110	AT1 160	AT1 200	AT1 230
% Loss	27.78	14.38	5.61	5.00	2.04	2.54

7.3 pH Tests

7.3.1 *Methodology*

pH is a measure of acidity or alkalinity (Krauskopf 1979). It is based on the concentration of the hydrogen ion, which is usually between 1 and 10^{-14}. This is translated into a scale of 0 to 14; 0 being highly acidic, 7 being neutral and 14 being highly alkaline. Since sea water is alkaline (Krauskopf 1979), and freshwater, due to the presence of humic acids, tends to be acidic, especially where peat formation has taken place, it was hoped that changes in pH might provide insights into the relative influences of sea and land in the formation of the deposits.

The colorimetric method of pH determination (e.g. Allen *et al.* 1974) was used, immediately after the sample was removed from the ground, in order to avoid possible contamination from any sources whether it be air moisture or packaging for example. Tests were undertaken where stratigraphy had significantly altered, and not near stratigraphic boundaries to avoid contamination.

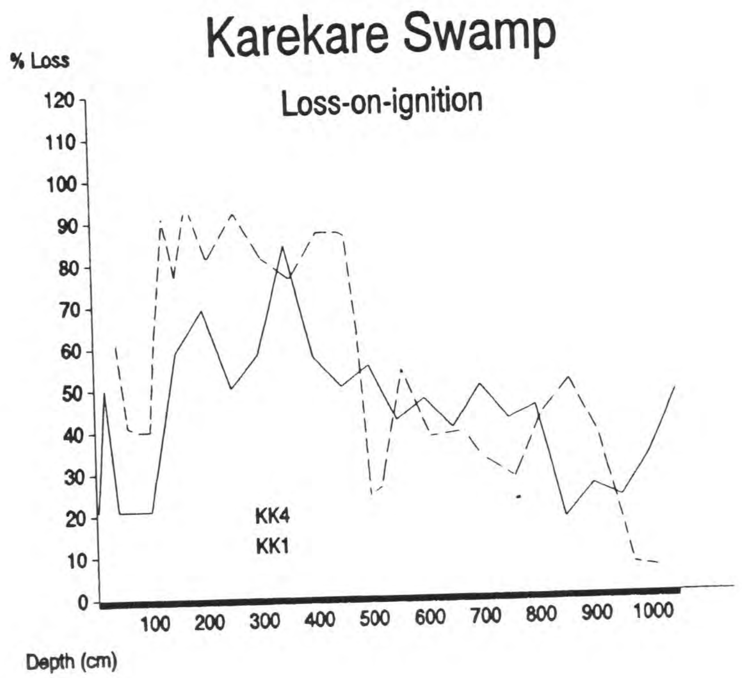
From 806.5 cm depth (see Table 7.6), coral sand started to intrude and would naturally boost the alkalinity, so no more pH tests were carried out.

Table 7.4 KAREKARE SWAMP (KK1)

Depth (cm)	% Loss	Depth (cm)	% Loss	Depth (cm)	% Loss
KK1 0-10	21.29	KK1 395-405	57.34	KK1 795-805	45.17
KK1 35-45	21.26	KK1 445-455	49.70	KK1 845-855	17.93
KKI 95-105	20.66	KK1 495-505	55.10	KK1 895-905	25.58
KK1 145-155	59.22	KK1 545-555	42.32	KK1 945-955	22.71
KK1 195-205	68.87	KK1 595-605	47.14	KK1 995-1005	32.72
KK1 245-255	50.19	KK1 645-655	40.36	KK1 1045-1055	47.51
KK1 295-305	57.85	KK1 695-705	50.39		
KK1 345-355	84.49	KK1 745-755	42.39		

Table 7.5 KAREKARE SWAMP (KK4)

Depth (cm)	% Loss	Depth (cm)	% Loss	Depth (cm)	% Loss
KK4 20	50.5	KK4 210	80.8	KK4 560	54.2
KK4 40	61.58	KK4 260	91.6	KK4 610	38.0
KK4 60	41.00	KK4 310	80.8	KK4 670	38.7
KK4 80	39.35	KK4 360	75.9	KK4 700	33.1
KK4 100	38.98	KK4 410	86.9	KK4 760	27.6
KK4 110	60.6	KK4 450	86.50	KK4 810	42.6
KK4 130	90.52	KK4 460	85.8	KK4 860	50.7
KK4 150	77.16	KK4 480	63.35	KK4 910	37.8
KK4 170	91.51	KK4 500	24.02	KK4 970	9.6
KK4 180	92.5	KK4 520	25.6	KK4 1010	6.1



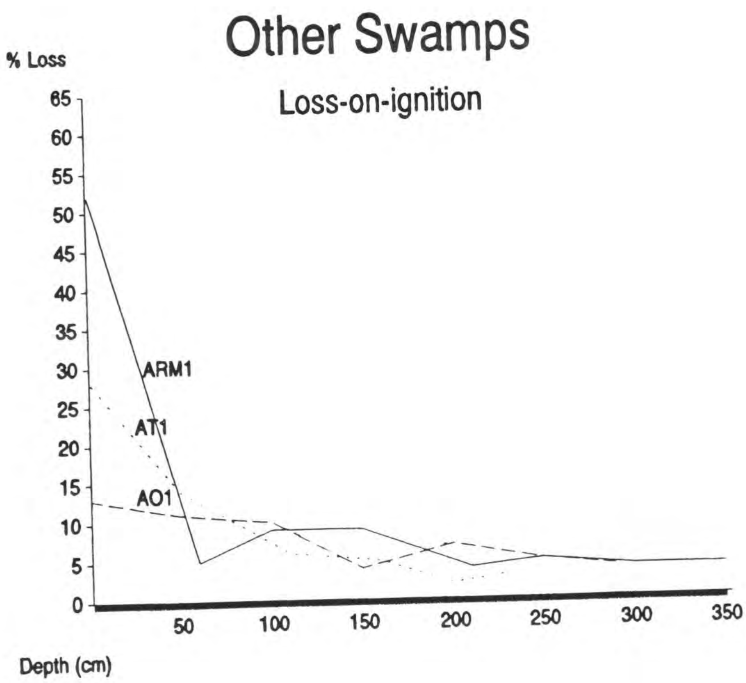


Figure 7.1 Loss-on-ignition Tests

7.3.2 *Potential Sources of Experimental Error*

Some exposure to air moisture on opening the sample holder is unavoidable, though if done soon after exposure begins, the significant corrupting effects can be averted.

There is always the possibility of localised pH results if the deposits are too heterogenous, though the results here seem to be internally consistent and not warranting overly much concern.

7.3.3 *Results*

KAREKARE SWAMP

Table 7.6 KK1

Depth (cm)	80.0	111-125.5	125.5-137	170.5-208	324-356.5	513.5-565	639-640.5	644.5
pH	6.0	6.0	6.0	7.0	7.0	6.5	6.5	7.0

These results demonstrate that the deposits are mildly acidic, except for two samples which are neutral.

7.3.4 *Interpretation*

The pH results are not clear enough to suggest that sea influences, or at least the influence of nearby coralline material, may have been important (due to the fact that swamps tend towards acidity, whilst seawater is alkaline). The problem is that the changes in readings are not greater than the accuracy of measurement. Whilst the samples at depths of 170.5-208 cm and 324-356.5 cm correlate well with the chemical results suggesting marked events of a marine character, the results could just be due to post-depositional diagenisis and the present chemical environment. Hence, no definite conclusions can be reached.

7.4 X-Radiography

7.4.1 *Introduction*

Sediments, particularly those unconsolidated sediments composed of laminations, vary significantly in their density. Any kind of bedding, including fine laminations, and anomalies, caused for example by small shells or pebbles, can be detected by X-Radiography. The resolution of the technique is much finer than is revealed to the naked eye by visible light, and structures or features from within the body of the core sample can also be investigated in a non-destructive way. Structures that are simply too fine to discern in visible light can be distinguished through the technique's capacity for resolution.

X-Radiography has been applied to the analysis of archaeological sediments (Butler 1992) and of lake sediments (Lowe *et al.* 1981). It has the advantages of lack of sample preparation, of greater accuracy brought to sedimentological changes, and of non-destructiveness.

7.4.2 *Methodology*

The methodology of X-Radiography has been described in detail by Hamblin (1962) for consolidated sediments, and refined by Calvert and Veevers (1962) for unconsolidated sediments. This involves the cores being placed directly on the film and exposed to radiation. Problems encountered with blackening at the edges of cylindrical core samples, due to radiation passing through a lesser thickness of sediment, can be resolved either through multiple X-rays (Stanley and Blanchard 1967) or the use of an aluminium filter (Baker and Friedman 1969).

X-Rays were taken by Raewyn Carin of the Auckland Hospital X-Ray Department, using a SIEMENS GIGANTOS machine, an intensifying screen and MR detail cassette AGFA-GAVAERT with DU PONT MICROVISION X-RAY FILM. Technical details are as follows: KVP (Kilo Volt Peak)=50; Ampage=10 MAS (Milli Amps per Second); Focal Distance FFD= 100 cm.

7.4.3 *Potential Sources of Experimental Error*

The technique involves trial and error, at least initially, in order to find the correct combination of kilovoltage, milliamperage, exposure time, focal distance and type of film for the type of sediment under investigation (Hamblin 1962; Butler 1992). Skill, time and resources therefore can improve or reduce the quality of the images produced.

Variation in thickness of the sample can result in inconsistencies in the definition of the image. Filtering or a series of images can reduce the scale of this problem (see page 87).

Stratigraphic variation and change is recorded in fine resolution, but, unfortunately, so are features produced by sample preparation and preservation. The differential strengths and weaknesses of sediments in a core sample can lead to disruption when the sample is being transported. Storage conditions can mean desiccation, causing breaks and shrinkage in some areas. In order to avoid this, the samples were stored in a freezer before analysis began, so therefore, disturbance is more likely from the expansion of the water content, especially in the peaty part of the cores. However, this is not expected to have produced significant problems.

7.4.4 *Results*

Finer resolution of features was achieved. Fine banding was found at the transition point between gyttja and peat in KK1 just as was observed in KK4 where it was more visible. A clear boundary was found at about 1.35 m in KK1 between the top peaty layer containing a greater mineral content, and the more organic peat immediately below it. Finally, the gyttja revealed fine laminations which could be related to storm events.

7.5 Charcoal Counting

7.5.1 *Methodology*

The method is that used by Matt McGlone of DSIR Botany Division, Christchurch (Horrocks pers. comm. 1992). 50 views were selected at random. For each view, the main pollen type and the charcoal particles were counted. The charcoal was then calculated as a percentage of the total pollen count. For example, 200 % means that there was twice as much charcoal as pollen, and 50 % means that there was half as much charcoal as pollen. The following equation was used to calculate the results:

A. $\frac{\text{No. of charcoal particles} \times \text{\% of main pollen type}}{\text{No. of main pollen type}}$

Then equation A was multiplied by 100.

7.5.2 *Potential Error*

Charcoal counting is helpful as a rough guide and should not be taken as being too precise. Dark coloured particles especially in peaty materials could be confused with charcoal. Where pollen is less dense the charcoal count can appear greater, even though the density of charcoal has not changed.

7.5.3 *Results*

Table 7.7 KK4

Depth (cm)	% of Charcoal	Depth (cm)	% of Charcoal	Depth (cm)	% of Charcoal
KK4 O	104.5	KK4 170	1.0	KK4 530	1.0
KK4 30	77.0	KK4 190	4.0	KK4 550	2.5
KK4 60	159.5	KK4 290	0.0	KK4 570	10.0
KK4 90	212.5	KK4 390	11.5	KK4 670	6.6
KK4 100	275.0	KK4 440	0.0	KK4 790	9.0
KK4 120	140.0	KK4 470	0.0	KK4 890	5.5
KK4 130	175.0	KK4 490	5.5		
KK4 150	10.3	KK4 520	16.0		

Table 7.8 KK1

Depth cm	% of Charcoal	Depth (cm)	% of Charcoal
KK1 10	4.5	KK1 510	3.7
KK1 60	222.5	KK1 560	1.4
KK1 110	625.8	KK1 570	15.3
KK1 160	14.6	KK1 610	0.0
KK1 210	12.6	KK1 710	2.5
KK1 310	28.0	KK1 810	11.0
KK1 410	3.3	KK1 1010	0.0

7.5.4 *Interpretation*

Although minor peaks occur elsewhere in both cores (see Tables 7.7 and 7.8), a very much more significant and unusual peak occurs from 135 cm upwards. In KK1 (see Table 7.8), a smaller peak around 160-310 cm may be of importance too, though it is not at the same level of intensity as the higher and thus younger one.

7.6 Grain Size Analysis

7.6.1 *Methodology*

Grain size analysis was carried out by Peter Johnson of the Geography Dept. at Massey University, Palmerston North on KK1. Not enough material was left from KK4 to complete an adequate analysis for that core too. Samples were sieved in order to separate the larger fractions. No sample contained any grains greater than the sand fraction (> 2mm). The largest fraction in most samples was mud (silt and clay). The mud fraction was then sorted by a SediGraph into finer classes. Of the mud fraction, clay (<2mm) was the largest single fraction, and clay and fine silt accounted for most of the mass.

7.6.2 *Potential Error*

The size of the sample, especially for the SediGraph analysis, may mean that minor local variation throughout a deposit may mask overall trends. However, such variation is likely to be random in character, whereas the results show more or less consistent trends. Small, negligible errors can occur in the sieving process where an individual grain may be within a particle size on one side but greater on another, so that whatever size it will be recorded as will depend on the angle at which it approaches a gap in the sieve.

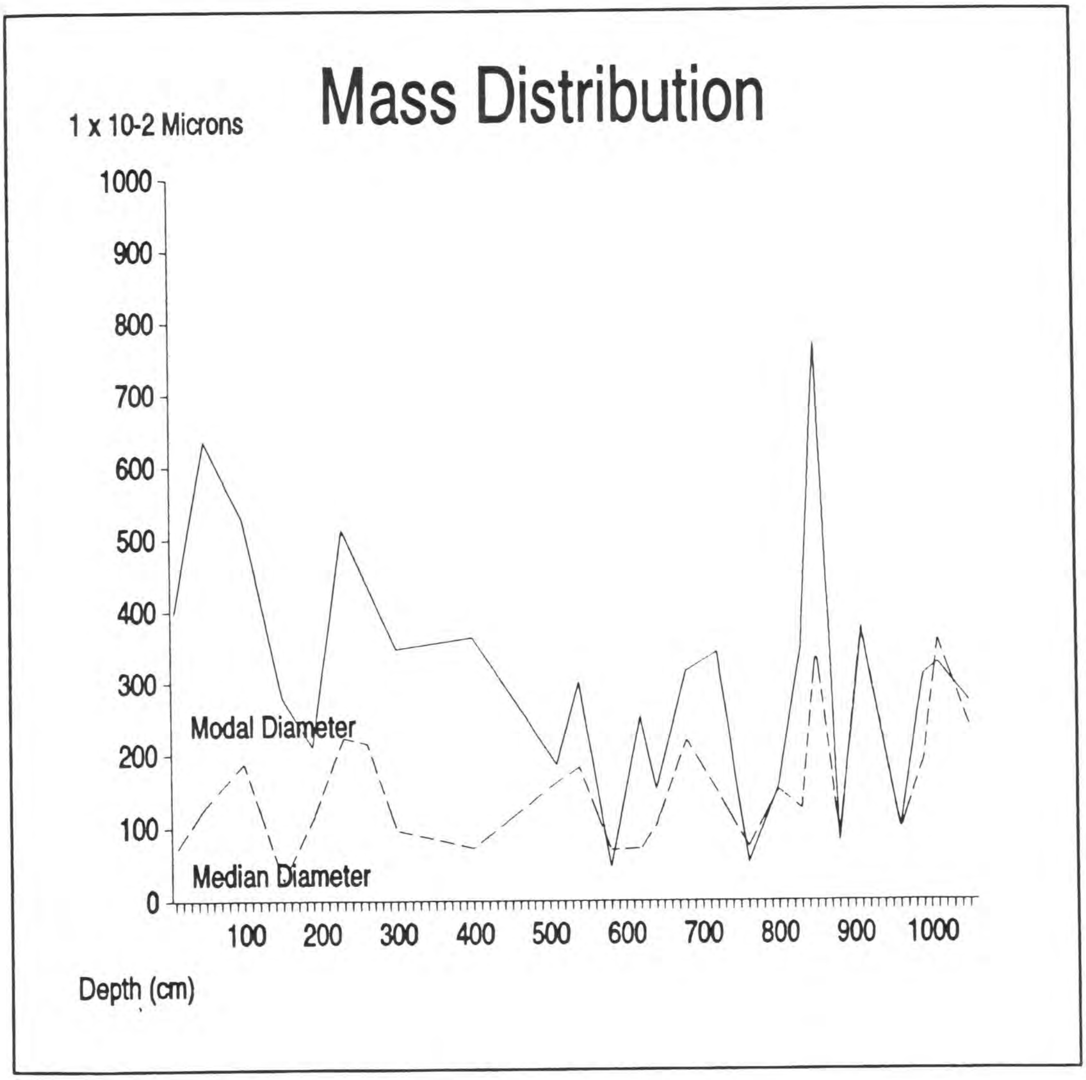


Figure 7.2 Mass Distribution (KK1)

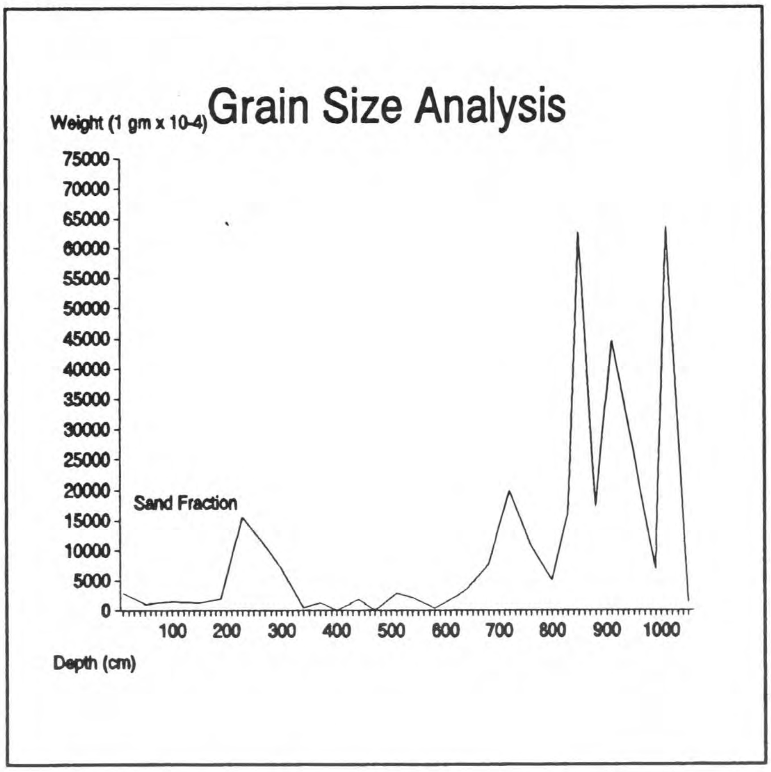


Figure 7.3 The Sand Fraction (KK1)

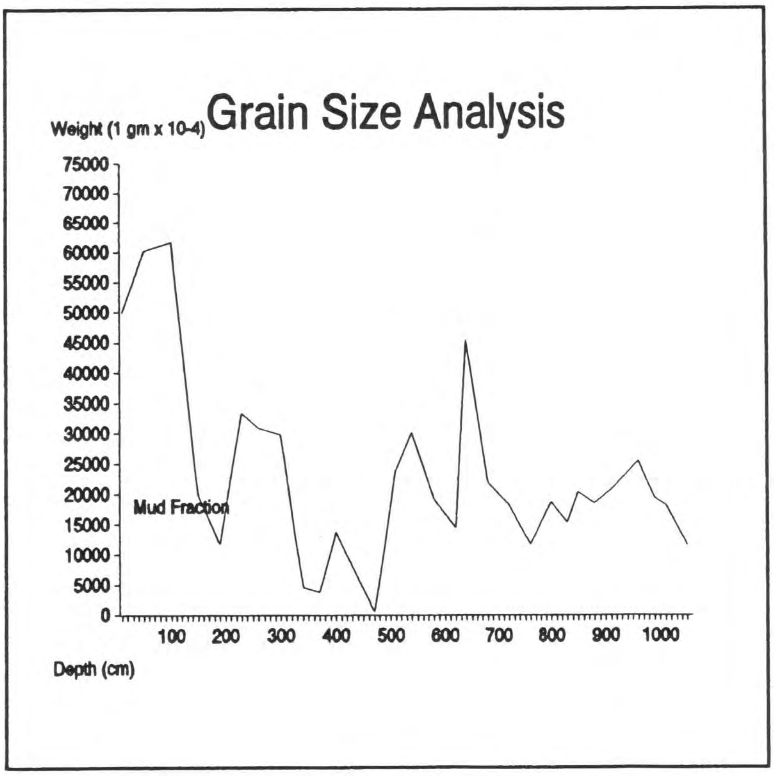


Figure 7.4 The Mud Fraction (KK1)

7.6.3 *Results*

See Appendix A.7. and Graphs 7.1, 7.2, 7.3, 7.4 and 7.5. The degree of sorting declines from the gyttja to the peat, with a gradual decrease in the clay fraction. From the beginning of the peat, there is an overall increase in silt fraction from 31.25-7.81 mm.

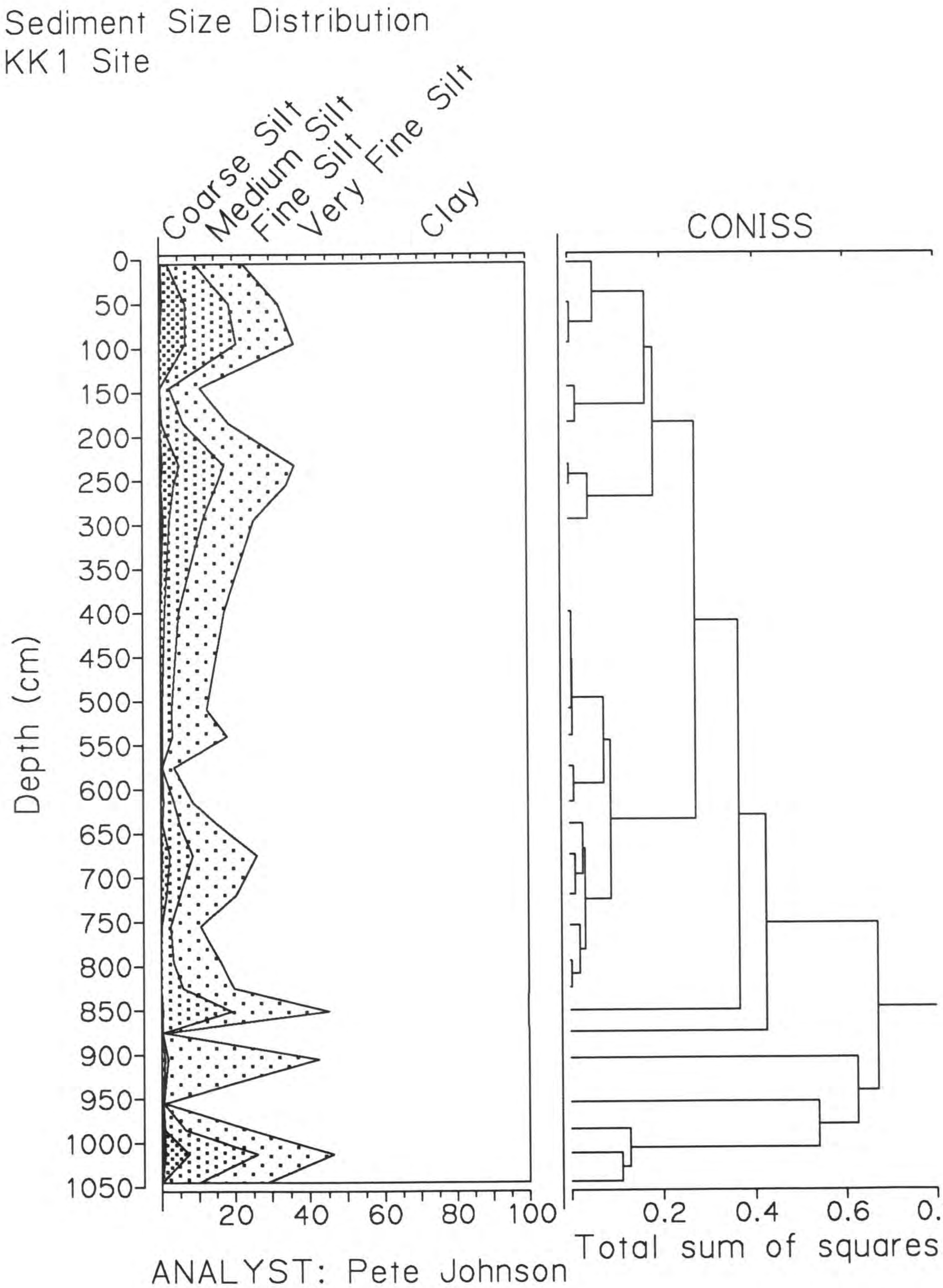


Figure 7.5 Sediment Size Distribution (silts and coarser clay) for KK1

7.6.4 *Interpretation*

The mass distribution (Figure 7.1) reveals that the degree of sorting was much greater in the gyttja than in the peat. This may be related to a dichotomy between the sources of deposition: allogenic, endogenic and authigenic (Dawson 1990). The first involves mineral and organic coming into deposits by aeolian or hydrological processes. Ombrogenic material would be insignificant. The second involves material being precipitated directly from water column. Finally, the third occurs as processes within sediment once it has been laid down. Possible seasonal changes in physical and chemical conditions within the sediment could arise, causing rapid diagenesis (Lewis 1984).

Allogenic material tends to reflect the catchment. Much of this fraction is deposited in solution, where processes in the water may lead to chemical precipitation or absorptive uptake of metals from aquatic solutions - i.e., endogenic particles. Transfer of chemical precipitates into gyttja is facilitated by settling, by filtering organisms or by flocculation.

The mineralogy of lake sediments alters relatively little after deposition, therefore the authigenic fraction is negligible (Mackereth 1966). The transfer of solutes between sediment and overlying water is important in determining the amount of particulate material arriving at the sediment/water interface, the amount that is trapped within the sediment and the amount that is returned to the water column. Endogenic and allogenic processes are the major factors in lake systems. On the other hand, in the peat, humic acids and higher temperatures, caused by the slow decay of organic materials in closer proximity to the effects of the sun's rays and oxygen, would have authigenically altered some of the materials. In other words, the mass distribution may have been lowered as a result. So, for example, coarse silt may have once been fine sand. The smaller particles would have been more greatly affected as their surface area to mass ratio is greater than larger particles. However, the more neutralising effect of seawater and/or calcium carbonate from the coral rubble ridge may have reduced these effects.

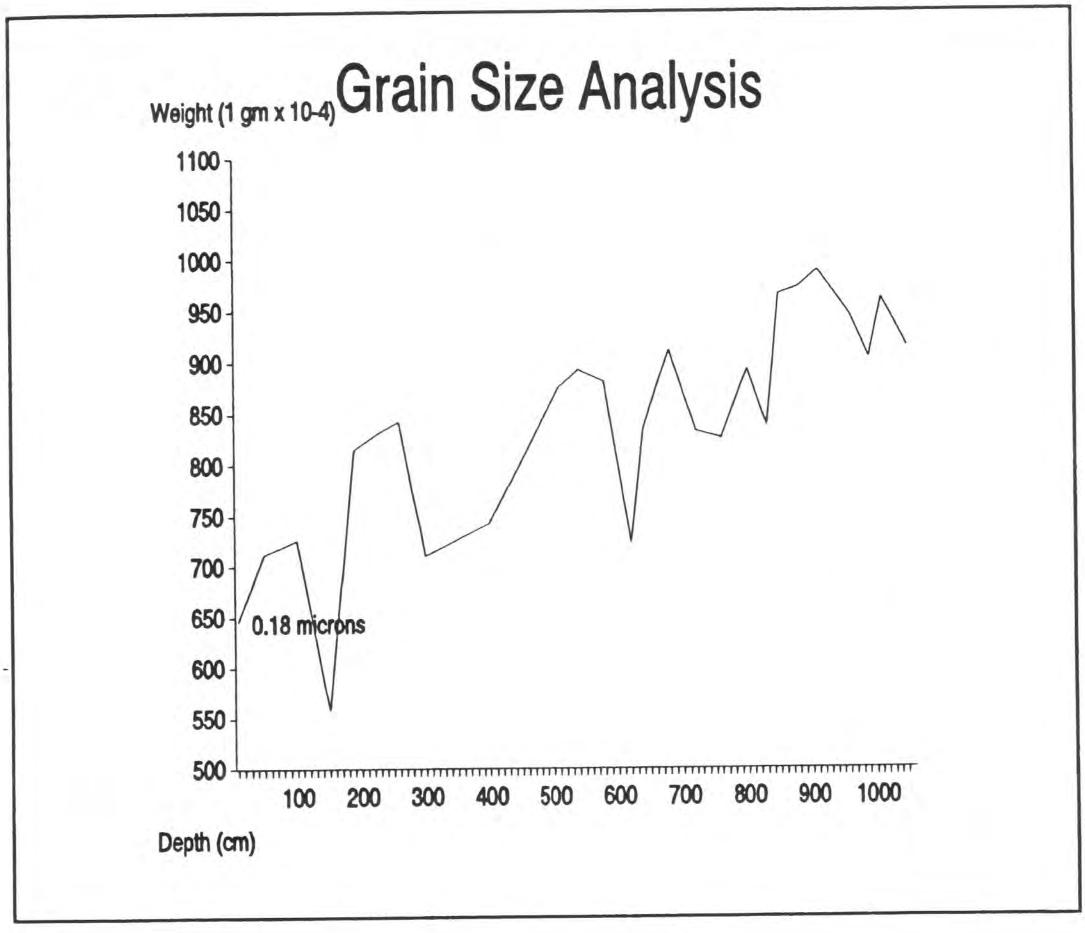


Figure 7.6 The 0.18 mm (Clay) Fraction (KK1)

A larger proportion of the mass distribution is below 0.18 mm (Figure 7.5) in the peat samples than the gyttja and finer silt is generally in higher proportions in the peat. Smaller proportions of sand in the peat may be related to other factors (see below and Figure 7.4). So this could well be a significant factor in degree of sorting as it would have a disproportionate effect on the various grain sizes.

The distribution of grain sizes within the mud fraction (SediGraph analysis - Figure 7.3) shows that a large part of the lack of sorting in the mass distribution of the peat samples is due to a gradual decrease in the clay fraction, which forms a significant component of the total sample. The higher up the samples therefore, the more they are affected by fluctuations in the silt fraction, which is less stable. From the beginning of the peat to the top of the sediments, there is an overall increase in silt fraction from 31.25-7.81 mm with peaks around 230-235 cm and 90-100 cm. The first peak also coincides with a peak in the sand fraction (Figure 7.2).

The sand fraction decreases above 700 cm to become a very minor component, except for a peak between 340 and 190 cm, which may explain the anomalously early date from a sample at 160-170 cm from KK4, if the levels are equivalent (KK4 levels tend to be slightly higher than their equivalents from KK1 due to the effects of the underlying topography of the solid geology - see Figure 5.4). This is because this sand peak matches closely in height an earlier sand peak between 700 and 800 cm, a layer which from comparison with KK4 might be expected to deliver a date similar to that anomalously produced in sample KK4 160-170 cm. Flenley (pers. comm. 1993) suggests that people, cultivating the edge of the swamp, may have thrown material into the centre. The edges of basins tend to have lower levels occurring nearer the surface, and material from these earlier levels may have been included in such humanly transported sediment. Alternatively, lower water levels as postulated in Chapter 9 below, may have meant that these earlier deposits became more susceptible to erosion, and thus contaminated the younger levels by natural means (*cf.* Newsome and Flenley 1988: 559).

Earlier peaks, below 800 cm, in modal and median diameter coincide with those of the sand fraction (Figure 7.2). This probably relates to the bands of coral sand, and no doubt silt, blow in from a then drier coral rubble ridge. Later modal peaks are due to an increase in the silt fraction, which are not accompanied by sand peaks (bar one), which might suggest that the source was not the coral rubble ridge. Indeed, bands of coralline material do not appear above 800 cm at all. Median diameter values stay within the clay fraction. This may be due to erosion caused by a combination of sediments drying out and cyclonic activity transporting the loose, desiccated material, or alternatively human activity. The former may be a better explanation for the earlier peak at 230-235 cm because the sediments better reflect earlier peaks, whilst the latter may better explain the peak at 90-100 cm because the sediments are greater than previous peaks and might suggest material coming from the land immediately surrounding the swamp which may have been cleared for access.

Sample KK4 140-150 cm, presents a special problem as it is a low point for all fractions, and comes between two large peaks in most of the fractions. The fact that three quarters of the SediGraph sample sediment falls within the clay fraction indicates very settled conditions. Sorting is poor, but due in all probability to sediment diagenesis through humic acids as mentioned above (*cf.* Lewis 1984). The time against depth graph (Figure 1, Appendix A.6) shows that the rate of sedimentation was slowing down around this stage. With sediments rising above a possibly sinking water table at least seasonally (see Chapter 9), and possibly the increasing stature and density of the vegetation acting more and more as a filter to larger particle sizes, the rate of sedimentation was lessened.

7.7 Chemical Analysis

7.7.1 *Methodology*

Samples prepared by Pete Johnson of the Geography Department, Massey University, were submitted to the ICP Facility at the Grasslands Research Centre, in Palmerston North, where an elemental analysis by means of ICP was undertaken by W. Martin.

Correlation analysis was undertaken by Prof. Robert R. Brooks of the Chemistry Department, Massey University, using the method described in Reeves and Brooks (1978: 387-391).

7.7.2 *Potential Error*

Some errors could have occurred if there had been any movement of chemicals in the profile independent of stratigraphic boundaries. Some elements can migrate in and out of layers under conditions of low redox and low pH. When the pH is low, iron becomes mobile. Under reducing conditions, iron and manganese become mobile.

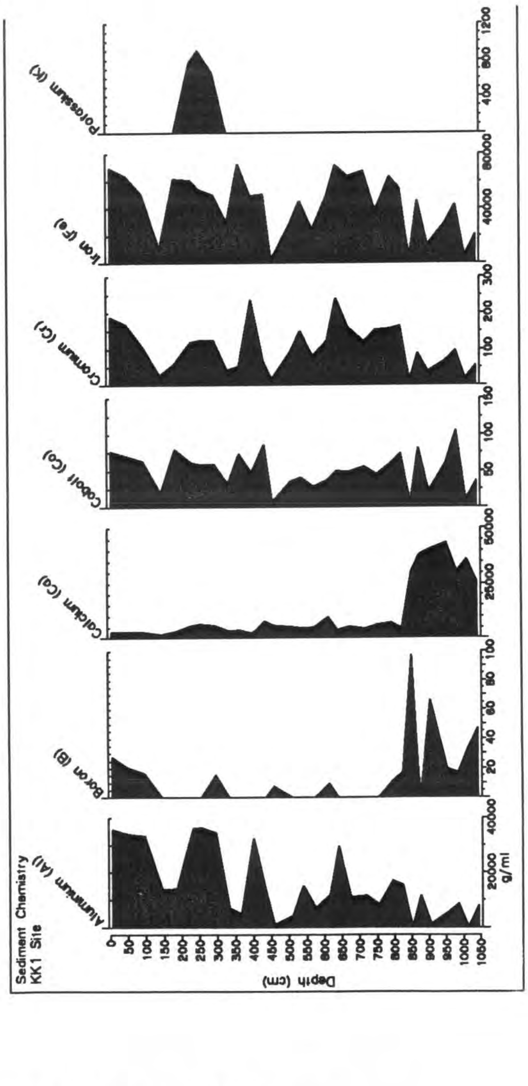
This is not likely to present too much difficulty as far as the pH is concerned, because the pH levels were not especially low, except the lower ones with bands of coral sand. Low redox, except for the upper peat layers, may have created problems. This can be evaluated in the interpretation by comparison with other elements.

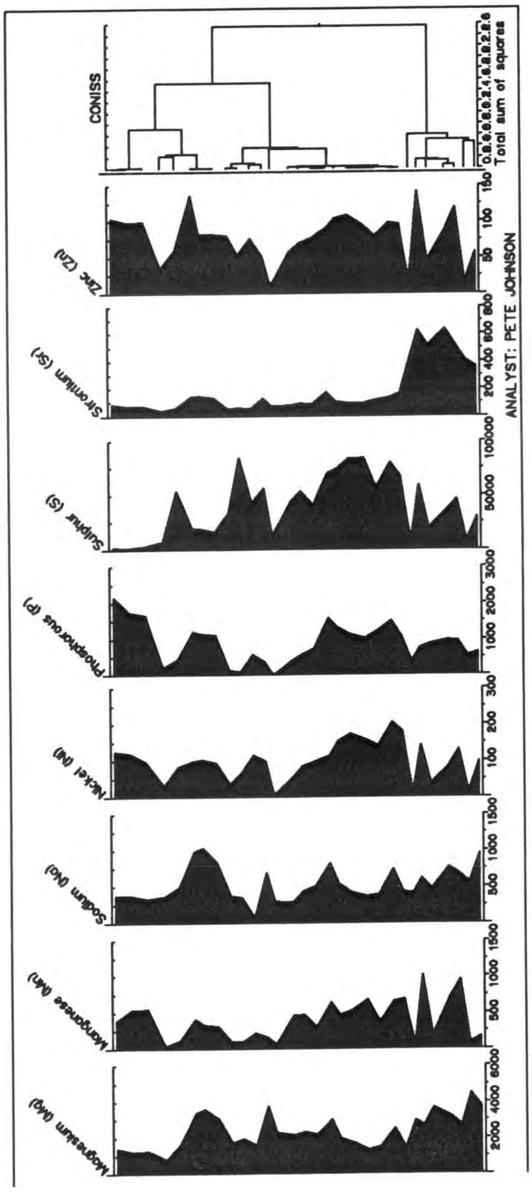
Some contamination could derive from the HCl used in the preparation of the samples, but this is a systematic error accounted for by the analysis of a control sample of the same HCl used in the preparation of the samples.

Elemental analysis was chosen instead of structural analysis. This means that whilst the overall concentration of an element can be considered, what form or forms that element has taken can not be determined. Funding resources did not stretch far enough to allow for both elemental and structural analyses to be undertaken. Elemental analysis has, however, proved to be highly instructive especially in combination with other techniques such as pollen and charcoal analysis (Kirch *et al.* 1992), so the lack of structural data is not necessarily a problem.

7.7.3 *Results*

See Appendix A.8. and Figure 7.6. Sr (strontium), Na (sodium), B (boron), Ca (calcium) and Mg (magnesium) show strong correlations with each other and appear in peaks at 200-300 cm, 465-474 cm, 610-620 cm and below 800 cm. Al (aluminium), Co (cobalt), Cr (chromium), Cu (copper), Fe (iron), Mn (manganese), Ni (nickel), P (phosphorus), and Zn (zinc) each have very highly significant correlations with most of the others.





see larger scale diagram
on Appendices II, B.2

Figure 7.7 Elemental Diagram

These have peaks between 200 and 300 cm and above 135 cm.

7.7.4 *Interpretation*

The influence of seawater is generally indicated by high values for Sr, K, Na, B, and Mg (Fairbridge 1972; Mason 1966). Conversely, seawater is very low in Fe. Below 800 cm, high values were obtained for Sr, Na, B, and Mg. The peaks in Ca at this time suggest that the form that this sea influence may have taken was in the form of the coral sand bands visible in the core samples below 800 cm. Thereafter, there are only very minor peaks in B, Sr and Ca. Fe is relatively low in value around these levels. All these elements, bar Fe and K, are demonstrated to have a very highly significant correlation with each other (though the B-Na correlation is only highly significant) in Appendix A.8.

Na and Mg show a relative decline in values except for peaks at 200-300 cm, 465-474 cm and 610-620 cm. Small peaks in Ca values above 800 cm conform to those of Na and Mg. The minute peaks in the other seawater elements above seem to correspond as well. This might suggest a sea influences in these peaks.

Ca has different sources: sedimentary carbonates have 30.2%; sandstones 3.9%; shales 2.2%; basalts 7.6% (Fairbridge 1972); and seawater 410 ppm (Brooks pers. comm. 1993). This means sedimentary carbonates are the biggest source. The largest negative relationship of the whole correlation analysis is Ca with Al, a basaltic element (Appendix A.8). Strontium is another possible indicator though hard to separate from basaltic influences: in carbonates it occurs at a percentage of 0.06%, whilst in basalts the percentage is 0.046% (Fairbridge 1972). In the above case, it seems likely that coral sand from the coral rubble ridge or seawater is the source of the peaks in these elements, as all very highly significant correlations with Sr are also associated with marine sources rather than basaltic ones. Sr, in fact, has negative correlations with the typically basaltic elements, especially Al (Appendix A.8).

Cr, Co and Ni are typical components of basaltic rock (Fairbridge 1972; Mason 1966). Sr is a possible indicator, though as shown above carbonates are almost as likely to be the source. These do all appear to fluctuate in tandem, even Sr (except for the early peaks below 800 cm associated with coral sand). Fe and Zn peaks seem to coincide with those of Cr, Co, and Ni as well. Zn become mobile under reducing conditions like Fe, but the relationship with the other elements may mean that there is more significance to the Zn and Fe peaks. Mn follows these other elements with significant, though not exact correspondence. Also, Al, Mo (molybdenum), Cu, P and K correspond closely to the above peaks. Al, Co, Cr, Cu, Fe, Mn, Ni, P, and Zn each have very highly significant correlations with most of the others, whilst K only has a highly significant correlation with Al out of all the elements tested for (Appendix A.8).

A problem occurs as far as the 200-300 cm peak is concerned. Mg occurs in basalts, but could equally be the result of seawater from sea surge, because K, Sr and Na are low in basalts and high in seawater. Mg does not show a similar rise during the peak above 135 cm in the other basaltic elements, which might suggest that the 200-300 cm peak involved a combination of material from different sources: gyttja, soil, coral rubble ridge and seawater being possible candidates (K, Sr and Na support this conclusion).

In the process of weathering, Na, Mg and Ca are the most susceptible elements to leaching out of the parent material, followed by K and Si (Krauskopf 1979). Al and Fe are the most resistant elements to weathering, especially in lateritic soils (Duchaufour 1982; Evans 1978). It is interesting to note the behaviour of Al through the profile compared to Na, Ca and Mg. In the layers containing coral sand (below 800 cm) Al is naturally low, as coral is poor in Al. From 800 to 300 cm, its values are higher due to the more terrestrial origin of the sediments (except noticeably the peaks of 465-474 cm and 610-620 cm mentioned above as possible intrusions of marine origin). Then from 300 cm upwards, values are much higher which indicates deposition under more erosive conditions than before.

The inland volcanic soils today are basically montmorillonitic, the coral rubble ridge on the seaward side is carbonatic, whilst the poorly drained depressions like Karekare swamp are more kaolinitic in texture (Leslie 1980)[44]. This is confirmed by very high values for Al in the top 135 cm. Montmorillonite tends to increase the proportions of other elements such as Mg, Zn, Cr and Ni (Mason 1966). The reason that the swamps are kaolinitic may thus have less to do with the catchment, which contains soils of a high pH, and more to do with their own internal pH regime, encouraging the formation of 1:1 lattices. The swamps are composed to a large degree of peaty material, which produces humic acids, albeit tempered by the influence of the catchment soils and rocks (basalt and coral), sea spray and sea surge. Kaolinite is favoured by acid condi-tions, whereas the opposite is true for montmorillonite (Mason 1966). The low values for Al below 800 cm may also be related in this way to pH levels. High values for elements such as Na and Mg may also be the result of low pH. This is confirmed by the negative relationship of Al with Mg and Na illustrated by the correlation analysis (Appendix A.8).

S (sulphur) has a unique history in this site, not behaving like any other element that was sampled for. Despite its association with organic materials, it does not appear to follow the values for the total organic content very closely, though

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[44] Kaolinitic soils have a 1:1 crystal lattice structure, and contain a higher proportion of Al, which is replaced in montmorillonitic soils by elements such as K and Na (Limbrey 1975).

it could be connected with inwashed organics. A link with soils is also possible, being associated with volcanic rocks and soils. There is a general decline in values for S above 330 cm and especially 135 cm, where it has unusually low values.

S can achieve high values when there is soil disturbance and when animal and human waste is present nearby (Butzer 1982), though disturbance in the form of construction can be unusually low in P (Deevey *et al.* 1979). However, it does not harmonise well with the P peak which is supposed to indicate this too. One explanation could be that because concentrations vary with the rate of discharge; so whilst sulphates decrease with dilution, suspended solids, Fe, Mn and phosphates increase in direct proportion to volume of water (Butzer 1982). In fact, there is a strong link between the amount of mud deposited and the S concentration; they vary in inverse proportion to each other.

This is demonstrated by a negative correlation value (Appendix A.8). Mo shows a highly significant correlation with S, and with no other elements, whilst *vice versa* S only has such a relationship with one other element. Interestingly then, Mo also has a negative relationship with P, according to the correlation analysis. The S value is probably less strongly negative *vis-à-vis* the P than Mo *vis-à-vis* P, because of the presence of authigenic S in the organic material in the swamp.

The clearance of vegetation in the top cultivated zone (top 135 cm), plus the construction of drainage channels would have facilitated the passage of water and suspended solids. This explanation works for the peat, but not for the gyttja. This is because, whilst the basin formed a lake, the water body itself would have impeded the movement of an external water current through it. A drier and open basin, such as formed by the present taro (albeit earlier atoll taro - on the basis of living memory and oral tradition) garden, would, on the contrary, relatively freely permit the passage of these water currents.

Problems can arise due to endogenic and authigenic reactions disrupting the relationships between SO_3 and other variables. More soluble ions are complexed with sulphates - for instance, there are positive relationships with MnO and Na_2O. This is not the case in KK1 as Na and Mn show no special relationship with S. There is a negative relationship with mineralogical components when it is organic in origin (*cf.* Dawson 1990). In very productive lakes, if the redox potential is low enough H_2S may be formed as a result of SO_3 reduction and the breakdown of organic matter. Perhaps the high values for S at the top of the gyttja may be due to this phenomenon.

The influence of organic materials is not clearly evidenced in any of the elements presented here. Iron is low in plant ash (100 ppm), but the values do not mirror the growth in peat and accompanying high organic content of the deposits (Fairbridge 1972; Mason 1966). The following elements are high in plants: K, Cl (chlorine), Na, S, P, Ca, Mg, N (nitrogen), O (oxygen), C (carbon) (Fairbridge 1972; Mason 1966). Higher values are not recorded for K, Na, S, P, Ca and Mg in the peat than the gyttja, so this suggests that the organic component is not exerting a significant influence over the chemistry of the samples.

P is considered to be a good indicator of human activity, due to leaching from bone, food remains and dung (Evans 1978), as well as soil run-off (Butzer 1982). There are problems, though, with P. When there is a pattern of alternate wet and dry seasons, organic materials are inclined to oxidise and decay, whereas organic compounds can migrate vertically, become rearranged or even lost. This reduces the significance of any pH, calcium carbonate, organic matter, and phosphate values in the profile. For example, organic matter, K, and N are gradually broken down or leached out of the horizon, whilst phos-phates may transfer from a soluble state to a fixed one or may move to the lower levels (Butzer 1982). In the case of the top deposits (especially above 135 cm) where this likely to have been the case, the phosphate has probably become fixed like Fe (see above).

There is a link between phosphate concentration and primary productivity (Smith, V.H. 1979). Low phosphorus values can indicate more open woodland as has been argued for a swamp catchment area on Lakeba, Fiji (Hughes *et al.* 1979). Shapiro *et al.* (1971) show that there is a strong correlation between sedimentary P and trophic conditions. It can be also allogenic and authigenic in origin. Authigenic sources are the biological uptake of dissolved inorganic P and subsequent deposition as particulate organic P, and also the absorption of P by humic complexes and Fe oxides or precipitated as Fe phosphates, which again would link P to Fe.

If the deposition of dissolved P is constant, P profiles can reflect productivity over time. This could imply that there was greater productivity at the time of gyttja formation than peat formation, apart from the two main peaks which are probably erosional in character. However, this could be explained by the faster rate of deposition, and the volume of water decreasing (which decreases the values of P, Mn and Fe - Butzer 1982) possibly due to increased aridity and/or a lower water table. A change in Fe content or redox conditions can change P, independent of its concentration in the water. Density dependent settling can also change spatial distribution (Frink 1967).

The presence of soluble iron, mobile (colloidal) silica, and available phosphates favours concentrations of such compounds or combinations thereof, in soil waters. This is particularly true in subsoil environments prone to alternate wetting and drying or alternate oxidising and anaerobic conditions (Butzer 1982). This could well explain the final two peaks at around 230-235 cm and 90-100 cm in Fe, Si and P.

Al_2O_3 is a major component of silicate minerals and is fairly inert and can be used as a control against potential biological influences on the chemistry of the sediments (Cowgill and Hutchinson 1966). However, it can also be absorbed on to clay minerals and be chelated with humus. Silica can have a negative relationship with Al_2O_3 and pH possibly due to increased solubility of Al at lower pH (Dawson 1990), though this should not be a problem in this core due to the acid to neutral pH.

MgO, CaO, Na_2O and K_2O are all major constituents of silicate minerals. Surface water does not usually contain much Na, K and Mg, so it does not have a significant biological uptake or chemical precipitation. Mackereth (1966) states that: 1) active erosion of raw unleached material leads to an increase in K, Na, Mg and Ca in the mineral fraction; 2) leaching should diminish the base content of mineral material prior to its erosive removal and deposition. Low pH causes more Ca to remain in solution. Ca is known to be attracted to organic lignands and is, therefore, non-allogenic. Jones and Bowser (1978) demonstrated that some Ca is endogenic, precipitated directly from water column, organically and inorganically.

