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. *Pakai`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).

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[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 requirements 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 archaeologically 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*.

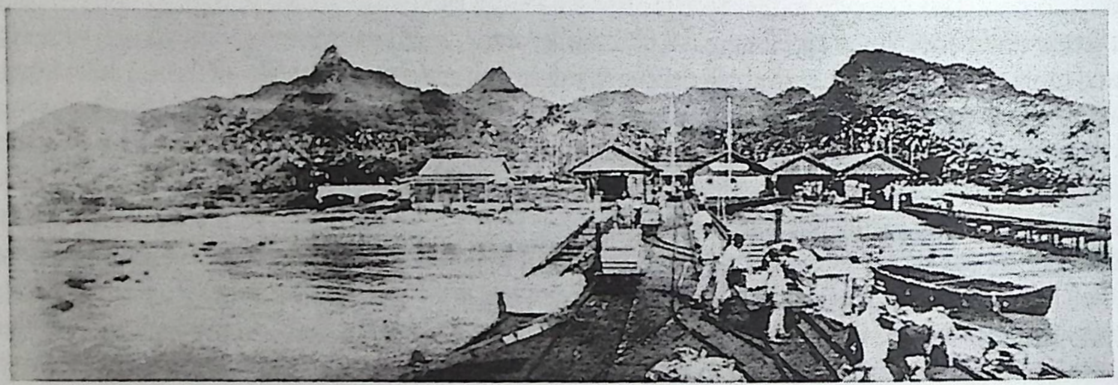


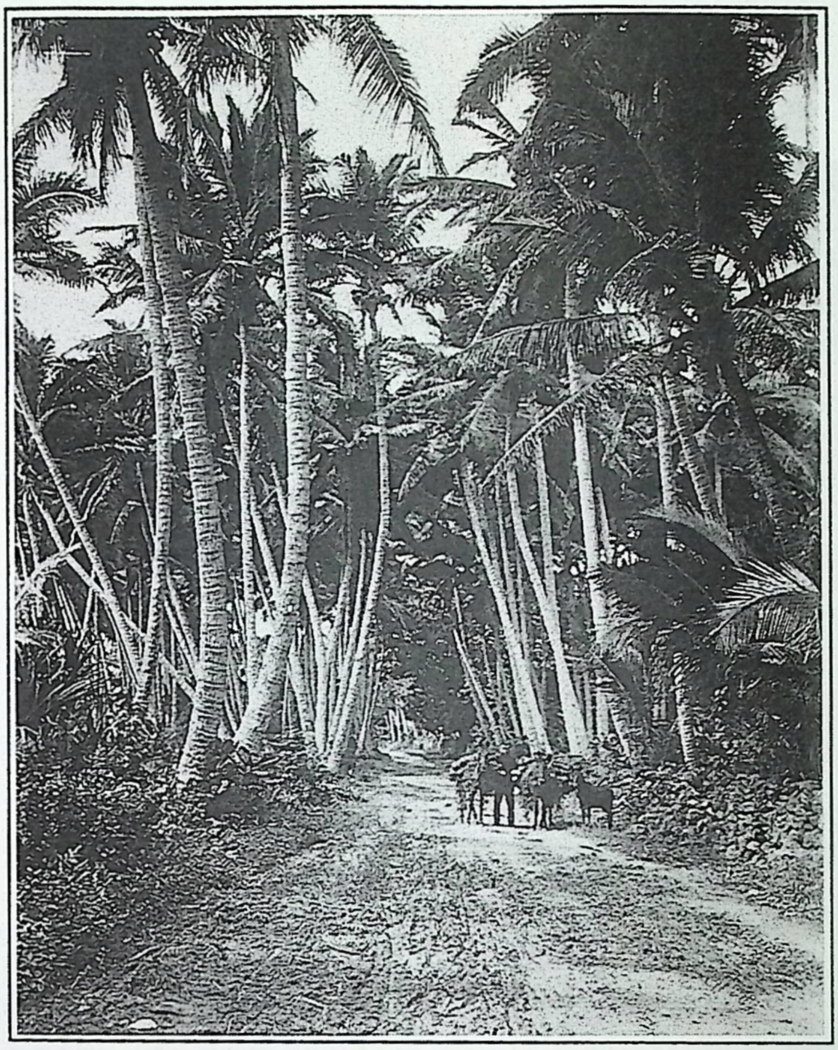
Plate 6.1 The wharves at Avarua, Rarotonga, 1911. Appendices to Journals, New Zealand House of Representatives 1911.

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.

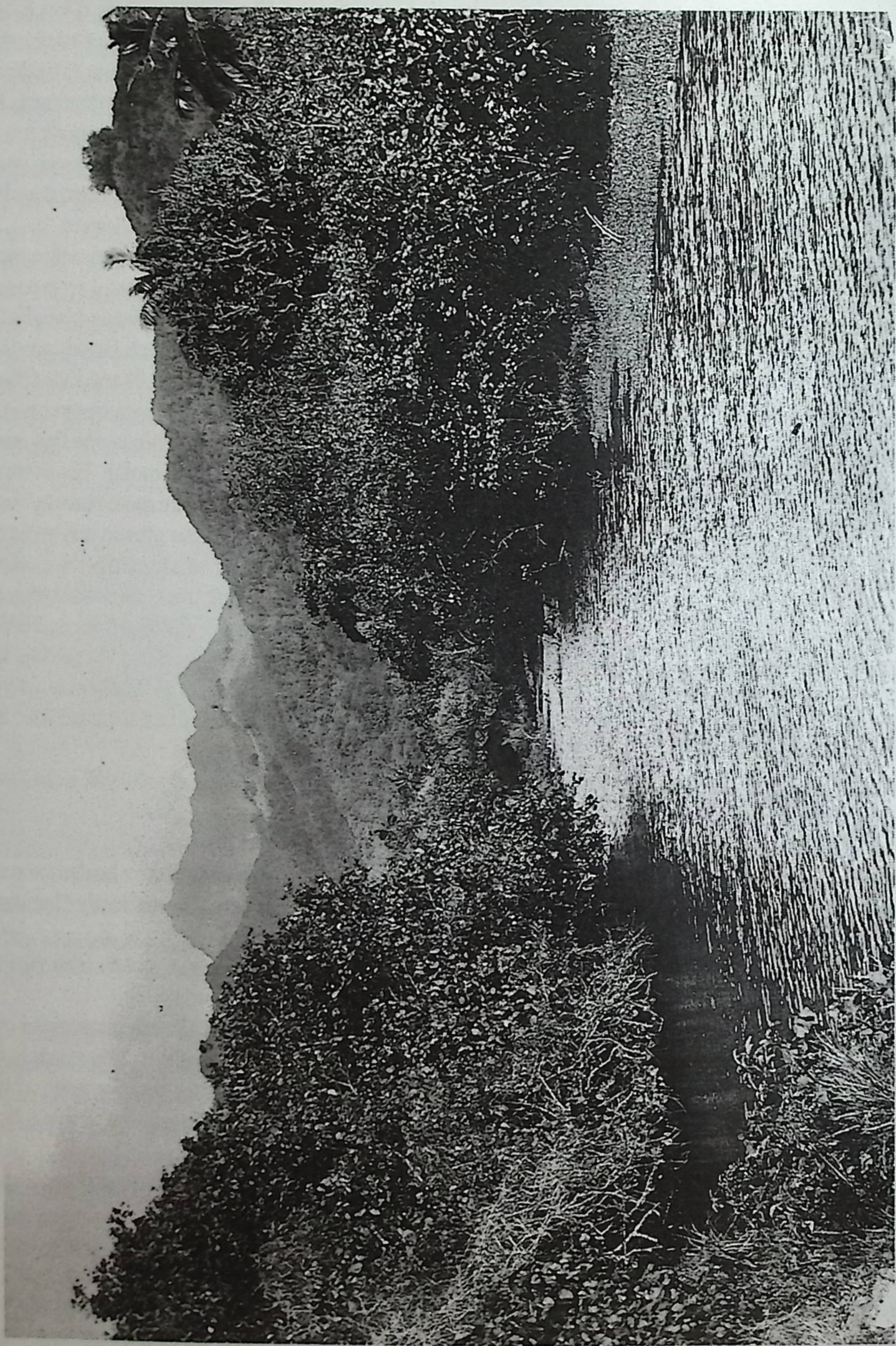


Plate 6.3. View up the Avana Valley by Josiah Martin, 1890's. Alexander Turnbull Library, Wellington. Ref. No. F 144851 ½