Na, in particular, presents a special problem here. Its overall trend is towards lower values for the higher levels up to about 400 cm. This could suggest a link with the increasingly low values for the clay fraction above the 0.18 mm diameter size. A peak between 200 and 300 cm matches that of the aforementioned elements of Mg, K and Ca. The lack of a peak above 135 cm (and lack of a trough) matches Ca and K, but not Mg and other elements like Al and Cr which might have been expected . Perhaps Na and Ca represent a sea influence like a major cyclone. Na_2O can be increased by presence of sea water, and K also.

Fe_2O_3 can occur in residual form in silicate minerals or in an extractable form as authigenic oxides, iron sulphides, carbonates and organic complexes. Also, high SO_3 values are connected with high iron sulphide values. The rate of supply (through environmental processes) and the preservation potential (due to limnological conditions) are important, because authigenic forms of Fe in lake sediments are potentially labile. Fe enters lake deposits via the deposition of mineral component, in solution or organic complexes formed in organic soils. Haworth and Lund (1984) showed that dissolved organics undergo an increase in Fe. Up to 330 cm, there is a strong link between the behaviour of Fe and S suggesting that the source of the Fe could well have been authigenic. S is also associated with organic material. However, above 330 cm, the source of Fe is probably from silicate materials, except for a peak at 190 cm, which again is connected with a S peak.

Fe has a low solubility under oxidising conditions, and vice versa with reducing conditions (Hull *et al.* 1982). The reduction of iron when it is buried may lead to upwards migration as it goes into solution, leading to higher values in the top part of the core. This might be a problem in this core, though the high values at the top of the core are more likely to be connected with fixation under oxidising conditions. Fe_20_3 has a possibly negative relationship with pH. Haworth and Lund (1984) link Fe and Mn, and Mn can be mobilised under reducing conditions too. However, Mn does not follow Fe values consistently, so the relationship should not be overstated here.

7.8 Radiocarbon Dating

7.8.1 *Methodology*

Samples were carefully taken by first removing the external surface of the core sample with a clean knife or scalpel, and then extracting uncontaminated material from well within the core sample itself. Stratigraphical boundaries were respected and not crossed in the collection of the samples. They were placed in fresh, unused sealed plastic bags, packed and sent to the radiocarbon laboratory.

All samples were dated by means of AMS, except four dates were submitted to the Beta Analytic Inc. laboratory in Florida, U.S.A., in 1990 (Beta 37134-37137). All others were submitted to the Nuclear Sciences Group in Lower Hutt, New Zealand in 1991 (NZA 2255-2283) and 1992 (NZA 3261-3283).

The results were calibrated by means of the University of Washington Quaternary Isotope Lab Radiocarbon Calibration Program Rev 3.0.3 (Stuiver and Reimer 1993), which is based on the methodology suggested by Stuiver and Pearson (1993) and Pearson and Stuiver (1993), with bidecadal-weighted averages of data from Pearson *et al.* (1993) and Linick *et al.* (1986).

7.8.2 *Potential Error*

The presence of a coral rubble ridge at the seaward end of the swamp may have caused carbon, deficient in C_{14}, to contaminate the organic material in the swamp, used for dating in this study (*cf.* MacDonald *et al.* 1991; Spriggs and Anderson 1993). However, had this been the case, the sequence of dates would have been unlikely to be so consistent. Only one date in the two cores was anomalous, and could be due to reworked sediments from earlier layers, though sand from the coralline beach ridge may have been involved. According to Spriggs and Anderson's (1993) protocol for the acceptance of radiocarbon dates, these results could be permitted on the basis that they form a close series of dates in stratigraphic order (criterion P).

The dates from the top 1.3 metres of both cores may have received some contamination from the increased charcoal. Charcoal, especially that resulting from the burning of mature trees, could have a high inbuilt age. However, these dates provide at least maximum dates for their context.

7.8.3 *Results*

See Appendix A.6. Only Karekare swamp out of all the swamps cored produced a basal date early enough to cover the whole period necessary for this study (c.8300 BP). The dates from two cores from Karekare swamp were internally consistent, except for one date in KK4 at 160-170 cm. This date was about 3000 years older than a date at 190-200 cm. All radiocarbon dates referred to in the text are calibrated, except where otherwise stated.

7.8.4 *Interpretation*

The radiocarbon sequences from KK4 and KK1 are consistent with each other. They show that the basin at Karekare first formed a lake from a little time before 8137 BP (gyttja deposits from 11 m), transformed into a marsh/swamp between 5000 and 4500 BP (peat deposits from 4.4 m in KK4 and 5.65 m in KK1), and, starting from a time somewhere between 2730 and 791 B.P, it was cultivated, as evidenced by an increased mineral component from 1.3 m.

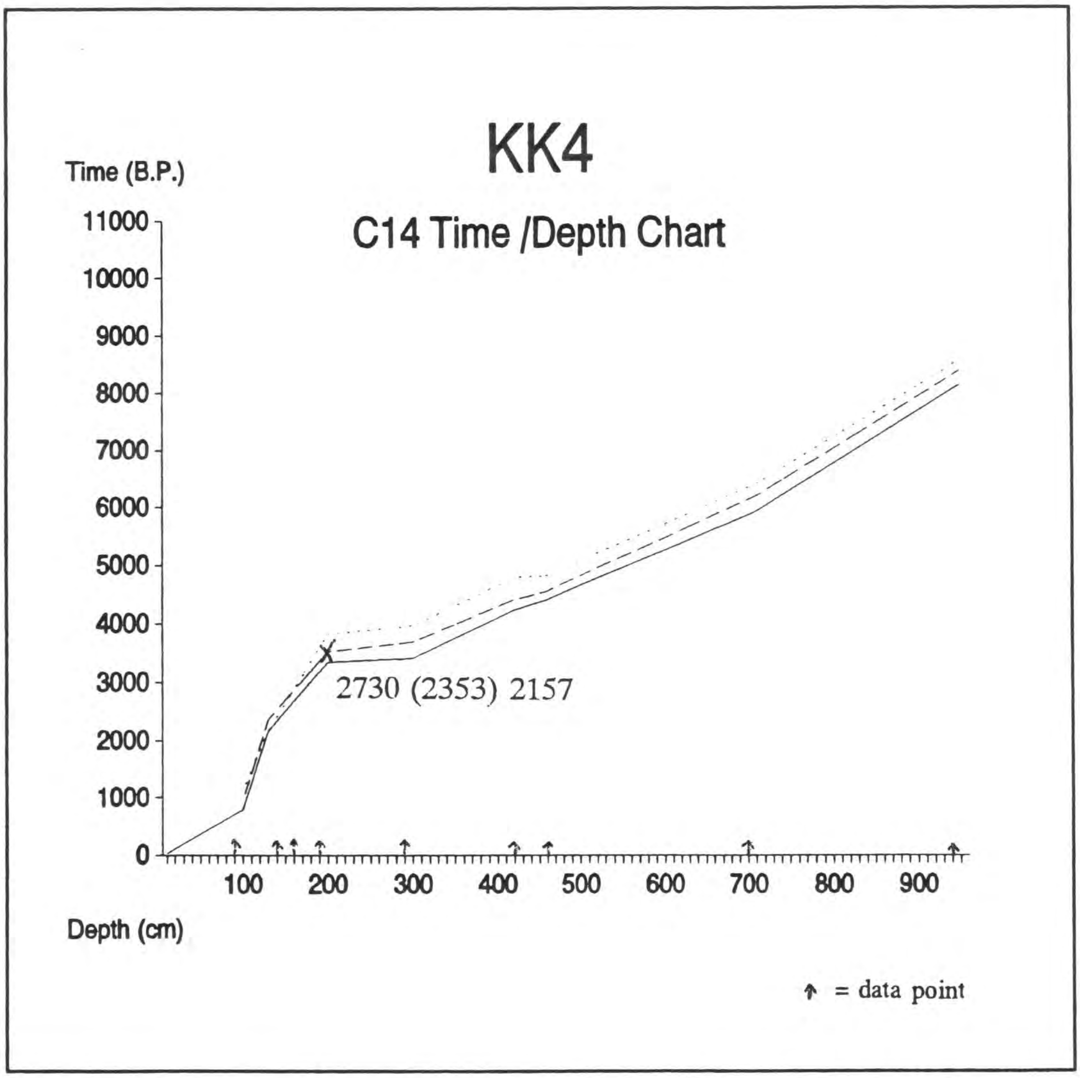

Figure 7.8 KK1 Time/Depth (Conventional Radiocarbon Dates at 1 s

The Time *vs* Depth graphs (Figures 7.7 and 7.8) reveals a rapid decline in deposition after the 2730 BP date, at a time when one would expect increased sedimentation, so there is a strong probability of truncation, compaction (due to drainage) or contamination through the effects of gardening.

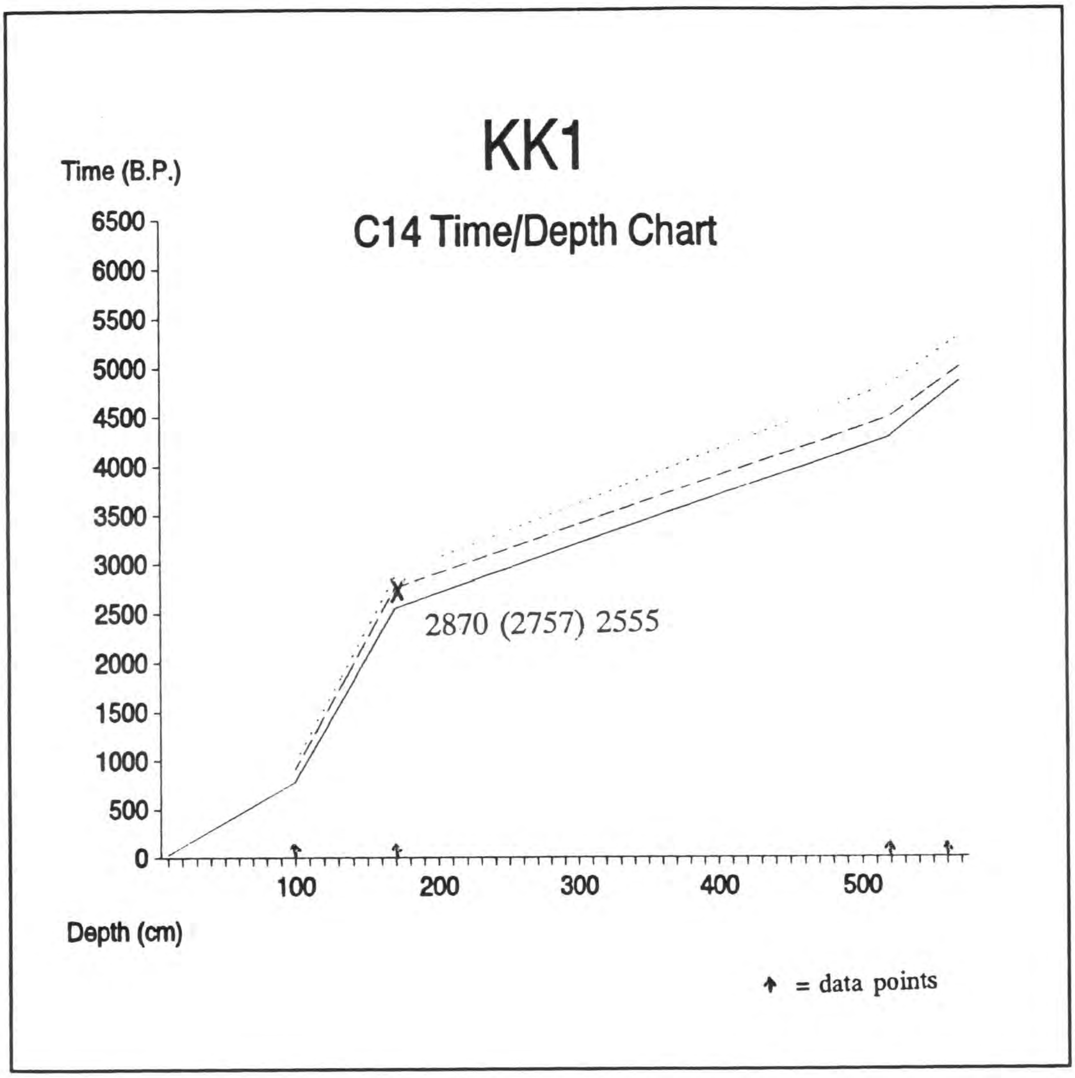

Figure 7.9 KK4 Time/Depth (Calibrated Radiiocarbon Dates at 2

7.9 Conclusion

Karekare swamp produced the following sequence. The dark brown-black gyttja with a small but significant organic content below c.7.5 m is likely to represent slow accumulation under reducing lacustrine conditions (c.6600 BP). The fact that the gyttja is not reddened at any point implies that sedimentation occurred under reducing conditions, confirming the above (Millar *et al.* 1965: 58). Sedimentation would have been caused by surface run-off, into a body of still open water, from the immediate surroundings and the nearby hillside and involved mainly eroded clays from the lateritic soils.

The sedimentary record is interrupted by three thin clay bands which cut across the gyttja at 450, 448 and 430 cm. After 440 cm (c.4500 BP), the sedimentation consists of peat formation with detritus inwash. These three clay bands probably represent relatively short events because of their thinness. Similar banding was picked up by the X-rays of KK1 at the equivalent point in the stratigraphy. Other such bands occur at widely differing levels in all cores: from KK1, 356.5-370, 371.5-374, 451-460, 761.5-763, 763.5-764 and many below 806 cm (transition to peat is at 565 cm); from KK2 and KK3, clay and clay banding is a significant factor throughout; from KK5, 185 cm (transition to peat is at 530 cm); from KK6, 125, 198-200, 250-255, 340, 350-360, 380-385, 420, 620-625, 632-636 cm.

Natural agencies which could have contributed to the intrusion of the clay banding and the onset of peat formation include cyclone impact, droughts, natural fires, and soil instability. Riverlets flowing over the vegetated surface of the swamp could be another explanation. Another possibility is that human agency (e.g. erosion caused by deforestation) could be involved in the change in sedimentation. If sea-level change was involved, then there would have been a point where the water level was such that, once the lake had been transformed into a marsh, a number of short term reversals caused by cyclones could have easily disrupted peat formation with renewed mineral sedimentation. Indeed, the grain size and chemical analyses do not distinguish these clay bands as being especially different from the samples above and below them.

Sedimentation from 440 cm takes the form of peat growth, with some wood,leaf and mineral content, being a mixture of autochthonous growth and allochthonous detritus respectively. Other cores from nearer the landward edge contain a considerable quantity of wood so one must postulate some sort of swamp or marsh woodland there. Indeed, the large amount of detritus in KK1 (see Plates in Appendix A.3) would suggest flooding took place, so marsh conditions are indicated. The evidence of pH tests suggest a moderate degree of sea influence as seawater is alkaline (Duchaufour 1982) and freshwater deposits are normally fairly acidic. These deposits, from within the gyttja onwards, seem to be only mildly acidic to neutral in pH.

In the peat, due to their greater surface to mass ratio, smaller particles would have been differentially affected by humic acids and higher temperatures, caused by the slow decay of organic materials in closer proximity to the effects of solar radiation and oxygen. This explains the lack of sorting further up the profile. Thus grain sizes below 0.18 mm in the peat samples and finer silt is found in higher proportions than in the gyttja. The lack of coarse sand in the peat is due to high values deriving from influxes of coral sand below 800 cm, and sediment diagenesis in the upper part of the gyttja (see the higher values for fine sand: 2 mm-62.5 mm). The decrease in the clay fraction, which forms a substantial part of the total sample means that the higher up the profile, the more the degree of sorting is affected by fluctuations in the silt fraction, which is less stable.

Above 700 cm (6193 BP), the sand fraction forms a very minor portion of the total sample, except between 340 and 190 cm, which might resolve the problem of the curiously early date from 160-170 cm in core KK4 (6546 BP), if it represents the same layer. A close correspondence between this sand peak and a sand peak between 700 and 800 cm (possibly equivalent in date judging from core KK4) could be important. People could have discarded material into the centre from their diggings around the swamp edges, and because lower layers often occur nearer the surface at the sides of basin deposits, anachronous material may have been deposited along with the actively forming peat (Flenley pers. comm. 1993). However, lowering water levels as proposed in Chapter 9 below, could have made these marginal, early deposits more susceptible to erosion, so that they could have been redeposited by rain and wind.

Alternatively, the anachronous date could be due to material from the coral rubble ridge being swept under a floating mat of peat and living vegetation. The correspondence of the sediment from this level with sediment from between 700 and 800 cm could be explained in terms of their having the same source. A cyclone could have caused both storm surge to deposit material from the coral rubble ridge and freshwater flooding to deposit basaltic material under the top layer of peat.

Siltation seems to be responsible for later modal peaks, which might suggest that the source was at least not solely the coral rubble ridge, especially as bands of coral sand do not appear above 800 cm at all (c.7056 BP). Desiccation may have caused erosion, in combination with cyclonic activity, either due to decreased precipitation or a lowering water table. Alternatively, clearance and cultivation by people may have led to the erosion. The peak at 230-235 cm (c.3052 BP) is perhaps best interpreted as due to the former reason, because the sediments correspond with earlier peaks, whilst the peak at 90-100 cm (913 BP) seems more likely to be due to the latter, because the material is of a much different character.

From about 120-130 cm (after 2353 BP and before 913 BP), there is an increase in the mineral component of the sediments. This section of sedimentation is known to have been interfered with by humans and is the part under direct cultivation in the present. This is more of an horizon than a deposit. It has been subject to mulching, and thus a possible deliberate introduction of mineral content. It has certainly been subject to much oxidisation (the continuous working over of the sediment between each harvest and planting), erosion (by means of aerial and aqueous transportation) and enforced stasis as far as peat formation is concerned. This zone may once have been much more extensive, and simply have been truncated, which could be supported by the disappearance of the wood component of the peat. It is important to appreciate, therefore, that this zone could be one in which there was formerly no evidence for human interference.

Below 800 cm, there were high values for elements like Sr and Na. This may have been due to the intrusions of coral sand. Ca peaks support this. The later behaviour of Na, Mg and Ca seem to indicate that they represent sea influence in this core.

Other elements like Cr, Al and Co are more suggestive of basalt. However, with the 200-300 cm peak, there is a rise in Mg, which could equally be from basalt or seawater, though K, Sr and Na are more suggestive of seawater. Mg, K, Sr and Na do not increase during the peak above 135 cm like other basaltic elements, implying that the 200-300 cm peak involved materials of varied origin such as gyttja, coral and seawater.

Sorting occurring in the weathering process could account for some of the trends. Al, which is generally more resistant to weathering, increases greatly from 300 cm upwards (3397 BP) no doubt due to the occurrence of more erosive conditions, due either to natural causes or people. The pH levels could be important too, so that in the levels above 800 cm, acidic conditions promote the formation of 1:1 lattices with Al and Si. Below 800 cm, high pH levels would have led to higher values of other elements such as Na and Mg.

There is an interesting dichotomy between S and P, which are both supposed to show increases with soil disturbance. It could be that this due to the rate of discharge: with S reducing with dilution, and P increasing with greater volumes of water (*cf.* Butzer 1982). S appears to vary in inverse proportion to the mud fraction. The drainage of the swamp or lowering water levels due to a sinking water table may have facilitated the passage of swift vadose water currents, above 135 cm in particular, thus leading to an increase in the mud fraction and P as against S. High values in S at the top of the gyttja may be caused by a low redox potential, so that the reduction of SO_3 and decomposition of organic matter led to increased H_2S. The greater values for P in the gyttja than the lower part of the peat may be the result of a higher rate of deposition in the gyttja due to constant phreatic supply, and the decreased volume of water in the lower peat.

A combination of soluble Fe, mobile silica, and available phosphates promotes the accumulation of compounds of these materials in soil water, particularly where the subsoil is subject to seasonal wetting and drying or oxidation and reduction (Butzer 1982). The two peaks at around 230-235 cm and 90-100 cm in Fe, Si and P may be caused by this.

Up to 330 cm, Fe and S show similar behaviour, which could suggest that they represent organic material. However, above 330 cm, Fe probably derives from erosion, except for a peak at 190 cm, which again is connected with a S peak. The high values for Fe at the top of the core could be due to upwards migration of Fe under low pH and low redox potential, but is more likely to be caused by fixation under oxidising conditions found near the surface.

The other swamps: Atupa, Arorangi Mormon Church, Aro`a and Muri produced much shorter sequences. Atupa swamp contained layers of clay and gyttja over layers of coral sand and gravel, becoming impenetrable by 200 cm. Arorangi Mormon Church swamp was composed of clays down to 350 cm, with small layers of peat and coral sand at various points. Aro`a swamp was composed of clays and gyttja down to 250 cm. Muri swamp contained clays and gyttja, giving way to coral sand by 180 cm at the bottom. Mineral content was much more significant in these swamps than at Karekare swamp, probably because of their location in shallow, linear depressions behind a storm ridge composed of coral sand, and in front of the hillside colluvial and alluvial deposits. The prospects for peat formation here would have been fairly limited and the two neighbouring deposits would have been regular suppliers of excess mineral sedimentation.

This chapter has brought the various strands of physical and chemical information together, so the next chapter will continue the investigation of the core samples with an analysis of the biological evidence in the form of pollen analysis.

CHAPTER 8 BIOSTRATIGRAPHY

The examination of the evidence from the core samples resumes with the biological evidence. The pollen analyses and taphonomy are appraised, and an interpretation based on the biological evidence is presented.

8.1 Sampling

The core samples and individual bagged samples were the same as those mentioned in the lithostratigraphy.

8.2 Pollen Analysis

8.2.1 *Sample Preparation*

Sample preparation (and counting procedure) follows well established procedures described by Faegri and Iversen (1975), Moore and Webb (1978) and Flenley (pers. comm. 1990).

A small sample of approximately 1 cm^3 is extracted from the bagged sample or core, using a clean and sterile knife blade. If taken from the core, it is extracted from well within the sample to avoid any possible contamination on the outside of the core. This is placed in a plastic test- tube for the duration of the preparation, and sealed from air contact between individual treatments.

Potassium Hydroxide digestion is used to break up the humic content of the sample. The sample is heated for a few minutes in 10% Potassium Hydroxide (KOH), and stirred to make sure the treatment could affect the sample generally. Then, the sample is centrifuged for 5 minutes at 2000 rpm. If necessary, the sample would be poured through a 1 mm sieve, and washed with distilled water.

Acetolysis is then used to break down cellulose. The pollen sample is next washed with distilled water, stirred, centrifuged (as above), and decanted. It is then washed in dilute acetic acid, stirred, centrifuged, and decanted. Finally, it is washed in glacial acetic acid, stirred, centrifuged, and decanted.

A mixture of acetic anhydride (9 ml) and concentrated sulphuric acid (2 ml) is prepared, and 2.5 ml of this is added to the sample in the fume cupboard. The preparation is heated for 4 minutes at 100°C, and stirred from time to time.

Glacial acetic acid is then added to the sample to halt the reaction. The sample is stirred, centrifuged and decanted. Dilute acetic acid is added, the sample stirred, centrifuged, and decanted. Then it is washed in distilled water, stirred, centrifuged, and decanted.

The sample is examined at this stage to check for the presence of silica grains, by mounting a fraction of it on a slide with a coverslip, and examining it under the microscope. If it proved necessary, the sample was sieved to remove fine particles, using a 8 micron gauze.

Hydrofluoric acid is used next to dissolve and thus remove the silica content. If much silica was found, then the sample is washed in 5% hydrochloric acid, stirred, centrifuged, and decanted. 40% hydrofluoric acid is added, filling half the tube. This is boiled for 2 minutes, and then an equal quantity of 5% hot hydrochloric acid is mixed in. The lid is put on the tube, the sample is centrifuged, and decanted. It is subsequently washed in distilled water, stirred, centrifuged, and decanted. The sample is examined once more under the microscope.

If need be, the sample will undergo oxidisation to remove lignin. A solution of 1cc/1ml of saturated sodium chlorate is made up, and added to the sample. Three drops of concentrated hydrochloric acid are put on to the preparation, and this is then left for a minute. The sample is stirred, centrifuged, and decanted. Then it is washed in distilled water, stirred, centrifuged, and decanted.

Finally, the sample is prepared for mounting. It is washed in industrial alcohol, stirred, centrifuged, and decanted. Next, it is washed in absolute alcohol, stirred, centrifuged, and decanted. Then it is washed in a mixture of 50% absolute alcohol and 50% Tertiary Butyl Alcohol (TBA), stirred, centrifuged, and decanted. Finally, it is washed in pure TBA, stirred, transferred to a small labelled tube, centrifuged, and decanted.

A small amount of TBA is added, together with a little silicone oil (AK 2000), stirred, centrifuged, but not decanted. This is placed in an oven overnight at a temperature of 50°C in order that the TBA should evaporate, leaving the silicone oil. The sample is stirred and a small amount placed on the slide. The coverslip is then placed carefully on top, and hot paraffin wax is added through the side of the coverslip, preventing the silicone oil preparation from escaping, once the paraffin wax cools and thus hardens.

8.2.2 *Counting Procedure*

The prepared slide is placed under the microscope - in this case, a Zeiss (West Germany) microscope on the mechanical stage. Using a magnification of x400, the slide is moved from one edge to another in a series of traverses, which are all noted, as is the direction of movement. Traverses should be at least 0.5 mm separate from each other.

Each grain is identified and noted. A record sheet has the names of the species expected and space for unexpected species in one column, and a column each for numbers of individuals and percentages. This record sheet, of course, records not only such details, but the name of the site, the particular core and the depth of the sample.

Unidentifiables are temporarily given a description, and name (such as Type 1.) so that their identification can be tackled at a later point in time. Also, all grains where the identification is either unknown or uncertain in any way should have their position recorded for later reference in another column provided on the record sheet.

When about 200 grains have been counted and identified, which is the acceptable minimum, then the totals are calculated and percentages worked out.

The literature used for identification included Tryon and Lugardon (1991), Huang (1972), Huang (1981), Heusser (1971) and the Sporae Pteridophytorum Sinicorum (1976), Large and Braggins (1991), Harris (1955), Parkes and Flenley (1990) and Macphail (n.d.). Also, a collection of about 800 reference slides of Pacific Island taxa kindly provided by Prof. J.R. Flenley of Massey University Geography Department was utilised.

8.2.3 *Presentation of Results*

See Appendices A.4. and A.10, and Figures 8.1 and 8.2. Pollen counts were successfully achieved at levels of 200 grains or more, except for KK4 670cm, KK1 910cm and KK1 960cm in Karekare swamp and all the samples from other swamps. Pollen density was generally low throughout the cores, and where counts of less than 200 grains were obtained, pollen density was especially low.

8.3 Taphonomy

8.31 *General approaches*

Though taphonomy generally relates to the conversion of a `biocoenosis' or living community through a `thanatocoenosis' or death assemblage to a fossil or sub-fossil assemblage, here a broader perspective is taken incorporating the sampling, analysis and interpretation of the sub-fossil record.

There is a dichotomy between the range of materials found in a thanatocoenosis and those found in a fossil assemblage due to the preservational environment. This is exacerbated by the concept of biological classification used for living organisms (Evans 1991): a fossil specimen may be anatomically identical to today (at least as far as the preserved parts might indicate), but this is no guarantee that its behaviour, biochemistry, capacity to produce fertile offspring, or any other factor would have been the same. However, usually these factors are more or less the same.

The peculiar progress of a particular species over a period of time may lead to an alteration in its ecological role (*cf.* Kenward 1978 with regard to insects); hence one should exercise a certain reservation concerning projecting present roles into the past. Indeed, it is far from established that present day ecologies form appropriate models for those of the past as special conditions attained in the past may be without parallel today (Thomas 1985).

Factors that can influence a species representation in a habitat are its adaptability to particular environments, levels of harmful parasites and browsing animals, competition with individuals of the same or another taxonomic group, genetic factors, such as being naturally not able to reach as high densities as other species, edaphic conditions and climatic factors, like temperature, precipitation levels and radiation.

There are some problems with the above list. Adaptability to an environment can mean also the ability of the species to withstand any adverse changes in the local environment, especially for plants on an island with no where and no means to go. Coope and Brophy (1972), for example, demonstrated how despite the significant climatic changes at the end of the last glacial period in Britain indicated by insect remains, the vegetation had had a certain amount of inertia in reacting, so that the warmest period of the Post-glacial was still largely treeless. The idea that one species might replace another through `competition' assumes that both occupy the same or a similar niche, that they are by some quirk dispersed evenly throughout the area surrounding the sampling site, and that there is limited amount of space. One caveat for the last of the factors, climatic change, is the effect of microenvironments, which can allow species to exist in areas where they would not normally.

An alternative strategy to the interpretation of taxa in terms of the present-day ecology is to consider the assemblages in terms of diversity and structure: in other words a more holistic approach.

Biocoenoses are located in regional environments of three dimensions with much in the way of diversity in these dimensions. The vegetation, itself, provides the vertical dimension. One can consider these in terms of spatial and temporal distributions: in terms of catenas and seres. On Rarotonga, there is the progression from mountain forest to coastal forest to lagoon and eventually to the ocean, and there is the possibility of hydroseral development in the lowland swamps from lakes, as evidenced by the presence of gyttja, to peaty swamp or rather marsh (seasonally flooded) as indicated to the author by George Tara`are. Seral development may also be occurring and have occurred in the fernlands of the lower slopes of the mountainous interior (McCormack pers. comm. 1990) with fernlands being invaded by *toa* (*Casuarina equisetifolia*), then presumably later by other trees. This is not certain though.

The process by which the biocoenosis is converted to a thanatocoenosis involves a variety of transport and preservational mechanisms. Firstly, all organisms are mobile at some stage of their life cycle. In the case of higher plants, these are the pollen grain and seed stages. Once members of a living community such as pollen grains are dead, they accumulate at ground level and are redistributed by flooding, wind, landslip, and in the case of pollen, organisms such as insects, birds and bats may already have removed them from their place of origin. When sealed by some enclosing matrix, such as deposits of gyttja, the character of the matrix - its pH, redox and water content, for example - determines the level and type of preservation that will eventuate. It should be borne in mind that the death assemblage is only one of a range of possibilities (Evans 1991). Pollen grains can reach flowers and fertilise ovaries; seeds and spores can sprout into new plants; and dead organisms can be eaten or burnt up before becoming part of any assemblage.

The thanatocoenosis is a 2-dimensional and atemporal arrangement. It does not necessarily distinguish diurnal, seasonal and annual patterning or the 3-dimensions of the biocoenosis. The catchment area for a thanatocoenosis may be quite extensive leading to a need to be able to separate *in situ*, the local site and regional components of the assemblage. Pollen found in lakes, for example, tends to reflect more regional effects the further it is away from the edges (Moore and Webb 1978). The size of the site will is important in deciding the relative proportions of these components, with smaller sites having more *in situ* and local taxa (Jacobsen and Bradshaw 1981).

Two important questions arise from a study of the formation of the sub-fossil assemblage (Evans 1991): firstly, how the different varieties of material were conveyed to the site and integrated into the assemblage, and secondly, whereabouts they originated from.

A major problem of taphonomy is the presence of allochthonous species in deposits with their own autochthonous species, which leads to difficulties of interpretation. Pollen preserved in freshwater deposits laid down in some basin-like depression has this problem as soon as *in situ* organic growth takes place. A study of the sediments is necessary to establish whether the sediments are horizons (local development due to physical and chemical weathering or *in situ* organic growth) or deposits (transported from elsewhere). If the sediments are deposits, then the means of transportation must be ascertained in order to determine how the sediments and any material contained therein may have been altered. Invariably, this division is not completely clear cut, with some allochthonous material still accumulating in a largely autochthonous medium, and *vice versa*. Thus, the sedimentological record should provide some clue as toward trends.

An investigation of these taphonomic processes is not simply a matter of how to elucidate the data, but these processes, themselves, are also an essential part of the site history (Evans 1991).

8.3.2 *Pollen production*

Different species vary in the quantity of pollen they can produce, and there is also variation in their flowering periodicity. Indeed, the same species may generate substantial differences in its annual pollen output, possibly because of climatic variation (Andersen 1974b). Some of the discrepancies between the modern pollen rain and vegetation plot studies (see Chapter 2) may be due to differences in pollen production as in the case of *Homalium acuminatum*, the most common inland tree species.

8.3.3 *Pollen dispersal*

Mode of pollination is a significant factor in determining the representation of plants in pollen diagrams. Most of the indigenous plants on Rarotonga are zoophilous (pollinated by animals): by insects, birds and/or bats. Much fewer are anemophilous or wind pollinated.

Some plants which tend not be represented at all in fossil or sub-fossil assemblages are the autogamous or self-pollinating plants, especially the cleistogamous ones which have flowers that do not open. A number of water plants are hyp-hydrogamous or water-pollinated plants and not represented in fossil pollen assemblages as their pollen has no exine.

There are differences between species as regards pollen dispersal ability, which is tempered to a certain extent by the local environment (Newnham 1990). This is especially true of dispersal and transport of grains by wind or water. The height and strength of a pollen source, and the weight and shape (morphology) of the pollen grains are also controlling factors.

8.3.3.1 Zoophilous dispersal

Although these taxa are not well-represented in pollen diagrams, one cannot conclude that they were absent in real life plant communities because of two main factors. Firstly, their dispersal mechanism means that they do not usually occur far from their source, unless transported by their animal vector in which case they reach another flower and are not wasted. Anemophilous pollen is also more likely to be dispersed by wind being adapted for that purpose. Secondly, entomophilous (insect dispersed) and cleistogamous pollen is usually produced in lesser quantities than anemophilous due to its being more effective, though some entomophilous species can produce as large a quantity of pollen as anemophilous species (Faegri and Iversen 1975).

On Rarotonga, most species are zoophilous. Insect pollinated taxa include (Corner 1988): *Fagraea* (by nocturnal moths); *Barringtonia asiatica* (by moths); *Calophyllum* (by a variety of insects); *Ficus* (by wasps); Euphorbidae (by small flies, beetles, honey-bees, wasps and plant bugs); *Artocarpus altilis* (by small flies, wasps and beetles); *Eugenia* (by flies, beetles and butterflies); and *Ixora* (by butterflies). Bird pollinated taxa include (Corner 1988): *Hibiscus rosa-sinensis* and *Erythrina*. Bat pollinated species include *Barringtonia asiatica* possibly (Cameron pers. comm. 1992). Some species combine insect pollination with wind like coconut trees. The insects that pollinate coconut trees include flies, wasps, and plant bugs - possibly ants too (Menon and Pandalai 1958).

8.3.3.2 Anemophilous dispersal

The dispersal of pollen by wind can be affected by the turbulence, speed and direction of the wind and air temperature and humidity, especially precipitation. Pollen grains from trees end up falling to the ground as large aggregates or in rain drops (Andersen 1974a).

Arona Ngari of the Cook Islands Meterological Service assisted the author with data concerning the direction and speed of winds in order to establish the effect this may have had on pollen distribution. The main and strongest wind comes from the east. This is due to the Trade Winds. Small valley winds exist, though they are weaker. For example, measurements taken from Totoko`itu where the Trade Winds do not have such a significant influence show the kind of strength such valley winds have (see Tables 8.1 and 8.2). Matavera hill has the highest values for wind speed, being in the direct line of the Trade Winds. Matavera coast has a slightly lower speed, probably due to turbulence from the mountains hindering the progress of the wind, and the airport has less still because it is on the leeward side of the island on the edge of the coastal plain.

Karekare swamp is just north of the Matavera valley, and on most days was subject to the Trade Winds coming off the sea, with the valley wind being suppressed by the force of the Trade Winds. However, it is possible that once the winds from the eastern valleys reached the coastal plain, that the Trade Winds, which move in a north-westerly fashion took aeolian particles further northwards up the coastal plain. Arona Ngari suggested to the author that the some wind from winds coming from the south-east over the mountains could end up slumping down the eastern valleys like Tupapa and Matavera causing slightly stronger winds than usual.

However, these figures show that the general trend would have been for pollen to have been blown from the shore to the swamp rather than from the mountains to the swamp. Hence any regional bias due to aeolian effects should be considered in terms of a slant towards the littoral vegetation.

Table 8.1 Mean Monthly Wind Speeds (Knots) on Rarotonga

Month	Airport	Matavera coast	Matavera hill	Totoko`itu
Jan	9	10	12	5
Feb	8	9	11	4
Mar	7	8	10	4
Apr	7	8	10	4
May	8	9	11	4
Jun	9	10	12	5
Jul	8	10	12	5
Aug	9	10	13	5
Sep	10	11	13	5
Oct	9	11	13	5
Nov	9	10	13	5
Dec	9	9	11	4

Table 8.2 Mean Daily Wind Run 1975-1982, Totoko`itu (Km).

Annual Mean	Jan	Feb	Mar	Apr	May	Jun
153	150	152	131	132	149	151
	Jul	Aug	Sep	Oct	Nov	Dec
	155	164	159	164	171	161

8.3.3.3 Water transport

The nature of the topography and the interplay of different transport vectors, especially water ensures that the deposition and redeposition of pollen will vary from site to site.

A look at the Location Map for the area around Karekare swamp and the topographical and soil map, should indicate a few points about the effects of water transportation of pollen grains and fern spores. Moore and Webb (1978) relate how fern spores in particular are subject to this form of transportation. Karekare swamp is not fed directly by the neighbouring streams of Tupapa and Manga-a-te-ao or Matavera. A small gulley at the south-western corner was observed by a landowner, Bill Cowan (pers. comm. 1990), to have a flowing stream during cyclones. Aside from this, no watercourse flows directly into Karekare swamp.

The Tupapa and, further away, the Manga-a-te-ao stream contribute to the swamp only during cyclone-related flooding. Therefore, it appears that the swamp is ombrotrophic, with some run-off from Oro`enga, the mountain immediately inland, for most of the year, with a seasonal rheotrophic contribution from flooding. The small gulley stream is unlikely to have contributed significantly to the formation of the swamp.

In the past, before the construction of drainage channels out to the reef in the early 1960's, freshwater flooding took place from the streams and tidal waves poured salt water into the swamp. Both this flooding and rain wash must therefore account for the water transportation of materials into the swamp. Other vectors which could have been operating in tandem with flooding and rainwash are colluviation and the cyclonic reworking of alluvial deposits returning old pollen and spores to the surface for renewed transportation. This would explain, at least in part, the relatively high pH for freshwater deposits, particularly for peat. Some alkalinity may be due to the presence of the coral rubble reef at the end of the swamp leaching CaO^{-2}_3 into the sediments.

8.3.3.4 Human transport

Human influence could have been at least in the later levels with any mulching activities involving soil, as recorded by Alamein Vakapora, one of the landowners and titleholders. Like colluviation this can lead to anachronistic and spatially confused combinations of pollen grains and fern spores. Another human influence on the representation of such pollen grains and spores is when humans clear the vegetation away from the edge of swamps or lakes. Such vegetation could hinder the progress of spores and pollen. The construction of drainage ditches and weeded patches for the growth of cultivated aroids would further facilitate the passage of pollen and spores, especially during floods.

Differential preservation of different pollen types, with some more easily identifiable than others. Sediment type may alter the degree of preservation, for instance, silts in particular can cause structural damage. The more sporopollenin a grain or spore contains, the more resistant it is to decay, especially the spores of ferns and fern allies (Havinga 1971; Sangster and Dale 1964).

8.3.4 *Pollen catchment*

Mode of transport and distance travelled by pollen are important factors. Jacobsen and Bradshaw (1981) developed the idea of a theoretical relationship between the size of a site with no inflowing stream and the relative proportions of pollen originating from different areas around the site. On the basis of their theory, the catchment of Karekare swamp would include the coastal forest and the lower slopes of the mountains, with a very small proportion from the upper slopes and valleys. The proportion of local swamp edge forest would be high.

8.3.5 *Pollen identification*

Pollen is variable concerning the degree to which individual taxa can be separated out. Most taxa can be distinguished to the level of genus, some can be distinguished to the level of species, though for some others, even down to family level is difficult (Faegri and Iversen 1975; Moore and Webb 1978).

Moraceae/Urticaceae are difficult to identify even to single family level, with some exceptions such as *Ficus*. The type represented here is more likely to be of the Urticaceae, because these tend to be more wind-pollinated and heavy pollen producers.

Confusion can arise out of such imprecision of definition. A single taxon may contain a significant degree of ecological diversity due to its comprising 2 or more lower taxa, like species for instance, with different distributions or adaptations. Failure to separate out such lower taxa would lead to ambiguity at the interpretation stage.

8.3.6 *Special problems with peat deposits*

Some vertical movement is possible, but it does not usually occur at a significant magnitude to warrant concern (Birks and Birks 1980; Rowley and Rowley 1956), though where peat deposits have been disturbed by humans, such as through drainage and burning, pollen data from near surface sediments could have been distorted (Newnham 1990).

Due to small size of core samples, some taxa, which are randomly locally populous may be overrepresented at certain times and at other times not. Microenvironments with their own local plant communities may also be represented due to the arbitrary nature of human selection of sampling sites. This can lead to false impression of events even within the same swamp.

The site's own geomorphology may increase the margin of interpretive error. Peat growth is dependent on a number of variables (like moisture, sunlight and nutrient levels) which may be variable throughout the swamp. Consequently, peat growth will not necessarily be uniform (Aarby and Tauber 1975). If there is any rheotrophic contribution to the swamp such as flooding, an uneven distribution of deposition can occur compounding the problem of stratigraphic correlation. Pollen distribution is affected by horizontal differences in peat growth, which is usual as peat formation commonly starts at the sides and gradually encroaches on the centre of a lake, transforming it into a swamp. As the peat closes in on a lake, it reduces the size of the lake thereby increasing the representation of more local taxa (Jacobson and Bradshaw 1981).

8.3.7 *The construction of pollen diagrams*

The method chosen to analyse the pollen may predispose the researcher to a certain range of conclusions about past ecologies. The sampling technique, method of analysis, and any human error in these processes may skew the results. Presentation and interpretation are the last taphonomic obstacles. How the pollen diagrams are arranged can influence interpretation, especially with combinations of species as `Trees' or `Herbaceous plants'. This may say something about the size of the plants, but not necessarily about their ecology: for instance, many herbaceous species inhabit woodlands rather than open-country environments and certain trees have more of a `pioneer' character, invading open areas.

Two types of diagrams can be used: percentage diagrams and `absolute' diagrams. Percentage diagrams involve counting at least 200 grains, and then calculating the percentages of the individual taxa from the total. `Absolute' diagrams involve introducing a standard sample of exotic pollen into the sample, and hence adjusting the individual samples for frequency of pollen occurring in them.

Percentage diagrams have been used in this study. These can create distortions when certain taxa are superabundant (Thomas 1985). Built into such diagrams, is the assumption that the vegetation saturates its environment, and that expansion of one species is always at the expense of another. Percentage diagrams are, on the other hand, not absolute in the sense that they represent only a sample of the population, and therefore are not capable of being an absolute measure of that population. `Absolute' diagrams are to a certain extent dependent on depositional rates and are really only meaningful if they can be applied to discrete time units (which is problematic, especially in the case of peat deposits), although they are more independent and less human assumptions and prejudices are present in them (Colinvaux 1978).

Methodology and statistical treatment of pollen data influences interpretation. Pollen accumulation rate (PAR) - the number of grains per unit area of sediment surface (cm^2) per unit time (year) - obtained from `absolute' pollen diagrams is useful in the sense that it can be related to the individual taxa independently of other taxa. However, most pollen profiles are dated too imprecisely for the detection of small scale variations between dated horizons. This leads to positive correlations between PARs for different taxa, so is not truly independent (Webb *et al.* 1978). Measured pollen concentrations and PARs contain new sources of error and biases including possibily inaccurate measurement of sediment volume and sedimentation rates. Therefore, percentage diagrams are generally preferred (Prentice and Webb 1986).

8.4 Interpretation

KK4

The stratigraphy, zonation (Grimm 1987; 1991a; 1991b) and pollen relative frequencies are shown in Figure 8.1.
Zone KK4 - 5 (samples KK4 670cm; KK4 690cm; KK4 790cm; KK4 890cm), which has a basal radiocarbon date of 8373 BP (Appendix A.6), consists of dark brown-black gyttja with a small but significant organic content (samples below c.7.5 m, Figure 8.1).
The pollen spectrum shows a high diversity of species with relatively low frequencies per species, with a modest number of forest taxa (*Cocos nucifera* being well-represented) and more open country taxa, such as *Pandanus*, Cyperaceae, Gramineae and some ferns occurring together. *Typha* is probably a localised contribution from the lakeshore and shallow water, where it grows at present.

In Zone KK4 - 5, the dark brown-black gyttja with a small but significant organic content (samples below c.7.5 m, Figure 5.5) is likely to represent slow accumulation under reducing lacustrine conditions. Sedimentation would have been caused by surface run-off, into a body of still open water, from the immediate surroundings and the nearby hillside and involved mainly eroded clays from the lateritic soils. Pollen grains would have been derived from a considerable area, including the coastal platform and mountain slopes, some arriving by aerial transport and others in water. *Pandanus* and the Cyperaceae might indicate a dry climate, while *Cocos nucifera* and other forest trees indicate some woodland cover.

These conditions imply a relatively dry climate, probably with immature soils, though *Acrostichum aureum*, *Pandanus* and the Cyperaceae could represent marginal swamp. The presence of *Hibiscus tiliaceus*, known to be very local because of the size of the pollen and its dispersal by insects, implies the presence of some open woodland, perhaps along the water's edge.

In Zone KK4 - 4 (samples KK4 490cm; KK4 520cm; KK4 530cm; KK4 550cm; KK4 570cm; KK4 580cm; KK4 590cm; KK4 620cm), gyttja continued to form, indicating the presence of still open water (c.5800 BP). Pollen grains entered the deposit by the same mechanisms as in Zone KK4 - 5, with some reduction in the source range being implied by an increase in the woodland group. High diversity continues, although the frequency of numbers per species becomes less uniform, suggesting a tendency towards specialisation in the source vegetation.

In Zone KK4 - 4, environmental change may have been caused by ameliorating climate and increased precipitation, permitting the expansion of the forest on the coastal plain. Rising sea levels and increasing soil maturation will also have contributed. An increase in woodland taxa included increases in *Cocos nucifera* and *Pipturus argenteus sim.*, suggesting a rise in forest cover, particularly on and near the coast, or that the coast was moving nearer due to sea level rise. A rise in sea level may be supported by the decline in *Acrostichum aureum* at this time.

The apparent rise in many forest taxa is matched by a decline in open country taxa like *Pandanus* and the Cyperaceae, though other indicators of open country like Compositae and Gramineae do not show an appreciable decline.

The *Cocos nucifera* pollen in the KK4 core is of special interest. Its occurrence down to 9 m proves that it was present well in advance of human arrival. Its increased relative frequency between 5 and 6 m, prior to the beginning of Zone KK4 - 3, could be human-induced, though it is naturally a significant component of coastal forest. Being at least in part wind-pollinated, high proportions of pollen could have come across the lake from the coastal ridge of coral rubble. On Atiu, *Cocos nucifera* pollen is represented from c. 7800 years BP (Parkes n.d.), and increases significantly from below a date of 3100 BP, which has been suggested as being due to human interference (Flenley 1990).

The transition between zones KK4 - 4 and KK4 - 3 is interrupted as two thin clay bands cut across the gyttja. The first is a temporary interruption whereas the second marks the end of gyttja deposition which is then superseded by peat accumulation. As the peat formed pollen would have been deposited from increasingly local sources, rather than the broad region implicated in the pollen rain deposited during Zones KK4 - 5 and KK4 - 4.

In this transition, the localisation of pollen sources due to changing sediment type may account for the rapidly increasing relative importance of *Acrostichum aureum* spores and the relative decline of the forest taxa and Moraceae/Urticaceae. The *Acrostichum aureum* is likely to have developed as a pioneer swamp and shallow water species. The forest taxa and Moraceae/Urticaceae groups decline in Zone KK4 - 4 may be more an accommodation of the higher *Acrostichum aureum* values in a diagram recording only relative abundances than an indication of absolute decline in forest presence or species diversity.

Natural agencies which could have contributed to the inwash clay banding in Zone KK4 - 3 and the onset of peat formation include cyclone impact, droughts, natural fires, and soil instability. Riverlets flowing over a mat of floating vegetation could be another explanation. Possibly human agency could be involved in the change in sedimentation, by causing erosion. Radiocarbon dates of 4563 and 4417 BP, which span the Zone KK4 - 4 to KK4 - 3 clay banding, indicate that this transition took place within a short period of time (see Appendix A.3).

Zone KK4 - 3 (samples KK4 290cm; KK4 390cm; KK4 440cm; KK4 470cm) consists of peat containing considerable quantities of wood. A series of different plants predominate one after the other: *Acrostichum aureum* ferns, then in Zone KK4 - 2, *Canthium barbatum* and other ferns, followed by *Pipturus argenteus* sim, *Pandanus* and *Cocos nucifera*. Forest trees decline in relative terms, but increase again in Zone KK4 - 2.

The pollen content of Zone KK4 - 3 is very much more local than before, because plants are now growing on the surface of this horizon. It conveys the impression of a plant succession under moist but stable conditions provided by the exposed clay and gyttja surface. *Acrostichum aureum* ferns became established first, perhaps with some unrepresented or undifferentiated species. Then organic matter began to accumulate allowing other plants to infiltrate. Alternatively, the *Acrostichum aureum* spores may be tree-ferns, in which case they may have been growing on the water's edge or on drier marginal areas of the swamp. *Acrostichum aureum* ferns decline, giving way first to *Canthium barbatum* and Compositae, then in zone KK4 - 2 to *Canthium barbatum* and other ferns and finally *Pipturus argenteus* sim., *Pandanus* and *Cocos nucifera* (see Figure 8.1).

The pollen from beyond the swamp show the continuation of woodland taxa and the Moraceae/Urticaceae through Zone KK4 - 2 (samples KK4 150cm; KK4 160cm; KK4 170cm; KK4 180cm; KK4 190cm), beginning about 3600 BP. It is not possible to establish whether there has been any decline in these groups in relation to the open country taxa, many of which may have been growing in the swamp.

Zone KK4 - 1 sees an increase in the mineral component of the sediments (samples KK4 0cm; KK4 30cm; KK4 60cm; KK4 90cm; KK4 100cm; KK4 110cm; KK4 120cm; KK4 130cm; KK4 140cm, and Figure 8.1). This zone starts between 2353 and 958 BP. The spectrum shows very low values for the woodland taxa and *Acrostichum aureum*, and a marked increase in *Pandanus* and ferns other than *Acrostichum aureum*, with high values for *Cocos nucifera* and *Pipturus argenteus* sim..