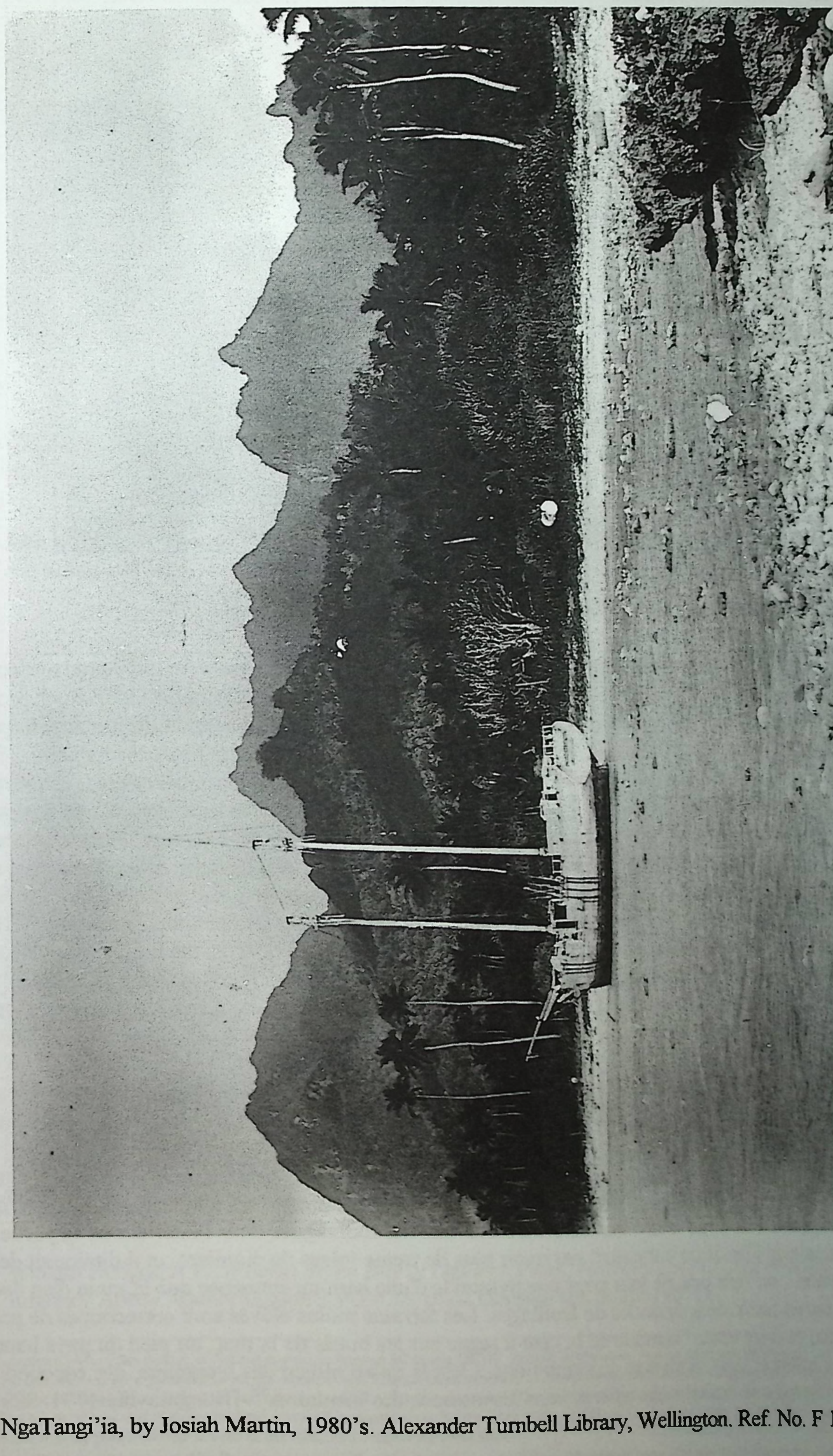


Plate 6.4 NgaTangi'ia, by Josiah Martin, 1980's. Alexander Turnbell Library, Wellington. Ref. No. F 144852 ½ .

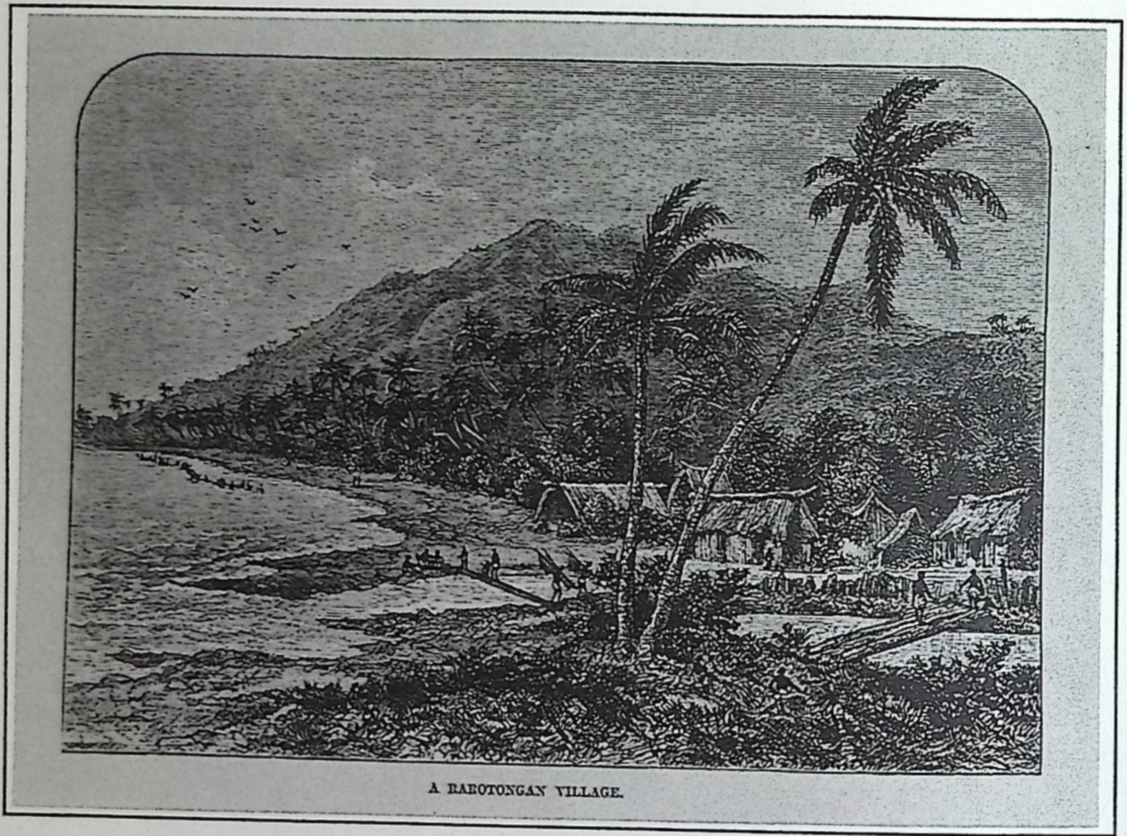


Plate 6.5 A *Rarotonga Village*, from William Wyatt Gill (1885:72).

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)

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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*

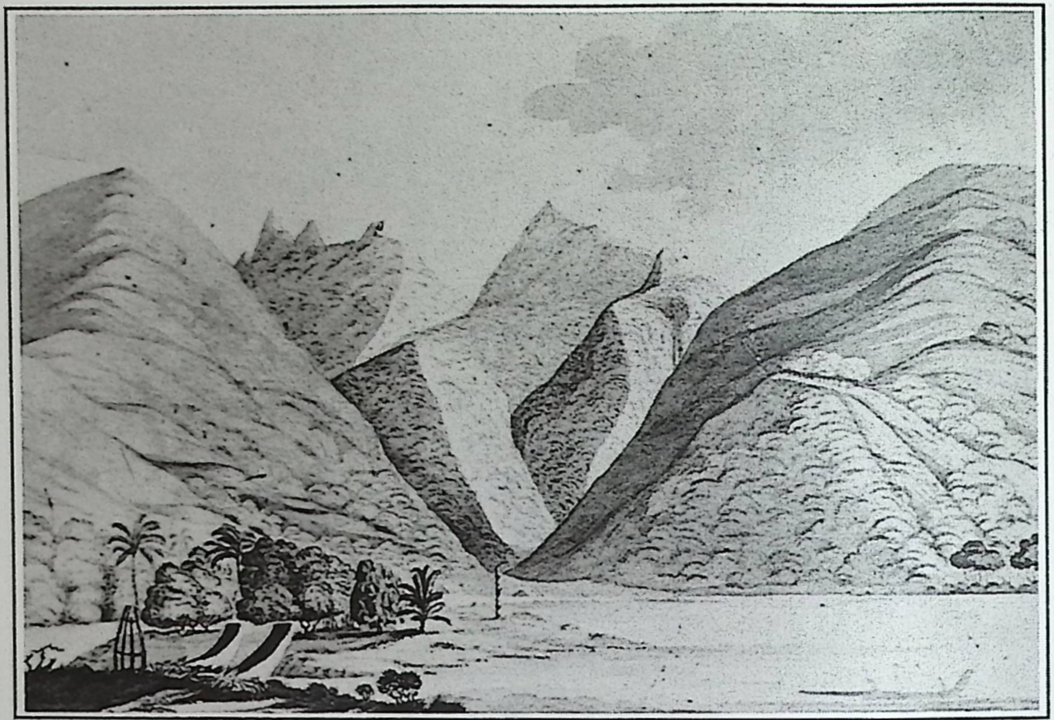

Plate 6.8 William Ellis *(A View in Vaitepiha Bay [August 1777]*, Mitchell Library, State Library of New South Wales, Sydney, Plate 3.82, p. 343 (Joppien and Smith 1987b).

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].

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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*

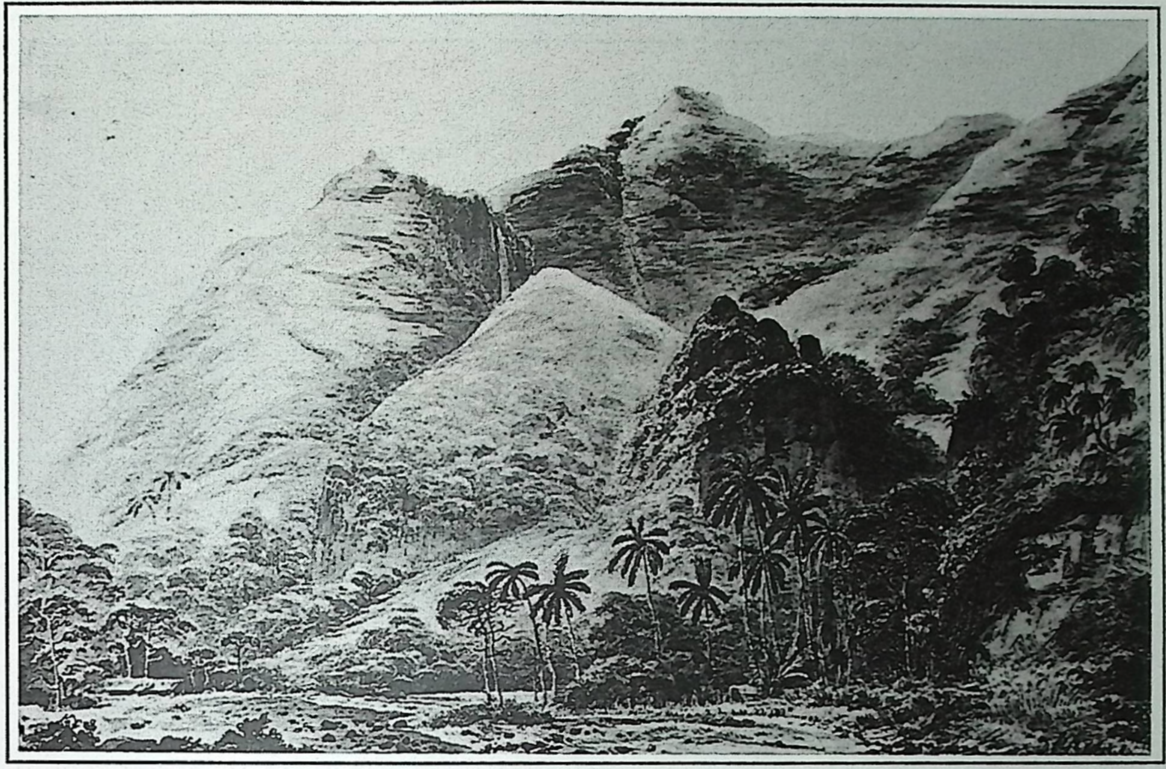

Table 6.9 John Webber, *A View in the Valley of Matavai Bay,* August-September 1777, British Library, London. Plate 70, p. 62 (Joppien and Smith 1987a)

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.....Ils 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).

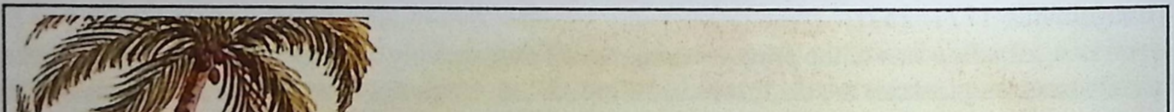

Table 6.11 George Tobin, *Scene of fishing, in Tehaha-Fa'a'a,* 1792 (Oliver 1988, Plate 20).

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

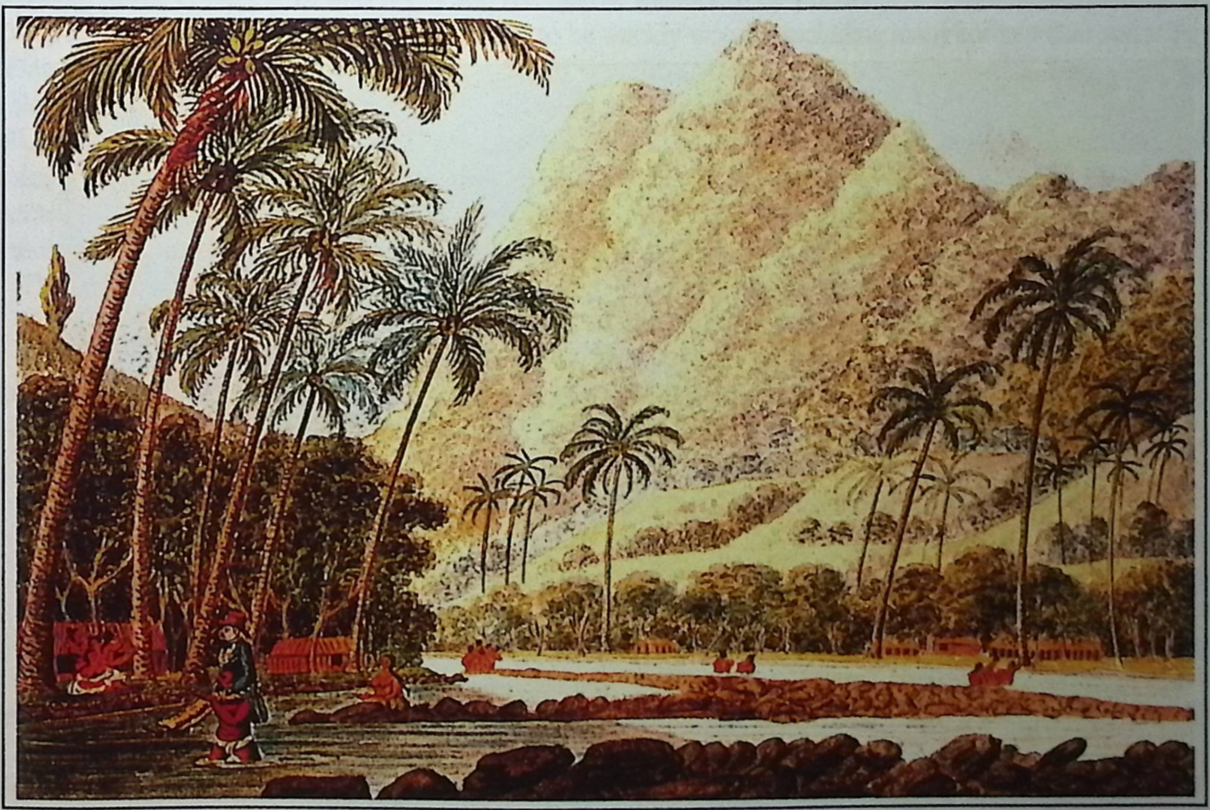

Table 6.13 George Tobin, *A view of Ha'apaino'o River*, 1792 (Oliver 1988, Plate 19).

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.

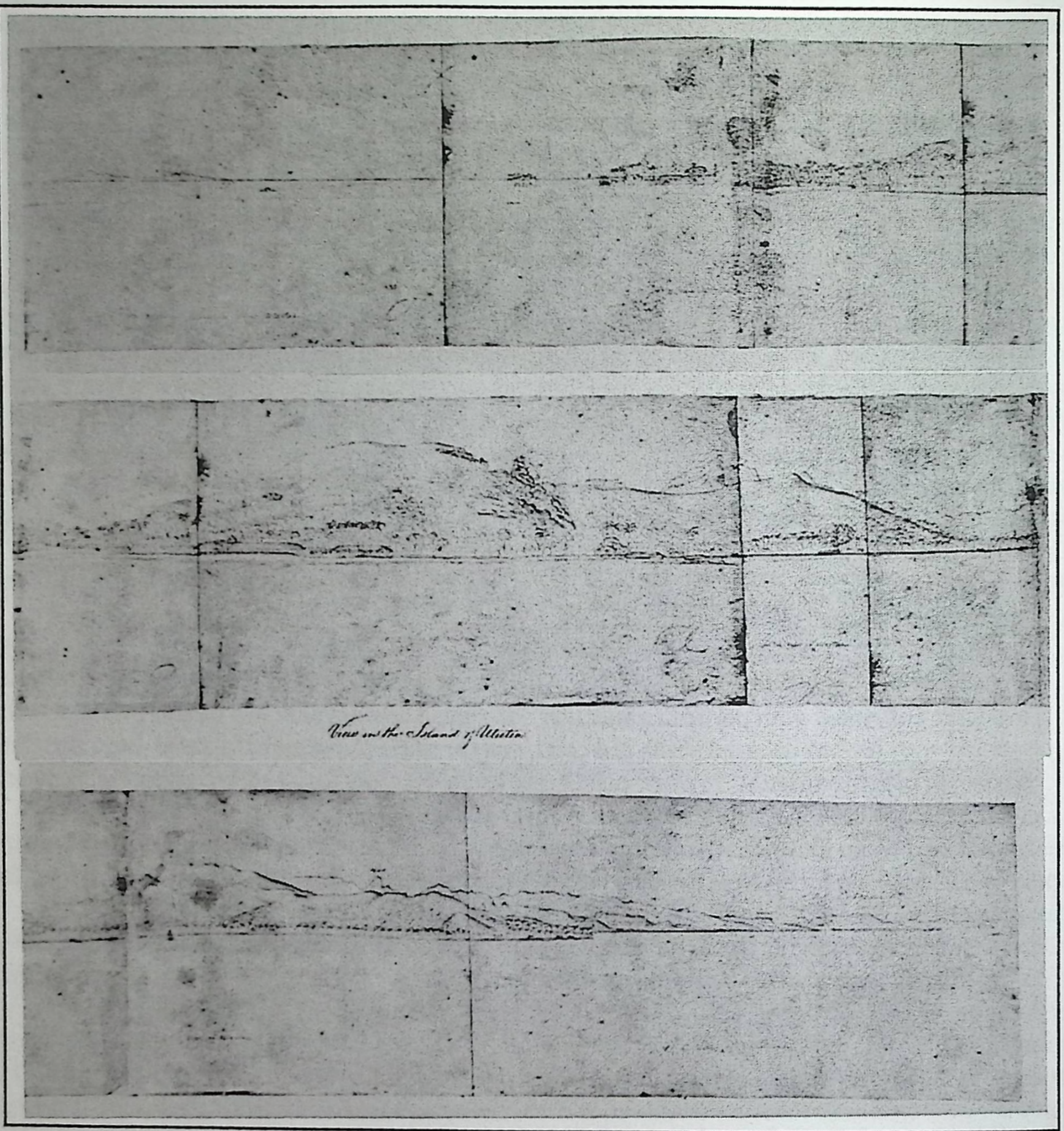


Plate 6.16 Spöring. *[View from the anchorage in Opua Harbour]*, Ra'iatea, 1769, British Library (David et al. 1988)

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.