The pollen spectrum from Zone KK4 - 1 implies open country conditions, though with a lower species diversity than in Zone KK4 - 5, suggesting more specialised conditions probably due to cultivation practises. The expansion of ferns other than *Acrostichum aureum* may reflect the extensive burning of the coastal ridges and some riverine valley or simply the easier conditions for the transportation of fern spores into the swamp due to the lack of vegetation that might have hindered the progress of such spores.

This zone has been mulched and gardened in the recent past and may have been truncated in places. Gardening causes oxidation. Some loss and differential sorting of pollen is expected as a result.

The summary pollen and spore diagram shows that from the transition from gyttja to peat, there has been an increase in herbaceous and pteridophyte growth over trees and shrubs probably reflecting the greater autochthonous component.

see larger scale diagram on Appendices II, B.3

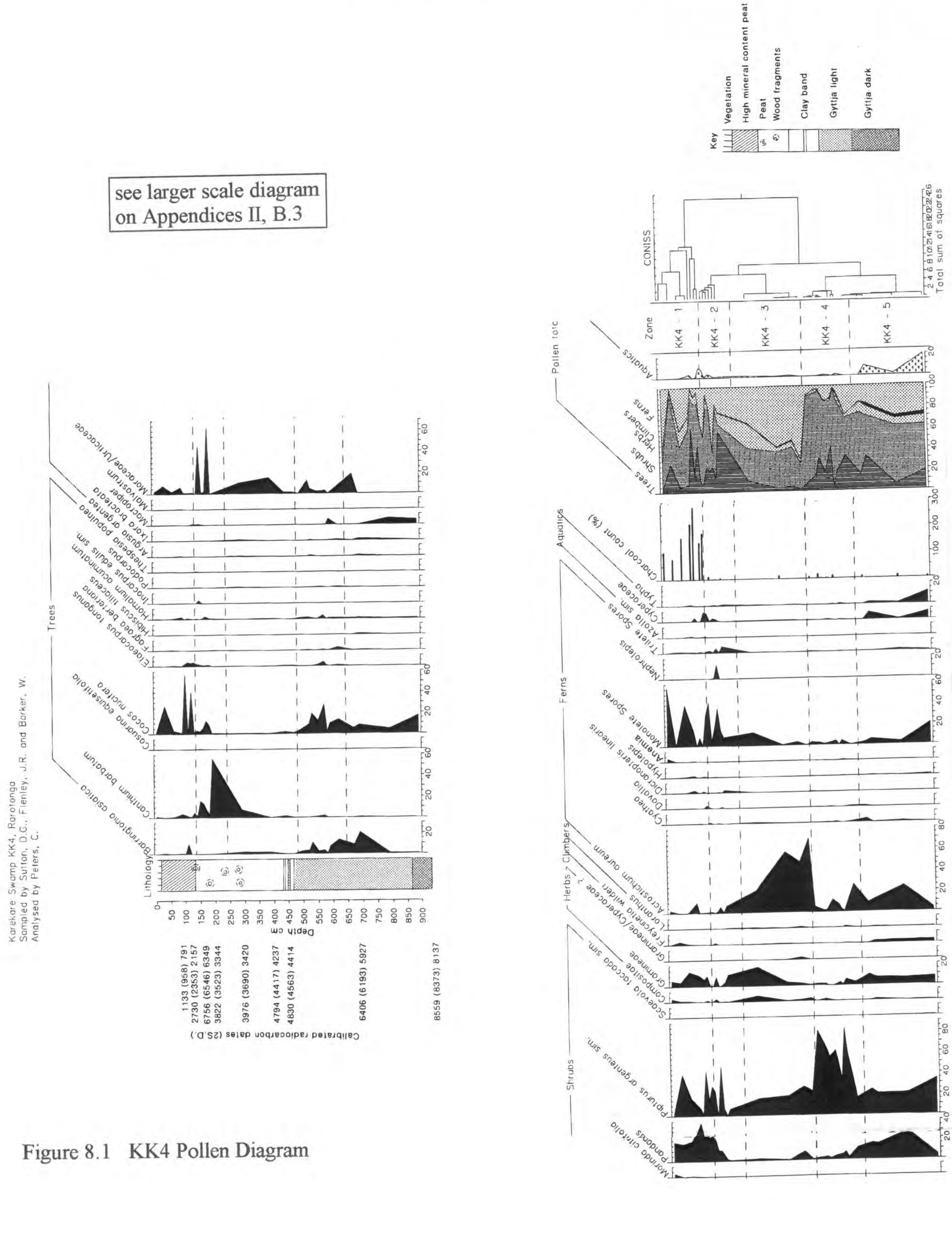

Figure 8.1 KK4 Pollen Diagram

KK1

In the core KK1, a similar zonation can be perceived in the upper levels with what also appears to be a hydroseral succession (Figure 8.2). Firstly, the swamp fern, *Acrostichum aureum* colonised the swampy ground forming hummocks, followed by a situation where *Acrostichum aureum* spores decline and *Canthium barbatum* values are high, due to its colonising the surface of the swamp. Finally, drier elements like the Moraceae/Urticaceae and *Pipturus argenteus* sim. invade, whilst the swamp forest declines.

In Zone KK1 - 5 (samples KK1 810cm; KK1 860cm; KK1 910cm; KK1 960cm; KK1 1010cm; KK1 1052cm), there is a high mineral content with gyttja interbedded with frequent lenses of coral sand. The Moraceae/Urticaceae, in particular *Pipturus argenteus* sim., are well represented. Ferns, coconut trees and *Barringtonia asiatica* are consistently represented too. However, samples KK1 910cm and KK1 960cm had very little pollen in them. The first two samples, KK1 1010cm and KK1 1052cm, show pollen from a wide range of sources including trees of the slope forest of the interior such as *Canthium barbatum* and *Elaeocarpus tonganus*. *Hibiscus tiliaceus* is recorded from one sample.

The pollen probably reflects the relative closeness of the coastal forest, especially with coral sand entering the deposits, which indicate the former presence of a lake. This no doubt would have raised the pH, contributing to the failure of the deposits at this stage to preserve the pollen well. The interior forest is nevertheless represented. Acrostichum aureum is recorded as a significant percentage, no doubt, growing on the lakeside at this point.

In Zone KK1 - 4 (samples KK1 560cm; KK1 570cm; KK1 610cm; KK1 660cm; KK1 710cm; KK1 760cm), mineral content is less than for the previous zone, but still high. Coral sand ceases to interrupt the deposition of gyttja, though there are some small infrequent clay bands. This zone has high values for coastal plants such as *Barringtonia asiatica* and *Pipturus argenteus* sim.. Forest trees are relatively well represented given their normally low values, and more consistently so than in the previous zone. *Acrostichum aureum* continues to be represented, increasingly so towards the top of the zone.

The build-up of lacustrine deposits, possibly as sea-levels rose and/or drainage was hindered by the laying down of these deposits, stabilised and improved conditions for the preservation of pollen. The water body would have impeded disturbance to sediments at its bottom and pH would have lowered with the cessation of coral sand entering the gyttja.

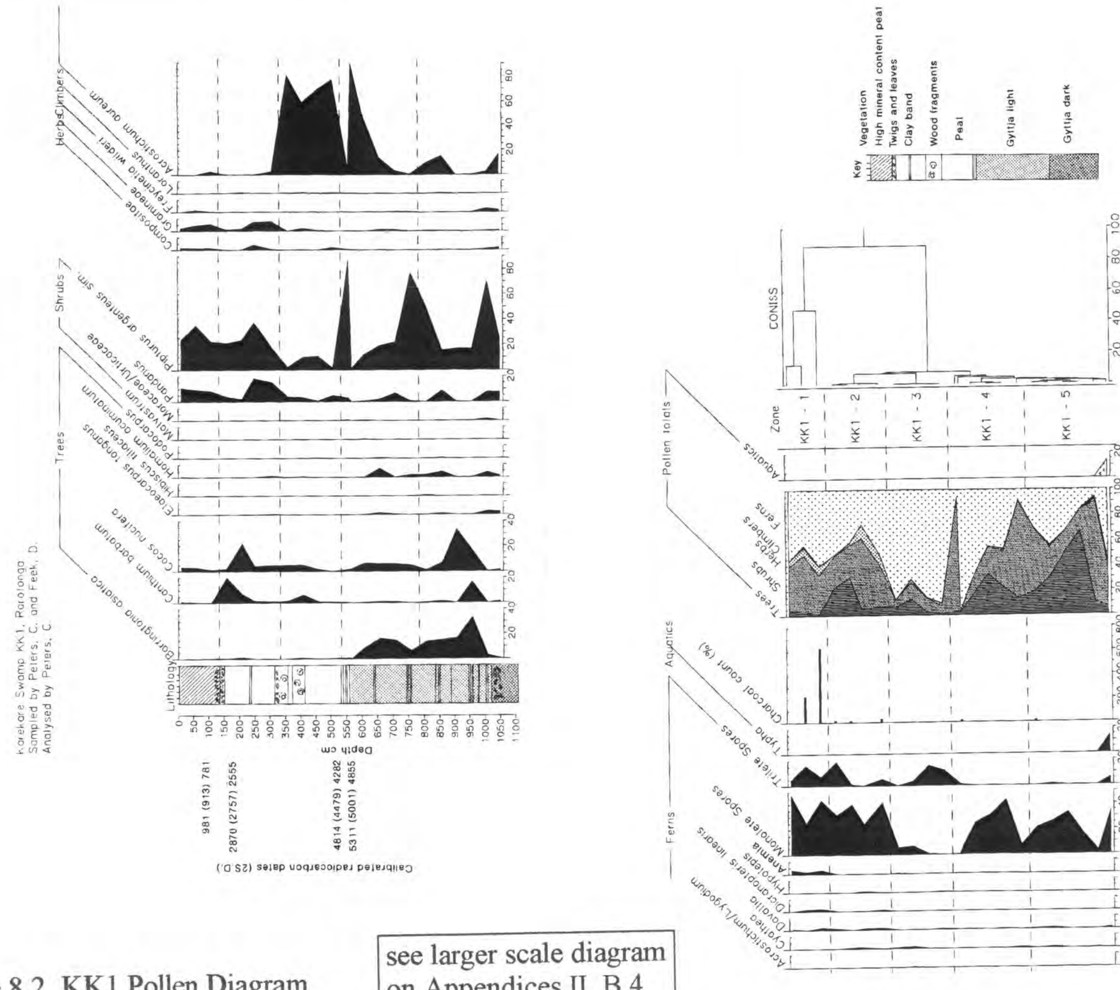

Figure 8.2 KK1 Pollen Diagram

see larger scale diagram on Appendices II, B.4

Coastal forest remains the major contributor to the pollen spectrum, with a consistent, even slightly higher than in Zone 1, representation of the interior forest taxa. *Acrostichum aureum*, a swamp fern, commences an expansion towards the end of this zone, possibly as the sides of the lake accumulated phytogenic deposits allowing the fern to encroach on the lake margins.

The transition between zones KK1 - 4 and KK1 - 3 (samples KK1 570cm and KK1 560cm) sees some banding on either side of the peat/gyttja transition (c.4500 BP). Black and clay banding occurs. The pollen and spores have low values for all taxa except *Pipturus argenteus* sim. and *Acrostichum aureum*, which have sudden peaks.

Zone KK1 - 3 (samples KK1 360cm; KK1 410cm; KK1 460cm; KK1 510cm) represents a transition from a lake to a marsh around 4500 BP. The banding may indicate that the transition was interrupted by short-term reversals caused by flooding, possibly cyclonic in origin. Alternatively, as suggested for KK4, human clearance may be responsible for erosion, which this banding may represent. The rise in *Acrostichum aureum* spores may betoken an invasion of the new drier surface by this fern. The decline in arboreal taxa may simply be due to increased local representation, especially as the sediments are increasingly the result of *in situ* production.

Zone KK1 - 3 is composed largely of peat and organic detritus, though with some continued inorganic component. Some clay banding continues to occur as in Zone 2, and in addition, there are occasional fragments of wood and roots. The behaviour of the pollen and spores could be interpreted as a hydroseral succession.

This zone has clay banding and wood fragments at the top, but is otherwise peat and fine detritus. The pollen and spores are dominated by *Acrostichum aureum*. Other taxa are reduced, though *Canthium barbatum* remains consistent, even achieving a value of 6.5% in sample KK1 410cm.

This could suggest that the surface of the swamp/marsh was colonised by *Acrostichum aureum* which led to an overrepresentation of this taxa vis-à-vis the other taxa. The value attained by *Canthium barbatum* may be due to this species invading a drier coastal plain if relative sea-level fell at this time as suggested below.

Zone KK1 - 2 (samples KK1 160cm; KK1 210cm; KK1 250cm; KK1 310cm) lacks clay banding, though wood fragments and larger detrital material were found in the lower part of this zone (c.3600 BP). *Acrostichum aureum* spores decline, while grasses and composites increase. Other ferns and coastal trees are also better represented, except *Barringtonia asiatica*. Taxa from the interior forest are still not so well represented, except *Canthium barbatum*.

Once *Acrostichum aureum* ferns had established a drier fundament for other plants, grasses and composites, which are generally weedy species, may have encroached on the swamp/marsh. Alternatively, the grasses and composites could represent weeds occurring after clearance of forest, though coming after a decline in *Acrostichum aureum* and before the increase in *Canthium barbatum* values. It has all the appearance of a hydrosere.

In samples KK1 210cm and KK1 160cm, there is a drop in *Pandanus* and reappearance of *Barringtonia asiatica*, whilst interior forest is not so well represented, except for *Canthium barbatum* which rises in proportion. Grasses and composites reduce in proportion too.

The *Canthium barbatum* peak occurs slightly later in time than in KK4, probably because this tree would have had to have colonised from that direction and possibly because the swamp surface is slightly lower at KK1 than KK4.

Canthium barbatum increased in the area around the marsh because the surrounding area may have been less prone to flooding due to lower sea-level, or it may have formed swamp forest as part of a natural succession. The growth of *in situ* plant material in the swamp/marsh itself suggests that water levels there at least were lower at Karekare. It may just be that it is naturally better represented than the other taxa of the interior forest, and that its increase demonstrates the expansion of this forest as a whole. On the other hand, the pollen spectrum may be showing a type of forest that no longer occurs: one in which certain elements of the interior forest, perhaps intermingling with elements of the coastal forest, were preferentially advantaged on the coastal plain where cyclonic floods and richer soils provided conditions unlike the slopes of the mountainous interior.

The disappearance and reappearance of *Barringtonia asiatica* and the low and reduced representation of the interior forest, except for *Canthium barbatum* could be just a problem of peat growth with more local representation and less of a contribution from surface rain-wash sediments, bringing pollen and spores with it.

Hibiscus tiliaceus scrub may have grown over the swamp at this stage, leading to a reduction in grasses and composites, but would not necessarily be detected in the pollen record as is demonstrated by a modern pollen rain study of a *Hibiscus tiliaceus*-dominated plot in Chapter 2.

Zone KK1 - 1 (samples KK1 10cm; KK1 60cm; KK1 110cm) has an increased mineral content, with a sharp rise in charcoal particles (commencing between 2757 and 913 BP). *Dicranopteris linearis* appears in this zone and there is a rise in grasses again. *Barringtonia asiatica* ceases to be represented and interior forest taxa are again better represented, apart from *Canthium barbatum* which is drastically reduced.

More grasses and composites suggest a more open environment, with interior forest taxa re-entering the deposits because the vegetation around the swamp is less dense allowing the freer passage of air and water, and clearance has allowed more erosional material to take spores and pollen grains from the hillsides, such as *Dicranopteris linearis*. Grasses and composites are from the cleared land around the swamp as well as fallow plots in the swamp itself. The lack of *Barringtonia asiatica* is more a problem of underrepresentation with regard to other taxa, because it occurs at significant numbers in the locality today, and this zone ends with the present time.

The summary pollen and spore diagram again appears to reflect a greater autochthonous contribution as in KK4.

8.5 Conclusions

It may be concluded that the changes taking place in zones KK4 - 3 and KK1 - 3 (c.4500 BP) could be explained by a concurrence of natural events (e.g. hydroseral succession, drought and natural fire), or by human impact or by a combination of human impact and natural factors. Though human impact is a possible explanation, it does not seem necessary to invoke it as the most likely cause of the events in Zone 3.

Zones KK4 - 1 and KK1 - 1 (beginning between 2353 and 958 BP) contain strong and consistent signals that indicate that very different processes are at work. The long term increase in the mineral component of the sediments and the percentage of charcoal particles, combined with the floral changes and the fact that this is the zone that includes the present humanly influenced conditions, suggests that it is indeed the result of human activities.

Having analysed the biological data, all the results from various lines of investigation are complete. Integrating these in to an overall interpretation is the subject of the next chapter

CHAPTER 9 DISCUSSION

In this thesis, human impact is considered without the subjectivity implicit in whether something can be labelled `degradation' or `damage'. However, the way in which human influence may have altered human-environment relationships will be discussed.

There is sometimes a confusion in the literature over what environmental destruction means. In actual fact, the environment can never be destroyed or even threatened, because it is a condition not a physical entity. Environmental destruction is more appropriately canvassed where human comfort and well-being are compromised. This can include spiritual and psychological threats to people, as well as physiological threats (Boyd pers. comm. 1991). People prefer to control landscapes in order to make sure that things change only when and how they want them to change (*cf.* the idea of imported landscapes in Kirch 1982; 1983). In many cases, stasis can actually be promoted by human interference instead of hindered. Polynesian islands may have been especially dynamic and changeable before human arrival - quite the opposite to that imagined in the present literature (*cf.* Zimmermann and Bierregaard 1986).

What constitutes environmental degradation is not always clearly defined. It is often assumed, for example, that massive deforestation is an integral part of human-environment relationships. Yet the type of economy and its impact on the landscape is not always considered carefully together with environmental data.

The significance of the results will be evaluated at the three different levels: the immediate locality of the swamp, the whole island of Rarotonga, Pacific islands (with the main emphasis on Polynesian islands).

9.1 Karekare Swamp: Interpretation of Local Environmental Changes

Karekare swamp produced evidence of a sequence of environmental changes. In basic outline this consists of the commence-ment of lake deposits, followed by peat and fine detritus deposits, and finally, a modern cultivation zone.

The fact that the gyttja is not reddened at any point itself implies the sedimentation occurred as slow accumulation under reducing lacustrine conditions (Millar *et al.* 1965: 58). Fe occurs in sufficient quantity at these levels, particularly in samples KK1 790-800 cm, KK1 820-830 cm and KK1 980-990 cm. The lack of a crumb-like structure supports the idea of lacustrine conditions (Flenley pers. comm. 1993). Sedimentation in the gyttja part of the sequence would have been caused partly by surface run-off into a body of still open water, from the immediate surroundings and nearby hillside, and partly by autochthonous organic material like algae. It involved mainly eroded clays from the lateritic soils. Subsurface water movement would have also contributed to the sediments.

Possible explanations for the later changes in lithostratigraphy and biostratigraphy, especially palynology (and in particular, those in at the transition from zone KK4 - 4 to KK4 - 3 and the transition from zone KK1 - 4 to KK1 - 3) include eight possible agents (as for Sutton *et al.* **in press**, plus amendments and additions) - seven natural agents and one human:

a) hydroseral succession b) cyclones c) droughts d) natural fires e) landslips f) climatic change

g) sea-level change h) human impact
Each of these is considered in order:

a) **Hydroseral succession**

The change from gyttja to peat may be an entirely natural process (*Verlandung*) resulting from the infilling of the lake and its overgrowth by swamp vegetation. Such an explanation involves only local hydrology, sedimentation and plant communities, without having to resort to more dramatic outside intervention - for example, from climatic change or the arrival of humans, and has the advantage of simplicity. Simplicity, however, does not imperatively imply truth. The author argues that the process evidenced here is a natural one. Certainly, some of the changes in grain size distribution and elemental concentration appear to indicate *in situ* processes, such as sediment diagenesis and kaolinisation, due to the augmenting organic component of the sediments through time changing the chemical conditions of the basin. In this respect also, the reduction in percentage of *Acrostichum aureum*, the swamp fern, in the second zones of both cores KK1 and KK4 (beginning about 3600 BP), and its increase again in the third zones is informative. In the first zones (beginning between 2350 and 960 BP), its percentage would appear to be more representative of marginal swamp, in the second zones, rising water levels may have drowned these marginal swamps, and in the third zones (starting about 4500 BP), the rising levels of sediment, possibly linked also with a reduction in water levels meant that the fern is indicative of the whole basin becoming a swamp.

It could be argued that the development of a swamp forest might have been expected if people had not interfered in the swamp/marsh ecology (Flenley pers. comm. 1992). However, there are two alternative explanations: one arguing that swamp forest did indeed occur and the other arguing that the lack of such forest or even scrub could be natural.

In the first alternative, if swamp forest occurred it would have most likely been dominated by *Hibiscus tiliaceus*, which is an aggressive pioneer species at least initially. It is able to withstand disturbed conditions such as flooding as it does in the valleys today. It is also a pioneer on Karekare swamp at the present in areas where taro patches have not been tended for some time. Yet, the author's modern pollen rain study shows (see Chapter 2), even with 70.45% canopy cover being *Hibiscus tiliaceus*, there is no guarantee of a single grain of its pollen being recovered. Also, perhaps *Canthium barbatum* may have had such a role in the past and today it is simply not present on the coastal plain to fulfil such a role. Its pollen grains are certainly found in relatively high numbers at the right point in the sequence. Moreover, relatives in the same genus elsewhere in Southeast Asia and the western Pacific are found in swamp forests (Flenley 1979; Whitmore 1975).

In the second alternative, one should note that there is no hard and fast case for swamp forest being an obligate part of any hydrosere. The old theory of hydroseres, indeed all seral development, is that there is a reliably predictable sequence of vegetation changes that will eventually lead to a `vegetation climax'. Walker (1970), however, demonstrated for post-glacial hydroseres in the British Isles that, even though only sites with an autogenic seral development had been selected, still 17% had a `lower' stage following a `higher' stage. Apart from these reversals, only 53% of all possible stages of hydroseral development are recorded, and a mere 23% significantly so. Seen in this light, it is unlikely, with a much smaller sample of hydrosere studies in the Pacific Islands, that any model or theory of such a consistent development could claim to be sufficiently credible.

Instead, another possible explanation for what occurred is proposed. Vegetation rafts are likely to be long-lived because the raft is depressed as more peat accumulates, and thus the surface conditions tend not to change (Walker 1970). Also, nutrient inflow is impeded which in turn lessens the growth of new plants and thus of peat. In the case of marginal reedswamp, the reeds hinder the through-flow of nutrients from the bank to the open-water: the epilimnion is thus starved of nutrients. Since Karekare swamp has no permanent watercourse draining into it, nutrients tended to enter via flooding and hill-wash. Circulation would not have been very efficient before human manipulation of water-flow took place. Therefore, growth may well have been significantly slower and more seasonal in the centre, and much higher at the edges where the nutrients would have been trapped.

This may be supported by the sediment and chemical analyses. Since S lessens with dilution, and P increases with dilution (*cf.* Butzer 1982), and S seems to behave in an inverse manner to the mud fraction, the drainage of the swamp or a sinking water table could have promoted the passage of vadose water, especially above 135 cm, causing an increase in the mud fraction (silt and clay) and P as against S. The high values for S at the top of the gyttja could be explained by a low redox potential, leading to SO_3 reduction and the decomposition of organic matter thus causing increased H_2S. This puts the explanation for the observed change in the natural category.

The first alternative, however, is considered the most likely because of the evidence of high frequencies of *Canthium barbatum* pollen at the appropriate position in the sequence for a hydrosere. The appearance of more xerophilous species after the decline in *Canthium* pollen values helps to confirm the idea of *Canthium* being part of a succession.

b) **Cyclones**

Cyclones may have caused a decline in forest pollen, through deforestation (if that is truly represented here), and heavy rain leading to soil erosion and clay inwash bands in Karekare swamp (at 450, 448 and 430 cm in KK4). These effects would normally be transitory, except where a series of cyclones in rapid succession or a particularly severe event had taken place (*cf.* Parkes *et al.* 1992).

Alternatively, it could be that the process of sedimentation, on arriving at a transition stage where peat formation was just possible, had two false starts, where normally fairly light cyclones had the ability to raise water levels sufficiently to return the depression back to its original status as a lake[45]. Also, there may have been no decline in forest taxa, merely the greater representation of local taxa. Again change from gyttja to peat is placed in the category of natural agency, and cyclonic activity is considered reasonably likely as a minor contributor to this change.

c) **Droughts**

A protracted drought could lead to a decline in forest pollen, a rise in Gramineae, and inwash of clay from soils exposed by deforestation. It could also depress the water table and thus hasten the process of *Verlandung*. The survival of many forest taxa and the fact that not all the cores contain the clay inwash layers, at the point of transition between gyttja and peat deposits, make such a regional change unlikely. Also, other similar inwash layers occur in cores from Karekare swamp at other points in the sequence that are not matched in other cores (see Appendix A.3).

d) **Natural Fires**

These can occur even in rain forest (Goldammer 1989), probably started by lightning. An increase in charcoal particle frequency in the sediments would be expected if fire had occurred. Only consistent repeated firings would maintain such a situation, because forest can quickly recover. The reduction in *Pipturus argenteus* sim. numbers would thus require additional reasons. This natural agency does not seem likely.

e) **Landslips**

By providing exposed soil for erosion, a landslip (this could include those caused by natural colluvial processes or burrowing birds or fallen trees) in the site's catchment could explain the inwash of clay. It would be unlikely to cause more than brief changes in the pollen record as the xeroseral succession in rain forest is rapid (Whitmore 1975). This agency too does not seem likely for the observed information.

f) **Climatic change**

General world climate changes occurred around the time of the change in sedimentation recorded for the third zones of both cores - that is 4500 BP (e.g. Roberts 1989) - involving a more arid phase in many parts of the world. Adamson *et al.*'s (1987) work, reviewing documented records for the Nile (north-east Africa), Murray-Darling (Australia), and Ganges (India) river basins during the last 200 years, demonstrates a remarkable agreement in the timing of major drought and flood events in all these places and fluctuations in the Southern Oscillation (SO). This supports the notion that areas influenced by the SO are very much part of a single system of climatic change. Seen in this light, in the islands of the tropical Pacific, it may not be coincidental that Anauwau swamp on Aneityum sees a transformation from siltation to paludification at about 4000 BP (Spriggs 1986). However, conditions, especially in more oceanic Polynesia, might have been less strongly influenced by these changes due to the buffering effect of the ocean. This agency is considered plausible, and is cautiously mooted as a contributory.

g) **Sea-level change**

A date of *circa* 4500 BP is also significant for sea-level change (see Chapter 3). Changes occurring elsewhere in the central Pacific Ocean, including the Cook Islands, show a highstand of 1-2 metres around 4000 to 5000 BP (e.g. Nunn 1991), followed by a drop in sea level until about 1,500 to 2000 BP when present levels were reached. Since freshwater is less dense than saltwater, and an island's freshwater lens rests on the saltwater of the ocean, it follows that sea-level changes should also affect the freshwater table. The beginning of the lowering of sea-level may have affected the water table in Karekare swamp, leading to drier conditions and allowing plants to colonize its surface. It is interesting to note that *Acrostichum aureum*, the swamp fern, undergoes a reduction in percentage between 5000 and 4000 BP according to both KK4 and KK1 cores. Higher water levels would have drowned the swampy/marshy margins of the lake eliminating any plants occurring there.

Correspondence between a sand peak at 160-170 cm in core KK4 and a sand peak between 700 and 800 cm in KK1 (possibly equivalent in date judging from core KK4) may be due to lowering water levels due to sea level change. It is also possible that drought could have made marginal, earlier deposits (see **Human impact** below) more susceptible to erosion, so that they could have been redeposited by rain and wind.

Sea influence is detectable below 800cm and possibly between 200-300cm (where elements typical of basalt, as opposed to seawater, did not correspondingly increase) in KK1 from the chemical analyses. However, the greater part of this is more likely to be due to influxes of material deriving from the coral rubble ridge than directly from the sea.

45 According to the living memory of George Tara`are (see section 6.1.2), the swamp could remain flooded for a few months a year due to the lack of adequate drainage before the construction of an outlet to the sea in the early 1960's.

h) **Human impact**

Forest clearance by people for agriculture (and other purposes like flushing out game) in rain forest areas normally involves forest decline, soil erosion, fire and rise of secondary elements, like ferns and grasses. In the case of swamp cultivation, such as for taro, it can also involve drainage and thus accelerated Verlandung[46]. All these types of change have been recorded in archaeological contexts in New Guinea (Flenley 1979; Walker and Flenley 1979). In such an eventuality, *Acrostichum aureum* ferns might have colonized the areas of the swamp which were not under cultivation. Zones KK4 - 1 and KK1 - 1 would then reflect human interference with previously pristine areas, so that only at this point were the immediate effects of cultivation evident.

However, problems occur with explaining the transition from gyttja to peat (KK4 - 4 to KK4 - 3 and KK1 - 4 to KK1 - 3) in terms of human impact. In short, the problem is that the types of evidence that could be invoked to support human impact do not occur in very convincing circumstances. Thus, there is the problem that banding due to clay inwash is found at different levels in all cores. Another problem is the lack of a significant charcoal particle increase at this time, if extensive human swiddening is to be postulated. Next, the swamp was actually a slightly salty marsh up until the 1960's, and was used primarily for the cultivation of *puraka* or atoll taro (Tara`are pers. comm. 1992)[47], in which case, drainage promoted by humans seems less plausible an explanation. The sediment testifies to this with the presence of detritus as well as peat. Finally, there is the lack of archaeological evidence for human presence on Rarotonga at this time (4500 BP), though this might be due to burial by later sedimentation (Sutton *et al.* 1993). In sum, though human impact is still a possible explanation, it does not really seem necessary to invoke it as the most likely cause of the events that led to zones KK4 - 3 and KK1 - 3.

A close match between the sand peak at 160-170 cm in core KK4 and the sand peak between 700 and 800 cm in KK1 (possibly equivalent in date judging from core KK4) may be due to humans disposing of material in the centre from tillage around the swamp edges. This is because lower layers often lie nearer the surface at basin edges, and thus earlier material may have been deposited along with the then actively forming peat (Flenley pers. comm. 1993). However, as mentioned above (see **Sea-level change**), a falling water table could have been responsible, leading to erosion by wind and rain. Also, there is, as for the third zones, the lack of archaeological evidence for settlement at this stage (c.3000 BP), though it matches Irwin's predicted time of settlement on the basis of systematic colonization (see Figure 3.1).

On the other hand, the anomalous date may have been caused by deposition of material from the coral rubble ridge under a floating mat of peat and living vegetation. The correspondence of the sediment from this level with sediment from between 700 and 800 cm in KK1 could be due to their having the same source. A cyclonic storm could have caused both sea surge to shift material from the coral rubble ridge and freshwater flooding to discard basaltic material under the top layer of peat.

Zones KK4 - 1 and KK1 - 1 (beginning between 2350 and 960 BP) contain strong and consistent signals that indicate that very different processes are at work than in the second zones of the two cores. The long term increase in the mineral component of the sediments and the percentage of charcoal particles, combined with the floral changes and the fact that these first zones are those which include the present humanly influenced conditions, suggests that it is indeed the result of human activities.

From about 120-130 cm in KK1 and KK4, there is an increase in the mineral component of the sediments. This section of sedimentation is known to have been interfered with by humans and is the part under direct cultivation in the present. This is more of an horizon than a deposit. It has been subject to mulching including possible deliberate introduction of mineral content. It has certainly been subject to much oxidation due to the continuous working over of the sediment between each harvest and planting, and due to exposure of the surface to the air, erosion (by means of aeolian and aqueous transportation) and enforced stasis as far as peat formation is concerned. The second zone in both cores may once have extended further upwards, and has simply been truncated, which could be supported by the lack of evidence for swamp forest in the pollen record at the top of the peat before the cultivation zone. It is important to appreciate, therefore, that this zone could be one in which there was no evidence for human interference until this was introduced during the reworking for cultivation.

Clearance of vegetation in the top cultivated zone (top 135 cm) of both cores, combined with drainage channels would have assisted the passage of water and suspended solids. This is because a drier and open basin formed by gardening activities would allow the passage of water currents, whereas even when the basin formed a lake, the water body itself would have hindered the movement of an external water current through it. This could help to explain the peak in P values at the top of the sequence in KK1.

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46 Swamp cultivation can sometimes involve raising the water table, though in this case, the plant succession suggests the opposite.

47 Even if one does not accept the idea that the crop was pre-European (Geraghty 1990), the swamp by accounts from living memory (Tara`are pers. comm. 1992; Utanga pers. comm. 1992) was not suitable for taro cultivation except around the edges during the dry season.

The author suggests that human impact may only have occurred in the final zone, though earlier human impact is not ruled out.

Conclusion

Rising sea levels at the beginning of the Holocene may have led to the formation of a lake at Karekare before 8137 BP with a beach ridge of coral rubble blocking the seaward end[48]. Local hydrology, due to the rising amount of accumulated sediment, was such that the lake was becoming shallower. The final transition to a marsh[49] may have been simply the continuation of this process, though a number of factors may have contributed. Human drainage and clearance activities leading to erosion may have been involved, though for the aforementioned reasons, the author thinks this is not the most likely solution. Climatic changes, leading to increased aridity, though not so marked as on continents, in conjunction with falling sea-levels may have led to an early transition to marshy conditions. Clay banding at this point may be cyclonic (or human induced) as such bands occur throughout the sequence.

Further support for the sea-level hypothesis may be seen in the dates from the other smaller swamps, all of which date to after 1500 BP, the period when sea-levels would have reached more or less present levels (Nunn 1991; Pirazzoli and Montaggioni 1988). Raised topography from east of Avarua to NgaTangi`ia due to the coral rubble ridge and the terraces (see Figure 1.4) mean, that at a highstand of 1-2 metres, the area of Karekare swamp would have been protected from transgression by the sea, whereas the rest of the coastal plain would have been swamped by seawater, the terraces and fans (see Figure 1.4 and 1.5) forming a cliff. From around 2000 to 1500 BP, the sea would have completely regressed, leaving the coastal plain exposed once again, allowing the formation of swamps to commence from that point in time only. Hence the dates for the other swamps (Atupa swamp, 1415 (1293) 1087 BP, Arorangi Latter Day Saints Church Site, 1176 (979) 797 BP and Aro`a swamp, 553 (465) 0 BP - 2 s) are relatively late.

An alternative suggestion is that if people were already on Rarotonga, erosion from cultivations could have caused progradation (*cf.* Spriggs 1981). Since the chronology and level of sea level rise, however, correlate well with the topographic and C^{14} dating evidence, the author prefers the former suggestion, though does not reject the latter. It is quite possible that some part of the process of coastal emergence could have been due to people, if indeed they were present at the time in question.

Following this transition at Karekare to a marsh, a hydroseral succession appears to have occurred, firstly with *Acrostichum aureum* ferns, then grasses and composites, and possibly some swamp forest may have then existed. This was ended, and possibly some deposits here may have been truncated or shrunk as a result, by cultivation and drainage. Peat formation would have been halted, and oxidation would have started to take effect, though mulching and the occasional flood may help reduce this effect.

Deforestation is not necessarily represented in the third zones of both Karekare cores due to the greater representation of local elements such as *Acrostichum aureum* ferns, *Canthium barbatum*, grasses and composites. In the first zones, it appears more genuine with more ferns, coastal taxa, but correspondingly no *Acrostichum aureum* or *Canthium barbatum* peaks. This level also has a peak in charcoal particle values and erosional material, including peaks in many of the elements analysed such as P and Al. All imply human activity.

Evidence of oral tradition and recent memory recorded in Chapter 6 indicates that Karekare swamp was a marsh until the 1960's: in other words it was subject to seasonal flooding. This meant that taro could not be grown all the year around, and that, at least in recent times, *puraka* or atoll taro was grown in the swamp all the year round. The fact that the peaty deposits at the top of the sequence contain much detritus is explained by the seasonal flooding and the relatively high pH is explained by saltwater storm surges during cyclones taking a long time to drain away. Also, people were reluctant to settle the area until the 1970's because of ghosts and spirits, though nevertheless they gardened the swamp (Tara`are pers. comm. 1992). Of course, this may not apply to the more distant past.

9.2 Rarotonga: Implications for the Environment of the Island as a Whole

If one begins by assuming the sea-level hypothesis mentioned above is correct, then before 2000 BP the available land for settlement and cultivation would have been significantly less than today. Except for a stretch of coast between Avarua and NgaTangi`ia, only the valleys, terraces and fans would have been available, and the terraces and lower parts of the fans

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48 This tallies well with Lake Te Roto on Atiu and Lake Te Roto Nui on Miti`aro, which both yielded dates of around 8,000 B.P. at their bases (Parkes *et al.* 1987). In the case of Lake Te Roto Nui, the depth below sea level was about 8.8 m correlating well with the depth to time ratio of Karekare swamp.

49 A „marsh" is a wetland that is covered by open water all the year round; a „swamp", on the other hand, is a wetland that undergoes some seasonal dessication.

would have, no doubt, been susceptible to flooding. In this case, any early sites on the coastal plain would necessarily be from the period 2000 BP onwards. If anything earlier existed it should be found further inland.

Given the proposition that the population did not use up all the available (and thus potentially colonizable) space, as suggested by missionary writings and oral tradition, the pollen diagrams will not always produce definitive results indicating human interference with the vegetation and may rarely indicate large-scale erosion (except possibly locally), especially since arboriculture seems to have been the predominant form of agriculture. Usage of different areas of the lowlands may have been discontinuous, leading to a situation where everywhere had received some human interference at least at one time, though this is difficult to test without the archaeological evidence.

Even today the land on Rarotonga is not all under use, and, indeed in colonial times, this served as a common source of complaint from the British Residents and the later (after 1901) Resident Commissioners that much land was wasted (Gilson 1980). To add to this, there were areas of swampy ground that had not been converted into taro patches, despite their suitability. Some of this was later drained or converted to taro patch in order to combat mosquitos which were spreading various tropical diseases in the 1920s and 1930s (Gilson 1980). For example, Karekare swamp was not connected by channel to the sea until the 1960's (thus being transformed from a marsh into a swamp), and part of the back of the swamp was covered in coconut trees, *puraka* and various weeds and shrubs until the 1940's.

The valleys cut in to the mountainous interior of Rarotonga have a flora consisting in the main (where they are not under cultivation or settled, such as Avatiu valley) of *`au* (*Hibiscus tiliaceus*) and various woodland ferns. Some of the ridges between the valleys are covered in the staghorn fern (*Dicranopteris linearis*), with or without the presence of the *toa* or ironwood tree (*Casuarina equisetifolia*). These two plant communities could suggest secondary vegetation in many cases, such as the Tupapa Valley, where the author has seen old pondfield gardens under *Hibiscus tiliaceus* growth. However, the communities are probably ancient in origin. The *Hibiscus tiliaceus* community grows in constricted parts of valleys on boulder streams, such as where the Murivai Stream flows on the bottom of the Maungaroa Valley, where there has clearly never been gardening or settlement and the environment is constantly disturbed due to cyclonic flash-floods. Equally, the fernlands are more extensive on the drier, leeward side of Rarotonga, so at least some degree of environmental influence is likely to be at play there.

The late nineteenth/early twentieth century photographic evidence and the late eighteenth century pictorial evidence (from other islands) shows that the interior mountains would have been likely forested, except for the occasional fernland on the lower slopes, and the coastal plain and valleys would have been wooded, with many of the trees being of economic value and an obviously large component of those being coconut trees on the coast.

More level areas up the valleys were sometimes occupied, like the Maungaroa `Valley' settlements (Trotter 1974 and Bellwood 1978). Still, some valleys, especially on the south coast, are very constricted and unlikely places for cultivation, being full of boulders and gravel from the streams. Perhaps, the survival of bird species, like the *kakerori* (*Pomarea dimidiata*) and the *`i`oi* (*Aplonis cinerascens*), may not have come to pass if these valleys had been cleared.

There has been much criticism of early estimates of Pacific Island populations (for instance, McArthur (1967) and Bedford *et al.* (1980), though McArthur (1967) believes Rarotonga to be a genuine case of severe population decline. Also, even the estimate of 6,000 to 7,000 is below that of the present day and yet the interior remains forested. This figure has a wide margin of error, and given John Williams' tendency to exaggerate (see Chapter 6), it may be misleading. Better and more controlled population estimates of 3,300, come later in the 1840's (William Gill 1856: 72), though after disease had claimed the lives of many people, so these figures must be seen as underrepresentative of the population before European contact. The present author suggests that the true figure lies in between 3,300 and 6,000 for the population of Rarotonga at European contact.

From the investigation into Rarotongan ethnobotany and ethnozoology in Chapter 6, a number of points are apparent. There was a concentration on the resources of the coastal plain, valleys and the shore. There were more types of plant used in these areas, with more uses per plant type, and there were more plants which had more regular and vital roles. The coastal plain and valley plants form the longest list of utilised plants, with some species being planted away from their natural habitat like the coconut and the pandanus. More herbaceous species were used in this zone, so this would have been the most open and disturbed zone, though trees and shrubs still accounted for the greater number of uses, often routine uses, and greater quantity needed. Some species characteristic of disturbed areas, or of regrowth after human exploitation, such as *mata* (*Paspalum orbiculare*) and the *`au* (*Hibiscus tiliaceus*), were of economic importance and can therefore be seen as deliberate rather than simply accidental.

Most useful shore plants were trees and shrubs, many having frequent uses, so that it would have been in the interests of people to have maintained this zone as forest, especially since the land is drought-prone (Leslie 1980) and because the trees there had such an important role in the economy. Some manipulation of the vegetation might, however, be expected like the deliberate extension of stands of coconut and the planting of cultivated varieties of coconut (*cf.* Lepofsky *et al.* 1992), though not to the extent of the cash crop plantations of the nineteenth and twentieth centuries. Large plantations of coconut trees would necessarily involve depletion of other useful shore trees, and coconut trees could be grown in the valleys and on the coastal plain, as indeed they were (*cf.* Williams 1843).

The soils and topography of the upland areas are not suitable for horticulture, both those under woodland as well as those under fern (Leslie 1980)[50]. Some trees of the upland areas were important sources of timber for certain items, not frequently made, and the presence of a few famine foods and medicines would have discouraged deforestation in that zone.

Animal resources were available in all zones, the lagoon and ocean zone being the most important. Fish were a staple food (William Gill 1856), and shellfish collection would most probably have been vital too (Parslow 1993). The adjacent shore may well have provided sea birds too. Mineral resources are available in all zones too, though only the shore zone possesses both coral and basalt, which are the most important. Clay and ochre which were of much lesser importance were available everywhere except the shore zone.

Domestic animals were available in the coastal plain and valley zone, though feral populations of domestic fowls may well have been available in the uplands too before European contact (Holyoak 1980). Domestic animals were consumed at feasts rather than on a daily basis. Wild land birds and some sea birds, like the herald petrel and the red-tailed tropic bird, were obtainable from the mountains too, and were no doubt of a supplementary nature in the diet of Rarotongans.

A model is required for landscape change on Rarotonga, based on biogeographic theory (see Chapter 3). Landscape and biome change can be seen as occurring at different levels with ecological change at the higher end and the effects on individual components at the lower end. Of prime consideration in this model are naturally the effects at the higher end, and especially with the way in which the ecosystem adapted to human presence.

In order to understand this, one must ponder the interrelationships between the organisms concerned, and between these organisms and their setting. Firstly, many animals are dependent on the survival of a certain variety of habitats and minimum size for those habitats. Certain plants living in those habitats may in turn be dependent upon these same animals for the dispersal of their seeds and pollen. The different size levels and roles of vegetation and animals are also interconnected, so that the vacation of some niche may disrupt a chain of interdependent roles. In fact, the degree of endemism of species tends to increase the area requirement of species and their dependence on indigenous forest (East and Williams 1984).

A series of principles devised by Diamond (1975; 1976) for the creation of nature reserves in order to maintain the greatest possible degree of diversity is presented:

1) Larger preserves are better than small ones;
2) The least division of the preserve the better;
3) If unavoidable, then these fragments should be as close as possible to each other;
4) Also these fragments should be arranged equidistant to one another and not linearly;
5) The effectiveness of these fragments may be significantly improved by connecting them with narrow strips of protected habitat;
6) Ideally, preserves should be as nearly circular in shape as possible in order to minimise dispersal distances within the preserve.

It is interesting to note that this last principle covers most high islands in the tropical southeast Pacific Ocean as they were in their natural state. Colonization of radial valleys would instantly partition the circle, though connections would still persist through the central pinnacles. For some species this might mean traversing a hostile climatic or vegetation zone, with the result that for such a species the partition would be very effective (and indeed for any other organisms dependent that species). Dispersal ability, moreover, decreases as one approaches the equator (Diamond 1985). The splintering of once uninterrupted tracts of forest can be even more hazardous to species diversity than any decrease in such forest (Diamond 1972; Diamond *et al.* 1987). Significantly large areas of uninhabitable territory prevent organisms forming large enough populations, obtaining sufficient nutrients and recolonizing unpopulated areas.

On the basis of biogeographic theories (especially Diamond 1975, 1976), the author presents the following model for landscape on Rarotonga.

a) Initially, the landscape was uninterrupted by human intervention, and natural relationships within the biome were established. The natural habitat, then rounded except perhaps for occasional fernlands and clearings, would have been an excellent shape for maximum possible diversity. Sea-level rise during the Holocene highstand (Clark *et al.* 1978; Clark and Lingle 1979) would have reduced the lowland vegetation zone, and may have reduced population numbers of many organisms during this time.

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50 There is a case of archaeological remains on such soils: the Raemaru and Upper Maungaroa clusters in the Maungaroa Valley. However, it has been suggested that these were look-outs (Bellwood 1978: 38 and 40 respectively). If indeed, agriculture was carried out in these locations, it may have been due to the lack of cultivable land. The constricted nature of the valley bottom and the gentleness of the slopes at the back of the valley may have led people to experiment, though it is unlikely the soil would have promoted good yields or that the experiment would have been sustainable.

b) People inhabited nucleated settlements at ecotones where valley, stream, coastal plain, lagoon and reef passage are most readily accessible (*cf.* Walter 1990 for the southern Cook Islands and Kirch 1985 for Hawai`i). These are where major valleys open onto the coastal plain, and where the coastal plain is relatively narrow, so settlements were close to the shore. Initially, wild resources may have been especially important, until plantations were established. Settlers may have extended the shoreline distribution of pre-existing useful species, especially coconuts, from the time of initial colonization. Henceforward, expansion (as dispersed settlement) would have been up valleys and along the flood plains, terraces and fans (hence drawing-pin shapes on the diagram), over which the *Ara Metua* passes (though possibly leaving contested and sacred areas free of interference - see Chapter 6), because that is where the best agricultural land is (Leslie 1980)[51]. The flood plains (except the very lower ones) and terraces are also more protected from cyclones, floods and drought occurring on lower and more coastal parts of the plain[52]. Gardening may well have extended to coastal swamps too.

Disruption was in the form of cultivated barriers to dispersal, though because of arboriculture, this may not have been so severe. This disruption would have been greater the further settlement progressed up the valleys and along the terraces (possibly below the terraces too). All habitats would have been at least represented and continuous with others, and some of secondary habitats due to swiddening activities would have provided opportunities for species less dependent on primary forest. Still, the low density of shy flightless birds may have caused these birds to decline when a significant and rich proportion of their habitat was reduced; enough, combined with hunting, to extirpate them (any plants relying on such birds for dispersal would have also been affected). Land molluscs confined to certain valleys would have been severely affected. The introduction of alien species, including rats, domestic fowls and cultivated plants would have also assisted in reducing diversity and disrupting relationships. Some of these exotics may have filled occupied niches and empty ones or shared niches with already existing occupants, not disrupting the overall ecology[53].

c) The European missionaries arrived, and the settlement was again nucleated and concentrated on the coastal plain, expanding right up to the coast after 1860. Cultivation still continued up the valleys, especially with the development of a cash economy, through to the mid-twentieth century, and in some cases, to the present, but eventually, this declined. This would have been the time of maximum disruption, with elongated tracts of natural habitat only connected by upper slopes in the interior, which is one of the worst possible shapes for a reserve. In addition, some habitats would have been severely reduced, especially the lowland plain and coast, reducing habitat variety and the extent of natural habitat generally. More species were imperilled, such as grey ducks and *kakerori* (see Appendix A.2.). Many introduced species were brought to Rarotonga, some of which are rapacious colonizers, including milletia vines and mynah birds. The difficulties in earning a living due to colonial rule and exploitation were also no doubt a contributing factor to landscape change, so that, for example, people were forced to misuse the lagoon resources to a degree that they have never fully recovered (Scott 1991: 200-201).

d) The coastal plain is settled fairly intensively in the late twentieth century, but many of the valleys are no longer cultivated (though there is possibly the beginnings of a trend to reopen them for cultivation). Although not as protective of the natural interrelationships and diversity as the island's original status, this stage saw the return of natural habitat to a roughly circular shape. This is as previously mentioned ideal for dispersal systems and other interrelationships to work better. However, habitat size was still reduced from the situation presented in b), and some habitats are now virtually non-existent, especially the coastal forest, now only truly present, though still disturbed, on the *motu* in the lagoon near Muri. With the emigration of people to other countries, especially New Zealand, many areas of regrowth have appeared, which may have assisted some indigenous organisms.

In this model, the wetlands between the coastal ridge and the terraces (and fans) may well have been significantly exploited much earlier than European contact, though caution is suggested because evidence from living memory from Karekare swamp (see section 6.2) indicates that not at least one of the major swamps was considered unsuitable for taro cultivation until its partial drainage in the 1960s. Prior to that it was used for *Cyrtosperma* cultivation, which if it occurred before European contact on Rarotonga, is likely to have been late anyway (Geraghty 1990). Williams (1843) notes taro cultivation in this area, though because *Cyrtosperma* had not yet been identified as a separate genus (Jackson 1895), it is not certain that Williams would have known the difference. The coastal ridges of sand and coral rubble are marginal in terms of cultivated plants except the coconut trees and other useful littoral trees mentioned in appendix A.5, and so these areas are

51 The terraces constitute a large part of the lowland encircling the mountains. They are mostly less than 500m from the shore, sometimes only 200m, though at one point 700m.