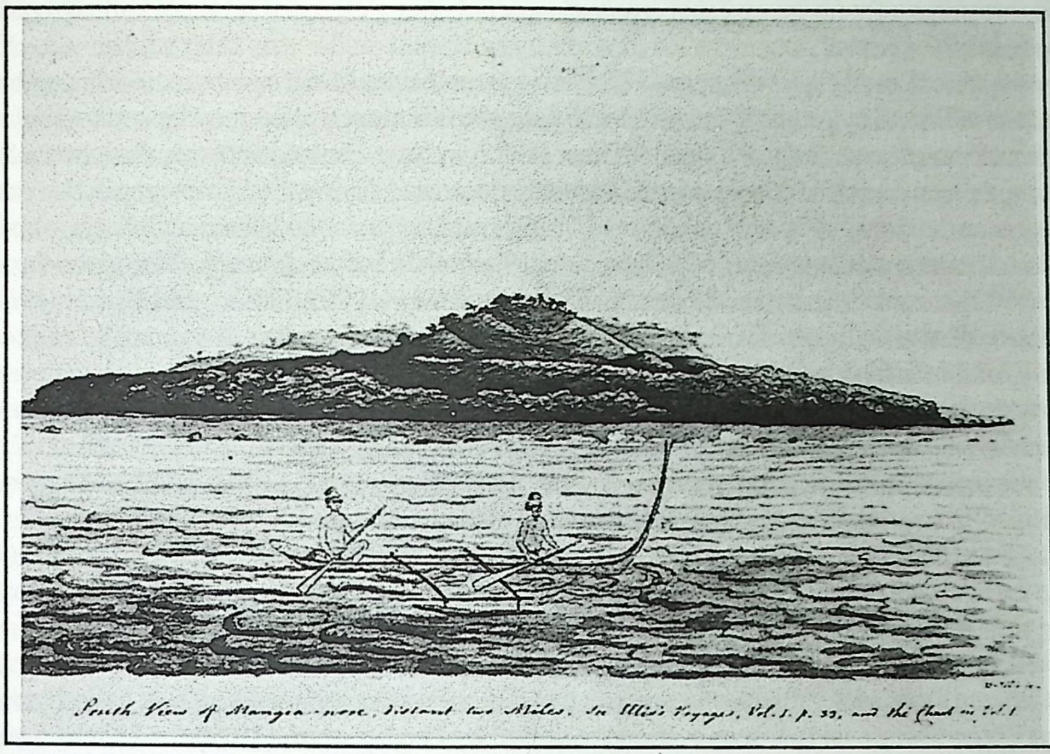


Plate 6.17 Ellis *[Two Men in a Canoe off Mangaia]*, March 1777, Turnball Library, Wellington. Plate 3.30, p. 290 (Joppien and Smith 1987b)

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.

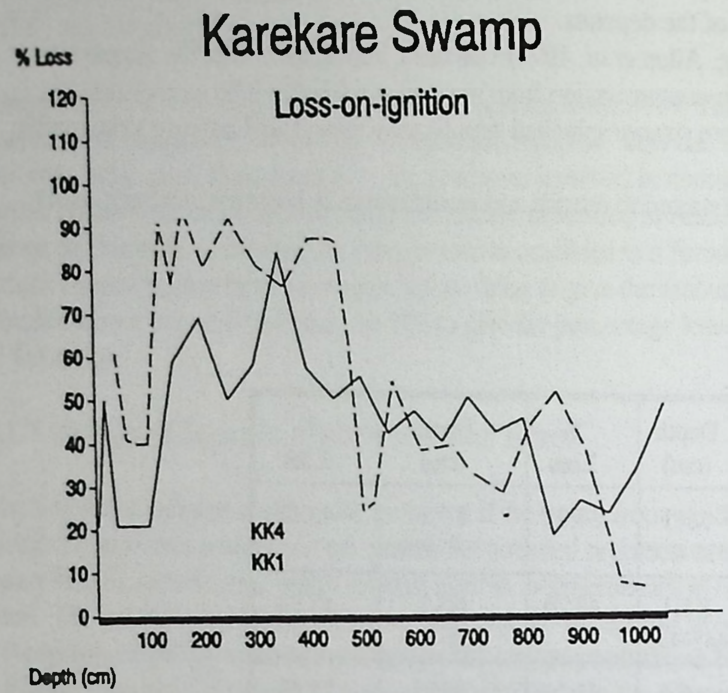
From 806.5 cm depth (see Table 7.6), coral sand started to intrude and would naturally boost the alkalinity, so no more pH tests were carried out.

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



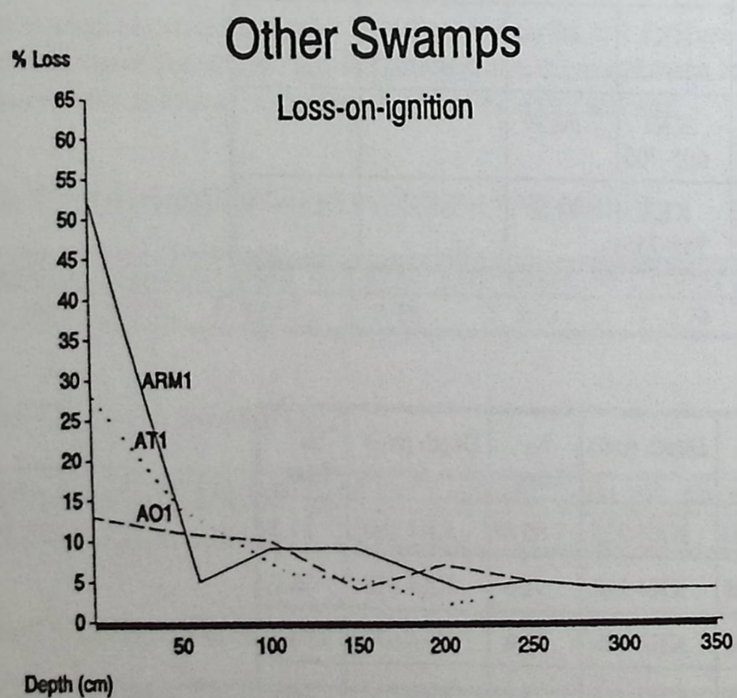


Figure 7.1 Loss-on-ignition Tests

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, milli-amperage, 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.