52 Possibly, sedimentation from valley clearance may have contributed to coastal emergence, to some interfluvial swamp formation and to some swamp terrestrialisation. Certainly, some excess sedimentation would be expected from clearance activities, though it is unclear how significant it would have been against a background of natural sedimentation. This would depend on the size of areas cleared, whether the areas downslope were vegetated and how soon the vegetation cover was restored.

53 For example, *Rattus rattus* may fulfil functions formerly the preserve of landcrabs.

not emphasised in the model as areas of clearance for gardens. Hence the emphasis on the more fertile terrace, fan and flood plain soils, which are all set back form the shore and mostly above the level threatened by the worst effects of storm surge.

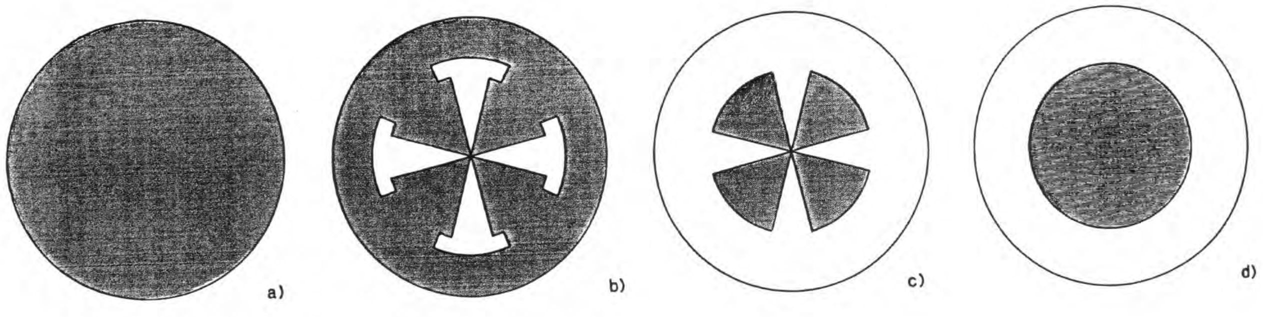

Figure 9.1 A theoretical model for environmental change on Rarotonga.

The most significant part of this model is that rather than proposing a gradual rise in environmental `degradation' and extinction, it sees changes as being punctuated by new events or trends, which when certain thresholds are crossed lead to a new equilibrium, such as in metastable equilibrium (*cf.* Butzer 1982: 22). Burrin and Scaife (1988: 217) argue that environmental systems tend to strive for a minimum potential, often by homeostasis, and that the concept of potential is closely tied to that of equilibrium. Thresholds are as important as control variables in contributing to change. Change is seen as discontinuous due to continuous change in the controlling variables (Burrin and Scaife 1988: 231). Human control should be seen as only one side of the problem as the response of natural environmental to changing phenomena is equally complex. For example, erosion-vegetation equilibria occur at the secondary level of vegetation, whereas it is frequently assumed that this occurs at the primary level (Thornes 1987). This is important because vegetation-free soil requires a continuous labour input, especially in the humid tropics, as the recovery or at least relaxation time can be short (Thornes 1987).

The author presents the idea that the survival of certain members of the avifauna, only to become extinct after being recorded in post European contact times, is not simply the tail end of a continuing process of extinction, but the result of the arrival of new conditions and new threats. The arrival of new threats did not necessarily include the removal of old threats, though it is argued here that the new threats were pivotal, or at least highly significant. Early changes and extinctions may not be related to these later events. Indeed, sometimes it is hard to be sure what is an early extinction and what is late because of the skimpy nature of records from the first European contact to the late twentieth century. For example, if Andrew Bloxham had not fortuitously visited Ma`uke in 1825 and recorded some of the avifauna, one might regard any skeletal remains of the species of starling and fruit dove, he saw, that might come to light in ancient Polynesian middens as `prehistoric extinctions'.

The model presented here also implies that once thresholds were reached new equilibria were attained, and that instability was not necessarily characteristic of the greater part of the history of human settlement on Rarotonga, and perhaps other Polynesian islands. However, this should not mask the important changes in the ecological structure. For example, the level of dynamism within the local ecology may been reduced by the barriers to dispersal (*cf.* Zimmermann and Bierregaard 1986).

9.3 Wider Implications for Environmental Changes on Pacific Islands.

Theoretical approaches to environmental archaeology have been discussed (eg Burrin and Scaife 1988; Butzer 1982), but have as yet received little or inadequate attention. One area in which this is most apparent is that of the question of the environmental impact of Polynesian settlers on the islands of the Pacific.

The first problem is the historic processual model of islands in a perfect `natural' state being radically altered and degraded by the settlers, and then, continuing degradation causes partial, or, in some cases, total abandonment. Associated with this problem is the issue of extinctions.

At times Polynesian archaeology seems obsessed with the concept of `extinctions', rather than the concepts of `succession' and `equilibrium'. The loss of a species or genus may have wider consequences or it may not. Equilibrium in a community or in the whole biome may be maintained by the individual species replacing themselves or being replaced by other species with similar roles (Begon *et al.* 1990: 646). It is important to consider the response of communities to invasion and extinction in wider successional terms, not just in terms of genetic discontinuity. These arguments can also be applied to other aspects of the environment. The presence of certain geomorphological structures and their association with human activities and natural ecologies could be investigated from the point of view of equilibrium and instability.

The tropical Pacific should be seen as a whole environment rather than a number of small microenvironments separated by vast tracts of non-environment. Such terms as `remote' and `extinction' and such concepts as genetic continuity or genetic relationship may not be so useful as they first seem. The tropical Pacific must be seen as a whole environment, related by structure and function.

With this in mind, one could question the assumption, implicit in much research conducted into Pacific Island ecologies, that such ecologies are tenuous and highly fragile (Fosberg 1963: 5). More likely, these ecologies are and were extremely dynamic. The ecologies of small islands are susceptible to rapid turn over in the number of species (Zimmermann and Bierregaard 1986) due to speciation and the disruptive effect of the occasional arrival of new species (via avian vectors since bird populations could have been much greater than thought prior to human colonization), all set, in tropical Polynesia, against a background of a dynamic and changeable climate involving storms, floods and droughts.

The whole concept of `climax vegetation' is highly dubious (Colinvaux 1986), because it assumes ecology and environment are naturally static or at least cyclical (the same patterns will always manifest themselves). For instance, in New Zealand, forest is usually assumed to be the `climax vegetation', except in exceptional circumstances such as in drought-ridden Central Otago. This may not have been the case, or even if it were, the composition of the forest probably varied widely in both space and time.

Few studies have attempted to integrate ethnography, ethnobotany, archaeology and geomorphology in order to examine human-environment relations. One such case was that of Tikopia (Kirch and Yen 1982), where again an exponential rise in population and environmental `degradation' was postulated, with accompanying warfare, leading to exile for some of the people. However, the evidence was not viewed from a detailed ecological perspective. Ecological theory is necessary to refine the analysis of such data.

9.3.1 *Extinction*

Sea birds may have once been the main vectors of new species to Pacific islands, only later to have been replaced by humans (Carlquist 1967). These new species may have been equally destructive and disruptive of these island environments as those introduced by human beings. Today, sea birds inhabit those smaller atolls and cays that are only visited by or sparsely inhabited by humans. This would not always have been the case - more logically they would have frequented the larger and richer islands, and would no doubt have achieved larger populations (this in turn would have made them even more important vectors for other organisms, especially plants, arriving on Pacific islands). The idea that the animal populations, including birds, would have been much greater is perhaps supported by the original name of Atiu, `Enua manu, which means land of animals (or birds - the word can be used for both), though the story of Atiu's discovery specifically mentions gnats (Pakura and Ngatamariki Manu 1984).

In their heyday as bird `sanctuaries', many islands first experience of human contacts may have been birding expeditions, much as has been recorded for smaller uninhabited islands such as Nassau (from Pukapuka) and Takutea (from Atiu). Distances, as has been shown both by experimental voyages and by computer simulation carried out by Irwin (1992), were not off-putting in terms of time taken, and would have certainly been worth while for the rich pickings that the author is postulating. One must above all consider structure, because this is of a more fundamental nature, and because, if the author is indeed right, genetic disturbances may be a pre-human and thus already well-established feature of island life. Did humans resemble other aspects of the pre-human environment- for example, the sea birds? After all, humans are also vectors of new organisms.

Endemic land birds are regarded in the literature as being without predators, so that their deliberate destruction by humans would have been inevitable. This is naive. In tropical Polynesia, large crabs and some sea birds attack both eggs and nestlings of different species of birds today. For instance, the *Kopeka* or Atiu Swiflet (*Aerodramus sawtelli*) not only builds its nest in dark caves: an adaptation avoiding predation by larger birds, but also builds it on the cave roof to avoid the claws of large land crabs. The effect of rats on landbirds is significantly different on tropical islands than on temperate islands, because of the presence of such land crabs as *Birgus latro*, the Coconut or Robber crab (Atkinson 1985). In other words, they have already developed some resistance to a similar type of predator.

The possibility that the Polynesian rat (*Rattus exulans*) was responsible for the extirpation of sea birds or even land birds does not therefore seem very likely. Though it no doubt preys on the weak, eggs and young of various birds, it would not have necessarily threatened species altogether, because it represents a type of already existing predation, unlike some of the

While human interference is likely, an alternative explanation is possible for what form that interference took. Firstly, it seems unusual that the first settlers would have settled the raised interior first rather than the coast or the swamplands, as appears to have happened on other Pacific islands (even on makatea islands, coastal archaeological sites can be found - on Ma`uke, one of the earliest known sites is coastal). It may be that the coast, swamplands and raised hilly area were used contemporaneously in the period of the earliest settlement, though still, evidence from elsewhere would suggest an emphasis on coastal settlement. The hilly area also has no water and does not appear to have archaeological traces of settlement, whereas lower lying areas, including the lower slopes of the interior, do (Bellwood 1978: 143). The soil is, in addition, easily erodible when exposed as more recent attempts at agriculture appear to show.

If the interior, was covered in fernlands and *Casuarina equisetifolia* trees before humans arrived, whilst the lower slopes of the hills by the swamplands and the swamplands themselves, on the other hand, were covered in dense vegetation, particularly forest, the same results could be obtained from the above research. This is because the vegetation on the lower slopes and on the swamps could have prevented the free-flow of natural erosional material as well as pollen and spores from the interior, so that the pollen record from Lake Tiriara would reveal the local pollen spectrum from the makatea and the lowland forest, except for a small percentage like between 5-20 % (though the lake may have been larger and have received more regional pollen). Even this small percentage may have been smaller if the interior was covered in ferns, as these are largely transported by rain wash.

Once people arrived, in order to exploit the rich swamplands, they would have had to have cleared away the vegetation from the swamps and make room on the lower slopes and valleys for their homes and other structures. Then, the network of drainage ditches and patches would have had to have been constructed. The lack of barriers against any movement of silt, especially during floods, would have allowed it to traverse the swampland and reach the lake. Drainage ditches, combined with regular weeding, would have facilitated this process. Soil from the interior could also have reached the swamplands by direct and deliberate mulching in the way described to the author by Vakapora Alamein on Rarotonga (see Chapter 6). Charcoal could come from a number of human burning activities, including the removal of regrowth from abandoned taro patches such as seen by the author on Rarotonga today.

In this way, the appearance of *Casuarina equisetifolia* from this time need not imply it was a human introduction since it could simply be a taphonomic problem. Its presence before Zone KK4 - 1 from Karekare swamp could suggest it may well be indigenous to the southern Cook Islands. However, as indicated below, its pollen can travel great distances, and its presence before initial human settlement must remain suspect.

Ellison (**in press**) now argues a date of 2500 BP for the first settlement of Mangaia on the basis of anthropogenic changes. Pollen diagrams, this time from a number of swamps showed similar types of changes as outlined above. It is suggested that an initial clearance of forest took place at this stage, with a more major island-wide clearance event at 1600 BP as proposed by Kirch *et al.* 1992. However, changes of time against depth reveal a sudden drop in sedimentation rate just after C-14 dates of *circa* 2500-2400 BP, when increased sedimentation due to erosion would usually be expected, especially with the *makatea* as a sediment barrier (at Karekare swamp, Rarotonga, the coral rubble ridge has a similar role). A lack of dates from the last metre or two of sediment hinders assessment of whether the sedimentation rate change was only temporary. Comparison with Karekare swamp implies the drop would continue.

An explanation for a fall in sediment accumulation is that the swamp was cultivated, causing some degree of truncation, compaction, oxidisation and mixing of the top sediments. In fact, Ellison (**in press**) states that the swamps are at present cultivated. Also dates within the top disturbed horizon may have been contaminated by the rise in charcoal values as recorded by Ellison (see 7.8.2). Hence the dates must be considered as *terminus postquem* and *terminus antequem* only. It is worth noting that some of Ellison's data comes from the swamplands around Lake Tirira, the cores from which showed no evidence of disturbance at 2500 BP (Kirch *et al.* 1992, though the Lake Tiriara core is being reconsidered with this in mind - Flenley pers.comm. 1993). The evidence from Lake Tiriara is much more likely to be reliable as no direct human interference with lacustrine deposits is probable. Possibly some minor local changes may not be recorded, though given the number of swamps from different areas that have yielded this evidence, the changes do not appear to be that localised.

Kirch and Ellison (1994) now argue that initial settlement would have been in the infilled valleys, which have between 1 and 6 metres of deposits on them, though according to their own dating everything below 2 metres would predate human settlement, and anyway this type of settlement pattern contradicts existing knowledge about early settlement patterns (*cf.* Walter 1990; 1993; **in press**). Their refutation of Spriggs and Anderson's (1993) claim that extinctions should have occurred more rapidly on the basis that the *makatea* would have been difficult to penetrate seems more convincing. The idea, however, that the vegetation changes (now suggested as being between 2450±80 BP and 1640±50 BP) recorded in the swamp deposits are evidence of early settlement is only backed up by the same evidence as above, and thus is still subject to the real possibility of truncation or contamination.

On Atiu, Parkes argues for a similar sequence of events as proposed by Kirch *et al.* (1991), except the beginnings of human impact appear at about 1310 BP, based on evidence from Lake Te Roto (Flenley and Parkes 1988; Parkes *et al.*

1987; Parkes n.d.). Using pollen, diatoms, and chemical analyses, she produced similar results to those from Lake Tiriara on Mangaia, though charcoal counts were inconclusive due to the low values encountered. *Casuarina equisetifolia* only appears with this period of interpreted human impact, except for a single grain well below this level (before 7579 BP), which was explained as being a case of long distance dispersal. In addition, *Hibiscus tiliaceus* also occurs for the first time, and is suggested as an aboriginal introduction. From the evidence of Karekare swamp, this is unlikely to be the case. Diatom evidence showed eutrophic conditions from the period of postulated human impact, no doubt due to erosional material entering the lake. Again, clearance of lowland forest and conversion of swampland to taro gardens could equally explain the data: even the rise in grasses and sedges could represent fallow areas (see Chapter 6). Once again, archaeological evidence on the upper slopes of the interior are lacking (Trotter 1974: 96).

From 7580 BP to 3100 BP, there are dramatic increases in coconut pollen, which could represent human cultivation of coconuts (Flenley 1990). Coconuts, while they appear to be indigenous in the southern Cook Islands (see 9.3.3), would no doubt as a food source have been cultivated. In this case, the dating of this event is well before existing archaeological evidence and well before any hitherto suspected date of colonization by humans. Though this may still be the correct interpretation, the event can be explained in terms of natural phenomena, without the need to challenge the existing archaeologically-based chronology.

At the bottom of the lake muds are peaty deposits suggesting lower sea level. It is possible that alternatively coconuts, which had survived in sink holes in the makatea, now expanded due to the rising water table, perhaps even into the lowland swamps and valleys. The presence of high values for *Acrostichum aureum*, the swamp fern, tends to support the idea of natural vegetation change, as rising water levels would have created a much greater area of swamp to grow on. Also the presence of more ferns and *Casuarina equisetifolia* in the bottom layers could imply that prevailing drier conditions permitted it to occur nearer the swamp than today. The fall in coconut values may be due to increased siltation leading to a greater ratio of sediment to pollen rain, or, if coconut trees were growing in the swamplands, to their clearance for taro gardens.

On Aitutaki, Allen (1992) argues that erosion due to clearance of forest and agricultural activity caused soil run-off into the lagoon, which in turn led to the demise of pearlshell there. She uses the supporting evidence of the decline in landbirds (Allen and Steadman 1990), the paucity of primary indigenous forest taxa in charcoal remains and the replacement of native landmolluscs by exotics. There are a number of problems with this explanation. The decline in native landbirds may not have been as drastic as she claims, as the evidence lacks detailed time control as shown in section 3.2.2. The charcoal remains are the result of selection by people, and as shown in section 6.3 and Appendix A.5, there was likely to have been a concentration on cultivated timber rather than primary forest species (though this may, of course, be a feature of later periods after cultural changes). The replacement of native landmolluscs by exotics in a cultural context is hardly surprising: it would be more informative to know how molluscan communities fared outside the areas of direct and constant human influence. Finally, lagoons naturally infill as Allen (1992: 194) admits, so evidence is needed to show that the rate of infilling increased and that this was greater than the natural rate.

In the Society Islands, Parkes and Flenley (1990), Flenley and Parkes (1988) and Parkes (n.d.) argue that Lac Temae on Mo`orea has evidence of degradation of the landscape on the basis that influxes of erosional material and pollen from the interior, especially the uplands, represent cyclonic activity where accompanied by an influx of calcareous material, and represent human deforestation where unaccompanied by such an influx. At about 1160 BP, the latter circumstance occurred which led Parkes and Flenley to propose this as the beginnings of deforestation at least in the vicinity of this site. This deforestation is alleged to have caused erosional deposits to block off the brackish lake of Lac Temae, which was formerly a lagoon.

In this instance, there is the problem that pollen from primary forest taxa actually undergo an increase at the point where human interference is implied by the above authors, though Parkes and Flenley argue this pollen is washed in with soil. Next, the general trend is towards progradation of the land as evidenced by a gradual decline in dinoflagellates even before the terrestrial basaltic deposits between 710 and 640 cm. The coincidence of a decline in *Pandanus* values at this time and later where dinoflagellates finally decline again, suggests its pollen may have entered the swamp via tidal waves from the coral *motu* between the lagoon and the sea. Since *Pandanus* values are highly significant throughout the sequence and are the largest component of the secondary tree taxa, this may indicate that there was no actual decline in interior forest, and in addition, there was no decline in *Pandanus* either.

As the authors suggest the present day absence of the arborescent composite, *Fitchia*, is significant. Its non occurrence suggests it has obviously become extinct at some stage - perhaps due to the extinction of an important pollinator like a bird, which may have become extinct due to the same reasons as proposed in the theoretical model for environmental change on Rarotonga (see section 9.2). It is unlikely that such a large pollen grain from a zoophilous flower would have been blown over from Tahiti, where *Fitchia* still exists.

A temporary ponding of Lac Temae at 710 cm may have increased the possibility for freshwater flooding and therefore for an increase in land deposits and a decrease in marine deposits. At about 6 metres, ponding began again, except permanently. Charcoal percentages may have increased due to the increased terrestrial component of the sediments, though it may still represent human activity even in this scenario. If a change occurred in the source of the sedimentation, the charcoal may represent people using fire in a limited and controlled way; if not, then it may more likely be connected to erosional events. Erosional material would still require a mechanism to transport it to the lake, whether people were involved or not. Rainwater may account for silt arriving in the lake, but larger detrital fragments might require a more forceful vector, unless the detritus was fairly local.

A pollen core taken from Lake Vaihiria, on Tahiti, spanned the last 500 years, and revealed a sequence of change, possibly involving human disturbance (Flenley 1987; Parkes *et al.* 1992). The lake was formed as a result of a landslip, and has a percentage of fern spores probably due to the extremely steep slopes around the lake. The pollen data shows that the lowest two metres (interpreted as representing 1500-1700 AD) have relatively higher values for primary and secondary forest taxa. Chemical analyses and loss-on-ignition tests indicate mesotrophic conditions. Except for fleeting episodes of disturbance evidenced by short changes in the pollen and diatom records, this period seems to have been relatively stable. These episodes have been attributed to cyclones and human activities.

The next two metres (1700-1900 AD) sees two discrete episodes with an increase in secondary taxa and Pteridophyta. Nutrient levels increase too, and the loss-on-ignition tests give the lower values. This is explained as being due to the increase in population and its extension further inland. Diatoms indicate increasing murkiness of water from around 2.25 m. Finally, introduced species occur in the top 0.84 m of sediment, and nutrient values decline again. Diatoms also indicate clearer water. This is interpreted as the end of disturbance after the decline in population due to introduced European diseases and the movement of the population to the coast.

One of the main problems with this interpretation is the fact that these episodes of disturbance are only represented by one or two samples each, and include rises in *Freycinetia impavida* sim., *Pandanus* and sedges. The first as a forest liana is hardly indicative of disturbance and the third is surely most likely to have grown on the lake margins, not competing with the primary forest at all. *Pandanus* too is a major component of the present day slope forest. *Pandanus* and *Freycinetia impavida* sim. are listed as primary taxa in the pollen diagrams, but are regarded as secondary in the text.

Indeed, greater values for secondary taxa like *Trema*[55] in the deepest two metres may be significant. The overall decline in magnetic susceptibility values may be connected with this. In addition, primary taxa are at their lowest levels in the sequence at this depth. Finally, there are so many fluctuations of a similar degree of magnitude that regular cyclonic activity could as easily be responsible. Parkes *et al.* (1992) do recognise that there is a possibility that the sequence is a natural one, though they opt for human impact on the basis of archaeologically recorded human presence in the area. The author, however, prefers the idea of a natural sequence due to steep contours of the land around the lake and the high frequency of peaks and troughs throughout the pollen sequence.

The idea that the lateritic soil[56] under fernlands represents degradation has become firmly entrenched in the archaeological literature (e.g. Kirch 1984: 139-143). Firstly, lateritic soil is not degraded, though laterite soil (which occurs with induration) is degraded. Secondly, the lateritic soils under forest as well as under fernland on Rarotonga are thin and immature and unsuitable for agriculture any way (*cf.* Leslie 1980). It is often argued also that the fernlands growing on laterite soil characterise a situation in which forest cover has been removed, leading to leaching and erosion, which in turn creates the soil conditions.

However, there are three good reasons to doubt the validity of this belief (McFarlane 1976: 46-52). One is the common association of laterite and grassland commonly put forward as one line of evidence. Yet, the edaphic nature of these grass communities suggest they exist because of the laterite rather than the laterite having been caused by them[57]. Forested areas, including areas supporting clearly documented cases of recently existing forest, on laterite soils are not unusual; something which would also apply to lateritic soils. A second is detailed investigations of how desilicification and iron stability are affected by vegetation, which indicate that laterite development and rich vegetation are not incompatible. The third is that the damaging effect of forests on truncated or unstable soils has been unsoundly used as evidence against laterite soils developing under forest cover. These arguments could equally be applied to the debate about the lateritic soils under fern cover.

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55 *Trema* seems to occur in all forest types on Tahiti. This may be due to landslips (caused by the steep slopes) frequent enough to allow its survival. Also, it could be that the forest was already `secondary', due to earlier human disturbance (Flenley pers. comm. 1993).

56 Laterite has been variously described in the past as a rock, weathered rock and a precipitate, but is now considered as a soil type (McFarlane 1976: 1-9).

57 In other words, the grasslands are commonly associated with laterite, but the laterite does not exclusively bear grasslands.

The soil of the fern-covered volcanic interior of Mangaia, it is suggested, was degraded by removal of a purported forest mantle (Kirch *et al.* 1991; 1992). It is at present successfully being forested with a variety of tree species (personal observation 1992), so there cannot be too much wrong with it (though fertilisers may have been used by foresters). This implies that either the fernlands were being continuously maintained or that forest was unable for some reason to establish without human-intervention. Parkes (n.d.) suggests that on Atiu, with a similar kinds of conditions, though on a smaller scale, *Casuarina* trees were deliberately planted on the volcanic interior. On both these islands, there is no archaeological evidence for settlement on the fern-covered interior; the nearest settlement is on the lower slopes of the interior (Bellwood 1978).

Another example is the `Opunohu Valley of Mo`orea. Although there is substantial evidence for settlement in the `Opunohu Valley, archaeological investigations there have revealed only one marae with associated platforms, and no other structures, in all the hilly area under fern growth today (*cf.* Descantes 1990: 169). Instead, settlement was associated with the inland streams and slopes on either side of them (*cf.* Descantes 1990).

Another well-known case of Polynesian deforestation is that of Easter Island (Flenley and King 1984; Flenley *et al.* 1991; Dransfield *et al.* 1984). Here again, there is the danger of archaeologists assuming that forest was removed largely by Polynesian settlers before European contact. Flenley and King attribute most of the vegetation changes to climatic variation, though state that the final deforestation was possibly human-induced, albeit with forest regeneration being prevented by rats.

Three volcanic craters were cored: the first revealed deforestation from after a 6,650 BP date[58], the second from at least 37,680 BP[59], and the third from 1,000 BP. The second crater revealed a lack of woodland from at least 37,680 BP, though this is not claimed as anthropogenic deforestation. It is interesting to note that there are always high values for grasses and ferns in the highest altitude core (Rano Aroi), so the higher ground must have been fairly open. In the Rano Kau (Kao) core, the vegetation must have been fairly shrubby with high values for *Triumfetta*[60], and only at Rano Raraku, the lowest lying of the cores, are palm trees predominant. These arguments are considered by Flenley *et al.* (1991), who base their conclusions on Rano Kau, the last site mentioned, due to the firmer dating. Though there is one date out of sequence in the Rano Kau core, this could be caused by the inversion of a floating mat (Flenley *et al.* 1991) or younger material being swept under a floating mat. The other dates do seem to give a consistent sequence.

Flenley *et al.* (1991) argue that Easter Island, at the time of initial Polynesian settlement, consisted of lowlands wooded with palm trees and *Sophora*, with a significant shrub layer, and higher altitudes, where shrubland with a significant herbaceous component predominated. The author only differs from Flenley *et al.* (1991) in that he proposes the possibility that there may have been a phase in between the extinction of the palm tree and early European contacts, where sizeable tracts of *Sophora*-woodland and shrubland continued to exist.

The number of trees that would be needed to shift the Moai statues, if the same timber were used several times over, many not be so great as to have seriously depleted the forests. Bahn and Flenley (1992: 173) also suggest the manufacture of large canoes (evidenced by petroglyphs) could have used palm timber (due to the lack of alternatives), though they admit this type of wood is far from ideal and its usage was uncommon in Polynesia. The importance of this as a cause depends on the frequency of manufacture and whether the Easter Island palm tree timber would have been suitable enough, especially for large canoes.

In fact, the testimony of the early European explorers may indicate some remaining woodland. Behrens, relating Roggeveen's 1722 visit, de Aguera, on the Spanish visit of 1770, and Forster and Cook, on Cook's 1777 visit, all mention some small tracts of low woodland (Heyerdahl 1961). They were unimpressed, due no doubt to the luscious vegetation they were finding elsewhere. Easter Islanders had to build protective enclosures, called *manavai*, against the force of the wind in order to grow *Broussonetia papyrifera* for their tapa cloth (Kooijman 1972), as well as other crops (Métraux 1940: 151-159). Earth dyes were used in place of the dyes gained from tree products used elsewhere in Polynesia, and these rubbed off very easily according to Roogeveen (quoted in Kooijman 1972). This suggests that Easter Island was not very suitable for forest growth (except perhaps for drought-hardy palm trees), and Roggeveen says the local environmental conditions were not conducive to the same (quoted in Kooijman 1972).

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58 This date is dismissed as being due contamination from inwashed material. Instead, a date of 1200 BP is claimed from a time against depth curve based on the remaining reliable dates.

59 This could be due to a relative increase in local taxa, like grasses, growing on the swamp. However, no swamp marginal grasses occur on Easter Island today, so caution is necessary in invoking this explanation.

60 This may be due to the location of the core site fairly near the edge of the swamp, which would give an advantage to the shrub and ground layers of the vegetation. Work in progress from a core further out in the swamp seems to be producing higher percentages of palm pollen (Flenley pers. comm. 1993).

Pollen work on Easter Island showed declining values for woodland taxa between 1200 and 800 BP (Flenley and King 1984; Flenley *et al.* 1991), including the pollen of an endemic palm tree[61] that no longer exists (Dransfield *et al.* 1984). It was suggested that over-use of resources due to increasing population, monument-building, and warfare led to deforestation, with rats participating in the palm tree's decline. More recently (Bahn and Flenley 1992) even suggest that, bar a few relict trees growing on the crater rim of Rano Aroi, which overlooks the sea, every tree was cut down by the time of European contact. Some support for this explanation was found in the discovery of root casts from large trees under an archaeological site by Mulloy and Figueroa (1978).

However, as Bahn and Flenley (1992: 172-173) argue, it could be that the introduced rats eating the fruits of these palm trees - for example, preserved fruits from a cave have been found having been gnawed by rodents (Dransfield *et al.* 1984) - were in fact the principal cause. The removal of the palm trees on the low lying areas by this means would have removed shelter from smaller trees helping to reduce their size over time due to high winds. This would explain the survival of low tracts of woodland when Europeans arrived; they would have been the natural woodland minus the palm trees. The removal of this woodland may have had something to do with the livestock from colonial sheep farming enterprises in the nineteenth and twentieth centuries (though the sheep farm did not include the southwestern corner), and of course the reduced standard of living of local Easter Islanders after their removal to one end of the island to make way for these ventures.

Much has been said regarding deforestation in New Zealand. While it is usually acknowledged that much of the clearance is post-European contact in origin, many have argued that equal or greater destruction of forest occurred before. Wilson (1990) shows that much of the deforestation was in fact after European contact. Deforestation by Maori is argued according to when the first Polynesian settlers are assumed to have arrived (for example, Sutton (1987) commenting on McGlone (1983), who rejects earlier dates and does not question the reliability of later ones involving large scale clearance and much charcoal).

Newnham's (Newnham *et al.* 1989; Newnham 1990) evidence from Lake Rotomanuka, in the Waikato, shows European exotics appearing at around 500 years ago, according to his calibrated scale, with a peak in fern spores immediately below it, apparently due to Polynesian clearance starting at 7-800 years ago. It would hardly be surprising if this were not all datable to the last 200 years, and that there has been either truncation and/or contamination.

Chester (1986: 71) used as evidence of traditional Maori practice widespread burning of forest, the journal of Colenso from 1841-1842 and two other sources from the 1840's, and does not mention the possibility that Europeans in the area during the late eighteenth / early nineteenth century would have had any influence beyond providing iron tools and European plants, and later on, increasing the area of grassland (Ibid: 265). Deforestation was seen as largely prehistoric. Bracken was interestingly present in significant amounts right the way through her sequences, with little fluctuation. Also, the main peaks in charcoal occur in the samples just below those containing European exotics, except in one case where a series of peaks occurs, with the last one occurring before the appearance of the European exotics. Given the spacing between dated samples, a similar situation to Newnham's pollen diagram from Rotomanuka could be involved.

A review of the historic context must lead one to entertain, if not in some degree be persuaded by, different conclusions. Europeans needed feeding, Europeans wanted timber, flax and agricultural produce to sell elsewhere like the colony of Sydney (and the port of Kororareka), which drew much of its food from New Zealand (Howe 1984), and Maori wanted metal, European cloth, muskets and other European trade goods. Also, some Maori wished a small number of Europeans to stay in order to learn more about European crafts, law, religion and anything else that might be considered useful to them. This trade brought Maori within the influence of the capitalist system, so that to sustain this trade, forest had to be felled to provide timber, and extra land had to be cleared for surplus cultivation. By the time Colenso arrived (*cf.* Schaniel 1985), there was also another demand on Maori food and raw material production, the new colonies of Auckland, Wellington, Wanganui, New Plymouth and Nelson (Sinclair 1988). These new arrivals would have been especially dependent on the Maori at this stage as they would not have had time to establish an economic base of their own[62].

Schaniel (1985), using documentary records, has revealed that this process started well before the establishment of the British colony. Potatoes, kumara, corn and watermelons were grown in increasing amounts to satisfy the demands of European traders (Ibid: 215-218). For example, Marsden wrote in his journal of 1819:

> I believe there is ten times more land in cultivation at the present time in the districts round the Bay of Islands than there was in 1814, when the missionary settlement was first formed. [Marsden 1932: 176].

The evidence, even from Auckland, which is so often claimed to have been at least partially deforested by Polynesian settlers (*cf.* Millener 1979) - the other part being volcanic activity - is not quite as supportive of the `ecological destruction'

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61 This has since been named `*Paschalococos disperta* J. Dransfield' (p.64 in Zizka 1992)

62 The records of the population of these towns are only of the European section. Half-castes and Maori are not mentioned, though they could account for a significant proportion of town-dwellers, especially the half-castes (Wilson, Dean, graduate student, Dept. of History, University of Auckland pers.comm. 1991).

argument as is sometimes implied. Despite the past density of Maori settlement (Davidson 1975) and years of contact with Europeans and the consequent capitalist influences, some paintings and photographs reveal some large areas of woodland on the Auckland isthmus. For example, a painting of 1844, showing the Te Wherowhero's meeting with British government officials, shows woodland at the bottom of Remuera (Platts 1971: 94, Figure 38), and a painting of John Kinder's from 1857 (Dunn 1985: 57, Plate 35) demonstrates the existence of woodland between Remuera and to Maungawhau (Mount Eden). A later photograph from about 1863 by John Kinder shows more of this woodland in the valley of Newmarket (Dunn 1985: 170, Photograph 177), although some of this was clearly being removed at this time for European settlement. Another of Kinder's paintings from 1855 discloses the presence of woodland in Grafton Gulley (Dunn 1985: 118, Plate 103) as does another contemporary painting (Platts 1971: 51, Figure 23) from the early 1840's.

It seems unlikely that a Maori population could have survived far from sizeable woodland areas. Firewood was needed to cook food every day, timber was needed to construct houses, storage pits (*rua*) or store houses (*pataka*) and canoes, and woodland itself was a source of wild food.

Pollen evidence from the Aotea Centre Excavations in Queen Street showed deforestation at around 7-800 years ago (Newnham 1990). The core taken by Newnham from Waiatarua shows how localised vegetation changes were, as there seemed to be a lack of significant vegetation change despite the eruption of Maungarei (Mount Wellington) nearby. In the case of Queen Street, which is in a gully, it is easy to imagine that the pollen represented would also be fairly local.

It is possible that a certain amount of the open-country vegetation was natural. Possibly, the water-table on the plateau was too low and the soils too thin and leached for forest to grow, whereas leached nutrients, soil and water flowed plentifully in the gullies and on the lower ridges, where swamp and pond formation took place.

The ideas of Chester (1986) were taken up by Sutton (1987) who proposed the possibility that human deforestation occurred over large areas between 0 and 500 AD should be investigated. The indications of deforestation could include factors such as a continuous charcoal record, silt influx and certain indicator species (for clearance) like bracken and various grasses. However, Enright and Osborne (1988) posed the alternative idea that natural events could have been responsible, and in the absence of archaeological evidence for earlier settlement, the archaeologists were obliged to provide proof. Grant (1988) asserted that it was normal for natural change to affect vast areas, and that burning episodes had transpired at other times during the last 8,000 years and earlier. Climatic change accompanied by periods of increased storminess, higher temperatures and flooding were the cause of greater levels of erosion and alluviation.

Nunn (1991) attributed deforestation in New Zealand to the Little Climatic Optimum when the climate would have been drier and vegetation more susceptible to fire on the basis that the orthodox date of human settlement occurred before the date for deforestation. He also concluded that human primacy was generally overrated as an agent of environmental change in the Pacific Islands, comparing the situation with the case of the northern Amazon Basin where it was declared that humans were responsible for large fires dating back to 6260 BP, though the evidence of human occupation only dated to 3750 BP; a conclusion in Nunn's view based on assumptions about human behaviour rather than solid material evidence.

Some studies show at least some sympathy with Nunn's view that too much environmental change has been ascribed to humans. Athens *et al.* (1992) combine human and natural change in their palynological and stratigraphical study of the history of lowland Hawaiian vegetation. They show that there was an abrupt decline around 1000 AD in native *Pritchardia* palms, *Dodonaea viscosa* and an unknown Tricolpate type 1. (probably a legume) on O`ahu, which they attribute to human impact. Only relict areas of *Pritchardia* woodlands were left. Some natural component is also recognised as possibly contributing, because there was already a steady decline in some species' pollen, like the Tricolpate type 1., and an increase in Cheno-am type pollen sometime prior to 1000 AD. While it is evident that the lowlands were cleared, with some areas producing secondary vegetation (as the author has proposed for Rarotonga - see above), unfortunately, events on the coastal zone (Sohmer and Gustafson 1987) were not represented in the diagram, except to say that *Cocos nucifera* appears to have been introduced.

However, Athens *et al*. (1992), challenge the notion that human activities were largely responsible for coastal progradation: sedimentation was at its lowest following Polynesian colonization, despite widespread and intensive occupation of the lowlands. An earlier article by Athens *et al*. (1989) in Micronesia came to the same conclusion. An apparently real lack of charcoal in the sediments on O`ahu suggested that fire was not always such an important part of clearance activities, with the plant material possibly being used directly as mulch.

In New Zealand, Grant's studies (1985; 1988; 1989) of sedimentation, McFadgen's (1985; 1989) investigations of sand dune deposition, and Jones' (1991) study of the Rangitaiki plains, suggest that the contribution of natural alluviation (and significant volcanic activity on the Rangitaiki plains) to the landscape make human impact negligable. In addition, McFadgen (1994) attributes sand dune deposition on Chatham Island to the same stormy weather that he (1985;1989) and Grant (1985; 1988; 1989) suggest caused alluviation on the main islands of New Zealand. Human settlement on Chatham Island (during an unstable phase) was in fact succeeded by dune stabilisation and soil formation.

9.3.3 *Plant distribution history*

Kirch developed the notion of `transported landscapes' in Polynesia, whereby humans modified new environments by introducing new organisms and landscape concepts from their original homelands (Kirch 1982; 1983). Some organisms were conveyed to new islands by accident rather than design, for example the weed *Ludwigia octivalvis* and the land mollusc, *Lamellidea pusilla*. Parts of the landscape would be converted into cultivations: for example, valley bottoms would be used for irrigated terracing, and forest would be cleared for shifting cultivation (Kirch 1982; 1983). Kirch (1982; 1983) argues that lowlands were conceived of in terms of agricultural systems, and that natural lowlands were converted into such systems by settlers. Agriculture in Oceania comprised two systems: pondfields for the cultivation of taro (*Colocasia esculenta*) and atoll taro (*Cyrtosperma chamissonis*) primarily, and swidden systems (`slash-and-burn') involving plants such as yams (*Dioscorea* spp.), plantains/bananas (*Musa* spp.) and kumara (*Ipomoea batatas*) (*cf.* Yen 1973 - though this last applies to East Polynesia in pre-European times).

However, this does not successfully incorporate all Polynesian cultivation systems, and is probably more reflective of the Hawaiian Islands and New Guinea than anywhere else. For example, tree crops, though significant in places like Tahiti, the Marquesas Islands and, of course, Rarotonga, do not fit into either category. Also, plantains can be grown for a number of seasons and can generate new plants from the same rootstock with continued mulching (Massal and Barrau 1956), without the necessity of swiddening. The assumption of intensive concentration on a small range of cultigens may not be valid everywhere, and may be inspired by the modern situation (*cf.* Entwistle and Grant 1989). A broad-based economy with a wide range of cultigens and wild organisms may be more appropriate in some cases (*cf.* Appendix A.5; *cf.* Palmer 1989).

In addition, Best (1989), referring to lowland Fiji, argued that such models are not able to compare modern agriculture with the past because the dryland cultigens like dryland taro, kumara and cassava were not available to the early settlers. On Rarotonga, the status of swidden crops is as follows: kumara may have been available, but does not appear, at least by the time ethnographic practices were recorded, to have been especially important; cassava (manioc), pawpaw, citrus fruits, tomatoes, and many other common crops today are European introductions; dryland taros (*Colocasia*) may have been available[63] (Savage 1962), though, like kumara, do not appear to have been important at least in later periods; and giant taro (*Alocasia*) was grown at the top of the valleys as a famine food according to oral tradition (see Chapter 6), and wherever it is grown today in lower locations, it is in places with plenty of moisture and shade. This leaves only plantains as a significant possible swidden crop, though mountain plantains (*Musa troglodytarum*) like giant taro have high moisture requirements (Afsenius 1988a) and are thus restricted in where they can grow.

Barrau (1965) divided Oceanic agricultural systems according to the natural habitat from which the cultigens originally came. Two systems were identified: one based on permanently humid rainforest, and the other on seasonally humid monsoon forest, savannah woodland and grassland.

Rarotonga's coastal plain and the lower parts of its valleys would fit into the second system, whilst the upper parts of the valleys correspond more to the first system. Hence, in the oral tradition evidence provided to the author (see Chapter 6) and the evidence of missionary records, it would seem that breadfruit trees and plantains were grown in the lower-lying areas because they are better adapted to the warmer, drier conditions, whilst the taro and mountain plantains were grown further up the valleys, where reliable all-the-year-around supplies of freshwater were available.

Another example of selecting a crop for a particular environment is atoll taro (*Cyrtosperma chamissonis*), which was grown in the swamps of the coastal plain of Rarotonga, where conditions more approximated that of atolls. Atoll taro is tolerant of flooding and saltwater (Tara`are pers. comm. 7/08/92). In the lowland alluvial plains of Viti Levu, Fiji, atoll taro was the principle crop no doubt due to the extremely poor drainage conditions in many places (Parry 1984). Taro (*Colocasia esculenta*) though a swamp plant, does not tolerate complete inundation of the corm (Tara`are pers. comm. 7/08/92).

Barrau's model is perhaps more suitable than Kirch's because it allows for a greater understanding and experience of the behaviour of the cultigens and where they fit into the landscape. Kirch's model may be more likely for colonists moving into an environment of which they have little previous knowledge, and where the reaction is more likely to be one of the imposition of the artificial on to the natural, rather than the fitting in of the artificial into the natural.

Some plants may have occurred on many islands and were simply utilised when found, without the need for any transportation. Other plants having a wide natural distribution may have been replaced anyway due to the availability of superior cultivars of the same species, so will appear to have a continuous history, even though the natural variety is no longer present. These plants would have already a natural place in the ecology of such islands, and would simply need to be favoured against other plants, not so useful.

63 Of the 23 cultivars of taro (*Colocasia*) mentioned, one was an introduction from Samoa, and only one cultivar was of dryland type. Even this (tarotaroa) is suspicious as it is very similar to the Maori name for *Xanthosoma* (taro tarua).

The case of coconuts is one such. Although sometimes postulated as human introductions (for example, Merlin 1985), pollen evidence from Lake Te Roto, Atiu, Lake Tiriara, Mangaia and now (in this study) Karekare swamp shows that they have been present from at least 8000 years ago, well before suspected human arrival. In addition, Spriggs (1986) has coconuts dated to 5040 ±370, 5410 ±100 and 5420 ±90 respectively from Anauwau swamp, on Aneityum in Vanuatu. The existing varieties of coconut are, though, most probably introduced: oral tradition from many islands records that coconuts were introduced (for instance, Manihiki and Rakahanga - Buck 1932a), and the archaeological record elsewhere documents the arrival of such cultivated varieties (Lepofsky *et al.* 1992). Non-cultivated coconut trees could then have been increased by introductions of cultivated forms and through deliberate planting and/or clearance of other trees where necessary.

Casuarina equisetifolia, the ironwood tree, has been conjectured by Merlin and Franklin as an indigenous tree, though utilised (Parkes n.d.), but this has been rejected by the work of Parkes on Lake Te Roto, Atiu and Lac Temae, Mo`orea (Parkes n.d., Parkes and Flenley 1990) and by Lamont on Lake Tiriara, Mangaia (Kirch *et al.* 1991, 1992, Lamont 1990), who found it only from the inferred date of human arrival onwards. Oral tradition (Kauta`i *et al.* 1984) from Atiu also states that the ironwood tree was introduced by Polynesian settlers.

However, as argued above, the pollen evidence can be interpreted differently, and both in the Karekare swamp and Lake Te Roto sequences, ironwood pollen occurs before the inferred date of human arrival (in the case of Lake Te Roto, well before). Although Parkes contends that this is pollen blown from other islands many kilometres to the west, this pollen type is neither especially small like many urticaceous pollen types, nor is it saccate like *Podocarpus*, so how far it could be dispersed in reality is debatable. Its bright red flowers might suggest that it is opportunist being both zoophilous and anemophilous, like coconuts. The evidence of the oral tradition again can be explained again in terms of better introduced varieties.

The appearance of *Casuarina* in the Easter Island sequences might support the notion that it could be dispersed over considerable distances, though it occurs only within the timespan of human occupation and might have been a human introduction later abandoned (Flenley *et al.* 1991). However, Close *et al.* (1978) have evidence of *Casuarina* pollen being dispersed from Australia to New Zealand, so this remains a very real possibility.

Hibiscus tiliaceus, on the other hand, regarded by Merlin (1985) as a Polynesian aboriginal introduction, appears in both KK1 and KK4 core samples from Karekare swamp from well before human arrival has been postulated. Also, given the large size and weight of its pollen grains and its low production of pollen (see Chapter 2), long distance dispersal can not be offered in this instance as an explanation.

Barringtonia asiatica, used for fish poison, and *Pandanus*, cultivated for its leaves and fruits, are both found in the earliest deposits from Karekare swamp, and the latter in those from Lake Te Roto, Atiu as well. Again perhaps, particularly in the case of *Pandanus*, cultivars have replaced the natural varieties.

These five examples are all represented in the shore forest today (see Chapter 2) and have suitable drift dissemination potential to have achieved natural transportation to Rarotonga (*cf.* Smith J.M.B. 1990).

Another problem of plant distribution is that of local intra-island dispersion of species and the spatial patterning of plant communities. In other words, do certain species have the same distribution as today, do certain species achieve the same numbers as in the past, or are they adversely or favourably affected due to changing conditions, and are the associations seen in modern communities really adequate enough to explain plant behaviour in the past as evidenced in the pollen diagrams.

Some of the upland trees on Rarotonga may have been found on the coastal plain, especially *Canthium barbatum*, which achieves high frequencies at the top of Zone 4 in Karekare swamp. Comparison with some other islands may be useful. It may be that if the situation for the basal layers of Lake Te Roto, on Atiu, and Lake Tiriara, on Mangaia represents lower sea-level, and consequently, a lower freshwater table as well, many forest taxa were forced into refugia either in sink holes in the makatea, or more likely they congregated on the edge of the swamp at lake Te Roto and may be the marshy edges of Lake Tiriara. This is important to consider because in terms of the Quaternary as a whole, the modern distributions and perhaps behaviour of Pacific Islands plants represent usually restricted and confined conditions.

It is useful to compare distributions of the same or related species elsewhere at the present time. *Canthium* ecology in south-eastern Queensland, Australia, shows a tendency towards coastal rainforest, sometimes near creeks and on poor soils and stony ridges (Stanley and Ross 1986). In the Sydney region of Australia, *Canthium* species again show a coastal distribution (Beadle *et al.* 1972). So perhaps *Canthium barbatum* could have been found on the coastal plain, including along the swamp and stream edges. Finally, evidence from Southeast Asia and the western Pacific shows members of the genus actually occurring in swamp forest (Flenley 1979; Whitmore 1975).

Other inland trees may also have been represented on the coastal plain, like *Elaeocarpus tonganus*, *Ixora bracteata*, *Hernandia moerenhoutiana*, *Homalium acuminatum*, *Fagraea berteriana* and *Alstonia costata*. *Ixora* and *Elaeocarpus* species in south-eastern Queensland are represented in coastal rainforest, though *Ixora* also occurs in dry forests and *Elaeocarpus* can occur on sandy soils on offshore islands (Stanley and Ross 1986). In the Sydney region, *Elaeocarpus* is located in gullies, sheltered places, coastline and adjacent plateaus. In Fiji, *Elaeocarpus* can grow from near sea-level (Smith, A.C. 1981) and *Ixora* as well, including in some cases in beach thickets (Smith, A.C. 1988). Near sea-level localities for *Elaeocarpus* are documented from Papua New Guinea (Henty 1981). *Hernandia moerenhoutiana* and *Homalium* species in Fiji occur from sea-level (Smith, A.C. 1981), as does *Alstonia* (Smith, A.C. 1988). One species of *Homalium* in Queensland is a lowland forest species (Briggs *et al.* 1982). *Fagraea berteriana* can grow from sea-level within its distribution in south eastern Polynesia. The climber, *Loranthus insularum*, in addition, can be associated with coastal forest, even on rare occasions on the edges of mangrove swamps (Smith, A.C. 1985). Examples from Southeast Asia and the western Pacific show *Elaeocarpus* species can be found in swamp forest (Flenley 1979; Whitmore 1975). Current distributions, therefore, may not be an accurate guide to the past.

Some trees, however, from such comparisons appear unlikely to have spread out on to the coastal plain: *Weinmannia samoensis*, *Metrosideros collina* and *Fitchia speciosa*. In Fiji, *Weinmannia* species are situated at above 150 m a.s.l. or even 300 m (Smith, A.C. 1985). *Metrosideros collina* is restricted to the cloud forest above 400 m a.s.l. today on Rarotonga, though occasionally individual specimens are found in the fernlands of the lower slopes (Merlin 1985). *Metrosideros collina* in Fiji also exists on open hillsides (Smith, A.C. 1985). *Fitchia* in its distribution over Rarotonga, the Society Islands, the Tuamotu Islands, the Marquesas Islands, Mangareva and Rapa (Iti) does not occur below 90 m a.s.l. (Brown, F.B.H. 1935), making it an unlikely candidate for the lowland forests, except the upper parts of the valleys perhaps. *Vernonia insularum*, an arborescent composite like *Fitchia* and occupying a similar niche to *Fitchia*, grows from 400 to 900 m a.s.l. in Fiji, where it is endemic (Smith, A.C. 1991).