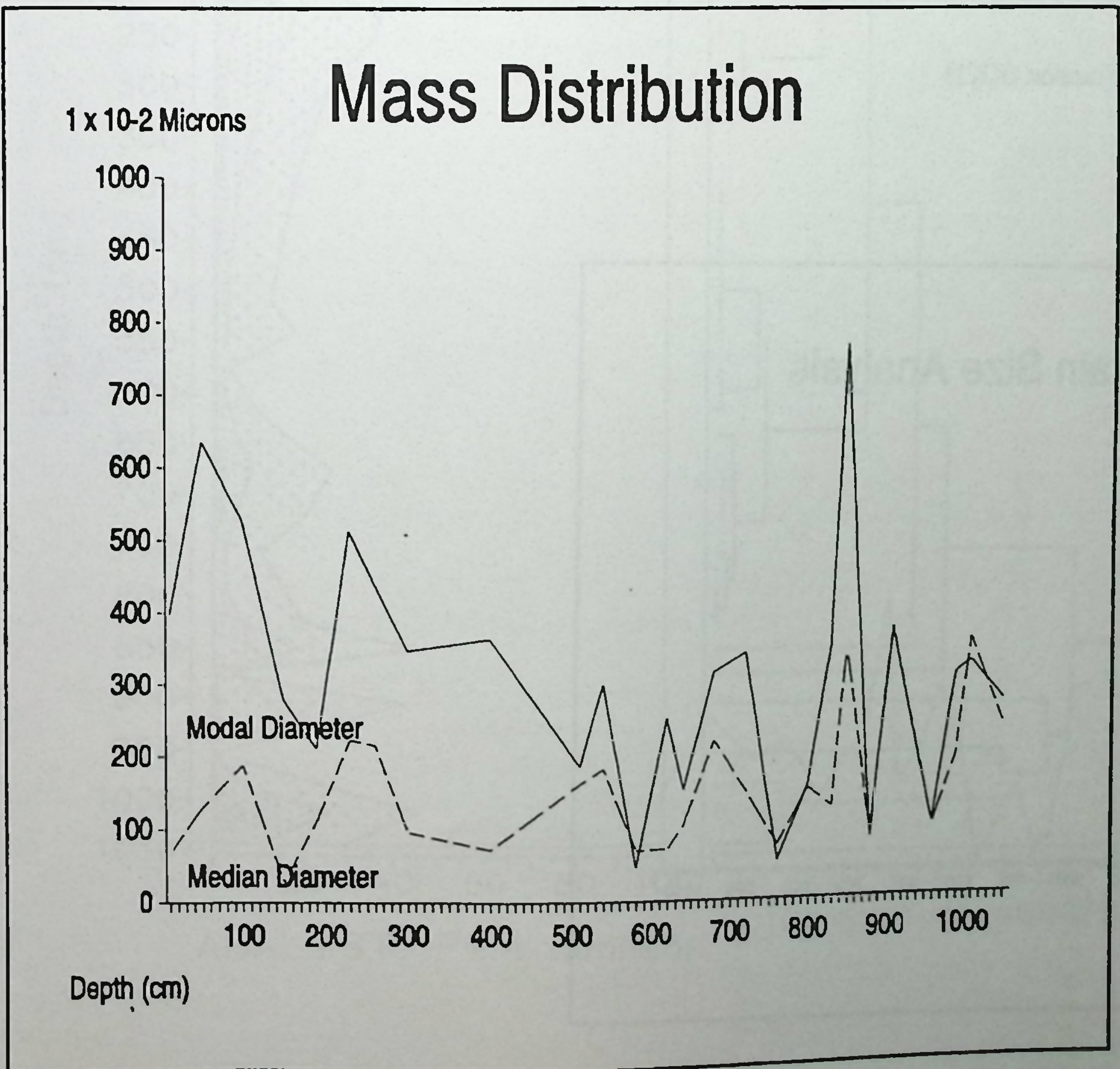


Figure 7.2 Mass Distribution (KK1)

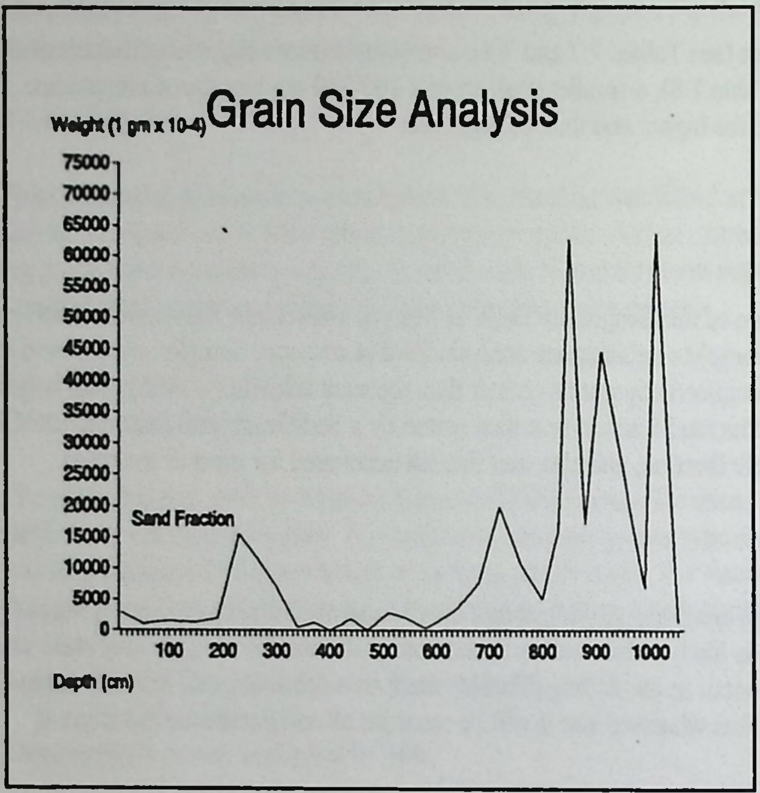


Figure 7.3 The Sand Fraction (KK1)

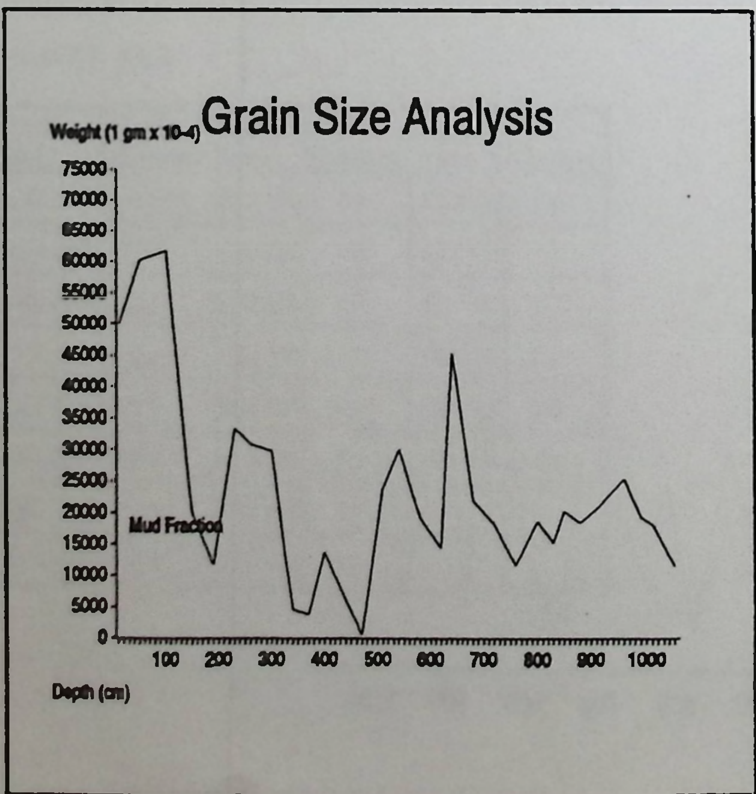


Figure 7.4 The Mud Fraction (KK1)

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.

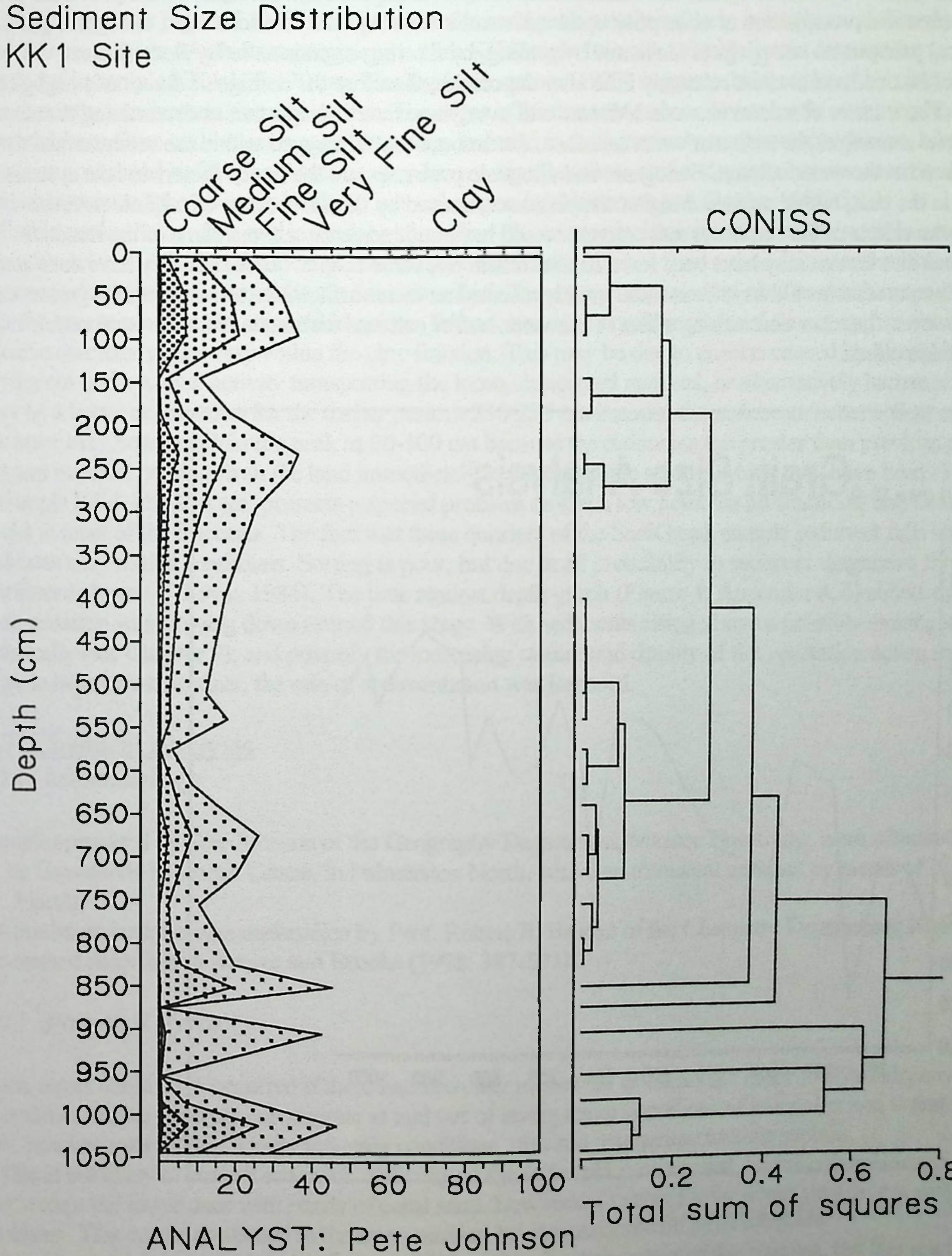


Figure 7.5 Sediment Size Distribution (silts and coarser clay) for KK1

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.