Finally, coastal trees may once have extended further inland. Some still do, like *Hibiscus tiliaceus*, *Casuarina equisetifolia* and *Terminalia glabra* (Sykes 1983; McCormack pers. comm. 1990 and 1992). *Pipturus argenteus* exists from sea-level coastal thickets and dense, dry or open coastal forest to 1000 m a.s.l. upland forests in Fiji (Smith, A.C. 1981). *Calophyllum inophyllum* in Fiji ranges over a number of habitats at or near sea-level, including beaches, coastal thickets and along stream banks (Smith, A.C. 1981). Also in Fiji, *Barringtonia asiatica* does not extend far inland usually, being found at or near sea-level on beaches, in coastal thickets and on the edges of mangrove swamps and lowland rivers (Smith, A.C. 1981). This possibly means that the coastal plain, but not the valleys, would have supported *Barringtonia asiatica* populations. *Terminalia catappa*, related to *T. glabra*, stretches back into inland Fijian forests where it is dry or open along streams or in clearings (Smith, A.C. 1985).

Casuarina equisetifolia poses a more intricate problem. It may have been introduced to Rarotonga by Polynesian settlers; it may have had a coastal distribution originally, only being transferred later to the fernlands of the lower mountain slopes by these same Polynesian settlers; or alternatively, it may have been indigenous to both habitats. Fijian evidence, itself governed by the same problems, shows a distribution from sea-level to 475 m a.s.l., and in association with dry areas like sandy beaches, coastal forest and rocky coasts at the lower levels, and with grass and reed-covered hillsides and open forest at the upper levels (Smith, A.C. 1981). In south-eastern Queensland, this species has a coastal distribution, being linked to strand communities or just growing on open sand (Stanley and Ross 1983). In the Sydney region of Australia, other members of the *Casuarina* genus are associated with coastal woodlands, open heaths and dry hillside forests (Beadle *et al.* 1972), indicating Rarotongan fernlands may not be out of character for the species concerned here.

Hibiscus tiliaceus, outside of Rarotonga, is located on sheltered shores, estuaries, and the edge of mangrove swamps on sandy substrates in south-eastern Queensland (Stanley and Ross 1986), and in coastal and lowland thickets, often along stream banks in Fiji (Smith, A.C. 1981). On Rarotonga, it is a weed on abandoned swamp gardens, is frequent along boulder stream beds up the valleys, is generally a pioneer species everywhere, occurs at low frequencies in the upland forests, and is a coastal species (Sykes 1983; Merlin 1985; personal observation 1990 and 1992).

The distribution of some of the cultigens elsewhere is illuminating. *Artocarpus altilis*, the breadfruit tree, is found usually near sea-level in and about villages in Fiji (Smith, A.C. 1981). *Aleurites molluccana*, the candlenut tree, in south-eastern Queensland, has a moist, coastal distribution (Stanley and Ross 1983), and is common in the makatea on Mangaia (Merlin 1991). On Rarotonga today, candlenut trees and breadfruit trees are coastal, extending up cultivated valleys, though never really penetrating into the upland forest (Sykes 1983; Merlin 1985; personal observation 1990 and 1992). In south-eastern Queensland, *Alocasia macrorrhiza*, giant taro, grows in or near rainforest (Stanley and Ross 1989), and in Fiji, in damp places and along river banks (Smith, A.C. 1979), suggesting moisture is important for this crop. Hence, it is found today on Rarotonga in moist, shady places up the valleys and occasionally on the coastal plain (personal observation 1990 and 1992). *Pandanus* species in south-eastern Queensland have a coastal distribution on beaches and rocky headlands (Stanley and Ross 1989).

Ficus tinctoria, the dye-fig tree, and *Ficus prolixa*, the banyan tree, (whether or not Polynesian introductions) appear to have a present day distribution on Rarotonga of lowland cultivated valleys and coastal plain (personal observation 1990 and 1992). In Fiji, there are situated on rocky coasts and beach thickets (Smith, A.C. 1981).

Finally, one should consider those plants that might have been expected to have been represented but which were not, and determine the reason. *Pritchardia vuylstekeana* is found today in pockets dispersed through the makatea on Miti`aro, and was identified from pollen dated to between 8611 ±70 and 5680 ±55 BP in a core taken from Lake Te Roto, Atiu (Parkes n.d.). It is also found in the makatea on the island of makatea in the Tuamotu group (Papy 1954; 1955). Other species of *Pritchardia*, in the Marquesas Islands (Brown, F.B.H. 1931) and Fiji (Smith, A.C. 1979) where found in valleys are suspected as having been artificially extended into these areas. *Pritchardia thurstonii*, in Fiji, interestingly is associated with limestone (Smith, A.C. 1979). It may thus be that *P. vuylstekeana* does not occur on Rarotonga, nor appears in the pollen diagrams form Karekare swamp, because of the lack of suitable habitat. A limestone coral rubble ridge does occur, but may have been an overly disturbed environment for the palm. Another possible reason is simply the greater geological age of Atiu and Miti`aro as compared to Rarotonga (see Chapter 1). *P. vuylstekeana* may have been dispersed to the area of the southern Cook Islands earlier than the formation of Rarotonga.

A number of coastal species are curiously missing like *Premna taitiensis* and *Triumfetta* spp., while others are poorly represented like *Sophora tomentosa* and *Pipturus argenteus*. *Premna* species, for example, in Fiji, have a wide distribution from beach thickets and dry lowland forest to forests up to about 200 m a.s.l. (Smith, A.C. 1991), and *Pipturus argenteus*, as mentioned above, has an even wider distribution in open forest conditions. The removal of natural vegetation from the lowlands and the drastic reduction of the shore communities, combined with the decline in the practising of traditional crafts (and hence the requirement for the survival of these shore communities) has assisted in the local extinction or endangerment of these species. The other factor being that with reduced space and dissection of a once continuous habitat would have to imply a corresponding deterioration in diversity (see Chapter 3).

The habitat is also a dynamic one with much disturbance, which may have hastened this process. In the Hawaiian Islands, Sohmer and Gustafson (1987) mention that some indigenous littoral species may be rare due to their being relatively recent arrivals, whist others have reduced in range since written documentation has been undertaken. A quarter of the indigenous non-endemic species in the Hawaiian Islands occur in the littoral zone. This is indicative of the zone's dynamism and the more frequent dispersal and turnover of plant species in it.

9.3.4 *Sea-level change and climatic change*

Does human interference in any way resemble climatic variations such as Cold Periods, and if so, would it have and has it provoked similar structural responses? One major problems is to distinguish human and environmental influences. Change in weather pattern and sea-level may create conditions that could be interpreted as artificial or humanly contrived.

Quaternary research in the tropics was very much neglected until it was realised that human origins lay in Africa (Roberts 1989). Until they were properly dated (using ^{14}C dating), fossil lake beds in the Sahel and the Rift Valley were thought to represent `Pluvial' periods corresponding to Glacial periods in the mid and high latitudes. In fact, these wetter periods in Africa and Arabia belong to the earlier part of the Holocene, from 9000 until about 5000 BP when lake levels reached their peak (Street-Perrott *et al.* 1985). Singh *et al.* (1974) arrive at similar results for lake beds in the Rajasthan desert, in north-west India. The dearth of studies from Central America makes it difficult to say with confidence what occurred there, though the existing evidence might confirm a drop in moisture levels around the same time as wet periods elsewhere like Africa and Arabia (Street-Perrott *et al.* 1985). Singh (1981) suggests that the fall in grass pollen from Lake Frome after 4200 BP indicates a marked fall in summer rainfall. This correlates well with Bowler's (1981) water-level fluctuation curve from Lake Keilambete, western Australia, showing a continuous reduction in water-level from about 4.5 to 3000 BP. Kershaw *et al.* (1981) have produced pollen diagrams demonstrating an expansion of wet sclerophyll forest elements in the south-eastern highlands of Australia, ending before 3000 BP and in the best-dated diagram not extending beyond 4000 BP. In northeastern Queensland, Australia, Kershaw has produced evidence of climatic warming beginning at some time between 6000 and 4500 BP (Kershaw 1983).

The work of Adamson *et al.* (1987) looked at the documented records for the Nile (north-east Africa), Murray-Darling (Australia), and Ganges (India) river basins during the last 200 years, and shows remarkable concurrence of major drought and flood events in all these places and fluctuations in the Southern Oscillation (SO). Where differential results occurred in the geomorphological record, these could be explained in terms of aeolian dust, incision and aggradation of deposits, and complications arising from inherited floodplain features. This suggests that the SO has a simultaneous effect on regions over which it operates, and this might also apply to the tropical Pacific Ocean.

Seen in this light, the appearance of grasslands in the highlands of New Guinea from around 5000 BP or earlier and in Sumatra from around 4000 BP or earlier might be significant, though these have been attributed to burn-off of forest by humans seeking land for cultivation (Flenley 1988; Newsome and Flenley 1988). Southern's (1986) work in Fiji, has grasslands appearing on the south coast of Viti Levu from after 4,300 BP, which she proposes could be the beginnings of forest clearance by humans, though she expresses serious doubts about such a possibility. Enright and Gosden (1992: 167) suggest that falling sea levels, and thus a lowering freshwater lens, may well correlate with greater aridity. Nunn (1991) argues for such a drop in sea level from a 1-2 metre highstand about this time.

It might be argued that the buffering effect of the Pacific Ocean may have reduced the strength of these climatic changes. Colinvaux and Schofield (1976) have produced pollen and stratigraphic evidence from the Galápagos Islands showing subtle, but not great, variation in the vegetation during the Holocene. A drier period is dated to from around 3500 BP, though it is clear that this was a gradual process, with no precise boundary. The changes may have been lessened by the high proportion of taxa represented, which grow near the lake from which the pollen cores were taken. Also, some anemophilous pollen came from outside the Galápagos Islands. The changes in the surface samples, which are attributed to the effects of grazing animals introduced 150 years ago, are not of a greater order than recorded elsewhere in the sequences. However, it may be that this is a genuine indication that global climatic change may be reflected in a more subtle way in the Pacific Ocean.

As Stockton (1990) argues, there is a potential confusion over timescales. Climatic change has been ordered into scales of magnitude: from sixth order changes such as the K-T boundary to first order changes such as minor annual changes in weather patterns (Butzer 1982). Nunn (1991) contends that a failure to distinguish between orders of change has led to much confusion in the Pacific region, for example in the areas of temperature and sea level change. There has been a tendency to belittle the natural variation in environmental norms, and create an impression that the Pacific islands were a Garden of Eden before the arrival of human beings. For instance, Fosberg described island ecosystems thus:

In most respects organisms present had evolved into an effective equilibrium with their environments. [Fosberg 1963: 5].

Glacial periods are associated with lower sea levels than the present, as the water is held up in the glaciers. In the south-west Pacific, this meant sea levels as low as 120 metres below the present sea level (Nunn 1991). In terms of Polynesia, the area falls within Zone V of the hypothesis expounded in Clark *et al.* (1978), Clark and Lingle (1979) and Peltier *et al.* (1978). Islands in this zone are predicted to have undergone emergence in the order of up to 2 metres around 5000 years ago. Also, for islands with a radius larger than 10 km, the relative sea level is almost independent of the upper mantle rheology, whereas islands with a radius less than 10 km, including the Cook Islands, simply fall in line with the global isostatic adjustment (Nakada 1986).

As discussed in Chapter 3, there are a number of studies with evidence supporting the above hypothesis, though the highstand in the mid-Pacific Ocean could have been a little later in date than predicted. The evidence from the swamps now investigated on Rarotonga may lend support to the idea of a mid-Holocene highstand, followed by a fall to present levels. In Karekare swamp, there is a transition from lake muds to swamp/marsh deposits. Since freshwater is less dense than saltwater, and an island's freshwater lens rests on the saltwater of the ocean, it follows that sea-level changes should also affect the freshwater table. The beginning of the lowering of sea-level from 4000 BP may have affected the water table in Karekare swamp, leading to drier conditions and allowing plants to colonize its surface.

More evidence comes from the other smaller swamps, all of which date to after 1500 BP, when sea-levels would have reached more or less present levels. The coral rubble ridge and the terraces from east of Avarua to NgaTangi`ia (see Figure 5.1) would have protected the area of Karekare swamp from transgression by the sea if a highstand of 1-2 metres had occurred, whilst the rest of the coastal plain would have been swamped by seawater, the terraces and fans (see Figure 5.2) forming a cliff. From around 2000 to 1500 BP, the sea having completely withdrawn, the coastal plain would have been opened up once again, allowing paludification to commence from that point in time only. Thus the dates for the other swamps (Atupa swamp, 1415 (1293) 1087 BP, Arorangi Latter Day Saints Church Site, 1176 (979) 797 BP and Aro`a swamp, 553 (465) 0 BP -2 s) are relatively late.

Ellison **(in press)** also has evidence from Mangaia of a marine highstand between 6500 and 4500 BP. Fine annual laminations in gyttja deposits, together with palynological evidence of wetland plant communities, indicate maximum lake depths at this period.

9.3.5 *Dating of Human Arrival*

The radiocarbon dates from early sites, including those form the Marquesas Islands and the Hawaiian Islands, have been reviewed. The possible range of the earliest dates from these sites included some much earlier dates than thus far proposed: Kirch suggested human colonization for the Marquesas Islands by the late first millennium BC, and for the Hawaiian Islands, 2-300 AD. Hunt and Holsen (1991) reviewed the radio-carbon sequence for the Hawaiian Islands, and suggested that humans may have been present as early as the first century AD, though a potential for erroneous dates from inbuilt age in charcoal samples still existed. They suggested taxonomic identification could be used to remedy this problem.

On the basis of existing dates and the idea of systematic colonization, Irwin (1990) proposed a series of dates for the colonization of areas including those not yet dated. The discovery (and settlement) of Central-eastern Polynesia was estimated to have occurred between 3000 BP and 1500 BP; South America, Norfolk Island, the Kermadec Islands and New Zealand were reached by 1000 BP and the Chatham Islands by 500 BP. Some smaller islands with harsher conditions and further away from their nearest neighbour were later deserted, because of the greater difficulties of existence there. Alternatively, they may never have been settled on a permanent basis and may have only been used as an extra, possibly seasonal resource for people from elsewhere (Irwin 1991).

However, the radio-carbon sequences have been coming under strict scrutiny and criticism. In Southeast Asia, Spriggs' work undermined some of the early dates for agriculture, and brought about changes in the relationships suggested by the then pattern of radiocarbon dates (Spriggs 1989). In New Zealand, Anderson, building on Sprigg's ideas of `Chronometric Hygiene' to the dating sequence, reduced the timescale of human settlement from 1000 to 700 years ago (Anderson 1991).

Reviewing the evidence from the pollen cores may shed some light on this. The radio-carbon sample, which produced the date for an eroded soil appearing at the top of a core from a lake on Atiu, was taken from within the erosion levels themselves (Parkes n.d.). If there was any contamination from older carbon, brought into the lake with soil-wash, then one would expect an anomalously older date. The date only refers to the last 1310 years, which is not especially early considering Irwin's proposed chronology (Irwin 1990).

Spriggs and Anderson (1993) have suggested that there is no evidence of settlement in East Polynesia before AD 300-600, and this only dubiously in the Marquesas Islands. This aside, colonization was proposed at AD 600-950 in the central, northern and eastern archipelagoes, and AD 1000-1200 at most in New Zealand. They revived the idea of a Pause between the settlement of West Polynesia and East Polynesia because of an apparent 1300-1600 year gap between their respective dates.

From the southern Cook Islands, Spriggs and Anderson (1993) accepted dates of AD 810-1170 from Urei`a, Aitutaki (Allen and Steadman 1991) and AD 890-1240 from the same site (Bellwood 1978). However, they rejected dates from lake and swamp sediments from the Cook Islands, the Society Islands and Easter Island (Flenley and King 1984; Flenley *et al.* 1991; Kirch *et al.* 1992; Parkes n.d.) because of suspected contamination, in particular from CO^{2-}_3 leached from the makatea deposits. However, the internal consistency of the swamp and lake chronologies from the southern Cook Islands could satisfy criterion P. from Spriggs and Anderson's (1993) own list for the acceptance of radiocarbon dates.

The Karekare swamp chronology is internally consistent bar one date, though this can be related to a discrete erosional episode and need not mar the overall reliability of the chronology. The time against depth curves (see Figures 7.8, 7.9; Appendix A.6) is also smooth, except for the top zone where cultivation may well have truncated or compacted the sediments making the earlier end of the date brackets suspect. The dating from Karekare swamp suggests that, somewhere between 2350 and 960 BP, the swamp was first cultivated (existing archaeological evidence from Rarotonga suggests that settlement took place by 1260 AD - Trotter 1974: 146). This is not inconsistent with either the Atiu and Mangaia evidence (Kirch *et al.* 1992; Parkes n.d.) or Sprigg's and Anderson's (1993) view, though it does not resolve which is the more likely. A possibility, however, still exists that the date is much earlier and closer to 2350 BP.

As discussed above (9.3.2), Ellison's interpretation of dates from swamps on Mangaia may well be subject to the same problem of truncation as suggested for Karekare swamp. The closeness of the circumstances of these two cases may mean that similar interpretive problems will be encountered with other cultivated swamps. Further investigations may be better directed at lakes and other non-cultivated deposits in order to resolve this problem.

Kirch and Hunt (1993) have recently proposed early dates for the settlement of Samoa, though one of the earlier dates of 2900 $\pm$110 BP is in a layer above one of 2630 $\pm$100 BP, and when left out of the sequence[64], creates a gap of 810 years at one standard deviation between the two earliest dates of 3620 $\pm$80 BP and 3820 $\pm$70 BP and the rest of the sequence which is highly consistent. Even at two standard deviations, there would still be a significant gap. This means the two earliest dates fail to meet criterion K from Spriggs and Anderson (1993), which would mean that they would be regarded as questionable. Finally, criterion G from Spriggs and Anderson's (1993) discard protocol would also reject the two earliest dates on the basis that they are not consistent with the dating for the similar cultural material from other acceptably dated sites.

Kirch (1993b) argues that the mollusc shells dated were not water worn, retaining their original surface colouration, suggesting rapid deposition, though the collapse of a submarine sand bank as a single causative event may not require the shells to be water worn and would still make them anachronous. However, this date may be correct and cannot be entirely dismissed. Further dating showing similar results will be needed to confirm it, if it is to be accepted.

9.3.6 *Influence of environment on settlement history*

Irwin's model of systematic and continuous colonization (1989, 1990), increasing in pace through time suggests that exponential population growth was not the decisive factor in the expansion across the Pacific Ocean. The important factor,

[64] This would fail to meet criterion C. of Spriggs and Anderson's (1993) discard protocol.

as proposed by Keegan and Diamond (1987), was enough surplus to set up the new colonies, though marine resources may have obviated or lessened this requirement.

Kirch (1984: 14, 68, 72-76, 159-160) advanced the view that, for example on high islands, small populations would have begun on the coast in nucleated settlements at valley mouths, and once the marine resources and the avifauna were dissipated, cultivation and the control over land gradually became more important. When each valley section of the island was settled, populations would have spread up the valleys, utilising the different resources as they advanced up through the different ecological zones. In the Hawaiian Islands, these valley sections, the *ahupua`a*, had both early and late sites on the coast with progressively later sites found further up the valleys (Kirch 1985). This supported by settlement studies in the inland valleys of the Hawaiian Islands, Tahiti, Mo`orea and Rarotonga with late dates (after about 1200 AD - Bellwood 1987). This dearth of early inland sites supports the view of the first settlement being coastal, albeit on negative grounds.

In the southern Cook Islands, Walter (1990) found a correspondence between the early sites and reef passages too, because of the importance of marine resources and especially long-distance trade in the early economies. Walter (and Kirch 1986) regarded `archaic' assemblages as belonging to an early phase of widespread contacts, continuing from after the period of initial settlement until about the 13th to 14th centuries AD, when with islands became more reliant on and defensive of their local resources, with a pattern of dispersed settlement. Thereafter, long-distance contacts were terminated.

However, on Mangaia, Kirch *et al.* (1992) have proposed that the hilly interior was settled first and swiddened until the forest and soils were depleted, and only then was the makatea utilised, followed by the swamplands in between.

Kirch (1984: 101-104) applied an evolutionary model, albeit tempered with multifactorial approaches, to the processes that occurred up to the time of European contact. He proposed that populations would have started off from relatively small founder groups, gradually splitting off into different lineages, which would subdivide themselves until the whole island was settled. These various lineages would then compete for resources and status, whilst their populations rose. Ecological disaster would then result as competition led to over-exploitation of resources, and this combined with warfare would reduce the population. Then the process would begin again. Bahn and Flenley (1992) have recently suggested a similar model (inspired by the Club of Rome's predictions for global environmental problems) for Easter Island, though more ecologically based.

Some islands lost their human populations altogether. Pitcairn, Necker, Nihoa, Raoul and Norfolk Island have all produced archaeological evidence and the presence of cultivated plants (Anderson 1980; Bellwood 1987; Emory 1928; Heyerdahl and Skjölsvold 1965; Specht 1984). It may be that the harshness of the environments of these islands, many being small and drought-prone, made survival unnecessarily difficult (Bellwood 1987; Irwin 1991). Such islands were found to be too distant from neighbours if plotted out (Irwin 1990). Some uninhabited islands were utilised from time to time (and at some periods had been settled on a permanent basis) if they were close to a larger neighbouring island. Examples of this are Nassau, near Pukapuka, in the northern Cook Islands (Bellwood 1987).

In the model presented above for Rarotonga (9.2), the ecotones where valley, freshwater stream, coastal plain, lagoon and reef passage are most readily accessible could have been selected in an initial colonization phase. Initially, wild resources may have been especially important, until plantations of cultigens were established. From there, expansion would have been up the valleys and along the terraces, over which the *Ara Metua* passes (though leaving contested and sacred areas free of interference - see Chapter 6), because that is where the best agricultural land is (Leslie 1980). These areas would also be more protected against cyclonic winds and floods, as well as from the drought experienced on the lower and more coastal parts of the plain, though it could be argued that some settlement and agriculture may still have taken place there. Instead, the author suggests the coastline could have been largely a source of trees producing raw materials and coconuts. It may be that such factors should be investigated for other high islands.

Had there been any settlement before 1500-2000 BP, higher sea-levels may have meant that except for a stretch of land between Avarua and NgaTangi`ia, the lowland plain would have been unavailable for such settlement. In this case, in most areas, settlement may have started in the valley bottoms, because even the terraces would have been subject to more cyclonic forces such as storm surge and wind. Pure freshwater would have been driven further back too, though perhaps not very much because of the effects of gradient. Though not required to account for coastal progradation, an argument for a contribution to this process from increased sedimentation due to the deforestation of valleys by an early settlement could be made on the basis of a comparison with the conclusion of Spriggs' (1986) study on Aneityum, Vanuatu. At the moment, however, there is a lack of archaeological evidence for such an early settlement.

9.4 Résumé

Human settlement and landscape change on Rarotonga has been discussed in the light of evidence obtained in this project, and its broader significance for other Pacific Islands reviewed. In the next and last chapter, the major conclusions are summarised for the reader's convenience.

CHAPTER 10 CONCLUSIONS

A concise presentation of the major conclusions of this thesis ensues, employing the same format as for Chapter 9.

10.1 Karekare Swamp: Interpretation of local environmental changes

At the beginning of the Holocene, rising sea-level could have eventually led to development of a lake at Karekare before 8137 BP with a beach ridge of coral rubble blocking the seaward end. Accumulating sediment together with local hydrology meant that the lake would have become shallower (with or without any external considerations), consequently forming a marsh, though other factors may also have been involved. An important and perhaps vital reinforcement factor to this could have been falling sea-level. Increased aridity caused by climatic change is another possible contri-buting factor. Human activities such as drainage and clearance causing erosion could have been responsible, though this is not considered here to be the most likely solution.

A former highstand in sea-level between 5000-4000 BP and 2000-1500 B.P may have inundated the coastal plain, the terraces and fans forming a cliff, except for an area of raised topography from east of Avarua to NgaTangi`ia created by the coral rubble ridge and the terraces. From around 2000 to 1500 BP, the sea would have completely regressed, leaving the coastal plain exposed once again, allowing the formation of swamps to commence from that point in time only.

With the formation of a marsh, there followed what is interpreted as a hydrosere beginning with *Acrostichum aureum* ferns, then some swamp forest, finally being replaced by drier elements, such as *Pipturus argenteus* sim. and *Pandanus*. Truncation or shrinkage or compaction or a combination of these factors due to cultivation and drainage finally terminated the hydrosere between 2730 and 791 BP. Peat formation would have been halted, and oxidation would have started to take effect, though mulching and the occasional flood may help reduce this effect.

10.2 Rarotonga: Implications for the environment of the island as a whole

A model based on biogeographic theories (especially Diamond 1975, 1976) is proposed for landscape change on Rarotonga.

a) The landscape before human intervention would have contained no artificial barriers to natural relationships within the biome. The natural habitat would have been rounded, except perhaps for occasional fernlands and clearings, and thus close to the ideal shape for the perpetuation of maximum possible diversity. Sea-level rise during the Holocene highstand (Clark *et al. 1978*; Clark and Lingle 1979) would have reduced the size of the lowland vegetation zone, and may well have reduced population numbers of many organisms during this time.

b) People would have settled the valley mouths, which are the ecotones where valley, freshwater stream, coastal plain, lagoon and where possible, reef passage are most easily attainable. These are where major valleys open onto the coastal plain, and where the coastal plain is relatively narrow, so settlements were close to the shore. Settlers may have increa-sed the shoreline distribution of pre-existing useful species, particularly coconuts, from the time of first colonization. At first utilising wild resources, cultigens would gradually become more important as settlement proceeded up the valleys and along the terraces, fans and floodplains though avoiding disputed and religious areas free of disturbance - see Chapter 6). These cultural areas have the best soils, would have been more sheltered against cyclonic winds and floods, and relatively free from the droughts that happen on the lower and more coastal parts of the plain (though it could be argued these were not such strong deterrents, and agriculture and settlement expanded belyond the terraces, flood plains and fans). Coastal swamplands also may well have been gardened.

Cultivation may have formed obstacles to dispersal, though arboriculture in many instances would have ameliorated the situation. All habitats would have been at least represented and continuous with others. However, shy flightless birds living at low density may have suffered when a significant and rich proportion of their habitat was reduced; enough, combined with hunting, to extirpate them. Plants dependent on birds for their dissemination or pollination would have also been affected. Land molluscs confined to certain valleys would have been severely affected. The introduction of exotic taxa may have assisted in diminishing diversity and disrupting associations. However, some of these exotics may have filled occupied niches and empty ones or shared niches with already existing occupants, not disrupting the overall ecology. For example, *Rattus rattus* may perform functions formerly the preserve of landcrabs.

c) Settlement became nucleated and concentrated on the coastal plain with missionary influence from 1823, extending right up to the coast after 1860. Cultivation still persisted up the valleys, particularly with the creation of a cash economy, through to the mid-twentieth century, and in some areas, up to the present, but this finally dwindled. This phase of maximum disruption, with elongated stretches of natural habitat only connected by the upper slopes of the interior, had one of the worst possible forms for a reserve. Also, this phase would have seen the drastic reduction of some habitats, especially the lowland plain and coast, decreasing the variety of habitat and the overall limits of the natural habitat. More taxa were endangered and a great number of new exotic taxa were brought to Rarotonga, some of which are vora-cious colonizers. The difficulties in earning a living due to colonial rule and exploitation were also no doubt a contri-buting factor to landscape change.

d) In the late twentieth century, intensive settlement of the coastal plain has meant many of the valleys are no longer cultivated (though the trend may be to reopen them for cultivation again). Though the island probably had more diversity and more possibilities for interrelationships before the arrival of humans, the return of natural habitat to a roughly circular shape did much to restore something of the natural diversity. However, habitat size is still much less than that described in b), and some habitats are now virtually non-existent, especially the shore forest, now only truly present, though still disturbed, on the *motu* in the lagoon near Muri. Emigration of people to other countries has resulted in many areas of secondary regrowth appearing, which may assist some indigenous organisms.

10.3 Wider Implications for Environmental Changes on Pacific Islands.

10.3.1 *Extinction*

Unicausal explanation for this phenomenon needs to be questioned. If hunting or even human presence, itself, were the only reason for extinction, then the mere fact that other members of apparently extinction-prone genera survive to this day on other islands in the western Pacific and used to survive up to European contact in islands of the eastern Pacific (sometimes into the twentieth century), despite human presence and, no doubt, predation, would have to be ignored.

The view that Polynesian settlers extirpated the fauna of every island they visited by hunting may have led to an oversimplification of the situation and the overlooking of other important factors. It may have simply been unavoidable that bird populations would have been displaced. Possibly this is the reason why many smaller islands were abandoned at the time of European contact: that there was a realisation that if seabirds were left no land to themselves then there would be no seabirds.

By investigating the problem from the point of view of settlement patterns, economy and ecology, it may be possible to relate extinctions to discrete time periods. For many of the animals, especially birds, declared to have been pre-European contact Polynesian-induced extinctions there is such limited chronological data that it really is not possible to be certain whether such a statement is true or not. Also, because of the fact that the skeletal evidence is practically all from archaeo-logical assemblages, cultural and economic factors are not entirely separable from the natural ecological ones.

It could well be that whilst some extinctions are related to initial colonization of islands, others may be associated with the economic, religious and social changes brought about by missionaries, merchants and colonial authorities.

10.3.2 *Alternative suggestions for other sites*

Other studies on Pacific Islands were reviewed and re-interpreted in the light of this investigation on Rarotonga. It is suggested here that whilst early Polynesian settlers certainly altered their landscapes, it is not necessary to invoke quite as much alteration as is sometimes inferred. Human interference with the landscape is often highlighted at the expense of natural explanations. In addition, single factors are rarely if ever responsible: usually, even in the case of human inter-ference, a number of factors are involved. For instance, it is easier to achieve and maintain a landscape clear of forest in a warm dry area than a warm humid area. A more cautious approach to assigning changes to human influence was taken, and to the degree of change implied by the evidence, because it is the author's opinion that the evidence has been overused by many writers to promote the idea of dramatic and overly large-scale human interference with the landscape.

It is proposed that early Polynesian colonists adapted their economy to the landscape and did not attempt to impose a totally alien system on the local ecology of newly settled islands. With experience gained on islands to the west, the colonists would probably have been able to recognise the optimum situations for growing particular crops, and how best to utilise the local ecology to their advantage. They may not have caused all of the major changes they are supposed to have caused. The timing and scale of human interference with the landscape is challenged in this thesis, building on various ideas expressed in recent publications by Anderson, Nunn and Spriggs (Anderson 1991; Nunn 1990b; Nunn 1991; Spriggs 1989; Spriggs 1990; Spriggs and Anderson 1993).

10.3.3 *Plant distribution history*

Cocos nucifera, *Hibiscus tiliaceus*, *Barringtonia asiatica*, *Pandanus*, *Canthium barbatum*, *Elaeocarpus tonganus*, *Ixora bracteata*, *Homalium acuminatum*, *Fagraea berteriana*, possibly *Pipturus argenteus* and *Casuarina equisetifolia*, and various ferns such as *Acrostichum aureum* (though this last is no longer present) were present before human arrival.

Cocos nucifera seems to have a wide natural distribution form the existing evidence and is confirmed by the fossil pollen from Karekare swamp, Rarotonga. However, wild coconuts no doubt were replaced by cultivars, and their natural distribution and density favoured as against other species by humans. *Hibiscus tiliaceus* is another example where humans have probably altered the natural distribution of an indigenous species.

The local intra-island arrangement of species and plant communities were considered. Clearance of most of the shore forest in the last 130 years may be responsible for the absence of species such as *Premna taitiensis* and *Triumfetta* spp., and the paucity of species like *Sophora tomentosa* and *Pipturus argenteus*. The fact that such habitats are dynamic with much disturbance may have accelerated this process. Evidence from the palynological study shows that there may once have been swamp forest dominated by *Canthium barbatum*, though *Hibiscus tiliaceus* could have been an important element even though none of its pollen was found in the relevant samples.

The cultural patterning of the Rarotongan landscape was investigated. In terms of Barrau's two system agricultural model (1965), the coastal plain and the lower parts of its valleys would fit into the dryland monsoonal system, whilst the upper parts of the valleys correspond more to the perennial wetland system. Oral tradition (see Chapter 6) and missio-nary records suggest that breadfruit trees and plantains were grown in the lower-lying areas because they are better adapted to the warmer, drier conditions, whilst the taro and mountain plantains were grown further up the valleys, where reliable all-the-year-around supplies of freshwater were available.

10.3.4 *Sea-level change and climatic change*

Clark *et al.* (1978) and Clark and Lingle (1979) proposed that sea-levels in the mid-Pacific Ocean (Zone 5.) rose from the end of the last glaciation to reach a mid-Holocene highstand of between 1 and 2 metres about 5000 years ago. Later studies have produced evidence supporting the above hypothesis, though with the highstand being a little later in date than theorised. For example, Yonekura *et al.* (1988) calculated the highstand on Mangaia to be at 1.7 m between 4000 and 3400 BP.

The swampland data from Rarotonga could well confirm the idea of a mid-Holocene highstand, followed by a fall to present levels. In Karekare swamp, the freshwater lens, resting on the ocean's saltwater, could have risen causing or at least facilitating a transition from a lake to a marsh. The lowering sea-level from 5000-4000 BP may have affected the water table in Karekare swamp, leading to drier conditions and allowing plants to colonize its surface.

The other smaller swamps all date to after 1500 BP when sea-levels would have reached more or less present levels. The coral rubble ridge and the terraces from east of Avarua to NgaTangi`ia (see Figure) would have shielded the area of Karekare swamp from transgression by the sea if a highstand of 1-2 metres had transpired, whilst the rest of the coastal plain would have been inundated by seawater, the terraces and fans (see Figure) forming a cliff. From around 2000 to 1500 BP after the sea had withdrawn, the coastal plain would have been dry again, allowing marshes and swamps to form. Hence the relatively late dates for the other swamps (Atupa swamp, 1415 (1293) 1087 BP, Arorangi Latter Day Saints Church Site, 1176 (979) 797 BP and Aro`a swamp, 553 (465) 0 BP - 2 s).

10.3.5 *Dating of Human Arrival*

Human arrival on Rarotonga, at least in the area of Karekare swamp, postdates 2730 BP and antedates 791 BP. The reason for this imprecision is probably due to the effects of gardening truncating, shrinking or compacting the sediments in some way. From lake sites on Atiu and Mangaia, where such factors have not been a problem, mid-first millennium AD dates have been obtained. These dates relate to pollen and sediment changes interpreted as being the result of garde-ning and clearance activities. They could be considered as minimum dates for initial colonization, because settlement may have taken place on other parts of these islands first and/or gardening activities may have assumed a lesser role in the initial stages of settlement. Such dating would not be incompatible with Karekare swamp.

10.3.6 *Influence of environment on settlement history*

As suggested above (10.2), the first colonization of Rarotonga would have involved the ecotones where valley, fresh-water stream, coastal plain, lagoon and reef passage are most readily accessible. Wild resources may have been more significant at the beginning until gardens were sufficiently productive. Thence, expansion would have continued up the valleys and along the terraces, over which the *Ara Metua* passes (though leaving contested and sacred areas free of interference - see Chapter 6), following the prime agricultural land (Leslie 1980). Other advantages of these areas would have been greater protection against cyclonic winds and floods, and droughts such as occur on the lower and more coastal parts of the plain.

The shoreline could have largely been a source of trees producing raw materials and coconuts. Perhaps these could be considerations for other high islands.

Any early settlement before 1500-2000 BP, if it existed, may have had to have been influenced by higher sea-levels, because except for a stretch of land between Avarua and NgaTangi`ia, the lowland plain may well have been inaccessible. In most areas then, settlement may have commenced in the lower part of valleys, because even the terraces would have been exposed to more cyclonic forces such as storm surge and wind. Pure freshwater would have been impelled further back too, though not a great distance due to the mitigating effects of gradient.

APPENDICES I

A.1 Glossary of Polynesian Terms

Ara Metua	ancient road around the whole island of Rarotonga, following the base of the mountainous interior, also known as the `Great Road of To`i'
Ara Noa	ancient roads on Rarotonga running from the interior to the coast, at right angles to the *Ara Metua*
Ara Tapu	road built under the influence of the London Missionary Society missionaries around the whole island of Rarotonga, following the coastline
`Are kai	cookhouses
Ariki	chief of a tribe or *vaka tangata*
`Atinga	regular tribute or payment made to senior title holders
Kikau	coconut leaf, removed from the tree, for use in thatching, basketry or any kind of weaving
Kiri`au	inner bark of the *`au* used for cordage, weaving and for making *tamaka* (*kiri`au*)
Kirikiri (*teatea*)	(white) coral gravel spread over prepared surfaces such as *paepae* or *marae* platforms
Koutu	courts of the *ariki*, used among other things for investiture of new *ariki*
Mata`iapo	chief below the rank of *ariki*, head of a *ngati*
Motu	lagoon islet
Ngati	a sub-division of a tribe, the lineage owning a *tapere* or sub-division of a *tapere*
Paepae	fore-court and approach path to houses adjoining the *Ara metua*
Paepae `are	house platforms
Ra`ui	a sacred prohibition on the use of a resource, especially a food resource
Rangatira	chief below the rank of *ariki* and usually also that of *mata`iapo*
Tamaka	reef sandals to protect soles of feet against the sharp coral
Tapere	sub-division of a *vaka tangata*
Tapu	sacred, restricted, forbidden
Ta`unga	priest
Tumu Korero	talking chief or recognised expert in oral tradition
Umu	earth oven
Vairakau	traditional herbal medicines
Vaka	a fishing boat; a ship (*pai*) ; a tribe and a tribal area (*tangata*)

A.2 Glossary of Latin names of organisms

Latin	Maori	English
Plants (common cultigens and other plants not mentioned in A.5)		
Aleurites moluccana	*Tuitui*	Candlenut Tree
Alocasia macrorrhiza	*Kape*	Giant Taro
Artocarpus altilis	*Kuru*	Breadfruit Tree
Cocos nucifera	*Tumunu*	Coconut Tree
Codiaeum		Croton
Colocasia esculenta	*Taro*	Taro
Commelina diffusa	*Mauku vai*	Commelina
Cordyline terminalis	*Rau-Ti*	Cordyline
Crinum asiaticum	*Lili*	Lily
Cyrtosperma chamissonis	*Puraka*	Atoll Taro
Hibiscus tiliaceus	*`Au*	Beach or Tree Hibiscus
Inocarpus edulis	*I`i*	Tahitian chestnut
Millettia australis		Millettia Vine

Musa nana	*Meika*	Banana
Musa paradisiaca	*Meika*	Banana
Musa troglodytarum	*`Uu*	Mountain Plantain
Pandanus tectorius	*`Ara ta`a tai*	Screw-Pine
Saccharum officinarum	*To*	Sugar Cane
Animals		
Acridotheres tristis	*Manu Kavamani*	Mynah Bird
Acrocephalus kerearako	*Kerearako*	Cook Islands Warbler
Aerodramus sawtelli	*Kopeka*	Atiu Swiflet
Anas superciliosa (poecilorhyncha)	*Mokora Rere-vao*	Grey Duck
Anous stolidus	*Ngoio*	Brown Noddy
Anous tenuirostris	*Rakia*	Black Noddy
Aplonis cinerascens	*`I`oi*	Rarotonga Starling
Columba livia		Feral Pigeon
Ducula pacifica	*Rupe*	Pacific Pigeon
Egretta sacra	*Kotuku*	Pacific Reef Heron
Fregata ariel	*Kota`a Iti*	Lesser Frigate Bird
Fregata minor	*Kota`a Nui*	Great Frigate Bird
Gallus gallus	*Moa* (+*Moa Rere-vao*)	Domestic Fowl (Feral Fowl)
Gygis alba	*Kikaia*	White Tern
Halcyon tuta	*Kotare (Ngotare)*	Chattering Kingfisher
Halcyon ruficollaris	*Ngotare*	Mangaia Kingfisher
Heteroscelus incanus	*Kuriri*	Wandering Tattler
Numenius tahitiensis	*Kivi*	Bristle-thighed Curlew
Phaethon rubricauda	*Tavake*	Red-Tailed Tropic Bird
Phaethon lepturus	*Rakoa*	White-Tailed Tropic Bird
Pluvialis dominica	*Torea*	Lesser Golden Plover
Pomarea dimidiata	*Kakerori*	Rarotonga Flycatcher
Porzana tabuensis	*Mo`omo`o*	Spotless Crake
Pseudococcus pandanii		Pandanus Mealy Bug
Pterodroma heraldica	*Koputu*	Herald Petrel
Ptilinopus rarotongensis	*Kukupa*	Cook Islands Fruit Dove
Sterna fuscata	*Tara*	Sooty Tern
Sula dactylatra		Blue-faced Booby
Sula leucogaster		Brown Booby
Sula sula	*Toroa*	Red-footed Booby
Urodynamis taitensis	*Karavia*	Long-tailed Cuckoo
Vini peruviana	*Kuramoo?*	Blue Lorikeet
Vini kuhlii	*Manu kura*	Red Lorikeet

A.3 Stratigraphy

KAREKARE SWAMP

KK1

10/90 From the author's fieldnotes

Core samples: 0-80, 80-130, 130-180, 180-230, 230-280, 280-330, 330-380, 380-430, 430-480, 480-530, 530-580, 580-630, 630-680, 680-730, 730-780, 780-830, 830-880, 880-930, 930-980, 980-1030, 1022-1072.

Depth (cm)	Description
PEAT AND CLAY	
0-16	Yellowish black 5Y 2/2. Muddy loose humus. Th2 Sh1 Dh1.
16-26	Yellowish black 5Y 2/2. Compact humus with little mineral content. Clay size particles.
VISIBLE CHARCOAL BEGINS (FROM 84)	
26-96	Yellowish black 5Y2/2. Compact humic clay with increased mineral content. Some fibres. From 84, some flecks of charcoal. At 80 - pH = 6.0. See Plate A.3.1.
96-105.5	Transition to grey material. Charcoal flecks increasing. More fibrous material, though still very minor component. See Plates A.3.1 and A.3.10.
105.5-108.5	Black brown 10YR 3/1. Clay with less humic content than before - mostly mineral. Flecks of charcoal. Increasingly compact.
108.5-111	Band of Black brown 10YR 2/3. Slightly more humic than above. Flecks of charcoal.
111-125.5	As for 105.5-108.5, except fine bands of discolouration - e.g. at 113 and 115.5 of Dark brown

	10YR 3/4. Charcoal flecks. pH = 6.0. Compact.

VISIBLE CHARCOAL ENDS

125.5-137	Blackish brown 5YR 2/2. Clay with more humus - even leaves preserved. pH = 6.0. Colouration not regular - some lighter patches of Black brown 7.5YR 2/2. See Plates A.3.2 and A.3.11.

PEAT

137-147	As above, except lighter bands cease and there are increasing amounts of fibre with leaves and roots being preserved. Tl2 Th1 Sh1.
147-164.5	Darker bands of 10YR 1/1 come to dominate, though there are smaller bands of other colours present such as 10Y 2/1 at 147.5, and very thin bands of Blackish brown 5YR 2/2 material as above. Very little mineral content. See Plates A.3.2 and A.3.12.
164.5-170.5	Black 5Y 2/1. Substantially fibrous and humic - nil mineral content.
170.5-208	Yellowish black 5Y2/2. Very fibrous, but less so than above layer. Small clay fraction. Much less compact - soft. In parts very soft. pH = 7.0. See Plates A.3.13 and A.3.14.
208-216.5	As above, except more compact.
216.5-223	As for 164.5-170.5.
223-315.5	As for 170.5-208, though perhaps a little more compact. 230-280 very fibrous - many roots and very watery. See Plates A.3.3 and A.3.15.
315.5-324	5YR 1/1. Very fibrous (roots and leaves) and still soft, but not so watery. More compact.

WOOD FRAGMENTS BEGIN

324-356.5	Dark greyish 5Y 4/4 with bits of yellow. Humic and very lignous. Fibrous and Black 10YR 1/1 background. Compact. Peat. pH = 7.0. See Plate A.3.4.
356.5-370	Black brown 7.5YR 2/2. Humic clay band. Compact.
370-371.5	As for 324-356.5.
371.5-374	As for 356.5-370.
374-411	As for 324-356.5, except for a thin band of Yellowish black 5Y 2/2 at 374 and at 381,and a band of Black brown 2.5Y 2/2 at 399-400. More wood fragments. See Plate A.3.5.

WOOD FRAGMENTS END

411-464.5	A mixture of 5Y 4/4 and 5Y 2/2 with black flecks either as separate bands or a mix. 5Y 4/4 - humic 5Y 2/2. More clay. A band of 2.5Y 2/2 at 439.5. A mixture of 2.5Y 2/2 and 5Y 4/4 and a band of 7.5YR 2/2 clay at 451-460.
464.5-486	Reddish black 10YR 1/1. Peat - fibrous and humic - nil mineral content. Bands of Black brown 2.5Y 2/2 at 483-483.5 and 485-486, with a lense of Yellowish brown 2.5Y 2/2 in the latter band. See Plate A.3.6.
486-502.5	As above, except some black and yellow flecks.
502.5-507	As for 464.5-486, except bands of Yellowish brown 2.5Y 5/4 and the rest is a bit stained by the yellow. Some Black brown 2.5Y 2/2 staining.
507-513.5	As for 464.5-486.
513.5-560	As for 502.5-507. pH = 6.5. Bands of Black 10Y 2/1 at 534.5-535.5, 555-556 and 559.5-560. See Plate A.3.7.

GYTTJA

560-571	Dark brown 7.5YR 4/3 gyttja with band of Black 10Y 2/1 at 568.5 and another between 562 and 564. Ld2 Sh2.
571-577.5	Brown 7.5YR 4/4 gyttja. Bands of Black reddish brown 5YR 2/3 at 574.5 and 577.5.
577.5-582.5	Black brown 2.5Y 3/4 gyttja with band of 2.5Y 4/4 at 581-582. See Plate A.3.8.
582.5-586.5	Black brown 2.5Y 2/2 gyttja.
586.5-591.5	Black brown 2.5Y 3/4 gyttja.
591.5-598	Black brown 2.5Y 2/2 gyttja.
598-604.5	Black brown 2.5Y 3/4 gyttja.
604.5-607.5	Bands of 2.5Y 4/4, 2.5Y 3/4 and 2.5Y 2/2 gyttja.
607.5-638.5	Black brown 2.5Y 2/2 gyttja. Fibrous bands at 624, 625 and 627. See Plate A.3.16.
638.5-639	Transition to mineral clay.
639-640.5	10Y 3/1 mineral clay. pH = 6.5.
640.5-644.5	Black brown 2.5Y 3/4 gyttja.
644.5-743	Black brown 2.5Y 2/2 gyttja. Lenses of clay at 654.5, 661 and 672. Fibrous bands at 705, 711, 713.5, 715, 720, 720.5 and 728. pH at 644.5 = 7.0.
743-750.5	Black brown 2.5Y 2/2 gyttja. Slightly lighter than above. Some clay lenses of 10Y 3/1.
750.5-806	Black brown 2.5Y 2/2, though slightly different shade to the above. Lense of 2.5Y 3/4 at 751.5-752. Band of clay at 761.5-763 and 763.5-764. Fibrous band of 771.5 and 774.

CORAL SAND BEGINS

806-848	10Y 2/1 gyttja. More compact. Band of 10YR 2/2 between 806.5 and 807.5, and a clay and coral sand band just above that. Another band of clay and coral sand at 811-812. See Plate A.3.17.
848-856.5	Coral sand and 10Y 2/1 gyttja.
856.5-857.5	Clay band and 10Y 3/1 gyttja.
857.5-866	10Y 2/1 gyttja. More compact than before. Band of coral sand at 861.5.
866-898	Becoming lighter - Black 7.5Y 2/2 gyttja. Band of coral sand at 877. Thin band of 10Y 3/1 gyttja at 890.5. Clay/gyttja band of Yellowish black 7.5Y 3/1 at 894.5-896.
898-904.5	Black 5Y 2/2 gyttja.
904.5-910	Black 5Y 2/2 gyttja with coral sand - sometimes the coral sand is concentrated as a pure band.
910-932	Black 5Y 2/2 gyttja. Band of 10Y 3/1 clay at 911.5-912.
932-932.5	Thin band of fine coral sand, followed by coral sand and 7.5Y 3/1 gyttja.
932.5-939	Black 10Y 2/1 gyttja.
939-956	Black 10Y 2/1 gyttja and coral sand. Concentration of coral sand at 950-951.
956-976	Black 10Y 2/1 gyttja. Fine coral sand and Black 10Y 2/1 gyttja at 963-963.5. Fine band of coarser coral sand at 963.5. Gyttja becoming slightly lighter after 966.
976-983.5	Fine coral sand band at 976, followed by Black 10Y 2/1 gyttja and slightly coarser coral sand.See Plate A.3.9.
983.5-1011	Black 10Y 2/1 gyttja. Very thin band of fine coral sand at 985.
1011-1015.5	Coral sand in a high concentration, with gyttja and some dark flecks.
1015.5	Thin band of Black brown 10YR 2/2 gyttja, slightly more humic than before.
1015.5-1026.5	Black 10Y 2/1 gyttja. Band of coral sand at 1017-1017.5. Fine band of 10Y 3/1 clay at 1019.5.
1026.5-1028.5	Bands of 10YR 2/2 and coral sand with Black 10Y 2/1 gyttja.
1028-1072	Black 5YR 1/1 gyttja. Coral sand scattered thinly through out, especially down to 1035. Much humic material leaves and roots. Also large mineral content of clay particle size.
1085	Bottom of sediments reached by the head of the corer (screw part), so proper sampling was not possible. Small pieces of weathered basalt were clinging to the head of the corer when it was brought to the surface.

KK2

Core samples: 0-50, 50-100, 100-150, 150-200, 200-250, 250-300, 300-350, 350-359.

Depth (cm)	Description
CLAY	
0-26	Black reddish brown 5YR 2/3 clay loam. Ag1 Th1 Dh1 Sh1.
26-31	Transition to humic clay.
31-52	Black 7.5YR 2/1 humic clay.
DETRITUS	
52-62	Humic detritus. Th2 Sh1 Dh1.
62-73	Wood.
73-90	Wood and other organic detritus.
90-114	Black 5YR 1/1. Fine detritus silt and clay. Bands of Black brown 10YR 2/3 soft oily clay at 94-96.
114-128	Wood.
128-132.5	Black 5YR 1/1. Fine detritus mud.
132.5-137.5	Wood.
137.5-173	Black 5YR 1/1. Fine detritus silt and clay, including rootlets and wood fragments. Fine bands of Black brown 10YR 2/3 soft oily, but compact, clay at 140, 142-142.5 and 145-146.5.
173-179.5	Black brown 10YR 2/3 soft oily, but compact, clay, with some organic detritus.
179.5-184.5	As above, but banded with silt and clay, and organic detritus, including some bands of pure detritus.
184.5-189	Black brown 10YR 2/3 soft oily, but compact, clay. A little organic detritus present.
189-190	Transition to detritus.
190-268.5	Black 5YR 1/1. Fine detritus silt and clay, but with much more detritus and rootlets than previously. Twig at 242.5-244. Less detritus from 256 downwards.
268.5-284	Wood
284-292	Black 5YR 1/1 detritus silt and clay with pure organic detritus bands of Black 10Y 2/1 silt and clay.
292-296.5	Black brown 10YR 2/3 soft oily clay, interbedded with organic detritus.

296.5-314.5	Black 10YR and 5YR 1/1 silt and clay and detritus, with fine silt and clay becoming soft muddy detritus.
314.5-318	Wood.
318-359	Black 5YR 1/1 silt and clay, and detritus. Twig at 335.5-338.5.

KK3

Core samples: 0-50, 50-100, 100-150.

Depth (cm)	Description
CLAY	
0-32.5	Brown 10YR 4/6 loamy clay. Ag1 Th1 Dh1 Sh1.
32.5-114	Becoming gradually darker - 10YR 3/2, with some black flecks. Rootlets penetrating. Band of soft Light brown 7.5YR 5/6 clay at 65.
114-141	Brown 7.5YR 4/4 Compact loamy clay.
141-150	Contaminated by muddy water.

KK4 (MR 1)

9/02/90 From fieldnotes of Prof J.R. Flenley

Thomas Auger used.

Depth (cm)	Descript, Nig, Strat, Elas, Sicc, Hum, Comp.
0-100	Dark Brown soft peat/detritus with wood at 110-130, 3, 0, 1, 1, 1, Th2 Sh1 Dh1.
150-200	As above, except with some wood, Tl2 Th1 Sh1.
200-250	As above, except with wood at 225.
250-300	As above, except abundant wood.
300-440	As above, without wood. Grey clay (1 cm) band at 430.
440-450	Brown nekron gyttja, 3, 1, 0, 1, 2, Ld2 Sh2. Grey clay (1 cm) band at 448.
450-500	As above. Grey clay (1 cm) band at 450.
500-650	As above.
650-858	Very soft nekron gyttja, 3, 1, 0, 1, 2, Ld2 Sh2.
858-910	Black gyttja, peat and wood at 899, 4, 0-1, 0-1, 2, 2, Ld2 Sh2
910-930	Black gyttja, mud and detritus, 4, 0-1, 0-1, 2, 2, Ld2 Sh2 Dh+.
930-1000	Very soft nekron gyttja as for 650-858. Soft orange-brown clay on head of core.
1000-1090	Soft orange-brown clay, 2, 0, 0, 2, -.

KK4 B (MR1 B)

Stratigraphy the same except:

At 831	Transition to Black gyttja form Peat.
At 950	Transition to Orange clay from Black gyttja.

KK5 (MR2)

13/02/90 From fieldnotes of Dr J.R. Flenley

Depth (cm)	Descript, Nig, Strat, Elas, Sicc, Hum, Comp.
0-200	Dark brown peat / detritus, 3, 0, 1, 1, 1, Th2 Sh1 Dh1. Wood at 150-160. Band of grey clay (2 cm) at 185.
200-285	As above with abundant wood.
285-315	As above with grey clay, Ag1 Th1 Dh1 Sh1.
315-350	As above without grey clay.
350-400	As above with ?rose thorns.
400-500	As above with thorns, fruits and wood.
500-530	As above without thorns, fruits and wood.
530-560	Black gyttja.
560-600	Dark brown nekron mud.
600-650	Very soft - would not open. Rods ran out.

KK6 (MR3)

13/02/90 From fieldnotes of Prof J.R. Flenley

Thomas Auger

Depth (cm)	Descript, Nig, Strat, Elas, Sicc, Hum, Comp.
0-35	Grey clay (made ground).
35-50	Peat.

50-198	Peat and wood. Band of grey clay at 125.
198-200	Grey clay and peat mixture.
200-250	Peat.
250-255	Grey clay.
255-400	Peat and spines. Bands of grey clay at 340, 350-360 and 380-385.
400-450	Peat, spines and wood. Band of grey clay at 420.
450-460	Grey clay and peat (mainly peat).
460-480	Peat.
480-530	Black detritus (small - fine).
530-585	Dark grey - brown nekron mud.
585-620	Black peat. Very thin pale yellow band of ?clay.
620-625	Grey clay.
625-632	Black peat.
632-636	Grey clay.
636-650	Black peat.
	Ran out of rods.

ATUPA SWAMP

AT1

13/02/90 From fieldnotes of Prof J.R. Flenley

Depth (cm)	Descript, Nig, Strat, Elas, Sicc, Hum, Comp.
0-44	Crumbly loam ?reworked, 3, 0, 0-1, 3, 1, Ag3 Dh1 Sh+.
CLAY	
44-66	Blue-brown clay, 2-3, 0, 0, 3, 1, Ag4 Dh+ Sh+.
66-78	Brown-blue clay, 2-3, 0, 0, 3, 1, Ag4 Dh+ Sh+.
78-111	Blue-brown clay, 2-3, 0, 0, 2-3, 1, Ag4 Dh+ Sh+.
GYTTJA	
111-121	Black gyttja. Coral fragments and snail shells, 4, 1, 1, 2-3, 2, Ld2 Sh2.
121-138	Coral sand, white and light brown. Weathered basalt, 2, 1, 0, 3, -, Gs4.
138-161	Gyttja and coral sand, 3, 1, 0, 3, 2, Ld1 Sh1 Gs2.
161-185	Coral sand and weathered basalt fragments (5 cm), 3, 0, 0, 2, -, Gs2 Gg2.
	Impenetrable band.

AT2

Depth (cm)	Descript, Nig, Strat, Elas, Sicc, Hum, Comp.
CLAY	
0-100	Black crumbly clay/gyttja, 4, 0, 0-1, 3, 2, Ld1 Sh1 Ag2 Dh+.
100-110	Blue clay, 2-3, 0, 0, 2, -, Ag4.
110-140	As 0-100.
GRAVEL	
140-175	Coarse black gravel (1 cm), 4, 0, 0, 1, -, Gg4.
175-200	Coral sand.
	Impenetrable

AT3

Depth (cm)	Descript, Nig, Strat, Elas, Sicc, Hum, Comp.
0-80	Black clay gyttja, 4, 0, 0, 3, 2, Ld1 Sh1 Ag2.
80-120	Gyttja and blue clay, 3, 1, 0, 3, 2, Ld+ Sh1 Ag3.
120-130	Gyttja and gravel, 4, 0, 0, 2, 2, Ld+ Sh+ Ag1 Gg3.
130-150	Black gravel, 4, 0, 0, 2, -, Gg4.

AT4

Thomas Auger

Depth (cm)	Descript, Nig, Strat, Elas, Sicc, Hum, Comp.
0-30	Black gyttja and clay, 4, 0, 0, 3, 3, Ld1 Sh1 Ag2
30-50	As above with coral fragments.
50-57	As above with snail shells.
57-100	Coral sand.

AT5

Thomas Auger

Depth (cm)	Descript, Nig, Strat, Elas, Sicc, Hum, Comp.
0-40	Black gyttja/clay.

40-80 Blue clay.
80-130 Clay/gyttja.
130-150 As above with gravel.
150-162 Fell out. Gravel?
162-178 Black gravel (1-2 cm).
178-188 Black gravel and coral sand.

ARORANGI MORMON CHURCH SITE

ARM1

7/02/90 From the fieldnotes of Prof J.R. Flenley

Feek Borer

Depth (cm)	Descript, Nig, Strat, Elas, Sicc, Hum, Comp.
0-5	Black peat, 4, 0, 2, 2, 2, Th2 Sh2.
5-16	Coral sand, 1, 2, 0, 3, -, Gs4.
16-24	Brown clay, 2, 2, 0, 3, -, Ag4.
24-60	Coral sand, darker below, 2-3, 0, 0, 3, 4, Gs4 Sh+.
60-72	Black clay, 4, 0, 0, 3, 4, Ag3 Sh1.
72-100	Brown clay ?organic content, 3, 0, 0, 3, 4, Ag4 Sh+
100-159	Brown clay, paler below, 3-2, 0, 0, 3, 4, Ag4 Sh+.
159-172	Black woody peat, 4, 0, 4, 3, 4, Tl3 Sh1.
172-200	Beige-brown clayey ?gyttja, 2, 1, 0-1, 3, 4, Ag3 Sh1.
200-350	Brown clay, 3, 1, 0, 3, -, Ag4.

ARO`A SWAMP

10/02/92 From the fieldnotes of Prof J.R. Flenley

AO1

Depth (cm)	Descript, Nig, Strat, Elas, Sicc, Hum, Comp.
0-7	Orange and blue mottled clay, 2, 0-1, 0, 2, -, Ag4 Dh+.
7-18	Brown clay, 2, 0-1, 0, 2, -, Ag4 Dh+.
18-70	Clay and fine detritus, dark brown, 3, 1, 1, 2, 2, Ag2 Ld1 Sh1.
70-89	Grey clay, almost pure, 2, 0, 0, 2, -, Ag4 Dh+.
89-200	Dark brown gyttja and clay, 3, 1, 0-1, 2, 2, Ld1 Sh1 Ag2 Dh +.
200-250	As above, but more clay, Ag3 Ld+ Sh1 Dh+.

MURI SWAMP

12/02/90 From the fieldnotes of Prof J.R. Flenley

MU1

Depth (cm)	Descript, Nig, Strat, Elas, Sicc, Hum, Comp.
0-57	Grey clay and gyttja, 3, 0, 0, 2, 2, Ld+ Dh+ Sh2 Ag3.
57-100	White coral sand, 0, 0, 0, 2, -, Gs4.

MU2

Depth (cm)	Descript, Nig, Strat, Elas, Sicc, Hum, Comp.
0-62	Grey mottled clay and gyttja, 3, 0, 0, 2, 2, Ag3 Sh1 Ld+.
62-90	Grey / orange mottled clay, 3, 0, 0, 2, -, Ag4.
90-100	White coral sand, 0, 0, 0, 2, -, Gs4.

MU3

Depth (cm)	Descript, Nig, Strat, Elas, Sicc, Hum, Comp.
0-66	Grey mottled clay and gyttja, 3, 0, 0, 2, 2, Ag3 Sh1 Ld+.
66-95	As above, 3, 0, 0, 2, -, Ag4.
95-100	White coral sand, 0, 0, 0, 2, -, Gs4.

MU4

Depth (cm)	Descript, Nig, Strat, Elas, Sicc, Hum, Comp.
0-50	Grey clay and gyttja, 3, 0, 0, 2, 2, Ag3 Sh1.
50-78	Grey mottled clay, 3, 0, 0, 2, -, Ag4.
78-100	Grey clay, 3, 0, 0, 2, -, Ag4.
100-130	Orange clay and basalt fragments, 2, 0, 0, 2, -, Ag4 Gs+.
130-135	Dark grey clay and basalt fragments (? buried soil), 3, 0, 0, 2, -, Ag4 Gs+.
135-149	Orange clay and basalt fragments (? buried soil), 2, 0, 0, 2, -, Ag4 Gs+.
149-180	Dark grey clay and basalt fragments (? buried soil), 3, 0, 0, 2, -, Ag4 Gs+.

KK1 Plates

Plate A.3.1 KK1 80-130cm Colour print

Plate A.3.2 KKl 130-180, Colour Print

Plate A.3.3 KKl 230-280, Colour Print

Plate A 3.4 KKl 330-380, Colour Print

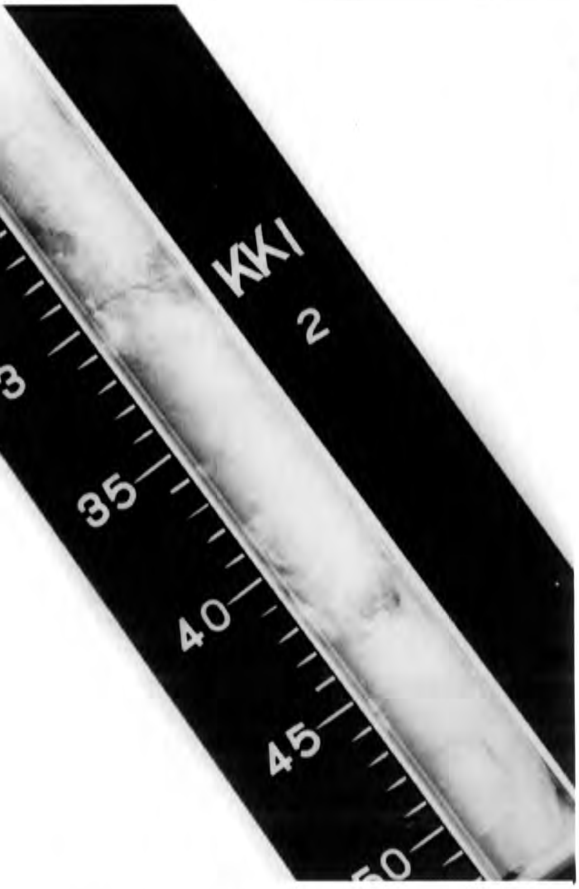
Plate A.3.5 KKl 380-430, Colour Print

Plate A.3.6 KKl 480-530, Colour Print

Plate A.3.7 KKl 530-580, Colour Print

Plate A.3.8 KKl 580-630, Colour Print

Plate A.3.9 KKl 980-1030, Colour Print



te A.3.10 KKl 100-130, X-Ray Print

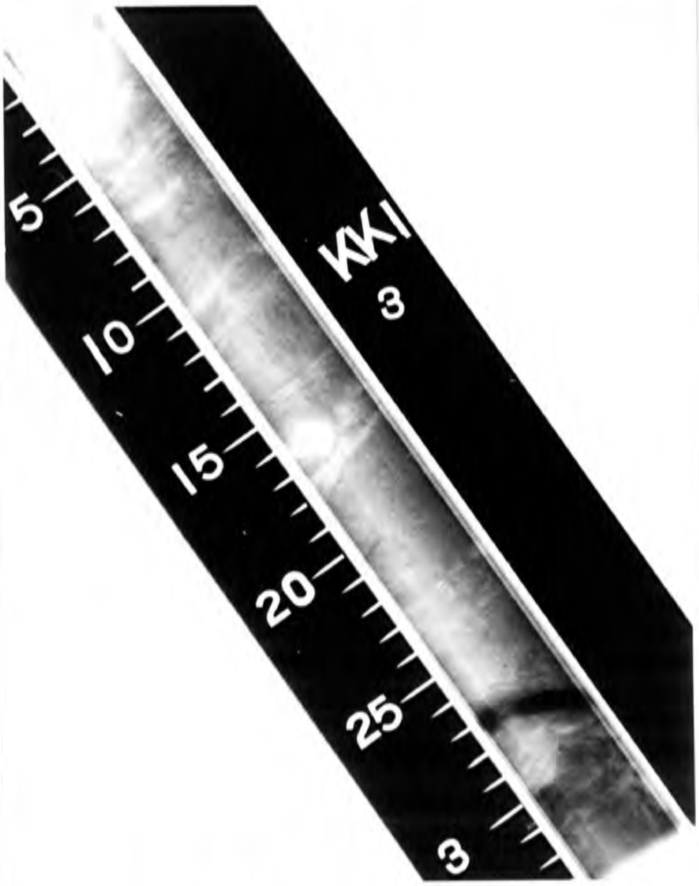
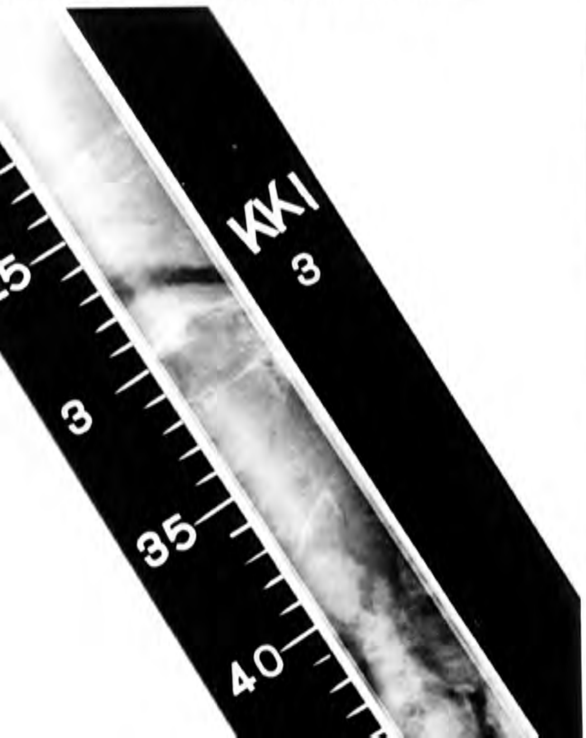


Plate A.3.11 KKl 130-160, X-Ray Print



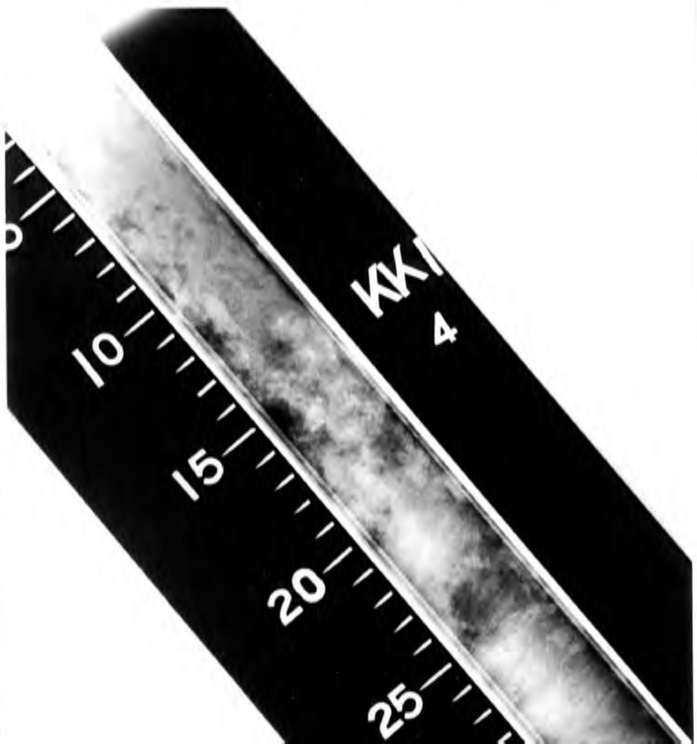


Plate A.3.14 KKl 195-230, X-Ray Print

Plate A.3.15 KKl 230-260, X-Ray Print

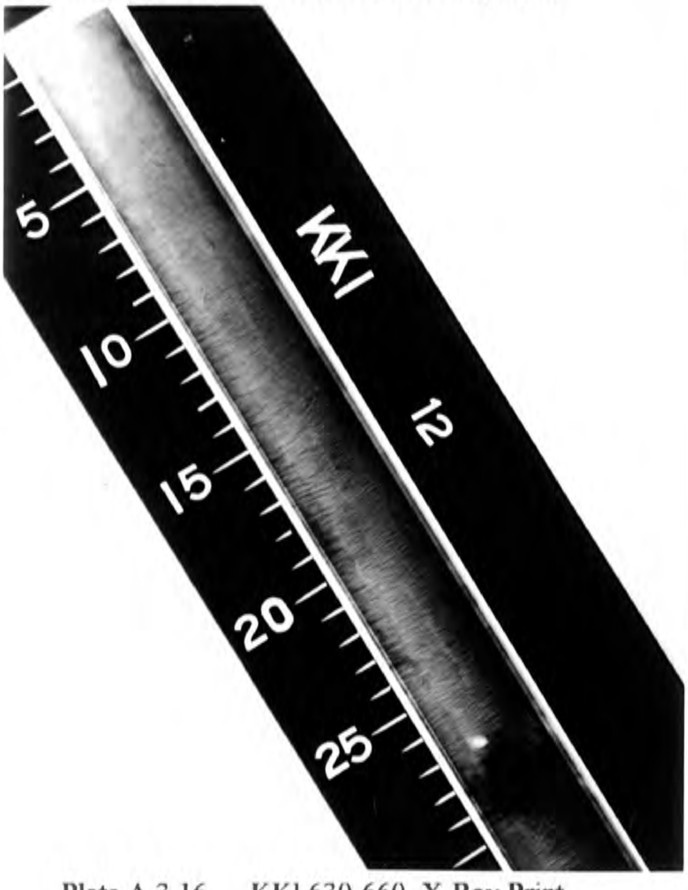


Plate A.3.16 KKl 630-660, X-Ray Print

Plate A.3.17 KKl 830-860, X-Ray Print

A.4 Pollen Tables

KAREKARE SWAMP

KK4

Samples: KK4 0cm; KK4 30cm; KK4 60cm; KK4 90cm; KK4 100cm; KK4 110cm; KK4 120cm; KK4 130cm; KK4 140cm; KK4 150cm; KK4 160cm; KK4 170cm; KK4 180cm; KK4 190cm; KK4 290cm; KK4 390cm; KK4 440cm; KK4 470cm; KK4 490cm; KK4 520cm; KK4 530cm; KK4 550cm; KK4 570cm; KK4 580cm; KK4 590cm; KK4 620cm; KK4 670cm; KK4 690cm; KK4 790cm; KK4 890cm.

KK4 0cm	Percentage	Numbers
Canthium barbatum	1.0	2.0
Cocos nucifera	1.5	3.0
Homalium acuminatum	0.5	1.0
Moraceae/Urticaceae	2.0	4.0
Morinda citrifolia	3.0	6.0
Pandanus	18.0	36.0
Pipturus argenteus sim.	2.0	4.0
Compositae	3.0	6.0
Gramineae	5.5	11.0
Acrostichum aureum	2.5	5.0
Anemia	3.5	7.0
Monolete Spores	58.5	117.0
Total		**202.0**

KK4 30cm	Percentage	Numbers
Barringtonia asiatica	0.5	1.0
Cocos nucifera	25.0	54.0
Moraceae/Urticaceae	7.5	16.0
Pandanus	16.0	34.0
Pipturus argenteus sim.	38.0	81.0
Compositae	1.0	2.0
Gramineae	4.0	8.0
Freycinetia wilderi	3.0	6.0
Trilete Spores	1.0	2.0
Total		**204.0**

KK4 60cm	Percentage	Numbers
Canthium barbatum	0.5	1.0
Cocos nucifera	3.0	6.0
Elaeocarpus tonganus	0.5	1.0
Fagraea berteriana	0.5	1.0
Homalium acuminatum	0.5	1.0
Moraceae/Urticaceae	2.0	4.0
Morinda citrifolia	0.5	1.0
Pandanus	19.5	39.0
Pipturus argenteus sim.	17.0	34.0
Compositae	1.0	2.0
Gramineae	14.0	28.0
Freycinetia wilderi	0.5	1.0
Hypolepis	0.5	1.0
Monolete Spores	40.0	80.0
Trilete Spores	1.0	2.0
Total		**202.0**

KK4 90cm	Percentage	Numbers
Barringtonia asiatica	0.5	1.0
Canthium barbatum	3.5	7.0
Cocos nucifera	1.0	2.0
Homalium acuminatum	2.0	4.0
Argusia argentea	0.5	1.0
Malvastrum	0.5	1.0
Moraceae/Urticaceae	6.5	13.0
Pandanus	37.5	77.0
Pipturus argenteus sim.	6.5	13.0
Gramineae	10.5	22.0
Acrostichum aureum	10.0	20.0
Dicranopteris linearis	2.5	5.0
Hypolepis	1.5	3.0
Anemia	0.5	1.0
Monolete Spores	14.0	28.0
Trilete Spores	0.5	1.0
Azolla sim.	1.0	2.0
Typha	1.0	2.0
Total		**203.0**

KK4 100cm	Percentage	Numbers
Canthium barbatum	2.5	5.0
Cocos nucifera	54.5	109.0
Elaeocarpus tonganus	2.0	4.0
Moraceae/Urticaceae	1.0	2.0
Pandanus	24.5	49.0
Pipturus argenteus sim.	2.0	4.0
Compositae	0.5	1.0
Gramineae	8.5	17.0
Dicranopteris linearis	0.5	1.0
Trilete Spores	0.5	1.0
Cyperaceae	3.5	7.0
Total		**200.0**

KK4 110cm	Percentage	Numbers
Canthium barbatum	1.5	3.0
Cocos nucifera	10.0	22.0
Elaeocarpus tonganus	4.0	9.0
Homalium acuminatum	1.0	2.0
Moraceae/Urticaceae	1.0	2.0
Pandanus	26.5	58.0
Pipturus argenteus sim.	44.0	96.0
Gramineae	7.0	15.0
Acrostichum aureum	0.5	1.0
Cyathea	0.5	1.0
Monolete Spores	8.5	18.0
Trilete Spores	0.5	1.0
Total		**228.0**

KK4 120cm	Percentage	Numbers
Canthium barbatum	0.5	1.0
Cocos nucifera	40.0	80.0
Elaeocarpus tonganus	3.0	6.0
Homalium acuminatum	0.5	1.0
Moraceae/Urticaceae	1.0	2.0
Pandanus	23.0	46.0
Pipturus argenteus sim.	16.0	32.0
Compositae	1.5	3.0
Gramineae	9.5	19.0
Acrostichum aureum	0.5	1.0
Dicranopteris linearis	1.5	3.0
Hypolepis	1.0	2.0
Monolete Spores	0.5	1.0
Trilete Spores	1.0	2.0
Cyperaceae	0.5	1.0
Total		**202.0**

KK4 130cm	Percentage	Numbers
Canthium barbatum	4.0	8.0
Cocos nucifera	1.5	3.0
Elaeocarpus tonganus	3.5	7.0
Macropiper	1.0	2.0
Moraceae/Urticaceae	1.0	2.0
Pandanus	22.5	45.0
Pipturus argenteus sim.	26.0	52.0
Gramineae	1.0	2.0
Acrostichum aureum	0.5	1.0
Davallia	2.5	5.0
Hypolepis	0.5	1.0
Monolete Spores	27.5	55.0
Azolla sim.	0.5	1.0
Cyperaceae	9.0	18.0
Total		**202.0**

KK4 140cm	Percentage	Numbers
Canthium barbatum	1.5	3.0
Cocos nucifera	3.0	6.0
Elaeocarpus tonganus	2.0	4.0
Homalium acuminatum	0.5	1.0
Thespesia populnea	0.5	1.0
Macropiper	0.5	1.0
Pandanus	19.0	38.0
Pipturus argenteus sim.	22.0	44.0
Compositae	0.5	1.0
Gramineae	0.5	1.0
Acrostichum aureum	1.0	2.0
Cyathea	1.0	2.0
Davallia	0.5	1.0
Monolete Spores	39.0	78.0
Trilete Spores	1.5	3.0
Cyperaceae	7.5	15.0
Total		**201.0**

KK4 150cm	Percentage	Numbers
Canthium barbatum	15.5	31.0
Casuarina equisetifolia	0.5	1.0
Cocos nucifera	2.5	5.0
Elaeocarpus tonganus	1.5	3.0
Inocarpus edulis sim.	3.0	6.0
Macropiper	1.0	2.0
Moraceae/Urticaceae	2.5	5.0
Pandanus	10.5	21.0
Pipturus argenteus sim.	45.5	91.0
Compositae	2.5	5.0
Gramineae	6.0	12.0
Freycinetia wilderi	1.5	3.0
Monolete Spores	5.0	10.0
Trilete Spores	2.0	4.0
Cyperaceae	0.5	1.0
Total		**200.0**

KK4 160cm	Percentage	Numbers
Canthium barbatum	13.0	26.0
Cocos nucifera	5.5	11.0
Elaeocarpus tonganus	0.5	1.0
Homalium acuminatum	0.5	1.0
Macropiper	0.5	1.0
Moraceae/Urticaceae	1.0	2.0
Pandanus	10.0	20.0
Pipturus argenteus sim.	45.5	91.0
Acrostichum aureum	1.5	3.0
Hypolepis	0.5	1.0
Monolete Spores	18.0	36.0
Nephrolepsis	0.5	1.0
Trilete Spores	0.5	1.0
Cyperaceae	3.0	6.0
Typha	0.5	1.0
Total		**202.0**

KK4 170cm	Percentage	Numbers
Canthium barbatum	7.5	15.0
Cocos nucifera	12.0	24.0
Elaeocarpus tonganus	1.0	2.0
Homalium acuminatum	2.5	5.0
Moraceae/Urticaceae	2.0	4.0
Pandanus	6.0	12.0
Pipturus argenteus sim.	7.0	14.0
Gramineae	1.0	2.0
Acrostichum aureum	5.5	11.0
Cyathea	0.5	1.0
Dicranopteris linearis	0.5	1.0
Monolete Spores	35.5	71.0
Nephrolepis	13.0	26.0
Trilete Spores	4.0	8.0
Cyperaceae	2.0	4.0
Typha	0.5	1.0
Total		**201.0**

KK4 180cm	Percentage	Numbers
Canthium barbatum	3.0	6.0
Cocos nucifera	8.5	17.0
Elaeocarpus tonganus	1.5	3.0
Homalium acuminatum	1.0	2.0
Moraceae/Urticaceae	63.0	126.0
Pandanus	1.5	3.0
Pipturus argenteus sim.	0.5	1.0
Compositae	0.5	1.0
Gramineae	4.0	8.0
Acrostichum aureum	0.5	1.0
Davallia	1.0	2.0
Monolete Spores	14.5	29.0
Trilete Spores	0.5	1.0
Cyperaceae	0.5	1.0
Total		**201.0**

KK4 190cm	Percentage	Numbers
Canthium barbatum	55.5	111.0
Cocos nucifera	0.5	1.0
Fagraea berteriana	0.5	1.0
Homalium acuminatum	0.5	1.0
Pandanus	0.5	1.0
Pipturus argenteus sim.	6.5	13.0
Gramineae	11.0	22.0
Loranthus	0.5	1.0
Acrostichum aureum	6.5	13.0
Dicranopteris linearis	2.5	5.0
Monolete Spores	8.5	17.0
Trilete Spores	6.0	12.0
Typha	1.0	2.0
Total		**200.0**

KK4 290cm	Percentage	Numbers
Barringtonia asiatica	2.0	4.0
Canthium barbatum	7.5	15.0
Cocos nucifera	0.5	1.0
Ixora bracteata	1.0	2.0
Podocarpus	0.5	1.0
Argusia argentea	0.5	1.0
Moraceae/Urticaceae	10.5	21.0
Pandanus	2.0	4.0
Pipturus argenteus sim.	17.0	34.0
Compositae	5.5	11.0
Gramineae	18.5	37.0
Loranthus	0.5	1.0
Acrostichum aureum	21.5	43.0
Cyathea	1.0	2.0
Monolete Spores	10.5	21.0
Cyperaceae	0.5	1.0
Typha	0.5	1.0
Total		**200.0**

KK4 390cm	Percentage	Numbers
Barringtonia asiatica	2.0	4.0
Cocos nucifera	0.5	1.0
Homalium acuminatum	0.5	1.0
Moraceae/Urticaceae	15.5	33.0
Pandanus	0.5	1.0
Pipturus argenteus sim.	19.0	40.0
Compositae	0.5	1.0
Gramineae	3.0	7.0
Freycinetia wilderi	0.5	1.0
Acrostichum aureum	57.0	122.0
Monolete Spores	0.5	1.0
Cyperaceae	0.5	1.0
Total		**213.0**

KK4 440cm	Percentage	Numbers
Canthium barbatum	1.5	3.0
Cocos nucifera	2.0	4.0
Elaeocarpus tonganus	0.5	1.0
Moraceae/Urticaceae	1.5	3.0
Pandanus	8.0	16.0
Pipturus argenteus sim.	26.0	52.0
Compositae	1.5	3.0
Gramineae	7.5	15.0
Gramineae/Cyperaceae?	2.0	4.0
Loranthus	1.0	2.0
Acrostichum aureum	45.5	91.0
Monolete Spores	3.0	6.0
Cyperaceae	0.5	1.0
Typha	0.5	1.0
Total		**202.0**

KK4 470cm	Percentage	Numbers
Cocos nucifera	1.0	2.0
Elaeocarpus tonganus	0.5	1.0
Moraceae/Urticaceae	1.5	3.0
Pandanus	0.5	1.0
Pipturus argenteus sim	22.0	48.0
Compositae	3.0	6.0
Gramineae	0.5	1.0
Acrostichum aureum	77.0	147.0
Total		**209.0**

KK4 490	Percentage	Numbers
Barringtonia asiatica	2.0	5.0
Cocos nucifera	4.0	8.0
Homalium acuminatum	1.0	2.0
Pandanus	2.0	4.0
Pipturus argenteus sim.	77.0	173.0
Gramineae	1.0	2.0
Acrostichum aureum	5.0	11.0
Dicranopteris linearis	0.5	1.0
Monolete Spores	3.0	6.0
Trilete Spores	0.5	1.0
Total		**213.0**

KK4 520cm	Percentage	Numbers
Barringtonia asiatica	3.5	7.0
Cocos nucifera	9.0	18.0
Fagraea berteriana	0.5	1.0
Homalium acuminatum	1.5	3.0
Moraceae/Urticaceae	12.5	25.0
Pandanus	3.0	6.0
Pipturus argenteus sim.	64.0	128.0
Compositae	2.0	4.0
Gramineae	1.5	3.0
Acrostichum aureum	1.5	3.0
Monolete Spores	2.0	4.0
Total		**202.0**

KK4 550cm	Percentage	Numbers
Barringtonia asiatica	2.5	5.0
Canthium barbatum	1.0	2.0
Cocos nucifera	12.5	25.0
Elaeocarpus tonganus	1.0	2.0
Podocarpus	0.5	1.0
Moraceae/Urticaceae	2.0	4.0
Pandanus	4.0	8.0
Pipturus argenteus sim.	61.0	122.0
Acrostichum aureum	11.5	23.0
Cyathea	0.5	1.0
Davallia	0.5	1.0
Monolete Spores	2.0	4.0
Cyperaceae	1.0	2.0
Total		**200.0**

KK4 580cm	Percentage	Numbers
Barringtonia asiatica	0.5	1.0
Cocos nucifera	2.5	5.0
Elaeocarpus tonganus	0.5	1.0
Moraceae/Urticaceae	3.0	6.0
Pandanus	7.5	16.0
Pipturus argenteus sim.	83.0	176.0
Compositae	0.5	1.0
Gramineae	0.5	1.0
Acrostichum aureum	2.5	5.0
Total		**212.0**

KK4 670cm	Percentage	Numbers
Barringtonia asiatica	9.0	10.0
Cocos nucifera	5.5	6.0
Homalium acuminatum	1.0	1.0
Moraceae/Urticaceae	19.0	21.0
Pandanus	16.0	18.0
Pipturus argenteus sim.	24.0	26.0
Gramineae	10.0	11.0
Acrostichum aureum	9.0	10.0
Cyathea	4.0	4.0
Davallia	1.0	1.0
Monolete Spores	1.0	1.0
Total		**109.0**

KK4 530cm	Percentage	Numbers
Barringtonia asiatica	11.0	22.0
Canthium barbatum	0.5	1.0
Cocos nucifera	19.5	39.0
Homalium acuminatum	1.0	2.0
Ixora bracteata	0.5	1.0
Argusia argentea	1.0	2.0
Moraceae/Urticaceae	4.5	9.0
Pandanus	1.5	3.0
Pipturus argenteus sim.	57.0	114.0
Compositae	1.5	3.0
Loranthus	0.5	1.0
Acrostichum aureum	2.0	4.0
Cyathea	0.5	1.0
Monolete Spores	1.0	2.0
Total		**204.0**

KK4 570cm	Percentage	Numbers
Barringtonia asiatica	3.5	7.0
Canthium barbatum	2.0	4.0
Cocos nucifera	28.5	57.0
Elaeocarpus tonganus	4.0	8.0
Fagraea berteriana	1.0	2.0
Homalium acuminatum	3.5	7.0
Podocarpus	0.5	1.0
Moraceae/Urticaceae	2.5	5.0
Pandanus	5.5	11.0
Pipturus argenteus sim.	35.5	71.0
Gramineae	3.0	7.0
Loranthus	0.5	1.0
Acrostichum aureum	7.5	15.0
Cyathea	1.0	2.0
Monolete Spores	4.0	8.0
Typha	0.5	1.0
Total		**207.0**

KK4 590cm	Percentage	Numbers
Barringtonia asiatica	11.0	22.0
Cocos nucifera	14.5	29.0
Fagraea berteriana	0.5	1.0
Homalium acuminatum	1.5	3.0
Ixora bracteata	0.5	1.0
Macropiper	8.5	17.0
Pandanus	3.5	7.0
Pipturus argenteus sim.	38.0	76.0
Gramineae	8.5	17.0
Freycinetia wilderi	0.5	1.0
Loranthus	2.0	4.0
Acrostichum aureum	1.5	3.0
Hypolepis	0.5	1.0
Anemia	1.0	2.0
Monolete Spores	5.0	10.0
Trilete Spores	0.5	1.0
Cyperaceae	1.0	2.0
Typha	1.5	3.0
Total		**200.0**

KK4 690cm	Percentage	Numbers
Barringtonia asiatica	19.5	39.0
Canthium barbatum	0.5	1.0
Cocos nucifera	8.0	16.0
Fagraea berteriana	0.5	1.0
Homalium acuminatum	1.0	2.0
Ixora bracteata	1.5	3.0
Argusia argentea	1.0	2.0
Pandanus	14.5	29.0
Pipturus argenteus sim.	19.5	39.0
Compositae	1.5	3.0
Gramineae	7.0	14.0
Freycinetia wilderi	2.0	4.0
Loranthus	0.5	1.0
Acrostichum aureum	11.0	22.0
Hypolepis	0.5	1.0
Monolete Spores	5.0	10.0
Cyperaceae	7.5	15.0
Typha	2.0	4.0
Total		**203.0**

KK4 790cm	Percentage	Numbers
Barringtonia asiatica	0.5	1.0
Cocos nucifera	4.5	9.0
Homalium acuminatum	0.5	1.0
Ixora bracteata	1.0	2.0
Macropiper	6.0	12.0
Pandanus	27.0	54.0
Pipturus argenteus sim.	21.0	42.0
Gramineae	5.5	11.0
Freycinetia wilderi	2.5	5.0
Acrostichum aureum	25.5	51.0
Cyathea	1.0	2.0
Monolete Spores	2.5	5.0
Trilete Spores	1.5	3.0
Cyperaceae	0.5	1.0
Typha	1.0	2.0
Total		**200.0**

KK4 890cm	Percentage	Numbers
Barringtonia asiatica	0.5	1.0
Cocos nucifera	14.5	29.0
Homalium acuminatum	0.5	1.0
Macropiper	4.0	8.0
Pandanus	3.5	7.0
Pipturus argenteus sim.	29.0	58.0
Scaevola taccada sim.	0.5	1.0
Compositae	0.5	1.0
Gramineae	6.5	13.0
Freycinetia wilderi	2.5	5.0
Loranthus	0.5	1.0
Acrostichum aureum	3.0	6.0
Hypolepis	1.0	2.0
Monolete Spores	17.5	35.0
Trilete Spores	0.5	1.0
Cyperaceae	8.0	16.0
Typha	12.5	25.0
Total		**210.0**

KK1

Samples:

KK1 10cm; KK1 60cm; KK1 110cm; KK1 160cm; KK1 210cm; KK1 250cm; KK1 310cm; KK1 360cm; KK1 410cm; KK1 460cm; KK1 510cm; KK1 560cm; KK1 570cm; KK1 610cm; KK1 660cm; KK1 710cm; KK1 760cm; KK1 810cm; KK1 860cm; KK1 910cm; KK1 960cm; KK1 1010cm; KK1 1052cm.

KK1 10cm	Percentage	Numbers
Canthium barbatum	1.0	2.0
Cocos nucifera	3.5	7.0
Homalium acuminatum	0.5	1.0
Malvastrum	0.5	1.0
Pandanus	11.0	24.0
Pipturus argenteus sim.	24.0	52.0
Compositae	2.0	4.0
Gramineae	2.5	5.0
Davallia	1.0	2.0
Monolete Spores	49.5	105.0
Trilete Spores	5.0	10.0
Total		**213.0**

KK1 60cm	Percentage	Numbers
Canthium barbatum	0.5	1.0
Cocos nucifera	3.0	6.0
Pandanus	9.5	19.0
Pipturus argenteus sim.	35.5	71.0
Compositae	1.5	3.0
Gramineae	4.5	9.0
Freycinetia wilderi	1.5	3.0
Dicranopteris linearis	1.5	3.0
Anemia	1.5	3.0
Monolete Spores	25.0	50.0
Trilete Spores	16.0	32.0
Total		**200.0**

KK1 110cm	Percentage	Numbers
Barringtonia asiatica	0.5	1.0
Cocos nucifera	1.0	2.0
Pandanus	8.5	17.0
Pipturus argenteus sim.	22.5	45.0
Compositae	1.5	3.0
Gramineae	5.5	11.0
Freycinetia wilderi	0.5	1.0
Acrostichum aureum	3.0	6.0
Davallia	2.0	4.0
Dicranopteris linearis	2.0	4.0
Anemia	3.0	6.0
Monolete Spores	42.5	87.0
Trilete Spores	7.0	14.0
Total		**201.0**

KK1 160cm	Percentage	Numbers
Barringtonia asiatica	0.5	1.0
Canthium barbatum	20.0	40.0
Cocos nucifera	2.0	4.0
Pandanus	4.0	8.0
Pipturus argenteus sim.	21.0	42.0
Gramineae	1.0	2.0
Davallia	1.0	2.0
Monolete Spores	31.5	63.0
Trilete Spores	19.0	38.0
Total		**200.0**

KK1 210cm	Percentage	Numbers
Barringtonia asiatica	1.5	3.0
Canthium barbatum	7.0	14.0
Cocos nucifera	22.0	44.0
Pandanus	2.0	4.0
Pipturus argenteus sim.	23.5	47.0
Loranthus	0.5	1.0
Gramineae	1.5	3.0
Cyathea	1.0	2.0
Monolete Spores	40.0	80.0
Trilete Spores	1.0	2.0
Total		**200.0**

KK1 250cm	Percentage	Numbers
Canthium barbatum	1.5	3.0
Cocos nucifera	4.0	8.0
Pandanus	18.5	37.0
Pipturus argenteus sim.	37.5	75.0
Compositae	4.0	8.0
Gramineae	7.0	14.0
Cyathea	1.0	2.0
Davallia	1.0	2.0
Hypolepis	1.0	2.0
Monolete Spores	24.5	49.0
Total		**200.0**

KK1 310cm	Percentage	Numbers
Canthium barbatum	1.0	2.0
Cocos nucifera	5.0	10.0
Elaeocarpus tonganus	0.5	1.0
Homalium acuminatum	1.0	2.0
Pandanus	15.5	32.0
Pipturus argenteus sim.	17.5	36.0
Compositae	0.5	1.0
Gramineae	8.0	16.0
Acrostichum aureum	3.0	6.0
Cyathea	3.5	7.0
Davallia	1.5	3.0
Dicranopteris linearis	1.0	2.0
Monolete Spores	41.5	86.0
Trilete Spores	2.0	4.0
Total		**208.0**

KK1 360cm	Percentage	Numbers
Canthium barbatum	1.5	3.0
Cocos nucifera	5.0	10.0
Pandanus	4.0	8.0
Pipturus argenteus sim.	2.0	4.0
Acrostichum aureum	80.5	161.0
Cyathea	1.0	2.0
Anemia	0.5	1.0
Monolete Spores	6.0	12.0
Total		**201.0**

KK1 410cm	Percentage	Numbers
Barringtonia asiatica	1.0	2.0
Canthium barbatum	6.5	13.0
Cocos nucifera	5.0	10.0
Homalium acuminatum	0.5	1.0
Pandanus	3.5	7.0
Pipturus argenteus sim.	10.0	20.0
Gramineae	2.0	4.0
Loranthus	0.5	1.0
Acrostichum aureum	59.0	118.0
Acrostichum aureum/ Schizaea	0.5	1.0
Cyathea	1.5	3.0
Monolete Spores	7.0	14.0
Trilete Spores	3.5	7.0
Total		**201.0**

KK1 460cm	Percentage	Numbers
Canthium barbatum	1.0	2.0
Cocos nucifera	1.5	3.0
Podocarpus	0.5	1.0
Pandanus	0.5	1.0
Pipturus argenteus sim.	11.0	23.0
Gramineae	0.5	1.0
Acrostichum aureum	69.0	147.0
Monolete Spores	0.5	1.0
Trilete Spores	16.0	34.0
Total		**213.0**

KK1 510cm	Percentage	Numbers
Barringtonia asiatica	0.5	1.0
Canthium barbatum	0.5	1.0
Pandanus	5.0	10.0
Pipturus argenteus sim.	1.5	3.0
Compositae	2.0	4.0
Loranthus	0.5	1.0
Acrostichum aureum	78.5	157.0
Davallia	0.5	1.0
Hypolepis	0.5	1.0
Trilete Spores	12.5	25.0
Total		**204.0**

KK1 560cm	Percentage	Numbers
Barringtonia asiatica	1.0	2.0
Canthium barbatum	0.5	1.0
Cocos nucifera	1.5	3.0
Moraceae/Urticaceae	0.5	1.0
Pandanus	3.0	6.0
Pipturus argenteus sim.	87.0	173.0
Compositae	0.5	1.0
Acrostichum aureum	5.0	10.0
Trilete Spores	1.5	3.0
Total		**200.0**

KK1 610cm	Percentage	Numbers
Barringtonia asiatica	9.0	18.0
Canthium barbatum	0.5	1.0
Cocos nucifera	6.5	13.0
Malvastrum	0.5	1.0
Moraceae/Urticaceae	0.5	1.0
Pandanus	0.5	1.0
Pipturus argenteus sim.	12.0	24.0
Acrostichum aureum	46.5	93.0
Monolete Spores	24.5	50.0
Total		**202.0**

KK1 570cm	Percentage	Numbers
Barringtonia asiatica	0.5	1.0
Cocos nucifera	2.0	4.0
Pipturus argenteus sim.	1.0	2.0
Acrostichum aureum	89.5	179.0
Monolete Spores	6.5	13.0
Trilete Spores	0.5	1.0
Total		**200.0**

KK1 660cm	Percentage	Numbers
Barringtonia asiatica	16.5	33.0
Canthium barbatum	1.0	2.0
Cocos nucifera	6.0	12.0
Elaeocarpus tonganus	1.5	3.0
Homalium acuminatum	7.0	14.0
Podocarpus	0.5	1.0
Pandanus	2.0	4.0
Pipturus argenteus sim.	19.0	38.0
Gramineae	1.0	2.0
Acrostichum aureum	14.0	28.0
Monolete Spores	31.5	63.0
Total		**200.0**

KK1 710cm	Percentage	Numbers
Barringtonia asiatica	15.0	30.0
Canthium barbatum	1.0	2.0
Cocos nucifera	6.0	12.0
Elaeocarpus tonganus	0.5	1.0
Pandanus	7.0	14.0
Pipturus argenteus sim.	22.0	44.0
Gramineae	1.0	2.0
Freycinetia wilderi	0.5	1.0
Acrostichum aureum	3.5	7.0
Davallia	0.5	1.0
Monolete Spores	43.5	87.0
Total		**201.0**

KK1 760cm	Percentage	Numbers
Barringtonia asiatica	6.5	13.0
Cocos nucifera	5.0	10.0
Homalium acuminatum	2.0	4.0
Pandanus	0.5	1.0
Pipturus argenteus sim.	77.5	155.0
Freycinetia wilderi	0.5	1.0
Acrostichum aureum	0.5	1.0
Cyathea	1.0	2.0
Monolete Spores	7.5	15.0
Total		**202.0**

KK1 810cm	Percentage	Numbers
Barringtonia asiatica	14.0	28.0
Canthium barbatum	0.5	1.0
Cocos nucifera	1.0	2.0
Hibiscus tiliaceus	1.0	2.0
Homalium acuminatum	2.0	4.0
Pipturus argenteus sim.	49.5	99.0
Gramineae	0.5	1.0
Acrostichum aureum	9.5	19.0
Davallia	0.5	1.0
Monolete Spores	21.5	43.0
Total		**200.0**

KK1 860cm	Percentage	Numbers
Barringtonia asiatica	15.5	31.0
Canthium barbatum	1.5	3.0
Cocos nucifera	7.0	14.0
Elaeocarpus tonganus	1.0	2.0
Homalium acuminatum	4.5	9.0
Podocarpus	0.5	1.0
Pandanus	9.0	18.0
Pipturus argenteus sim.	15.5	31.0
Loranthus	0.5	1.0
Compositae	0.5	1.0
Gramineae	0.5	1.0
Acrostichum aureum	15.5	31.0
Cyathea	1.0	2.0
Davallia	1.0	2.0
Monolete Spores	26.5	53.0
Trilete Spores	1.0	2.0
Total		**202.0**

KK1 910cm	Numbers
Barringtonia asiatica	1.0
Cocos nucifera	2.0
Pipturus argenteus sim.	1.0
Monolete Spores	2.0
Total	**6.0**

KK1 960cm	Numbers
Barringtonia asiatica	2.0
Canthium barbatum	1.0
Cocos nucifera	1.0
Pipturus argenteus sim.	1.0
Monolete Spores	3.0
Total	**8.0**

KK1 1010cm	Percentage	Numbers
Barringtonia asiatica	3.0	6.0
Elaeocarpus tonganus	3.0	6.0
Homalium acuminatum	4.0	8.0
Moraceae/Urticaceae	1.5	3.0
Pandanus	8.0	16.0
Pipturus argenteus sim.	70.0	140.0
Compositae	1.0	2.0
Gramineae	0.5	1.0
Freycinetia wilderi	3.0	6.0
Acrostichum aureum	2.5	5.0
Cyathea	0.5	1.0
Monolete Spores	3.0	6.0
Total		**200.0**

KK1 1052cm	Percentage	Numbers
Barringtonia asiatica	0.5	1.0
Canthium barbatum	1.0	2.0
Cocos nucifera	1.0	2.0
Elaeocarpus tonganus	2.0	4.0
Homalium acuminatum	1.0	2.0
Pandanus	6.5	13.0
Pipturus argenteus sim.	20.5	41.0
Compositae	1.5	3.0
Gramineae	0.5	1.0
Freycinetia wilderi	1.5	3.0
Acrostichum aureum	14.0	28.0
Cyathea	5.0	10.0
Davallia	1.0	2.0
Monolete Spores	29.5	59.0
Trilete Spores	0.5	1.0
Typha	14.0	28.0
Total		**200.0**

ATUPA SWAMP

AT1

Samples: AT1 0cm; AT1 100cm; AT1 150cm; AT1 230cm.