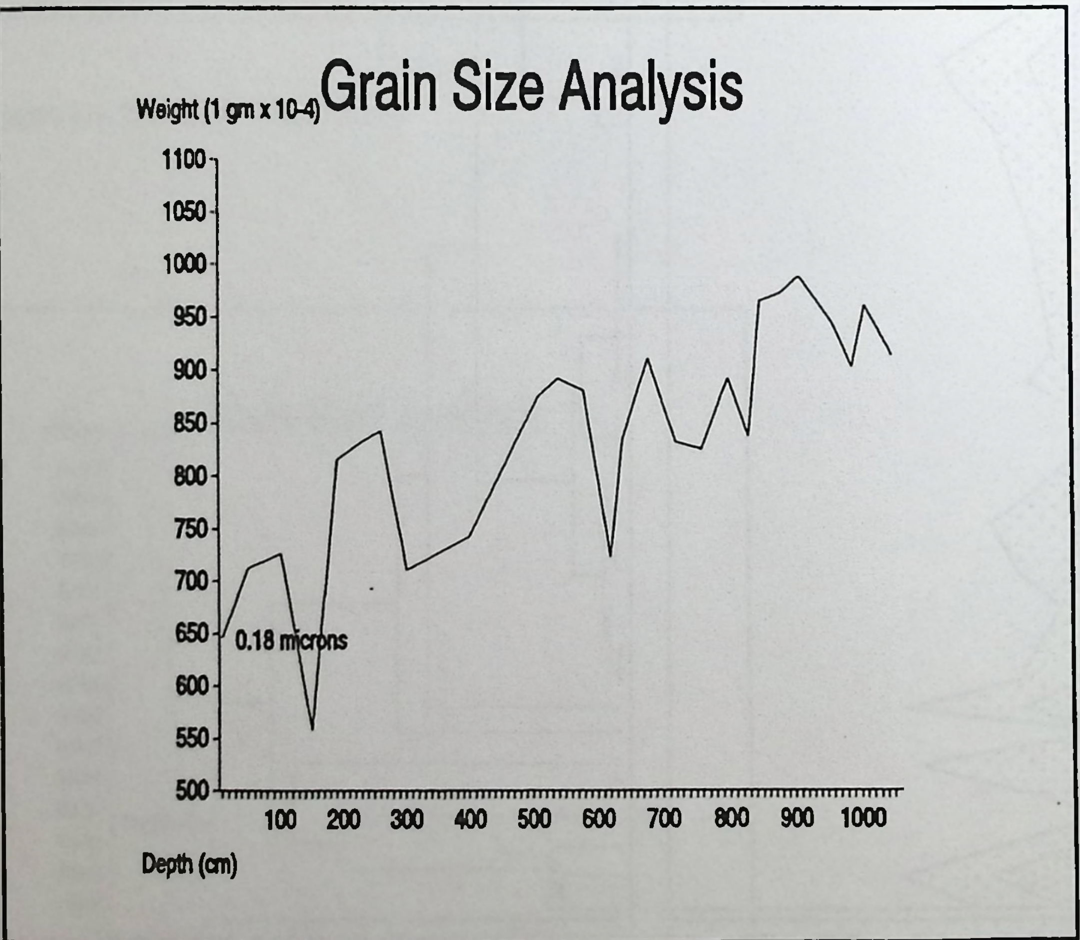


Figure 7.6 The 0.18 mm (Clay) Fraction (KK1)

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.

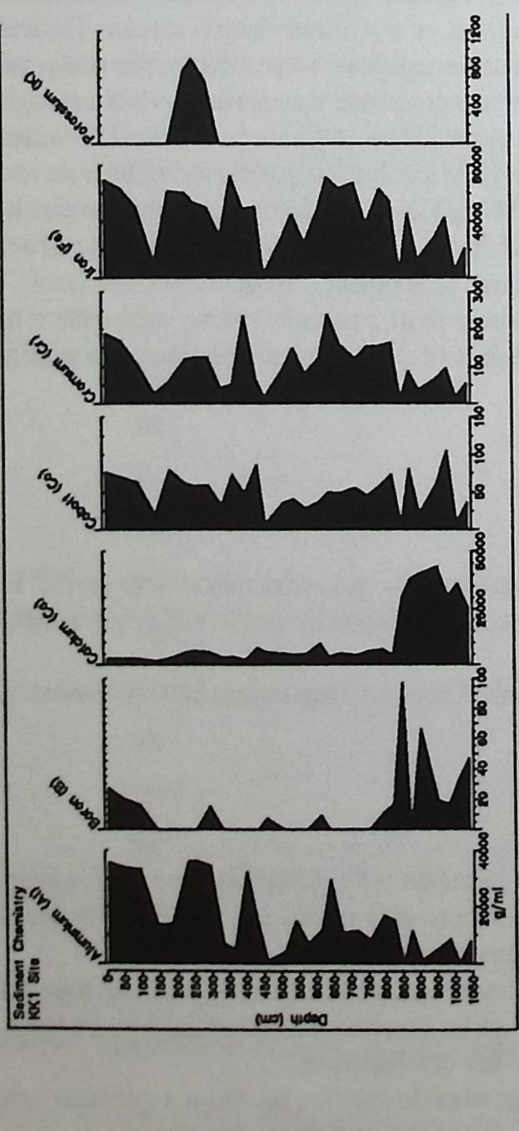
This is not likely to present too much difficulty as far as the pH is concerned, because the pH levels were not especially low, except the lower ones with bands of coral sand. Low redox, except for the upper peat layers, may have created problems. This can be evaluated in the interpretation by comparison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

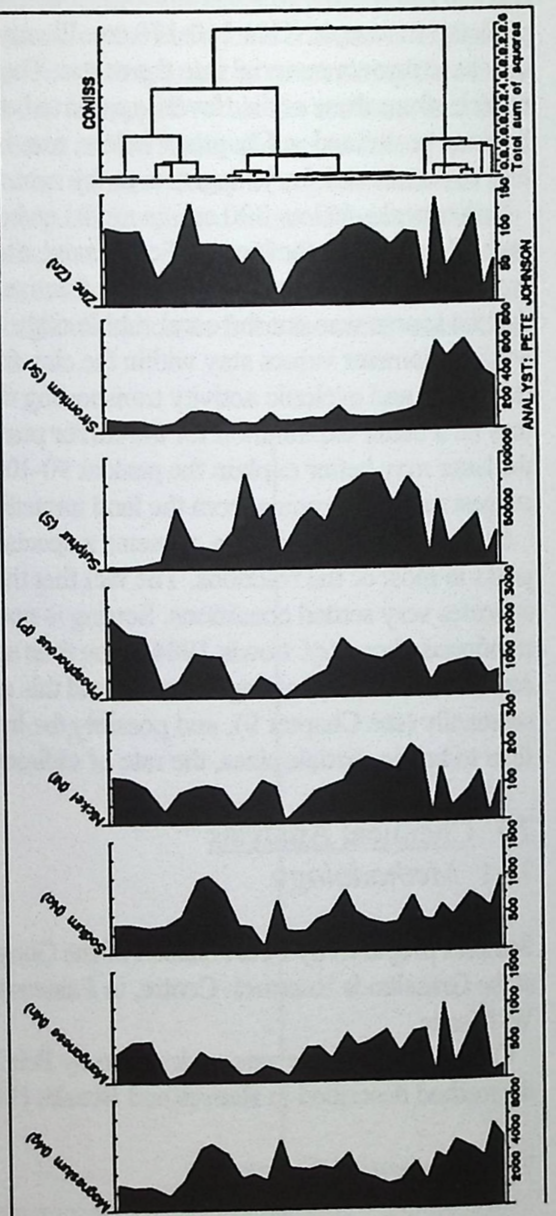
Some contamination could derive from the HCl used in the preparation of the samples, but this is a systematic error accounted for by the analysis of a control sample of the same HCl used in the preparation of the samples.

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_2O_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.