AT1 0cm	Numbers
Cocos nucifera	7.0
Moraceae/Urticaceae	4.0
Pipturus argenteus sim.	9.0
Premna?	1.0
Anemia	1.0
Monolete Spores	1.0
Trilete Spores	2.0
Total	**25.0**

AT1 100cm	Numbers
Cocos nucifera	1.0
Macropiper	5.0
Pipturus argenteus sim.	1.0
Total	**7.0**

AT1 230cm	Numbers
Pipturus argenteus sim.	1.0

ARO`A SWAMP
AO1
Samples: AO1 0cm; AO1 50cm; AO1 100cm; AO1 200cm.

AO1 0cm	Numbers
Cocos nucifera	2.0
Moraceae/Urticaceae	2.0
Pipturus argenteus sim.	2.0
Gramineae	4.0
Monolete Spores	9.0
Total	**19.0**

AO1 50cm	Numbers
Cocos nucifera	1.0
Moraceae/Urticaceae	1.0
Dicranopteris linearis	1.0
Monolete Spores	5.0
Total	**8.0**

AO1 100cm	Numbers
Monolete Spores	1.0

AO1 200cm	Numbers
Monolete Spores	4.0

A.5 An Ecological Zonation of Human Resources

The following section lists all the useful plants, with additional information on animals and minerals exploited, according to the zone(s) in which they are found. Then by each plant are listed the various uses of that plant. The sources for this are Buck (1927; 1944) and Whistler (1990). It is hoped through this to gain some idea of the extent and nature of traditional human exploitation of each zone. One caveat is that it is not so much the number of uses of the various plants in a particular zone so much as the relative importance, especially with quantity of material used, of the plants. Some plants occur in more than one zone. In this case, one has to consider where the plants are most common or most convenient for humans to gather them.

UPLAND
<u>Animal</u>
Birds: See Coastal Plain and Valley
Rats: See Coastal Plain and Valley
<u>Mineral</u>
Basalt See Shore
Clay See Shore
Ochre See Shore
UPLAND PLANTS
<u>Trees</u>
1) *Bischofia javanica/Koka*
Fruits medicines
2) *Casuarina equisetifolia/Toa*
See Shore Plants
3) *Celtis pacifica/Mokopine*
Wood children's tops
4) *Cerbera odollam/Reva*
Sap liniment for rheumatism
5) *Cyathea decurrens/Panga/`Eki*/Tree Fern
Pith famine food
6) *Cyathea parksiae/Panga/`Eki*/Tree Fern
Pith famine food
7) *Elaeocarpus tonganus/ Karaka* timber
8) *Fagraea berteriana/Pua*
Wood handicrafts
Flowers leis, scenting coconut oil
9) *Glochidion ramiflorum/Ma`ame*
Wood furniture, house posts
10) *Hernandia moerenhoutiana/Turina*
Wood canoes
11) *Hibiscus tiliaceus/`Au*
See Shore Plants
12) *Homalium acuminatum/Mato/Moto*
Wood posts, house construction, planting stick, canoe house beams (Davis pers. comm. 1992)
13) *Inocarpus fagifer/T`i*/Tahitian Chestnut
See Coastal Plain and Valley Plants
14) *Macaranga harveyana/`Enua*

Wood	boat planks
15) *Pittosporum arborescens/Kavakava*	
Wood	timber, firewood
16) *Santalum insulare/A`i* Bertero var. *mitiaro* Sykes (Miti`aro only)	
Wood	scenting coconut oil, curing headaches and earaches, mosquito repellant
17) *Sapindus c.f. vitensis/`Ake`ake* (Ma`uke only)	
Wood	timber, handaxes
18) *Streblus anthropophagum/*	
Matimati	food - edible fruit
19) *Syzygium malaccense/Ka`ika*	
See Coastal Plain and Valley Plants	
20) *Terminalia glabrata/Kauariki*	
See Coastal Plain and Valley Plants	

Small Trees and Shrubs

1) *Alyxia stellata/*	
Maire rakau	bark and leaves for garlands
2) *Angiopteris longifolia/`Ana`e*	
Rhizome	food
3) *Canthium barbatum/Matira*	
Wood	canoe booms, fishing pole for catching mackerel, house posts and rafter sticks, food -edible fruit
4) *Cordyline terminalis/Rau ti/*Ti tree	
See Coastal Plain and Valley Plants	
5) *Eugenia reinwardtiana/Nioi*	
Fruit	food (children)
6) *Fitchia speciosa/Neinei*	
Nectar	food
7) *Geniostoma/*	
`Ange	garlands, scenting coconut oil and bark cloth
8) *Ixora bracteata/`Itoa*	
Fruit	food eaten by children (Miti`aro only)
9) *Leucosyke corymbulosa/*	
Rau ta`uri	stakes in fishtraps
10) *Macropiper latifolium/*	
Kavakava atua	medicines
11) *Melastoma denticulatum/*	
`Ua matukutuku	children's food
12) *Myoporum sandwicense/Ngaio*	
Flowers	scenting coconut oil
13) *Solanum repandum/*	
Morirei	red dye (Mangaia)
14) *Tephrosia purpurea/Mata`ora*	
See Coastal Plain and Valley Plants	

Climbers

1) *Canavalia cathartica/*	
Kaka poti	pods used as toy boats by children
2) *Entada phaseoloides/Kaka vai*	
Stem	water can be obtained from cut stems, bark cloth for the poor (possible confusion with *kaka*: the roots of the Banyan Tree), rope for dragging canoes, leaf sweeps for fishing (Aitutaki)
Seeds	garlands
3) *Freycinetia wilderi/*	
Kiekie	circular fish traps, small fish traps, cylindrical fish traps
4) *Jasmimum didymum/*	
`Aketa	freshwater eel traps, baskets, trays
5) *Mucuna gigantea?/Kaka tea*	
Stem	jump ropes, temporary ropes, skipping ropes, swings

Herbaceous Plants

1) *Asplenium nidus/Kota`a*	
Fronds	wrapping up oven food, tips eaten, garden ornamentals, thatch for forest shelters
2) *Blechnum orientale/*	
Moumea	filling on top of ridge pole and beneath the ridge sheet (Mangaia), floor covering
3) *Dicranopteris linearis/*	
Tuanu`e	medicines
4) *Leucas decemdentata/*	
Pua`ikao	medicine for thrush, urinary tract infections,haemorrhoids and circumcision wounds
5) *Lindernia crustacea/*	
Tutae torea	medicine for children's ailments and some unrelated ailments

6) *Lycopodium cernuum/*	
Remu maunga	headleis
7) *Marattia salicina/*	
Para	food
8) *Microsorium sylvaticum/*	
Maire kakara	scented garlands
9) *Nephrolepsis hirsutula/*	
Toroutou	medicine for treating circumcision scabs
10) *Phymatosorus scolopendria/*	
Maire	medicine for a children's ailment, other illnesses, dancing skirts, wreaths
11) *Pteris tripartita/*	
`Are rupe	camouflage for catching pigeons (Tahiti)
12) *Zingiber zerumbet/Kip`enua*/Shampoo Ginger	
Rhizome	hair softener, medicine for haemorrhoids and prolapsed rectum

COASTAL PLAIN AND VALLEY

Animal

Birds:	
Bone	tattooing comb
Feathers[65]	headdresses, headbands, canoe stern, Mangaian kites, decoration, staff god ornaments, ornament for carved slabs (*unu* ? from Aitutaki and Mangaia), Atiu gods, Miti`aro gods, Ma`uke gods,
Mangaian gods	
Flesh	food
Bone	necklaces, fish hooks (Ma`uke), combs
Human hair	baldrics, ear ornaments, necklaces, armlets (Mangaia), anklets (Mangaia), Atiu gods, Mangaian gods, carved slabs from Mangaia (*unu* ?)
Pigs:	
Flesh	food
Tusks	fish hooks (Ma`uke)
Rats:	
Bone	tattooing comb
Flesh	food (Mangaia)

Mineral

Basalt	See Shore
Clay	body paint
Ochre	body paint

COASTAL PLAIN AND VALLEY PLANTS

Trees

1) *Aleurites moluccana/Tuitui*/Candlenut	
Bark	red dye, black dye, medicine
Kernels	tattooing pigment, body paint, wood paint, polishing wood, torches, *peipei* balls, jackstones (*pere*), food, used in massage for treating earaches and headaches
Leaves	lining of oven used in bark cloth manufacture
Wood	planting sticks
2) *Artocarpus altilis/Kuru*/Breadfruit	
Wood	tables, bark for cloth, gunwale strake or rail (canoes), canoe bailers, fish trap floats, childrens' *pua* or throwing discs, *pa`u* (skin drums), carved slabs (*unu*/religious carved slabs placed on a *marae* ? from Aitutaki)
Tapou/Gum	strengthener or adhesive for arm-sling, canoe caulking, birdlime when mixed with pounded candlenuts, weight on tip of *teka* (dart), adhesive for *manu tukutuku* (kites), adhesive for shell patch on trumpets
Leaf stem	rat traps
Stem tips	medicine for abdominal pains
Leaves	earth oven covers, solution of burnt leaves with banana trunk sap used as medicine for shingles
Fruit	food
3) *Barringtonia asiatica/`Utu*	
See Shore Plants	
4) *Caesalpinia major/Tataramoa*	
Seeds	children's games
5) *Calophyllum inophyllum/Tamanu*	

65 The red tail and wing feathers of the *Kura* or Red Parakeet were considered the most important for headdresses and religious objects; the feathers of the Red-tailed Tropic Bird, the Greater Frigate Bird and the Domestic Fowl were used as plumes; Tropic Bird feathers were used as decoration for canoe sterns; and the feathers of the White-tailed Tropic Bird, the Pacific Pigeon, Long-tailed Cuckoo and various seabirds were also used.

See Shore Plants

6) *Casuarina equisetifolia/Toa*

See Shore Plants

7) *Cocos nucifera/Tumunu*/Coconut

See Shore Plants

8) *Erythrina variegata/Ngatae*

Wood	fish net floats

9) *Ficus prolixa/Aoa/Ava*/Banyan

Wood	fire plough, bark cloth, purgative for serious diseases thought to be cancer
Aerial root	whip for top (*potaka*)

10) *Ficus tinctoria/Mati*

Berries	pounded together with *tou* for a red dye

11) *Guettarda speciosa/Ano*

See Shore Plants

12) *Hibiscus tiliaceus/`Au*

See Shore Plants

13) *Homalium acuminatum/Mato/Moto*

See Upland Plants

14) *Inocarpus fagifer/I`i*/Tahitian Chestnut

Wood	planting stick (Ma`uke), firewood
Bark	medicine for babies with teething problems, medicine for animals, especially pigs, with digestive or urinary problems
Fruits	medicine for animals, especially pigs, with digestive or urinary problems
Leaves	childrens' kites

15) *Spondias dulcis/Vi kavakava*/Polynesian Plum/

Otaheite Apple	medicine for thrush and urinary tract ailments

16) *Syzygium malaccense/Ka`ika*

Fruit	famine food
Bark	medicine for thrush and used as an emetic
Leaves	medicine for thrush

17) *Terminalia glabrata/Kauariki*

Wood	houses
Leaves	medicines to soak fractures and sprains

18) *Thespesia populnea/Miro*

See Shore Plants

Small Trees and Shrubs

1) *Abelmoschus moschatus/*

Vaivai tara	medicine for impotence, fractures, sprains and other unrelated ailments

2) *Alocasia macrorrhiza/*

Kape	food, famine food (according to Tara`are pers. comm. 1992)

3) *Amorphophallus paeoniifolius/*

Teve	famine food

4) *Broussonetia papyrifera/`Aute*/Paper Mulberry

`Aute wood	wooden peg for ripening breadfruits
`Aute	bark cloth for *tiputa*, *maro* and *pareu*
Purautea bark	fishing nets and lines
Papako bark	fishing nets and lines

5) *Cordyline terminalis/*

Rau ti /Ti tree	ornaments, medicine for sore throats, burns, used as a purgative, food, kilts, arm ornaments, leg ornaments, Mangaian kites, headdresses, famine food (according to Tara`are pers. comm. 1992)

6) *Cyrtosperma chamonis/Puraka*

Leaves	wrapping during retting process of bark cloth manufacture, oven covers
Stems	hats, mats

7) *Gardenia taitensis/*

Tiare maori

Flowers	leis, ear ornaments, scenting coconut oil, medicine for children's ailments, migraine headaches or sinusitis
Wood	cross bar in scoop net handles (Atiu, Ma`uke)

8) *Hibiscus rosa-sinensis/Kaute*

Flowers	medicine for children's ailments and to induce abortion, blotches of red dye

9) *Musa x paradisiaca/Meika*/Banana and Plantain

Banana stems	lining of oven used in bark cloth manufacture, pig fodder
Banana fruit	food

Rau-meika[66]	wrapping during retting process of bark cloth manufacture, *tiputa*, wreaths, covering for *pa`ata* or food stretcher/platform, mulch, for sleeping on, wrapping food
Rau-uru[67]	lining for *ma`i*[68] pit
Kua[69]	kite string, *kio* hook bait lashing, binding for *tumutumu* darts
Banana sap	medicine for shingles, kite glue
10) *Musa troglodytarum/`Utu*/Mountain Plantain	
Fruit	food, famine food (Afsenius 1988a.)
Trunk epidermis	hats, mats
Sap	black dye, medicine for shingles
Rau-`ti /Leaves	wrapping for fish to be cooked in earth oven (*umu*), weft, black dye
11) *Pandanus tectorius/`Ara ta`a tai*	
See Shore Plants	
12) *Piper methysticum/*	
Kava maori	drink, medicine for urinary tract
13) *Saccharum officialis/To*/Sugar cane	
Stems	food, medicines, frame for masks
14) *Schizostachyum glaucifolium/Ko`e maori*/Polynesian Bamboo	
Stems	knives, frame for masks, house walls, fishing rods, nose flutes, spears, water container ?
15) *Sida rhombifolia/Purumu*	
Stems	brooms, rakes
Bark	kilts
16) *Solanum viride/Poro`iti*	
Leaves	medicine for boils
Berries	famine food, necklaces, wreaths, head leis, games (Atiu), medicine for ringworm
17) *Tephrosia purpurea/Mata`ora*	
Leaves, Stems, Roots, Bark and Twigs	used as fish poison (though on a smaller scale than *Barringtonia asiatica* - Gill, W.W. 1885, p.142)

Climbers

1) *Abrus precatorius/Pitipiti`o*	
Seeds	leis, seed rattles
2) *Benincasa hispida?/*	
`Ua roro	calabashes
3) *Cucumis melo/*	
Pati?	food (Mangaia)
4) *Dioscorea nummularia?/*	
U`i purai	food (for famine, according to Buck 1944)
5) *Dioscorea pentaphyllum/Pirita*	
Tuber	food (for famine, according to Buck 1944)
Vine	circular fish traps (Ma`uke)
6) *Ipomoea batatas/Kumara/*	
Sweet Potato	food
7) *Lagenaria siceraria/*	
`Ue	gourds, calabashes, water containers

Herbaceous Plants

1) *Achyranthes aspera/*	
Kip varu	medicine
2) *Amaranthus viridis/*	
Va`ine`ara	medicine for burns, urinary tract ailments, and other ailments
3) *Centosteca lappacea/*	
Ko`eko`e	medicines
4) *Chrysopogon aciculatus/*	
Matie	floor covering
5) *Colocasia esculenta/*	
Taro	food, famine food in the form of po`i (according to Tara`are pers. comm. 1992), pink dye
6) *Curcuma longa/Renga*/Turmeric	
Rhizome	yellow dye, food, medicine for urinary tract diseases, jaundice and burns
7) Cyperaceae/	
Mauku	animal feed
8) *Dichrocephala integrifolia/*	

66 Green banana leaf
67 Dry banana leaves.
68 Fermented breadfruit paste.
69 Banana fibre

Takataka`iara	medicine (Nga Pu Toru)
9) Gramineae/	
Mauku	animal feed
10) *Kyllinga nemoralis/*	
Mauku `onioni	medicine
11) *Limnophila fragans/*	
Mapua	garlands
12) *Mariscus javanicus/Mauku tatau tai*	
Stem fibres	coconut cream, kava and medicine strainer
13) *Miscanthus floridulus/*	
Kaka`o	rafter sticks, house partitions, wall stakes (Mangaia), *teka* (darts), Mangaian kites
14) *Ophioglossum petiolatum/*	
Rau ta`i	medicines
15) *Oxalis corniculata/*	
Kiki`i	medicine for thrush, certain children's ailments, and other illnesses
16) *Paspalum orbiculare/*	
Mata	filling on top of ridge pole and beneath the ridge sheet, floor covering, oven lining
17) *Phyllanthus virgatus/*	
Moemoe	medicine for severe earache or meningitis and ear infections
18) *Polygonum dichotomum/*	
Tamore	medicines
19) *Rorippa sarmentosa/*	
Toatoa `enua	medicine for haemorrhoids and some other unrelated ailments
20) *Scirpus subulatus/*	
Raupo	thatching, coarse mats, children's rafts
21) *Siegesbeckia orientalis/*	
Kamika	scenting oil, garlands, medicines
22) *Solanum americanum/Poroporo*	
Leaves	famine food, medicine for boils
23) Swamp mud	black dye
24) *Tacca leontopetaloides/*	
Pia `enua	food, medicine, hats, adhesive for *manu tukutuku* (kites)

SHORE

Animals

Birds:	See Coastal Plain and Valley
Crabs:	food

Mineral

Basalt	food pounders, adzes, gouges, chisels, sling stones, road kerbing, metalling for roads and paths, religious and house platforms, boundary stones, stone walling, stone seats, sinkers for seine nets and fish traps, fish weir entrances
[Stalagmite/ Stalactite	sling stones, religious platforms[70], food pounders (Mangaia)]
Unident.Stone	anchors, sinkers for fish traps, Mangaian gods, oven stones, Mangaian god images

SHORE PLANTS

Trees

1) *Barringtonia asiatica/`Utu*	
Wood	bow and stern covers (canoes in Nga Pu Toru), *pa`u* (skin drums)
Kernels	fish poison, medicine for burns and other unrelated ailments
Fruit	food
Leaves	dressing for wounds, wrapping for fish to be cooked in earth oven
Stem epidermis	hats, mats
Sap	black dye, medicine for shingles
2) *Calophyllum inophyllum/Tamanu*	
Wood	bowls, food pounders, taro pounding tables, ridge posts, ridge poles, seats, thrones, bark cloth anvils, necklaces, canoe hulls, stern and bow pieces of canoes, booms (canoes in Nga Pu Toru), *potaka* (tops), *pate* (*tokere* - Aituataki - small slit gong), *ka`ara* (large slit gong), *pa`u* (skin drums), Mangaian gods?
Seeds	*peipei* balls
Toto/Sap	varnish for bark cloth
Leaves	medicine for skin sores and rashes
3) *Casuarina equisetifolia/Toa*	
Wood	wall stakes, bark cloth beaters, booms (canoes), connecting pegs for outriggers (Aitutaki), hand-fishing rods, torches, fish spears, cross piece in circular fish traps, cylindrical fish traps (Aitutaki), fishing net mesh gauges, scoop net frames, fishing rods, digging sticks, *pua* or throwing discs, bodkin for piercing

70 Such as those on *marae* and *koutu*.

	bark cloth in kite-making, bamboo spear points, god images, staff gods, Mangaian gods, sandal-making needles, *keke* lashing tightener, caulking implements, barracuda, hooks, house timber, posts, outrigger booms, axe handles,
	digging sticks, fishhooks, spears
Taiki[71] wood	thatching needles, canoe lashing needle (Atiu), war clubs, spears
Bark	medicine for thrush and urinary tract problems, to induce vomiting, red dye
Root	*Ruvettus* fish hooks
4) *Cocos nucifera/Tumunu*/Coconut	
Fronds/*Kikau*	baskets, food platters, food baskets, cooking containers, oven covers, thatch sheets for dwelling houses, cooking houses and canoe houses, thatching thread, wall sheets, sitting mats, sleeping mats, floor-covering mats, disc-pitching mats (Mangaia), fans, eyeshades, neck ornaments, kilts, leaf sweeps for fishing, everyday clothing (Pukapuka)
Coir	bags, headdresses, caps, adze lashing, slings, ornament for carved slabs (*unu* ? from Aitutaki and Mangaia), Atiu gods, Miti`aro gods, Ma`uke gods
Ka`a/Sennit	bags, cordage, ornamentation on god-staffs, adze lashing, canoe lashing, canoe charm (Mangaia), fish hook lashing, fish trap lashing, *manu tukutuku* (kites), *pa`u* (skin drums), ornamental lashing for spears, slings, sling stone carriers, slip nooses, Atiu gods, Miti`aro gods, Ma`uke gods, Mangaian gods, carved slabs (*unu* ? from Mangaia), binding thatch sheets to roofs, headdresses/skull caps, turtle nets
Kaka/Stipule	strainer for medicine, coconut cream, dye and kava, fire wood, torches, kindling material, wrapping for sinkers for seine nets, Atiu sennit and feather gods, padding under adze lashing, padding for where boom crosses the gunwales
Midrib	brooms, thread for pandanus thatch, tongs, feather attachments for headdresses
Shell	drinking cups, cooking vessels, containers, water bottles, scrapers, ear ornaments (Mangaia), fish hooks (Mangaia), *potaka* (tops), childrens' shoes, *tukituki teniteni* (childrens' game), canoe bailers
Coconut meat	food, famine food (according to Tara`are pers. comm. 1992)
Puru/Husk	lashing, rope, nets, clothing, food, coconut cream strainer, binding for headdresses, caulking canoes, padding for the gunwale strakes, cover for eel traps, rat trap nooses
Water	medicines, food
Oil	purgative, dyes, bark cloth varnish, polishing *puka* seeds for necklaces
Cream	yellow dye (Mangaia), red dye and shiny white finish (Aitutaki), food
Leaf midribs	dyeing frames, canoe lashing needle, *teka te manu`iri*, toboggans (*tupa`oro`oro*), thread used in *rau* thatch sheets
Leaflet midrib	teetotums, jew's-harp
Leaf tip	canoe charm (Mangaia)
Dry leaves	torches
Leaflets	hoops (*potaka*), windmills (*porotaka*), spinners (*kuere*), bull roarers (*patangitangi*), leaflet canoes (*vaka kopae*)
Roro/ Flower stipule	fire wood, kindling torches
Aka niu/ Rootlets	circular fish traps (Aitutaki)
Wood	house posts, ridge posts, clubs, spears, throwing sticks, medicine for things like fractures and filariasis
5) *Cordia subcordata/Tou*	
Wood	box for storing clothes, stern piece (canoes), *pa`u* (skin drums), posts, furniture, slit gongs, seats, clubs, paddles, spears, canoes (Tongareva)
Bark	children's ailments
Leaves	red dye, medicine for abdominal swellings, urinary tract ailments
6) *Guettarda speciosa/Ano*	
Wood	on atolls only: houses, furniture, canoes *etc.*
Leaves	on atolls only: oven covers, oven food wrapping, plates.
Flowers	scenting coconut oil
7) *Hernandia nymphaeifolia/Puka*	
Wood	doors, canoe hulls, *pa`u* (skin drums), stern and bow pieces of canoes, seine net floats
Seeds	leis, dancing skirts
8) *Hibiscus tiliaceus/`Au*	
Kiri`au/Bark	climbing bandages, coconut oil or cream strainers, slings, cordage, kilts or hula skirts (*titi*), *tamaka* or sandals, mats, torch binding, binding for wall plates, binding for thatch bundles, binding in fish traps, fishing nets and lines, tip of *tumutumu* and *okaoka* types of *teka* (dart), throwing attachment for *teka te manu`iri* and *teka koki`i*, throwing strip for *pua* or throwing discs, kite string and tail, spinning strip for tops (*potaka*), string figures, lashing for *pa`ata* or food stretchers/platforms, lashing cross booms of canoes to outriggers, temporary lashing for canoe hulls, pig ropes, medicine for fractures and sprains
Wood	carrying poles, fire plough, most house parts aside from ridge poles and ridge posts, wall stakes, stern and bow pieces of canoes, outrigger floats (canoes), canoe pole, canoe bailers, masts, paddles, floats for long fishing nets, handle for scoop nets, many-pointed spear shafts, digging sticks (for

[71] Heartwood of *toa*.

	planting sugar cane), *okaoka* (type of *teka*), *manu tukutuku* (kites), *potaka* (tops), stilts, *pa`ata* or food stretchers or platforms, firewood
Leaves	oven covers
Flowers	medicine for boils
9) *Pisonia grandifolia/ Puka tea*	firewood, animal fodder
10) *Thespesia populnea/Miro*	
Wood	*pate*, *kumete*, boat parts, paddles, adze-handles, furniture, bark cloth beaters, bark cloth anvils, necklaces, stern piece (canoes), *tupe* or pitching discs (Mangaia), Mangaian kites, *tokere* (small slit gong), clubs (Aitutaki)
Berries	teetotums, medicine for urinary tract ailments, abdominal swellings (and also as an antidote against the poison of the `no`u' fish - Gill, W.W. 1885, p.135)
Leaves and bark	medicine for ailments associated with teething of infants
<u>Small Trees and Shrubs</u>	
1) *Capparis cordifolia/ Papiro*	wreaths, sunshades (Aitutaki)
2) *Chamaesyce atoto/ Totototo* wood	tops
3) *Colubrina asiatica/ Tutu* stems	to attach membrane to drums, fishtraps, soap
4) *Morinda citrifolia/Nono*	
Wood	yellow dye
Roots	red dye, medicine from stonefish stings
Fruit	famine food, medicine for urinary tract ailments, diaphragmatic hernia, abdominal swellings
5) *Pandanus tectorius/`Ara ta`a tai*	
Rau-`ara/	
Fine Leaves	baskets, fans, sleeping mats, sails, *tiputa*, chiefly waist band, loin cloths, baldrics, belts, shoulders straps (Aitutaki), tip of *okaoka* (type of *teka*), childrens' shoes, *pa`u* (skin drums), ornamentation in *`au* kilts, neck ornaments, *kikau* basket handles
Rau/	
Coarse leaves	thatch sheets, thatch for *`are ei `au* (Mangaia), padding for where boom crosses the gunwales
Kai-`ara/	
Aerial roots	thatch sheet midribs, wall stakes, dyeing frames, wedge to tighten up temporary *kiri`au* canoe hull lashing, famine food, purgative, medicine for urinary tract ailments and other ailments, spinning tops
Leaf thorns	fish hooks
Wood	house timbers, *atarau*/raised platform on a *marae* (Akaoro marae, Mangaia)
Kati`ara	paint brush
Pandanus drupes	paint brushes, wreaths
`Inano/	
Male flower	scenting coconut oil, garlands
6) *Pemphis acidula/Ngangie*	
Wood	(not on Rarotonga) spears, walking sticks, fishhooks, fish gorges, shark hooks, coconut husking sticks, roof sheet needles, tool handles, firewood, pointed stick for octopus catching
7) *Pipturus argentea/`Oronga*	
Bark	ropes, binding for headdresses and kilts, fishing nets (strongest type) and lines, string figures, slings, Atiu and Ma`uke sennit and feather gods
Fruit	food (children)
Leaves	animal fodder
8) *Scaevola taccada/ `Utukava* wood	floats for long fishing nets
9) *Sophora tomentosa*	
Wood	firewood, coconut husking stick, hollowed-out stems for peashooters, pith for making dancing kilts
Seeds	leis, medicine
Leaves	fed to goats
10) *Triumfetta procumbens/Ngau*	
Leaves	(Ma`uke) medicine for boils
11) *Vitex trifolia/Rara*	
Leaves	medicine for postnatal problems among women
<u>Climbers</u>	
1) *Cassytha filiformis/ Tainoka*	wreaths, children's headbands, medicine for children's ailments, and sore throat
2) *Ipomoea littoralis/Pipi*	
Leaves and stems	medicine for infants (and as an antidote against the poison of the `no`u' fish - Gill, W.W. 1885, p.135)
3) *Luffa cylindrica/Po`ue*	

Leaves	medicine (Mangaia, Miti`aro, Ma`uke)
Herbaceous Plants	
1) *Portulaca lutea/*	
Katuri	food
OCEAN AND LAGOON	
Animal	
Birds:	See Coastal Plain and Valley
Fish:	
Maratea	fish which only priests were allowed to eat in Tauhunu village on Manihiki (Kauraka 1983, p.15)
Meat	food
Porcupine fish	
spine	knife or needle for splitting pandanus leaves
Sting-ray's	
tail	spear tips
Shellfish:	
Aplysia sp./	
Patito	small edible sea-slug or sea-hare on Rarotonga (Kauraka 1985, p.60)
Ka`i shell	scrapers and cutters for *rau`ara* preparation
Meat	food
Pa`ua shell	childrens' shoes
Pearl shell	fish hooks ?, staff god ornaments, necklaces
Shells[72]	scrapers, decorations, armlets (Mangaia), octopus-lure?, Mangaian gods, garlands, ornamentation on
kilts	
Triton shell	trumpets, Mangaian gods
Turbo shell	fish hooks (Mangaia)
Shark:	
Meat	food
Skin	*pa`u* (skin drums), padding under adze lashing
Squid and octopus:	
Meat	food
Turtle:	
Meat	food
Shell	fish hooks (Aitutaki), coconut grater
Whale:	
Bone	food pounders
Ivory	*rei* ear ornaments, necklaces
Mineral	
Calcite	food pounders
Coral	coconut grater, food pounders, sling stones, Mangaian gods, *kirikiri teatea*[73], road kerbing, metalling for roads and paths, fish weirs
Ngaika ?	dye fixer - possible introduction from Manihiki
Plants	
Sea weed	food
MISCELLANEOUS	
Bark cloth[74]	*tiputa*, *maro*, *pareu*, cloaks, waist bands, headdresses, turbans, cone-shaped caps, masks, swabs, *manu tukutuku* (kites), screen for *`are ei `au* (Mangaia), wrapping for staff gods, ornament for carved slabs (*unu* ? from Aitutaki and Mangaia), Ma`uke gods, Mangaian gods
Coloured seeds[75]	decorations, ornamentation on kilts
Flowers[76]	wreaths, decorations, necklaces
Miri leaves[77]	mixed with hot water to exorcise spirits (See good example in Kauraka 1982)
Tikoru[78]	wrapping for gods (Mangaia)
Unident. wood	fan handles, breadfruit pickers, coconut stool graters, weapon platforms (*`ata*), tattooing tapper, cylindrical wooden ear ornaments, charcoal for body paint, adze hafts, thwarts (canoes), carrying

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72 *Pare`o* ( small variety of cowrie), *Pipi* (a type of bivalve), *Ka`i*, *Ungaunga* (Cat's Eyes), *Pupu* (spiral shells).

73 White coral gravel used for flooring houses and religious platforms.

74 Bark cloth could be made from the inner bark of the Paper Mulberry (the best quality), the Breadfruit tree (good quality), the aerial roots of the Banyan tree (coarser brown cloth) and poorer people in Mangaia used *Entada phaseoloides*, a woody climber.

75 *Puka* (black seed), *Poepoe* (slaty blue seed), *Tavara* (red seed).

76 *Kaute*, *Tiare Maori*, *`Inano* (male Pandanus flower), *Miri*, *Poro`iti*, *Mapua*.

77 Term used for a number of types of plant with scented leaves like the introduced species of basil and mint, as well as the indigenous or aboriginally introduced *mapua* (*Limnophila fragrans*), sometimes called *miri mopua*.

78 Special thick white bark cloth.

stringers (canoes), skids (canoe-launching), amulets (canoe images), fowl traps, *teka kiore* and *teka koki`i* (darts), surf boards, crossbars for swings, beating sticks for slit gongs, bows and arrows ?

A.6 Radiocarbon Dates

All dates expressed in terms of B.P. (before A.D. 1950).
Calibration Method: University of Washington Quaternary Isotope Lab Radiocarbon Calibration Program Rev 3.0.3 (Stuiver and Reimer 1993)
References: Stuiver and Pearson 1993; Pearson and Stuiver 1993; Pearson *et al.* 1993; Linick *et al.* 1986.

KK4 (MR1)

Depth (cm)	Sample Type	NZA No.	δ13C per mille	Conventional C-14 (1 σ)	Calibrated Age (2 σ) Summary
90-100	Peat	3263	-25.81	1080 ±60	1133 (958) 791
130-135	Peat	3265	-28.34	2438 ±73	2730 (2353) 2157
160-170	Peat	3270	-26.16	5780 ±77	6756 (6546) 6349
190-200	Peat	2281	-26.2	3326 ±92	3822 (3523) 3344
290-300	Peat	2282	-27.6	3485 ±100	3976 (3690) 3420
420	Peat	2255	-26.6	4007 ±53	4794 (4417) 4237
460	Gyttja	2256	-25.5	4106 ±54	4830 (4563) 4414
700-710	Gyttja	2283	-35.6	5562 ±98	6406 (6193) 5927
		Beta Analytic Inc No.			
940-950	Gyttja	37137	-28.8	7680 ±100	8559 (8373) 8137

KK1

Depth (cm)	Sample Type	NZA No.	δ13C per mille	Conventional C-14 (1 σ)	Calibrated Age(2 σ) Summary
95-105	Peat	3261	-23.2	930 ±61	981 (913) 781
165-175	Peat	3282	-26.52	2679 ±57	2870 (2757) 2555
515-525	Peat	3283	-28.54	4077 ±60	4814 (4479) 4282
560-570	Gyttja	3262	-31.39	4558 ±66	5311 (5001) 4855

Other Swamp Sites

Sample ID	Sample Type	Beta Analytic Inc No.	Conventional C-14 (1 σ)	δ13C per mille	Calibrated Age (2 σ) Summary
AO1 90-100cm	Organic Mud	37134	350 ±100	-23.4	553 (465) 0*
AT1 150-160cm	Organic Mud	37135	1410 ±80	-26.4	1415 (1293) 1087
ARM1 160-170cm	Organic Mud	37136	1120 ±70	-26.1	1176 (979) 797

NZA dates in full:

NZA No.	Conventional C-14 (1 σ)	Calibrated Age 1 σ limits	Calibrated Age 2 σ limits	Median Age
2255	4007 ±53	4522-4464	4794-4777	4417
		4457-4403	4603-4596	
		4369-4357	4570-4237	
2256	4106 ±54	4814-4760	4830-4414	4563
		4699-4674		
		4649-4513		
		4474-4450		
2281	3326 ±92	3680-3679	3822-3790	3544
		3635-2297	3761-3759	3523
			3730-3344	3478
2282	3485 ±100	3835-3566	3976-3947	3690
			3935-3460	
			3420-3420	
2283	5562 ±98	6295-6163	6406-5927	4507
		6156-6083		4479
		6077-6030		4446
		6006-5997		

NZA dates in full:

NZA No.	Conventional C-14 (1 σ)	Corrected Age 1 σ limits	Corrected Age 2 σ limits	Median Age
3261	930 ±61	937-781	981-702	913
3262	4558 ±66	5283-5102	5311-4855	5042
		5093-4963		5001
		4952-4875		4998
3263	1080 ±60	1057-926	1133-1105	958
			1095-888	
			873-824	
			816-791	
3265	2438 ±73	2702-2651	2730-2301	2353
		2481-2335	2261-2157	
3270	5780 ±77	6702-6698	6756-6402	6546
		6673-6450	6368-6349	
3282	2679 ±57	2790-2743	2870-2713	2757
			2566-2555	
3283	4077 ±60	4562-4411	4814-4759	4507
			4699-4674	4479
			4649-4282	4446

Beta Analytic Inc dates in full:

Beta Analytic Inc No.	Conventional C-14 (1 σ)	Corrected Age 1 σ limits	Corrected Age 2 σ limits	Median Age
37134	350 ±100	515-299	553-267	465
			205-143	
			17-0*	
37135	1410 ±80	1344-1255	1415-1124	1293
			1115-1087	
37136	1120 ±70	1068-934	1176-904	979
			853-835	
			806-797	
37137	7680 ±100	8481-8479	8559-8137	8373
		8430-8318		

A.7 Grain Size Analysis

A.7.1 Analysis of the Coarser Fraction

1)

Sample (KK1)	Total Weight	Grain size Anal.	ICP Anal.
0-10 cm	11.8512	7.5684	4.2828
45-55 cm	13.9108	7.5726	6.3382
90-100 cm	11.1149	7.0636	4.0513
140-150 cm	5.0772	4.6706	0.4066
180-190 cm	8.6493	7.6427	1.0066
230-235 cm	11.5773	8.0511	3.5262
250-260 cm	11.3605	7.7770	3.5835
290-300 cm	10.6803	7.2823	3.3980
330-340 cm	4.7245	4.2247	0.4998
360-370 cm	7.8240	7.0480	0.7760
399-401 cm	3.1035	2.7000	0.4035
430-440 cm	8.3870	7.3627	1.0243
465-475 cm	5.0315	4.4826	0.5489
505-515 cm	9.2299	8.2108	1.0191
535-545 cm	9.8654	6.5244	3.3410
570-580 cm	5.4432	4.9395	0.5037
610-620 cm	7.8580	6.8396	1.0184
635-645 cm	16.2400	14.6470	1.5930
670-680 cm	9.5535	6.0297	3.5238
715-725 cm	9.0955	8.0955	1.0000
750-760 cm	6.1788	5.6776	0.5012
790-800 cm	8.4893	5.3424	3.1469

Sample (KK1)	Weight 2mm-63mm Sand Fraction	Weight < 63mm Mud Fraction	Weight (Mud Fraction) for SediGraph
570-580 cm	0.0341	1.9268	1.9268
610-620 cm	0.2374	1.4451	1.4451
635-645 cm	0.3663	4.5394	2.3827
670-680 cm	0.7680	2.1892	2.1892
715-725 cm	1.9941	1.8278	1.8278
750-760 cm	1.0695	1.1609	1.1609
790-800 cm	0.5050	1.8654	1.8654
820-830 cm	1.5913	1.5338	1.5338
847-855 cm	6.2375	2.0351	2.0351
870-880 cm	1.7217	1.8508	1.8508
900-910 cm	4.4568	2.0729	2.0729
950-960 cm	2.1056	2.5420	2.2808
980-990 cm	0.6881	1.9361	1.9361
1010-1015 cm	6.3433	1.8186	1.8186
1040-1050 cm	0.1308	1.1411	1.1411

General Comments:

1) No samples had grains > 2mm.
2) Some macro-organics were > 2mm but were not weighed
3) The sand fraction for most samples contained organic remnants from H_2O_2 treatment.
4) All weights are in grams

A.7.2 SediGraph Results

Samples: KK1 (0-10); KK1 (45-55); KK1 (90-100); KK1 (140-150); KK1 (180-190); KK1 (230-235); KK1 (250-260); KK1 (290-300); KK1(399-401); KK1 (505-515); KK1 (535-545); KK1 (570-580); KK1 (610-620); KK1 (635-645); KK1 (670-680); KK1 (715-725); KK1 (750-760); KK1 (790-800); KK1 (820-830); KK1 (847-855); KK1 (870-880); KK1 (900-910); KK1 (950-960); KK1 (980-990); KK1 (1010-1015); KK1 (1040-1050)

KK1 (0-10)

SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/1 UNIT NUMBER: 1
SAMPLE ID: KK1 (0-10) START 16:06:51 02/04/93
SUBMITTER: Caradoc Peters REPRT 12:27:42 07/13/93
OPERATOR: Pete Johnson TOT RUN TIME 0:33:56
SAMPLE TYPE: Swamp sediment (<62.5mm) SAM DENS: 2.6500 g/cc
LIQUID TYPE: Water LIQ DENS: 0.9942 g/cc
ANALYSIS TEMP: 34.7 deg C LIQ VISC: 0.7272 mPa*s
BASELINE/FULL SCALE: 116/60 kilocounts/sec RUN TYPE: High Speed
STARTING DIAMETER: 100.00 mm REYNOLDS NUMBER: 1.69
ENDING DIAMETER: 0.18 mm FULL SCALE MASS %: 100
MASS DISTRIBUTION
MEDIAN DIAMETER: 0.68 mm MODAL DIAMETER: 3.97 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	99.6	0.4
31.25	99.2	0.4
15.60	97.3	1.9
7.81	89.9	7.5
3.91	76.7	13.2
1.95	64.1	12.6
0.18	35.4	28.7

KK1 (45-55)

SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/2 UNIT NUMBER:1
SAMPLE ID: KK1 (45-55) START 12:08:53 02/10/93
SUBMITTER: Caradoc Peters REPRT 12:28:40 07/13/93
OPERATOR: Pete Johnson TOT RUN TIME 0:34:59
SAMPLE TYPE: Swamp sediment (<62.5mm) SAM DENS: 2.6500 g/cc
LIQUID TYPE: Water LIQ DENS: 0.9942 g/cc
ANALYSIS TEMP: 34.7 deg C IQ VISC: 0.7271 mPa*s
BASELINE/FULL SCALE: 113/67 kilocounts/sec RUN TYPE: High Speed
STARTING DIAMETER: 100.00 mm REYNOLDS NUMBER:1.70
ENDING DIAMETER: 0.18 mm FULL SCALE MASS %: 100
MASS DISTRIBUTION
MEDIAN DIAMETER: 1.30 mm MODAL DIAMETER: 6.36 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	99.2	0.8
31.25	98.4	0.8
15.60	92.2	6.3
7.81	80.2	11.9
3.91	66.9	13.3
1.95	55.4	11.5
0.18	28.8	26.7

KK1 (90-100)

SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/3 UNIT NUMBER:1
SAMPLE ID: KK1 (90-100) START 15:10:51 02/10/93
SUBMITTER: Caradoc Peters REPRT 13:57:37 07/13/93
OPERATOR: Pete Johnson TOT RUN TIME 0:34:33
SAMPLE TYPE: Swamp sediment (<62.5mm) SAM DENS: 2.6500 g/cc
LIQUID TYPE: Water LIQ DENS: 0.9942 g/cc
ANALYSIS TEMP: 34.7 deg C LIQ VISC: 0.7269 mPa*s
BASELINE/FULL SCALE: 113/69 kilocounts/sec RUN TYPE: High Speed
STARTING DIAMETER: 100.00 mm REYNOLDS NUMBER: 1.70
ENDING DIAMETER: 0.18 mm FULL SCALE MASS %: 100
MASS DISTRIBUTION
MEDIAN DIAMETER: 1.88 mm MODAL DIAMETER: 5.28 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	99.0	1.0
31.25	99.1	-0.1
15.60	91.9	7.2
7.81	78.1	13.9
3.91	62.6	15.4
1.95	50.6	12.1
0.18	27.4	23.1

KK1 (140-150)

SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/11 UNIT NUMBER:1
SAMPLE ID: KK1 (140-150) START 11:42:15 07/02/93
SUBMITTER: Caradoc Peters REPRT 11:10:22 07/19/93

OPERATOR: Pete Johnson
SAMPLE TYPE: Swamp sediment
LIQUID TYPE: Water
ANALYSIS TEMP: 34.7 deg C
BASELINE/FULL SCALE: 106/76 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm
TOT RUN TIME 0:34:04
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9942 g/cc
LIQ VISC: 0.7274 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER: 1.69
FULL SCALE MASS %: 100

MASS DISTRIBUTION
MEDIAN DIAMETER: 0.28 mm MODAL DIAMETER: 2.79 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	99.4	0.6
31.25	100.1	-0.7
15.60	100.0	0.1
7.81	97.5	2.6
3.91	89.2	8.3
1.95	74.6	14.6
0.18	44.2	30.5

KK1 (180-190)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/12 UNIT NUMBER:1
SAMPLE ID: KK1 (180-190)
SUBMITTER: Caradoc Peters
OPERATOR: Pete Johnson
SAMPLE TYPE: Swamp sediment
LIQUID TYPE: Water
ANALYSIS TEMP: 34.7 deg C
BASELINE/FULL SCALE: 106/72 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm
START 12:51:39 07/02/93
REPRT 11:11:48 07/19/93
TOT RUN TIME 0:34:35
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9942 g/cc
LIQ VISC: 0.7272 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER: 1.69
FULL SCALE MASS %: 100

MASS DISTRIBUTION
MEDIAN DIAMETER: 1.11 mm MODAL DIAMETER: 2.11 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	98.5	1.5
31.25	99.3	-0.7
15.60	98.6	0.6
7.81	92.6	6.0
3.91	80.3	12.3
1.95	62.7	17.6
0.18	18.5	44.2

KK1 (230-235)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/4 UNIT NUMBER:1
SAMPLE ID: KK1 (230-235)
SUBMITTER: Caradoc Peters
OPERATOR: Pete Johnson
SAMPLE TYPE: Swamp sediment (<62.5mm)
LIQUID TYPE: Water
ANALYSIS TEMP: 34.7 deg C
BASELINE/FULL SCALE: 113/71 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm
START 17:13:07 02/10/93
REPRT 14:03:22 07/13/93
TOT RUN TIME 0:34:42
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9942 g/cc
LIQ VISC: 0.7267 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER: 1.70
FULL SCALE MASS %: 100

MASS DISTRIBUTION
MEDIAN DIAMETER: 2.23 mm MODAL DIAMETER: 5.13 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	100.1	-0.1
31.25	99.3	0.8
15.60	94.7	4.5
7.81	82.4	12.3
3.91	63.6	18.9
1.95	47.2	16.4
0.18	16.8	30.4

KK1 (250-260)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/5 UNIT NUMBER:1
SAMPLE ID: KK1 (250-260)
SUBMITTER: Caradoc Peters
OPERATOR: Pete Johnson
SAMPLE TYPE: Swamp sediment (<62.5mm)
LIQUID TYPE: Water
ANALYSIS TEMP: 34.7 deg C
BASELINE/FULL SCALE: 113/71 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm
START 11:19:23 02/11/93
REPRT 14:10:09 07/13/93
TOT RUN TIME 0:34:22
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9942 g/cc
LIQ VISC: 0.7271 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER: 1.70
FULL SCALE MASS %: 100

MASS DISTRIBUTION
MEDIAN DIAMETER: 2.15 mm MODAL DIAMETER: 4.39 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	99.4	0.6
31.25	99.1	0.3
15.60	95.6	3.5
7.81	83.9	11.7
3.91	65.0	18.9
1.95	48.0	16.9
0.18	15.8	32.2

KK1 (290-300)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/6 UNIT NUMBER:1
SAMPLE ID: KK1 (290-300)
SUBMITTER: Caradoc Peters
OPERATOR: Pete Johnson
SAMPLE TYPE: Swamp sediment (<62.5mm)
LIQUID TYPE: Water
START 12:30:59 02/11/93
REPRT 14:30:06 07/13/93
TOT RUN TIME 0:34:29
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9942 g/cc

ANALYSIS TEMP: 34.7 deg C
BASELINE/FULL SCALE: 113/69 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm
LIQ VISC: 0.7269 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER: 1.70
FULL SCALE MASS %: 100
MASS DISTRIBUTION
MEDIAN DIAMETER: 0.96 mm MODAL DIAMETER: 3.47 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	100.0	-0.0
31.25	99.2	0.9
15.60	97.5	1.7
7.81	88.5	9.0
3.91	74.6	13.9
1.95	60.2	14.4
0.18	29.0	31.3

KK1 (399-401)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/15 UNIT NUMBER:1
SAMPLE ID: KK1 (399-401)
SUBMITTER: Caradoc Peters
OPERATOR: Pete Johnson
SAMPLE TYPE: Swamp sediment
LIQUID TYPE: Water
ANALYSIS TEMP: 34.7 deg C
BASELINE/FULL SCALE: 106/68 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm
START 14:17:01 07/03/93
REPRT 11:12:45 07/19/93
TOT RUN TIME 0:34:45
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9942 g/cc
LIQ VISC: 0.7271 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER: 1.70
FULL SCALE MASS %: 100
MASS DISTRIBUTION
MEDIAN DIAMETER: 0.72 mm MODAL DIAMETER: 3.63 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	99.3	0.7
31.25	99.7	-0.4
15.60	98.5	1.2
7.81	94.7	3.8
3.91	82.2	12.4
1.95	67.7	14.5
0.18	25.8	41.9

KK1 (505-515)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/18 UNIT NUMBER:1
SAMPLE ID: KK1 (505-515)
SUBMITTER: Caradoc Peters
OPERATOR: Pete Johnson
SAMPLE TYPE: Swamp sediment
LIQUID TYPE: Water
ANALYSIS TEMP: 34.7 deg C
BASELINE/FULL SCALE: 106/83 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm
START 12:52:37 07/07/93
REPRT 11:13:59 07/19/93
TOT RUN TIME 0:33:20
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9942 g/cc
LIQ VISC: 0.7267 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER: 1.70
FULL SCALE MASS %: 100
MASS DISTRIBUTION
MEDIAN DIAMETER: 1.62 mm MODAL DIAMETER: 1.86 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	98.4	1.6
31.25	99.2	-0.8
15.60	98.8	0.5
7.81	96.2	2.6
3.91	86.7	9.5
1.95	58.4	28.3
0.18	12.5	46.0