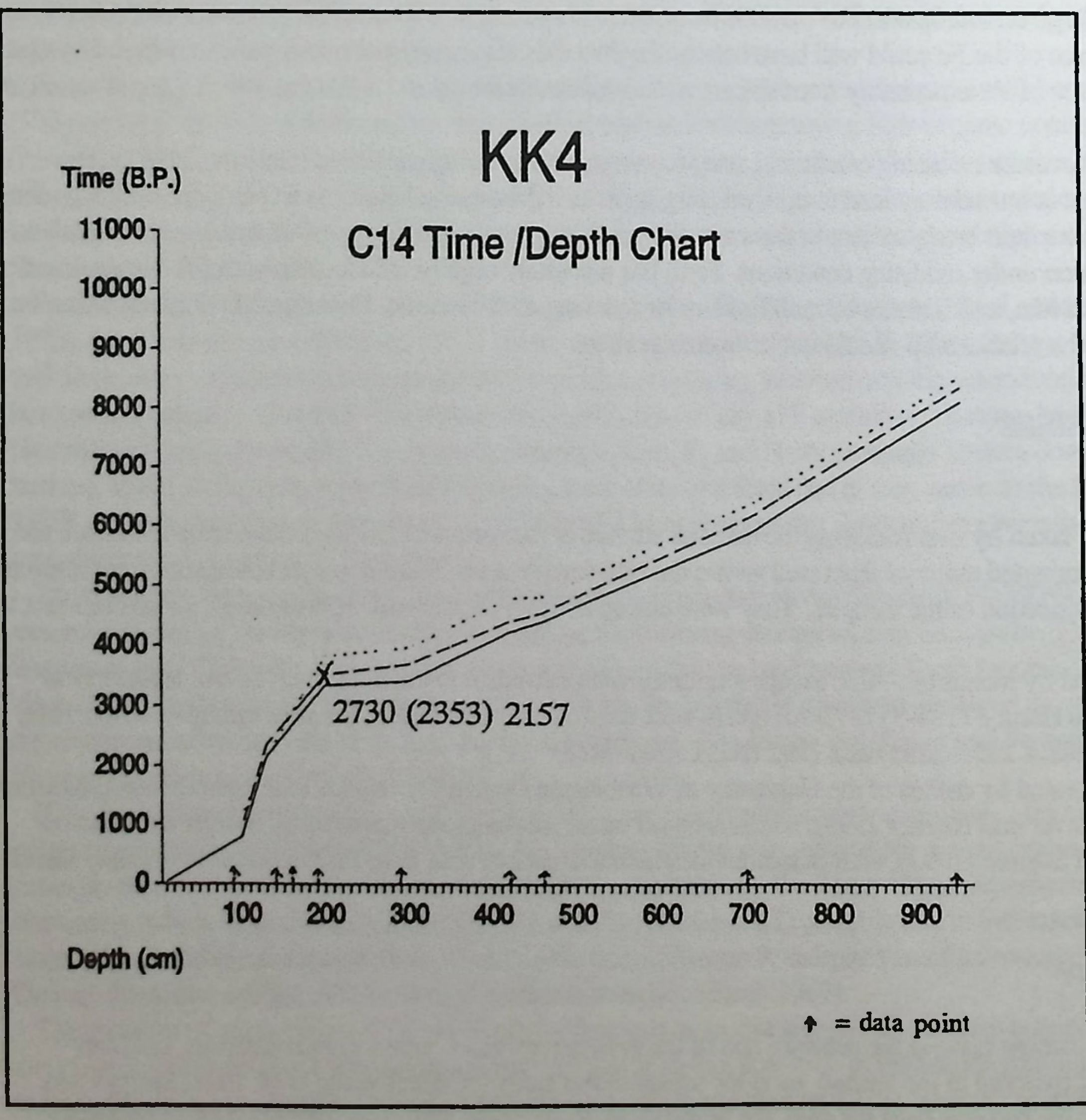

Figure 7.8 KK1 Time/Depth (Conventional Radiocarbon Dates at 1 s

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.

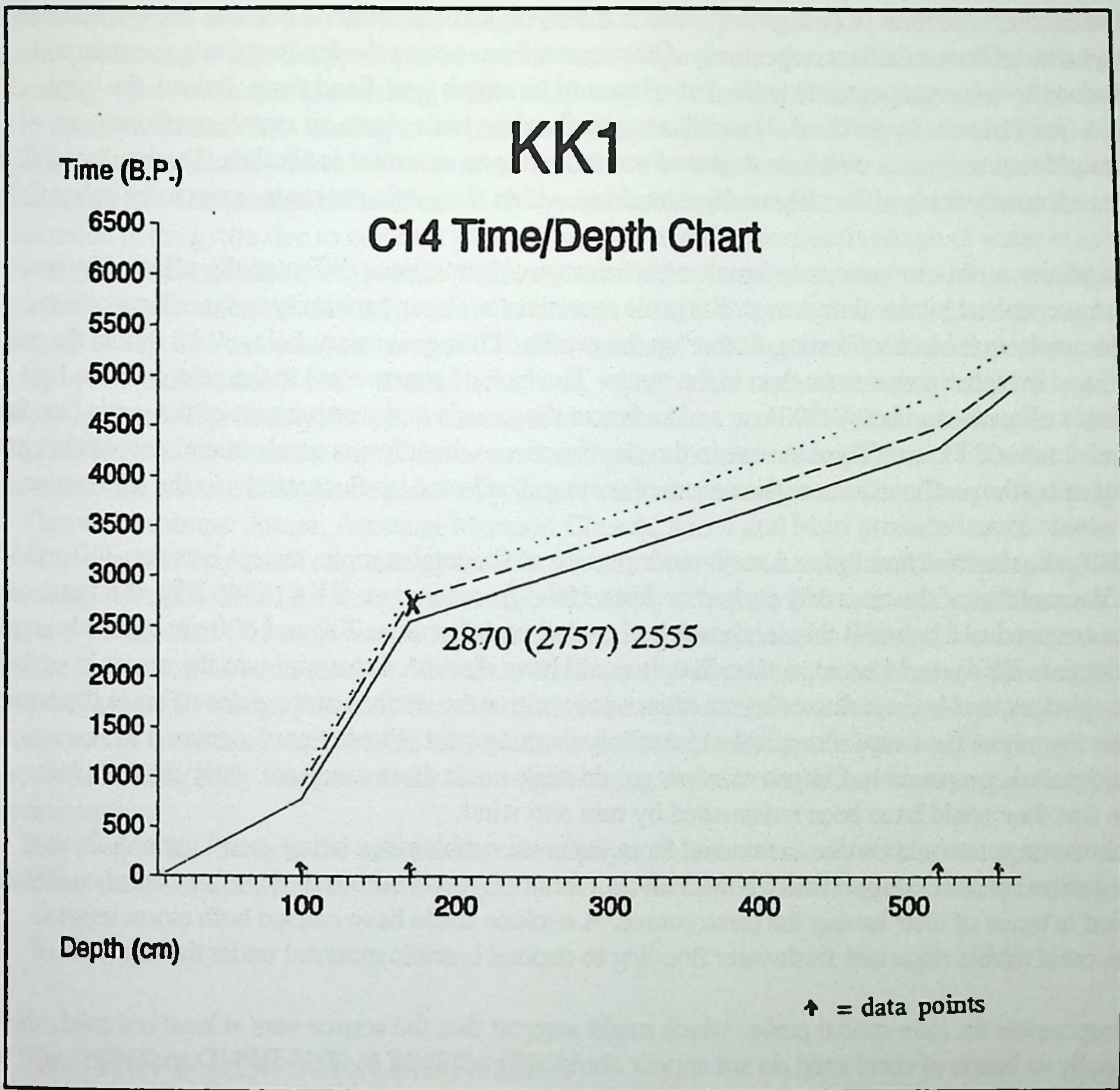

Figure 7.9 KK4 Time/Depth (Calibrated Radiiocarbon Dates at 2

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 cm³ 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 <u>Interpretation</u>