KK1 (535-545)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/7 UNIT NUMBER:1
SAMPLE ID: KK1 (535-545)
SUBMITTER: Caradoc Peters
OPERATOR: Pete Johnson
SAMPLE TYPE: Swamp sediment (<62.5mm)
LIQUID TYPE: Water
ANALYSIS TEMP: 34.7 deg C
BASELINE/FULL SCALE: 113/87 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm
START 15:37:41 02/11/93
REPRT 14:31:05 07/13/93
TOT RUN TIME 0:34:23
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9942 g/cc
LIQ VISC: 0.7267 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER: 1.70
FULL SCALE MASS %: 100
MASS DISTRIBUTION
MEDIAN DIAMETER: 1.82 mm MODAL DIAMETER: 3.01 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	99.3	0.7
31.25	99.5	-0.2
15.60	98.9	0.5
7.81	96.2	2.7
3.91	81.3	14.9
1.95	52.9	28.3
0.18	10.8	42.1

KK1 (570-580)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/19 UNIT NUMBER:1
SAMPLE ID: KK1 (570-580)
SUBMITTER: Caradoc Peters
OPERATOR: Pete Johnson
SAMPLE TYPE: Swamp sediment
LIQUID TYPE: Water
ANALYSIS TEMP: 34.7 deg C
BASELINE/FULL SCALE: 106/82 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm
START 14:50:00 07/07/93
REPRT 11:15:06 07/19/93
TOT RUN TIME 0:31:47
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9942 g/cc
LIQ VISC: 0.7268 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER:1.70
FULL SCALE MASS %: 100
MASS DISTRIBUTION

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	99.1	0.9
31.25	98.7	0.4
15.60	98.7	-0.0
7.81	98.8	-0.1
3.91	95.5	3.3
1.95	85.4	10.0
0.18	11.9	73.5

MEDIAN DIAMETER: 0.70 mm MODAL DIAMETER: 0.47 mm

KK1 (610-620)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/40 UNIT NUMBER: 1
SAMPLE ID: KK1 (610-620) START 13:05:30 07/08/93
SUBMITTER: Caradoc Peters REPRT 11:37:13 07/19/93
OPERATOR: Pete Johnson TOT RUN TIME 0:34:11
SAMPLE TYPE: Swamp sediment SAM DENS: 2.6500 g/cc
LIQUID TYPE: Water LIQ DENS: 0.9942 g/cc
ANALYSIS TEMP: 34.7 deg C LIQ VISC: 0.7270 mPa*s
BASELINE/FULL SCALE: 106/87 kilocounts/sec RUN TYPE: High Speed
STARTING DIAMETER: 100.00 mm REYNOLDS NUMBER: 1.70
ENDING DIAMETER: 0.18 mm FULL SCALE MASS %: 100
MASS DISTRIBUTION
MEDIAN DIAMETER: 0.71 mm MODAL DIAMETER: 2.52 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	98.2	1.8
31.25	101.8	-3.6
15.60	101.0	0.7
7.81	98.1	3.0
3.91	92.9	5.2
1.95	71.8	21.1
0.18	27.7	44.1

KK1 (635-645)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/21 UNIT NUMBER: 1
SAMPLE ID: KK1 (635-645) START 11:13:12 07/08/93
SUBMITTER: Caradoc Peters REPRT 11:16:12 07/19/93
OPERATOR: Pete Johnson TOT RUN TIME 0:34:29
SAMPLE TYPE: Swamp sediment SAM DENS: 2.6500 g/cc
LIQUID TYPE: Water LIQ DENS: 0.9942 g/cc
ANALYSIS TEMP: 34.7 deg C LIQ VISC: 0.7272 mPa*s
BASELINE/FULL SCALE: 106/74 kilocounts/sec RUN TYPE: High Speed
STARTING DIAMETER: 100.00 mm REYNOLDS NUMBER: 1.69
ENDING DIAMETER: 0.18 mm FULL SCALE MASS %: 100
MASS DISTRIBUTION
MEDIAN DIAMETER: 1.03 mm MODAL DIAMETER: 1.52 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	98.8	1.2
31.25	99.7	-0.9
15.60	99.3	0.5
7.81	94.6	4.7
3.91	84.3	10.3
1.95	67.9	16.3
0.18	16.5	51.4

KK1 (670-680)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/22 UNIT NUMBER: 1
SAMPLE ID: KK1 (670-680) START 11:44:34 07/09/93
SUBMITTER: Caradoc Peters REPRT 11:17:23 07/19/93
OPERATOR: Pete Johnson TOT RUN TIME 0:34:15
SAMPLE TYPE: Swamp sediment SAM DENS: 2.6500 g/cc
LIQUID TYPE: Water LIQ DENS: 0.9942 g/cc
ANALYSIS TEMP: 34.7 deg C LIQ VISC: 0.7273 mPa*s
BASELINE/FULL SCALE: 106/83 kilocounts/sec RUN TYPE: High Speed
STARTING DIAMETER: 100.00 mm REYNOLDS NUMBER:1.69
ENDING DIAMETER: 0.18 mm FULL SCALE MASS %: 100
MASS DISTRIBUTION
MEDIAN DIAMETER: 2.20 mm MODAL DIAMETER: 3.16 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	100.4	-0.4
31.25	100.1	0.2
15.60	97.9	2.2
7.81	91.7	6.2
3.91	74.2	17.5
1.95	45.5	28.7
0.18	8.9	26.6

KK1 (715-725)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/23 UNIT NUMBER: 1
SAMPLE ID: KK1 (715-725) START 12:57:08 07/09/93
SUBMITTER: Caradoc Peters REPRT 11:18:33 07/19/93
OPERATOR: Pete Johnson TOT RUN TIME 0:34:08
SAMPLE TYPE: Swamp sediment SAM DENS: 2.6500 g/cc
LIQUID TYPE: Water LIQ DENS: 0.9942 g/cc
ANALYSIS TEMP: 34.7 deg C LIQ VISC: 0.7272 mPa*s
BASELINE/FULL SCALE: 106/78 kilocounts/sec RUN TYPE: High Speed
STARTING DIAMETER: 100.00 mm REYNOLDS NUMBER:1.69
ENDING DIAMETER: 0.18 mm FULL SCALE MASS %: 100
MASS DISTRIBUTION
MEDIAN DIAMETER: 1.48 mm MODAL DIAMETER: 3.43 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	99.5	0.5
31.25	99.9	-0.3
15.60	98.4	1.5
7.81	94.9	3.6
3.91	79.4	15.4
1.95	57.3	22.1
0.18	16.8	40.5

KK1 (750-760)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/24 UNIT NUMBER: 1
SAMPLE ID: KK1 (750-760) START 11:23:43 07/10/93

SUBMITTER: Caradoc Peters
OPERATOR: Pete Johnson
SAMPLE TYPE: Swamp sediment
LIQUID TYPE: Water
ANALYSIS TEMP: 34.6 deg C
BASELINE/FULL SCALE: 106/85 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm

REPRT 11:19:47 07/19/93
TOT RUN TIME 0:32:27
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9942 g/cc
LIQ VISC: 0.7276 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER:1.69
FULL SCALE MASS %: 100

MASS DISTRIBUTION
MEDIAN DIAMETER: 0.74 mm   MODAL DIAMETER: 0.51 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	99.0	1.0
31.25	101.7	-2.7
15.60	101.6	0.1
7.81	99.2	2.4
3.91	91.1	8.2
1.95	70.9	20.1
0.18	17.5	53.5

KK1 (790-800)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/25 UNIT NUMBER: 1
SAMPLE ID: KK1 (790-800)
SUBMITTER: Caradoc Peters
OPERATOR: Pete Johnson
SAMPLE TYPE: Swamp sediment
LIQUID TYPE: Water
ANALYSIS TEMP: 34.7 deg C
BASELINE/FULL SCALE: 106/82 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm

START 13:05:58 07/06/93
REPRT 11:21:22 07/19/93
TOT RUN TIME 0:34:57
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9942 g/cc
LIQ VISC: 0.7272 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER:1.69
FULL SCALE MASS %: 100

MASS DISTRIBUTION
MEDIAN DIAMETER: 1.51 mm   MODAL DIAMETER: 1.56 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	97.7	2.3
31.25	98.0	-0.3
15.60	99.2	-1.2
7.81	95.8	3.3
3.91	83.0	12.8
1.95	59.2	23.8
0.18	10.8	48.4

KK1 (820-830)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/26 UNIT NUMBER: 1
SAMPLE ID: KK1 (820-830)
SUBMITTER: Caradoc Peters
OPERATOR: Pete Johnson
SAMPLE TYPE: Swamp sediment
LIQUID TYPE: Water
ANALYSIS TEMP: 34.7 deg C
BASELINE/FULL SCALE: 106/77 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm

START 14:04:15 07/06/93
REPRT 11:22:53 07/19/93
TOT RUN TIME 0:32:31
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9942 g/cc
LIQ VISC: 0.7271 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER:1.70
FULL SCALE MASS %: 100

MASS DISTRIBUTION
MEDIAN DIAMETER: 1.25 mm   MODAL DIAMETER: 3.48 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	98.9	1.1
31.25	99.2	-0.3
15.60	100.0	-0.8
7.81	94.0	5.9
3.91	80.1	13.9
1.95	61.3	18.8
0.18	16.3	45.1

KK1 (847-855)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/36 UNIT NUMBER: 1
SAMPLE ID: KK1 (847-855)
SUBMITTER: Caradoc Peters
OPERATOR: Pete Johnson
SAMPLE TYPE: Swamp sediment
LIQUID TYPE: Water
ANALYSIS TEMP: 34.6 deg C
BASELINE/FULL SCALE: 106/80 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm

START 09:37:29 07/07/93
REPRT 11:32:47 07/19/93
TOT RUN TIME 0:33:50
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9942 g/cc
LIQ VISC: 0.7277 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER:1.69
FULL SCALE MASS %: 100

MASS DISTRIBUTION
MEDIAN DIAMETER: 3.44 mm   MODAL DIAMETER: 7.70 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	99.0	1.0
31.25	99.1	-0.1
15.60	98.7	0.5
7.81	80.0	18.7
3.91	53.7	26.2
1.95	29.0	24.8
0.18	3.5	25.5

KK1 (870-880)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/28 UNIT NUMBER: 1
SAMPLE ID: KK1 (870-880)

START 12:31:06 07/10/93

SUBMITTER: Caradoc Peters
OPERATOR: Pete Johnson
SAMPLE TYPE: Swamp sediment
LIQUID TYPE: Water
ANALYSIS TEMP: 34.7 deg C
BASELINE/FULL SCALE: 106/64 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm

REPRT 11:24:14 07/19/93
TOT RUN TIME 0:33:40
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9942 g/cc
LIQ VISC: 0.7273 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER: 1.69
FULL SCALE MASS %: 100

MASS DISTRIBUTION
MEDIAN DIAMETER: 0.85 mm MODAL DIAMETER: 0.80 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	99.5	0.5
31.25	99.5	0.0
15.60	99.2	0.2
7.81	99.3	-0.1
3.91	98.4	0.9
1.95	93.6	4.8
0.18	2.8	90.8

KK1 (900-910)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/38 UNIT NUMBER: 1
SAMPLE ID: KK1 (900-910)
SUBMITTER: Caradoc Peters
OPERATOR: Pete Johnson
SAMPLE TYPE: Swamp sediment
LIQUID TYPE: Water
ANALYSIS TEMP: 34.7 deg C
BASELINE/FULL SCALE: 106/73 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm

START 10:09:42 07/08/93
REPRT 11:35:35 07/19/93
TOT RUN TIME 0:34:33
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9942 g/cc
LIQ VISC: 0.7274 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER: 1.69
FULL SCALE MASS %: 100

MASS DISTRIBUTION
MEDIAN DIAMETER: 3.77 mm MODAL DIAMETER: 3.72 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	99.1	0.9
31.25	99.4	-0.2
15.60	98.5	0.9
7.81	97.6	0.9
3.91	56.9	40.8
1.95	0.1	56.8
0.18	1.2	-1.1

KK1 (950-960)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/39 UNIT NUMBER: 1
SAMPLE ID: KK1 (950-960)
SUBMITTER: Caradoc Peters
OPERATOR: Pete Johnson
SAMPLE TYPE: Swamp sediment
LIQUID TYPE: Water
ANALYSIS TEMP: 34.5 deg C
BASELINE/FULL SCALE: 106/64 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm

START 09:10:05 07/08/93
REPRT 10:17:23 07/13/93
TOT RUN TIME 0:35:04
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9943 g/cc
LIQ VISC: 0.7305 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER: 1.68
FULL SCALE MASS %: 100

MASS DISTRIBUTION
MEDIAN DIAMETER: 0.96 mm MODAL DIAMETER: 0.99 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	100.7	-0.7
31.25	101.3	-0.7
15.60	100.8	0.5
7.81	100.8	0.1
3.91	100.4	0.3
1.95	100.8	-0.4
0.18	5.4	95.4

KK1 (980-990)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/31 UNIT NUMBER: 1
SAMPLE ID: KK1 (980-990)
SUBMITTER: Caradoc Peters
OPERATOR: Pete Johnson
SAMPLE TYPE: Swamp sediment
LIQUID TYPE: Water
ANALYSIS TEMP: 34.7 deg C
BASELINE/FULL SCALE: 106/67 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm

START 13:29:59 07/10/93
REPRT 11:28:15 07/19/93
TOT RUN TIME 0:34:19
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9942 g/cc
LIQ VISC: 0.7273 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER:1.69
FULL SCALE MASS %: 100

MASS DISTRIBUTION
MEDIAN DIAMETER: 1.92 mm MODAL DIAMETER: 3.10 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	99.7	0.3
31.25	98.9	0.8
15.60	98.7	0.1
7.81	93.0	5.7
3.91	75.3	17.7
1.95	50.5	24.8
0.18	9.7	40.8

KK1 (1010-1015)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/8 UNIT NUMBER: 1
SAMPLE ID: KK1 (1010-1015)
SUBMITTER: Caradoc Peters
OPERATOR: Pete Johnson

START 10:43:55 07/13/93
REPRT 14:32:03 07/13/93
TOT RUN TIME 0:34:59

SAMPLE TYPE: Swamp sediment
LIQUID TYPE: Water
ANALYSIS TEMP: 34.6 deg C
BASELINE/FULL SCALE: 107/65 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9942 g/cc
LIQ VISC: 0.7281 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER: 1.69
FULL SCALE MASS %: 100

MASS DISTRIBUTION
MEDIAN DIAMETER: 3.60 mm MODAL DIAMETER: 3.27 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	99.7	0.3
31.25	98.6	1.1
15.60	92.4	6.3
7.81	73.6	18.7
3.91	53.2	20.4
1.95	27.9	25.3
0.18	3.9	23.9

KK1 (1040-1050)
SediGraph 5100 V3.02
SAMPLE DIRECTORY/NUMBER: CONTRACT/33 UNIT NUMBER: 1
SAMPLE ID: KK1 (1040-1050)
SUBMITTER: Caradoc Peters
OPERATOR: Pete Johnson
SAMPLE TYPE: Swamp sediment
LIQUID TYPE: Water
ANALYSIS TEMP: 34.7 deg C
BASELINE/FULL SCALE: 106/73 kilocounts/sec
STARTING DIAMETER: 100.00 mm
ENDING DIAMETER: 0.18 mm
START 12:53:36 07/12/93
REPRT 11:31:32 07/19/93
TOT RUN TIME 0:33:58
SAM DENS: 2.6500 g/cc
LIQ DENS: 0.9942 g/cc
LIQ VISC: 0.7273 mPa*s
RUN TYPE: High Speed
REYNOLDS NUMBER: 1.69
FULL SCALE MASS %: 100

MASS DISTRIBUTION
MEDIAN DIAMETER: 2.38 mm MODAL DIAMETER: 2.72 mm

DIAMETER (mm)	CUMULATIVE MASS FINER (%)	MASS IN INTERVAL (%)
62.50	99.3	0.7
31.25	99.9	-0.6
15.60	100.1	-0.2
7.81	90.1	10.1
3.91	71.5	18.6
1.95	42.0	29.5
0.18	8.6	33.4

A.8 ICP Analysis Results

Raw Results

1) Al, As, B and Ca

Id.No.	Sample	Al	As	B	Ca
93/191-1	2M HCL	< 0.10	< 0.10	< 0.02	1.6
2	KK1 0-10	1026	< 1.00	0.80	88
3	KK1 45-55	963	< 1.00	0.59	84
4	KK1 90-100	945	< 1.00	0.47	84
5	KK1 140-150	433	< 1.00	< 0.20	56
6	KK1 180-190	398	< 1.00	< 0.20	92
7	KK1 230-235	882	< 1.00	< 0.20	149
8	KK1 250-260	928	< 1.00	< 0.20	172
9	KK1 290-300	882	< 1.00	0.40	156
10	KK1 330-340	122	< 1.00	< 0.20	63
11	KK1 360-370	134	< 1.00	< 0.20	106
12	KK1 399-401	425	< 1.00	< 0.20	31
13	KK1 430-440	332	< 1.00	< 0.20	197
14	KK1 465-475	71	< 1.00	0.54	432
15	KK1 505-515	111	< 1.00	< 0.20	142
16	KK1 535-545	410	< 1.00	< 0.20	130
17	KK1 570-580	142	< 1.00	< 0.20	98
18	KK1 610-620	315	< 1.00	0.25	251
19	KK1 635-645	714	< 1.00	< 0.20	94
20	KK1 670-680	298	< 1.00	< 0.20	147
21	KK1 715-725	296	< 1.00	< 0.20	117
22	KK1 750-760	148	< 1.00	< 0.20	111
23	KK1 790-800	397	< 1.00	0.26	117
24	KK1 820-830	400	< 1.00	0.45	125
25	KK1 847-855	6.9	< 1.00	6.8	2097
26	KK1 870-880	171	< 1.00	< 0.20	558
27	KK1 900-910	40	< 1.00	2.0	1216
28	KK1 950-960	149	< 1.00	0.53	1150
29	KK1 980-990	243	< 1.00	0.49	860
30	KK1 1010-1015	6.8	< 1.00	2.2	2428
31	KK1 1040-1050	222	< 1.00	1.3	702

2) Cd, Co, Cr and Cu

Id.No.	Sample	Cd	Co	Cr	Cu
93/191-1	2M HCL	< 0.01	< 0.01	< 0.02	< 0.01
2	KK1 0-10	< 0.10	2.2	5.4	1.3
3	KK1 45-55	< 0.10	2.0	4.8	1.4
4	KK1 90-100	< 0.10	1.8	3.1	1.1
5	KK1 140-150	< 0.10	0.63	0.91	0.28
6	KK1 180-190	< 0.10	2.2	1.7	0.58
7	KK1 230-235	< 0.10	1.5	2.9	0.73
8	KK1 250-260	< 0.10	1.5	3.2	0.86
9	KK1 290-300	< 0.10	1.5	3.2	0.78
10	KK1 330-340	< 0.10	0.57	0.74	0.12
11	KK1 360-370	< 0.10	1.9	1.4	0.33
12	KK1 399-401	< 0.10	0.63	3.1	0.50
13	KK1 430-440	< 0.10	2.2	1.7	0.36
14	KK1 465-475	< 0.10	0.61	1.3	0.10
15	KK1 505-515	< 0.10	0.93	2.4	0.23
16	KK1 535-545	< 0.10	1.1	4.1	0.72
17	KK1 570-580	< 0.10	0.55	1.6	0.34
18	KK1 610-620	< 0.10	1.0	3.3	0.56
19	KK1 635-645	< 0.10	1.2	5.8	0.96
20	KK1 670-680	< 0.10	1.3	4.3	1.1
21	KK1 715-725	< 0.10	1.4	3.1	0.78
22	KK1 750-760	< 0.10	0.80	2.7	0.46
23	KK1 790-800	< 0.10	1.4	3.7	0.88
24	KK1 820-830	< 0.10	1.9	4.3	0.98
25	KK1 847-855	< 0.10	0.51	1.0	0.30
26	KK1 870-880	< 0.10	1.2	1.3	0.31
27	KK1 900-910	< 0.10	0.66	1.2	0.21
28	KK1 950-960	< 0.10	1.6	1.8	0.54
29	KK1 980-990	< 0.10	3.0	2.7	0.78
30	KK1 1010-1015	< 0.10	0.72	1.3	0.38
31	KK1 1040-1050	< 0.10	1.0	1.5	0.40

3) Fe, K, Mg and Mn

Id.No.	Sample	Fe	K	Mg	Mn
93/191-1	2M HCL	0.78	< 0.60	< 0.15	< 0.009
2	KK1 0-10	2003	< 6.0	41	11.2
3	KK1 45-55	1810	< 6.0	35	15.3
4	KK1 90-100	1425	< 6.0	36	15.6
5	KK1 140-150	361	< 6.0	26	1.3
6	KK1 180-190	1714	< 6.0	46.5	3.3
7	KK1 230-235	1468	18.8	82	9.9
8	KK1 250-260	1379	23.0	92	8.4
9	KK1 290-300	1272	16.8	78	7.9
10	KK1 330-340	523	< 6.0	30	1.8
11	KK1 360-370	1892	< 6.0	51	2.6
12	KK1 399-401	644	< 6.0	21	2.8
13	KK1 430-440	1282	< 6.0	96	4.2
14	KK1 465-475	225	< 6.0	167	4.6
15	KK1 505-515	737	< 6.0	57	12.2
16	KK1 535-545	1229	< 6.0	63	12.8
17	KK1 570-580	493	< 6.0	43	6.0
18	KK1 610-620	1296	< 6.0	80	17.1
19	KK1 635-645	1720	< 6.0	47	11.4
20	KK1 670-680	1693	< 6.0	46.5	14.2
21	KK1 715-725	1707	< 6.0	34.5	17.0
22	KK1 750-760	676	< 6.0	27	6.6
23	KK1 790-800	1473	< 6.0	59	15.3
24	KK1 820-830	1422	< 6.0	37.5	17.8
25	KK1 847-855	307	< 6.0	207	4.9
26	KK1 870-880	672	< 6.0	39.5	15.0
27	KK1 900-910	410	< 6.0	110	6.0
28	KK1 950-960	762	< 6.0	85	18.9
29	KK1 980-990	1212	< 6.0	77	27.0
30	KK1 1010-1015	376	< 6.0	304	6.3
31	KK1 1040-1050	578	< 6.0	103	4.7

4) Mo, Na, Ni and P

Id.No.	Sample	Mo	Na	Ni	P
93/191-1	2M HCL	< 0.10	3.7	< 0.02	< 0.20
2	KK1 0-10	< 0.10	14.5	3.6	62.0
3	KK1 45-55	< 0.10	14.4	3.4	49.5
4	KK1 90-100	< 0.10	13.1	2.7	47.0
5	KK1 140-150	< 0.10	15.3	1.0	6.8
6	KK1 180-190	0.16	17.4	2.3	12.2
7	KK1 230-235	< 0.10	27.5	2.4	29.0
8	KK1 250-260	< 0.10	30.0	2.6	29.5
9	KK1 290-300	0.11	25.0	2.4	28.5
10	KK1 330-340	< 0.10	10.2	0.63	2.5
11	KK1 360-370	0.89	12.8	1.7	2.4
12	KK1 399-401	< 0.10	4.7	1.5	7.4
13	KK1 430-440	0.49	21.5	2.5	9.3
14	KK1 465-475	0.43	25.5	0.49	< 2.0
15	KK1 505-515	1.3	11.3	1.4	10.5
16	KK1 535-545	0.81	15.6	2.3	15.7
17	KK1 570-580	< 0.10	13.7	1.9	14.6
18	KK1 610-620	0.22	25.5	3.0	42.0
19	KK1 635-645	< 0.10	16.7	3.7	32.0
20	KK1 670-680	0.14	14.9	4.6	30.0
21	KK1 715-725	0.28	13.0	4.0	26.0
22	KK1 750-760	0.33	10.6	2.5	21.5
23	KK1 790-800	0.29	21.0	4.8	35.0
24	KK1 820-830	0.70	15.0	4.7	27.5
25	KK1 847-855	< 0.10	33.0	0.97	27.5
26	KK1 870-880	0.30	12.8	2.1	11.2
27	KK1 900-910	0.12	18.0	1.2	26.0
28	KK1 950-960	0.38	24.0	2.2	26.0
29	KK1 980-990	0.61	23.0	3.7	27.0
30	KK1 1010-1015	0.11	42.0	1.1	37.0
31	KK1 1040-1050	< 0.10	30.0	2.7	17.4

5) Pb, S, Se and Si

Id.No.	Sample	Pb	S	Se	Si
93/191-1	2M HCL	< 0.10	0.64	< 0.20	5.7
2	KK1 0-10	< 1.00	57	< 2.0	34.0
3	KK1 45-55	< 1.00	53	< 2.0	44.0
4	KK1 90-100	< 1.00	98	< 2.0	46.5
5	KK1 140-150	< 1.00	238	< 2.0	27.0
6	KK1 180-190	< 1.00	1495	< 2.0	14.5
7	KK1 230-235	< 1.00	481	< 2.0	21.0
8	KK1 250-260	< 1.00	492	< 2.0	26.0
9	KK1 290-300	< 1.00	410	< 2.0	29.0
10	KK1 330-340	< 1.00	583	< 2.0	17.6
11	KK1 360-370	< 1.00	2192	< 2.0	9.0
12	KK1 399-401	< 1.00	562	< 2.0	10.4
13	KK1 430-440	< 1.00	1432	< 2.0	13.3
14	KK1 465-475	< 1.00	956	< 2.0	10.7
15	KK1 505-515	< 1.00	1158	< 2.0	6.6
16	KK1 535-545	< 1.00	1441	< 2.0	9.5
17	KK1 570-580	< 1.00	805	< 2.0	7.0
18	KK1 610-620	< 1.00	1858	< 2.0	8.9

Id.No.	Sample	Pb	S	Se	Si
93/191-1	2M HCL	< 0.10	0.64	< 0.20	5.7
19	KK1 635-645	< 1.00	1782	< 2.0	13.0
20	KK1 670-680	< 1.00	2215	< 2.0	13.2
21	KK1 715-725	< 1.00	2125	< 2.0	12.3
22	KK1 750-760	< 1.00	996	< 2.0	9.4
23	KK1 790-800	< 1.00	1870	< 2.0	14.4
24	KK1 820-830	< 1.00	1742	< 2.0	19.0
25	KK1 847-855	< 1.00	550	< 2.0	109.0
26	KK1 870-880	< 1.00	870	< 2.0	25.5
27	KK1 900-910	< 1.00	595	< 2.0	58.0
28	KK1 950-960	< 1.00	952	< 2.0	127.0
29	KK1 980-990	< 1.00	1313	< 2.0	79.0
30	KK1 1010-1015	< 1.00	569	< 2.0	133.0
31	KK1 1040-1050	< 1.00	835	< 2.0	55.0

6) Sn, Sr and Zn

Id.No.	Sample	Sn	Sr	Zn
93/191-1	2M HCL	< 0.02	0.005	0.21
2	KK1 0-10	< 0.20	2.5	3.2
3	KK1 45-55	< 0.20	2.1	3.0
4	KK1 90-100	< 0.20	2.1	3.0
5	KK1 140-150	< 0.20	1.3	1.3
6	KK1 180-190	< 0.20	1.7	1.9
7	KK1 230-235	< 0.20	3.5	3.5
8	KK1 250-260	< 0.20	3.8	2.3
9	KK1 290-300	< 0.20	3.4	2.3
10	KK1 330-340	< 0.20	0.95	1.6
11	KK1 360-370	< 0.20	1.6	1.6
12	KK1 399-401	< 0.20	0.69	1.2
13	KK1 430-440	< 0.20	3.3	1.5
14	KK1 465-475	< 0.20	5.5	0.93
15	KK1 505-515	< 0.20	2.0	1.7
16	KK1 535-545	< 0.20	2.5	2.1
17	KK1 570-580	< 0.20	1.7	1.7
18	KK1 610-620	< 0.20	4.6	2.6
19	KK1 635-645	< 0.20	2.6	2.7
20	KK1 670-680	< 0.20	2.5	3.1
21	KK1 715-725	< 0.20	2.3	2.6
22	KK1 750-760	< 0.20	2.0	1.6
23	KK1 790-800	< 0.20	3.2	2.5
24	KK1 820-830	< 0.20	4.4	2.7
25	KK1 847-855	< 0.20	29.0	1.4
26	KK1 870-880	< 0.20	9.2	2.3
27	KK1 900-910	< 0.20	15.5	1.6
28	KK1 950-960	< 0.20	16.8	2.5
29	KK1 980-990	< 0.20	14.6	3.6
30	KK1 1010-1015	< 0.20	27.5	1.4
31	KK1 1040-1050	< 0.20	9.9	1.8

Statistics

Element	Mean	Median	TrMean	StDev	SeMean
Al	387.0	306.5	369.5	319.4	58.3
B	0.676	0.200	0.418	1.262	0.230
Ca	402.0	136.0	286.0	597.0	109.0
Co	1.317	1.250	1.279	0.629	0.115
Cr	2.650	2.700	2.565	1.392	0.254
Cu	0.6123	0.5500	0.5942	0.3495	0.0638
Fe	1092.0	1250.0	1090.0	552.0	101.0
K	7.353	6.000	6.415	4.212	0.769
Mg	74.1	54.0	64.0	59.9	10.9
Mn	10.07	9.15	9.73	6.30	1.15
Mo	0.2957	0.1300	0.2492	0.2972	0.0543
Na	19.07	16.15	18.54	8.11	1.48
Ni	2.470	2.400	2.441	1.194	0.218
P	23.83	26.00	23.04	14.80	2.70
S	1024.0	911.0	1008.0	660.0	120.0
Sr	6.09	2.90	4.79	7.41	1.35
Zn	2.174	2.200	2.154	0.723	0.132

Element	Min	Max	Q1	Q3
Al	6.8	1026.0	140.0	503.2
B	0.200	6.800	0.200	0.532
Ca	31.0	2428.0	93.0	463.0
Co	0.510	3.000	0.705	1.825
Cr	0.700	5.800	1.375	3.400
Cu	0.1000	1.4000	0.3250	0.8650
Fe	225.0	2003.0	564.0	1528.0
K	6.000	23.000	6.000	6.000
Mg	21.0	304.0	37.1	86.7
Mn	1.30	27.00	4.67	15.30
Mo	0.1000	1.3000	0.1000	0.3925
Na	4.70	42.00	13.08	25.12
Ni	0.490	4.800	1.475	3.450
P	2.00	62.00	11.02	30.50
S	53.0	2215.0	536.0	1557.0
Sr	0.69	29.00	2.00	6.43
Zn	0.930	3.600	1.600	2.700

Correlation Analysis
Values represent r (the correlation coefficient).

	Al	B	Ca	Co	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	S	Sr
B	-0.295															
Ca	-0.481	0.772														
Co	0.449	-0.287	-0.230													
Cr	0.673	-0.294	-0.430	0.384												
Cu	0.777	-0.207	-0.325	0.588	0.876											
Fe	0.637	-0.381	-0.507	0.733	0.720	0.785										
K	0.535	-0.111	-0.134	0.097	0.109	0.176	0.172									
Mg	-0.357	0.645	0.864	-0.259	-0.373	-0.329	-0.436	0.061								
Mn	0.182	-0.185	-0.021	0.521	0.505	0.561	0.396	-0.070	-0.183							
Mo	-0.328	-0.204	-0.133	0.208	-0.019	-0.199	0.069	-0.216	-0.099	0.242						
Na	-0.075	0.496	0.695	-0.034	-0.226	-0.111	-0.214	0.361	0.853	-0.015	-0.227					
Ni	0.412	-0.303	-0.349	0.578	0.759	0.796	0.734	0.004	-0.389	0.675	-0.001	-0.126				
P	0.584	0.155	0.123	0.344	0.646	0.780	0.477	0.118	0.079	0.519	-0.359	0.235	0.557			
S	-0.362	-0.250	-0.195	0.178	0.175	0.005	0.379	-0.282	-0.157	0.276	0.449	-0.135	0.470	-0.216		
Sr	-0.449	0.793	0.988	-0.158	-0.392	-0.275	-0.471	-0.112	0.818	0.070	-0.121	0.695	-0.279	0.155	-0.181	
Zn	0.594	-0.251	-0.235	0.656	0.668	0.804	0.696	0.232	-0.328	0.785	-0.085	-0.024	0.757	0.683	0.100	-0.150

Significance of values for r is:

r £ 0.35	Not significant	[P £ 0.05]
0.35 < r £ 0.45	Significant	[0.1 £ P < 0.05]
0.45 < r £ 0.55	Highly significant	[0.001 < P < 0.1]
0.55 < r	Very highly significant	[P £ 0.001]*

*If P (probability function) < 0.001, there is a less than 0.1% chance that there is no relationship; therefore a greater than 99.1% chance that there is a relationship.

A negative value for r implies an inverse relationship.

APPENDIX A.9

Modern Vegetation Plots[79]:

a) Oneroa plot 1. - the seaward side of the *motu*

Guettarda speciosa

0.15=0.1795	0.25=0.4976	0.20=0.3177	0.30=0.7148	0.32=0.8139	0.17=0.2307	0.17=0.2307
0.29=0.6706	0.34=0.9195	0.23=0.4208	0.20=0.3177	0.48=1.8337	0.26=0.5385	0.50=1.9906
0.16=0.2043	0.24=0.4584	0.24=0.4584	0.80=5.0910	0.15=0.1795	0.18=0.2570	0.24=0.4584
0.24=0.4584	0.51=2.0714	0.15=0.1795	0.20=0.3177	0.25=0.4976	0.24=0.4584	0.25=0.4976
0.38=1.1499	0.20=0.3177	0.24=0.4584	0.17=0.2307	0.17=0.2307	0.24=0.4584	0.32=0.8139
0.53=2.2379	0.24=0.4584	0.20=0.3177	0.17=0.2307	0.19=0.2865	0.43=1.4698	0.17=0.2307
0.18=0.2570	0.20=0.3177	0.17=0.2307	0.23=0.4208	0.19=0.2865	0.25=0.4976	0.24=0.4584
0.25=0.4976	0.20=0.3177	0.18=0.2570	0.25=0.4976	0.23=0.4208	0.28=0.6249	0.25=0.4976
0.19=0.2865	0.28=0.6249	0.19=0.2865	0.55=2.4053	0.16=0.2043	0.18=0.2570	0.19=0.2865
0.67=3.5700	0.39=1.2115	0.24=0.4584	0.16=0.2043	0.19=0.2865	0.19=0.2865	0.77=4.7144
0.20=0.3177	0.25=0.4976	0.20=0.3177	0.18=0.2570	0.20=0.3177	0.19=0.2865	0.43=1.4698
0.20=0.3177	0.32=0.8139	0.22=0.3848	0.23=0.4208	0.32=0.8139	0.20=0.3177	0.25=0.4976
0.22=0.3848	0.17=0.2307	0.18=0.2570	0.15=0.1795	0.18=0.2570	0.24=0.4584	0.19=0.2865
0.23=0.4208	0.33=0.8659	0.33=0.8659	0.32=0.8139			

Casuarina equisetifolia

1.10=9.6321	0.78=4.8383	1.90=28.7285	2.75=60.1870	0.74=4.3595	0.40=1.2748	0.85=5.7510
1.02=8.2754	1.90=28.7285	0.17=0.2307	0.20=0.3177	0.18=0.2570	0.25=0.4976	1.02=8.2754
0.54=2.3181	0.39=1.2115	0.25=0.4976	0.18=0.2570	0.45=1.6106	0.21=0.3505	0.29=0.6706
0.19=0.2865	0.28=0.6249	1.84=26.9335	0.90=6.4422	2.18=37.8276	1.59=20.1249	2.62=54.6288
2.70=58.0070	1.16=10.7057					

Hernandia nymphaeifolia

0.35=0.9747	0.32=0.8139	0.76=4.5996	0.44=1.5394	0.17=0.2307	0.53=2.2379	0.32=0.8139
0.24=0.4584	0.45=1.6106	0.21=0.3505	0.22=0.3848	0.37=1.0899	0.17=0.2307	0.19=0.2865
0.47=1.7577	0.25=0.4976	0.18=0.2570	0.70=3.8987	0.38=1.1499	0.36=1.0315	0.16=0.2043
0.60=2.8652	0.64=3.2621	0.42=1.4019	0.25=0.4976	0.40=1.2748	0.42=1.4019	0.18=0.2570
0.27=0.5809	0.16=0.2043	1.14=10.3377				

Scaevola taccada

0.19=0.2865	0.18=0.2570	0.17=0.2307
0.20=0.3177	0.17=0.2307	0.16=0.2043

Leguminosae sp.

0.15=0.1795
0.17=0.2307

Cocos nucifera

0.28=0.6249
0.48=1.8337

Morinda citrifolia

0.22=0.3848

b) Regeneration plot near Ariana Bungalows, Tupapa.

Hibiscus tiliaceus

0.18=0.2570	0.23=0.4208	0.20=0.3177	0.27=0.5809	0.60=2.8652	0.16=0.2043	0.30=0.7148
0.25=0.4976	0.39=1.2115	0.30=0.7148	0.19=0.2865	0.22=0.3848	0.28=0.6249	0.22=0.3848
0.24=0.4584	0.24=0.4584	0.30=0.7148	0.36=1.0315	0.46=1.6833	0.26=0.5385	0.25=0.4976
0.26=0.5385	0.39=1.2115	0.53=2.2379	0.25=0.4976	0.30=0.7148	0.40=1.2748	0.62=3.0604
0.25=0.4976	0.34=0.9195	0.83=5.4822	0.16=0.2043	0.52=2.1538	0.32=0.8139	0.24=0.4584
0.30=0.7148	0.53=2.2379	0.25=0.4976	0.23=0.4208	0.30=0.7148	0.39=1.2115	0.27=0.5809
0.43=1.4698	0.55=2.4053	0.16=0.2043	0.30=0.7148	0.35=0.9747	0.29=0.6706	0.17=0.2307
0.38=1.1499	0.35=0.9747	0.47=1.7577	0.27=0.5809	0.17=0.2307	0.50=1.9906	0.65=3.3654
0.15=0.1795	0.24=0.4584	0.29=0.6706	0.20=0.3177	0.16=0.2043	0.32=0.8139	0.20=0.3177
0.25=0.4976	0.18=0.2570	0.18=0.2570	0.35=0.9747	0.25=0.4976	0.19=0.2865	0.67=3.5700
0.24=0.4584	0.34=0.9195	0.21=0.3505	0.75=4.4788	0.25=0.4976	0.37=1.0899	0.16=0.2043
0.18=0.2570	0.50=1.9906	0.18=0.2570	0.25=0.4976	0.36=1.0315	0.41=1.3396	0.43=1.4698

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79 Results are presented in the following manner:
0.15 (circumference in m)=0.1795 (basal area in m^2)

0.17=0.2307	0.20=0.3177	0.19=0.2865	0.45=1.6106	0.29=0.6706	0.30=0.7148	0.23=0.4208
0.34=0.9195	0.38=1.1499	0.29=0.6706	0.21=0.3505	0.25=0.4976	0.20=0.3177	0.15=0.1795
0.15=0.1795	0.17=0.2307	0.46=1.6833	0.25=0.4976	0.25=0.4976	0.22=0.3848	0.27=0.5809
0.19=0.2865	0.85=5.7510	0.33=0.8659	0.22=0.3848	0.69=3.7875	0.37=1.0899	0.19=0.2865
0.68=3.6779	0.28=0.6249	0.48=1.8337	0.36=1.0315	0.62=3.0604	0.28=0.6249	0.42=1.4019
0.50=1.9906	0.24=0.4976	0.61=2.9620	0.24=0.4584	0.30=0.7148	0.60=2.8652	0.26=0.5385
0.34=0.9195	0.48=1.8337	0.49=1.9113	0.16=0.2043	0.30=0.7148	0.41=1.3396	0.26=0.5385
0.32=0.8139	0.33=0.8659	0.61=2.9620	0.16=0.2043	0.30=0.7148	0.44=1.5394	0.25=0.4976
0.19=0.2865	0.16=0.2043	0.22=0.3848	0.32=0.8139	0.38=1.1499	0.35=0.9747	0.25=0.4976
0.27=0.5809	0.53=2.2379	0.48=1.8337	0.32=0.8139	0.20=0.3177	0.17=0.2307	0.74=4.3595
0.16=0.2043	0.20=0.3177	0.15=0.1795	0.24=0.4584	0.18=0.2570	0.19=0.2865	0.26=0.5385
0.27=0.5809	0.40=1.2748	0.26=0.204				

Syzygium sp.

0.28=0.6249	0.84=5.6158	0.20=0.3177	0.98=7.6454
0.15=0.1795	0.78=4.8383	0.70=3.8987	1.24=12.2418

Ceiba pentandra

2.02=32.4722

Hibiscus rosa-sinensis

0.18=0.2570
0.23=0.4208

c) Oneroa Plot 2. - the landward side of the *motu*

Cocos nucifera

1.48=17.4234	1.28=13.0356	1.50=17.9001	0.37=1.0899	1.41=15.8196	0.37=1.0899	1.40=15.5948
1.49=17.6609	1.67=22.1952	1.45=16.7348	1.29=13.2412	1.39=15.3716	1.27=12.8316	1.41=15.8196

Casuarina equisetifolia

0.86=5.8879	0.24=0.4584	0.87=6.0263	0.16=0.2043	0.16=0.2043	0.20=0.3177	0.28=0.6249
0.19=0.2865						

Scaevola taccada

0.23=0.4208	0.18=0.2570	0.19=0.2865	0.20=0.3177	0.17=0.2307	0.21=0.3505	0.15=0.1795
0.22=0.3848	0.17=0.2307	0.15=0.1795	0.16=0.2043	0.15=0.1795	0.15=0.1795	0.16=0.2043
0.17=0.2307	0.16=0.2043	0.15=0.1795	0.16=0.2043	0.17=0.2307	0.15=0.1795	

Argusia argentea

0.18=0.2570	0.18=0.2570	0.18=0.2570	0.16=0.2043	0.28=0.6249	0.16=0.2043	0.30=0.7148
0.50=1.9906	0.35=0.9747	0.30=0.7148	0.15=0.1795			

Hibiscus tiliaceus

0.15=0.1795
0.19=0.2865

Guettarda speciosa

0.18=0.2570

d) *Inocarpus* dominated Forest at the top of the Avatiu Valley. 14° of slope up the ridge, and 18° of slope on either side of the ridge.

Inocarpus edulis

3.74=111.2950	2.29=41.7393	0.69=3.7875	2.22=39.2136	1.10=9.6321
6.25=310.8380	1.09=9.4569	5.04=202.1189	0.16=0.2043	3.55=100.2875

Homalium acuminatum

0.16=0.2043	0.87=6.0263	0.53=2.2379	1.18=11.0800
0.70=3.8987	0.24=0.4584	0.71=4.0115	0.35=0.9747
1.46=16.9677	0.18=0.2570	2.97=70.1974	0.37=1.0899
2.23=39.5696	0.22=0.3848	3.00=71.6303	

Angiopteris longifolia

0.15=0.1795	0.15=0.1795	0.16=0.2043	0.15=0.1795	0.15=0.1795
0.15=0.1795	0.15=0.1795	0.15=0.1795	0.16=0.2043	0.15=0.1795
0.17=0.2307	0.15=0.1795	0.15=0.179		

Fagraea berteriana

1.15=10.5209 1.45=16.7348 0.63=3.1605

Cecropia palmata

0.79=4.9639
0.78=4.8383

Canthium barbatum

0.30=0.7148
0.31=0.7636

Elaeocarpus tonganus

0.17=0.2307

Bischofia javanica

0.32=0.8139
0.80=5.0910

Hibiscus tiliaceus

0.19=0.2865

e) Slope and Ridge Forest: Avatiu side of the Cross-Island Track - *Homalium* and *Fitchia* dominated. *Circa* 200m a.s.l.. 22° of slope up the ridge and 30°.

Homalium acuminatum

0.60=2.8652	0.44=1.5394	1.08=9.2833	0.35=0.9747	0.96=7.3349	.16=0.2043	0.24=0.4584
0.24=0.4584	0.17=0.2307	0.23=0.4208	0.63=3.1605	0.19=0.2865	0.67=3.5700	0.35=0.9747
0.32=0.8139	0.85=5.7510	0.48=1.8337	0.22=0.3848	0.52=2.1538	0.89=6.2991	0.60=2.8652
1.55=19.1200	0.92=6.7334	0.54=2.3181	0.19=0.2865	0.16=0.2043	0.38=1.1499	0.40=1.2748
0.21=0.3505	0.55=2.4053	0.89=6.2991	0.97=7.4894	0.19=0.2865	0.43=0.9195	0.55=2.4053
3.36=89.8530	0.54=2.3181					

Fitchia speciosa
0.15=0.1795 0.32=0.8139 0.16=0.2043 0.18=0.2570 0.18=0.2570 0.16=0.2043 0.15=0.1795
0.18=0.2570 0.15=0.1795 0.21=0.3505 0.18=0.2570 0.29=0.6706 0.15=0.1795 0.22=0.3848
0.18=0.2570 0.15=0.1795 0.22=0.3848 0.21=0.3505 0.17=0.2307 0.15=0.1795 0.15=0.1795
0.18=0.2570 0.23=0.4208 0.15=0.1795 0.22=0.3848 0.18=0.2570 0.16=0.2043 0.19=0.2865
0.20=0.3177 0.18=0.2570 0.21=0.3505 0.23=0.4208 0.19=0.2865 0.15=0.1795 0.16=0.2043
0.19=0.2865 0.18=0.2570 0.15=0.1795 0.21=0.3505 0.16=0.2043 0.17=0.2307 0.16=0.2043
0.17=0.2307 0.15=0.1795 0.25=0.4976 0.15=0.1795 0.15=0.1795 0.15=0.1795 0.19=0.2865
0.18=0.2570 0.21=0.3505 0.15=0.1795 0.22=0.3848 0.29=0.6706 0.17=0.2307 0.16=0.2043
0.15=0.1795 0.16=0.2043 0.21=0.3505 0.18=0.2570 0.26=0.5385 0.22=0.3848 0.21=0.3505
0.17=0.2307 0.17=0.2307 0.20=0.3177 0.22=0.3848 0.21=0.3505 0.20=0.317

Canthium barbatum
0.16=0.2043 0.29=0.6706 0.26=0.5385 0.22=0.3848 0.20=0.3177 0.29=0.6706 0.31=0.7636
0.28=0.6249 0.31=0.7636 0.39=1.2115 0.30=0.7148 0.20=0.3177 0.37=1.0899 0.25=0.4976
0.31=0.7636 0.32=0.8139 0.31=0.7636 0.26=0.5385 0.20=0.3177 0.20=0.3177 0.24=0.4584
0.22=0.3848

Elaeocarpus tonganus
0.43=1.4698 0.25=0.4976 0.39=1.2115 0.28=0.6249 0.32=0.8139 0.27=0.5809 0.18=0.2570
0.27=0.5809 0.24=0.4584 0.27=0.5809 0.25=0.4976 0.31=0.7636 0.48=1.8337 0.46=1.6833
0.39=1.2115 0.20=0.3177 0.50=1.9906 0.31=0.7636

Meryta paucifolia
0.15=0.1795 0.19=0.2865 0.20=0.3177
0.24=0.4584 0.17=0.2307 0.21=0.3505
0.18=0.2570 0.28=0.6249

Fagraea berteriana
0.51=2.0714 0.44=1.5394 0.22=0.3848 0.47=1.7577
0.23=0.4208 0.40=1.2748 0.40=1.2748 1.04=8.6049
1.35=14.5085 1.37=14.930 1.72=23.5342

Hibiscus tiliaceus
0.30=0.7148 0.45=1.6106 0.24=0.4584 0.24=0.4584
0.31=0.7636 0.41=1.3396

Hernandia moerenhoutiana
1.26=12.6293

Xylosma suaveolens
0.21=0.3505 0.19=0.2865 0.41=1.3396 0.20=0.3177
0.50=1.9906 0.21=0.3505

Angiopteris longifolia
0.15=0.1795 0.15=0.1795

Weinmannia samoensis
0.16=0.2043 0.46=1.6833
0.65=3.3654 0.33=0.8659
0.61=2.9620 0.67=3.5700

Ixora bracteata
0.19=0.2865 0.41=1.33960
0.19=0.2865 0.18=0.2570
0.16=0.2043

Pittosporum rarotongense
0.35=0.9747 0.32=0.8139

Alstonia costata
0.52=2.1538

Glochidion ramiflorum
0.44=1.5394 0.43=1.4698
0.67=3.5700 0.17=0.2307

h) Cloud Forest - ridge on Old Te Manga Track. *Circa* 440m a.s.l.. 22° of slope up the ridge and 50° of slope down from the ridge top. The other side of the ridge top was not surveyed as it was a sheer drop.

Metrosideros collina
0.76=4.5996 0.36=1.0315 0.53=2.2379 0.60=2.8652 0.20=0.3177 2.10=35.0883 0.37=1.0899
0.18=0.2570 0.26=0.5385 0.80=5.0910 0.36=1.0315 1.35=14.5085 0.20=0.3177 0.55=2.4053
1.10=9.6321 1.39=15.3716 0.77=4.7144 0.28=0.6249 0.18=0.2570 0.68=3.6779 0.75=4.4788
0.51=2.0714 1.95=30.2687 1.50=17.9001

Fagraea berteriana
1.55=19.1200 0.48=1.8337 1.28=13.0356 0.28=0.6249 2.00=31.8290 0.15=0.1795 1.05=8.7721
0.16=0.2043 0.75=4.4788 0.20=0.3177 0.68=3.6779 0.40=1.2748 1.28=13.0356 0.98=7.6454
0.94=7.0309 1.45=16.7348 0.49=1.9113 0.45=1.6106 0.38=1.1499 0.70=3.8987 1.30=13.4484

Weinmannia samoensis
0.22=0.3848 0.47=1.7577 0.55=2.4053 0.15=0.1795 0.45=1.6106 0.65=3.3654 0.70=3.8987
0.18=0.2570 2.10=35.0883 0.59=2.7700 0.31=0.7636 0.16=0.2043 1.05=8.7721 0.17=0.2307
1.17=10.8920 0.37=1.0899 1.38=15.1501

Elaeocarpus tonganus
0.16=0.2043 0.80=5.0910 0.26=0.5385

Ascarina diffusa
0.22=0.3848 0.34=0.9195 0.36=1.0315 0.38=1.1499

Angiopteris longifolia
0.15=0.1795 0.15=0.1795 0.16=0.2043 0.16=0.2043

Canthium barbatum
0.24=0.4584

Cecropia palmata
0.18=0.2570 0.54=2.3181

Homalium acuminatum
0.18=0.2570

Alstonia costata
0.20=0.3177

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