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

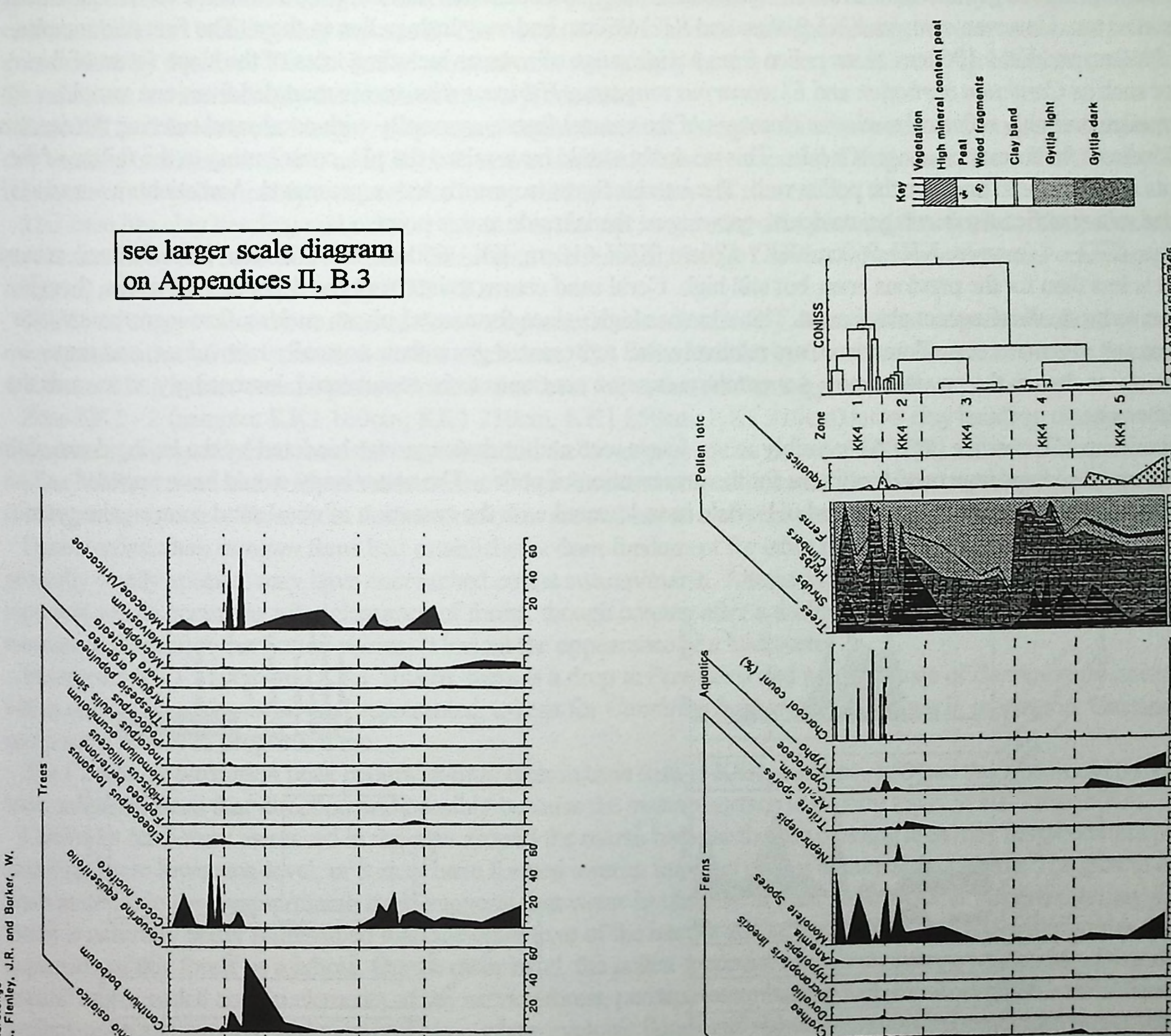

Figure 8.1 KK4 Pollen Diagram

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.

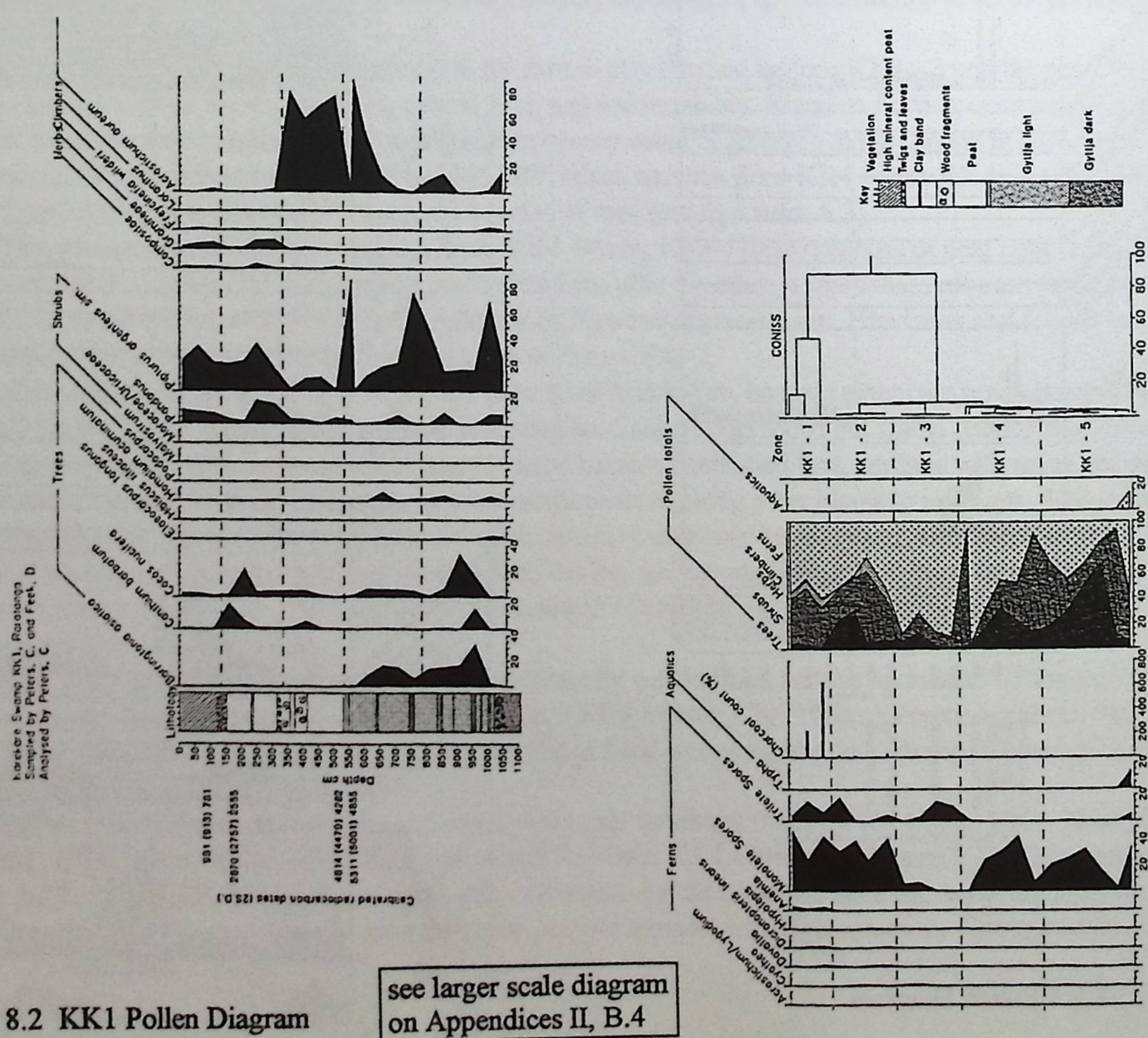

Figure 8.2 KK1 Pollen Diagram

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.

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[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 Mīti`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

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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.

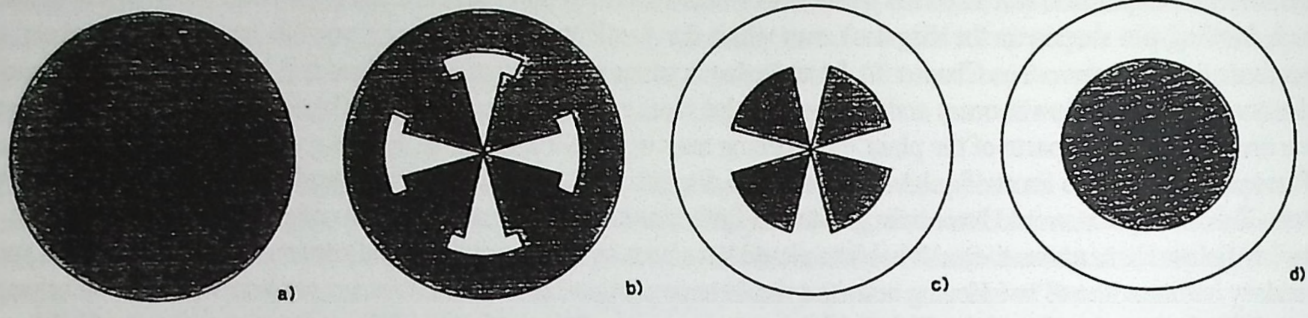

Figure 9.1 A theoretical model for environmental change on Rarotonga.

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 more aggressive rats, especially the black rat (*Rattus rattus*). evidence of this can be seen on Suwarrow, which has the greatest numbers and diversity of nesting sea birds in the Cook Islands (Holyoak 1980), some of the birds making nests near or on the ground surface, and yet the Polynesian rat is present - as the only rat species (Matisoo-Smith pers. comm. 1993).

A look at the ecology of a number of extant members of the genera that are typically represented on Polynesian islands as extinct endemics may elucidate some of the problems. Surviving members of the genus *Gallicolumba* suggest that these ground-doves were usually secretive, not venturing beyond the protective cover of the forest (Grzimek 1972; Watling 1982). They are solitary, or at most occur in pairs and small groups, and do not occur at any great density (Beehler *et al.* 1986). Their diet consists of seeds, fruits, buds, young leaves and shoots from the ground, and insects (Beehler *et al.* 1986; Grzimek 1972; Watling 1982). Their habitat ranges from mountains (up to 1600 m in New Guinea) to the lowlands, from rocky ridge forest to dense and humid forest (Beehler *et al.* 1986; Sibley and Monroe 1990). They are mainly ground-dwelling cursorial birds, escaping predators by outpacing them, though some will fly if forced to (Grzimek 1972; Beehler 1986; Watling 1982). Nests are placed on the ground (Grzimek 1972), or one to three metres above it (Watling 1982), and usually only one egg is laid (Grzimek 1972), though sometimes two (Watling 1982).

The above information suggests that members of the genus are fairly rigidly attached to natural forest cover, and would be affected by any segmentation and fragmentation of their habitat, being shy of open ground. Low density would also be a liability in such circumstances. As far as hunting is concerned, they are fast runners and are not gregarious, so they should not be considered easy prey. It could be that the laying of single eggs may make the egg less detectable by predators than if was in a batch. However, this would reduce the recovery rate if the bird were threatened, especially if the birds were under pressure due to reduced feeding grounds. Small mammal predators would not necessarily endanger such birds as for instance, *Gallicolumba stairi* survives in Fiji, Tonga and Samoa, despite the presence of rats and, in Fiji, even the presence of the mongoose (Watling 1982).

Another dove genus, *Macropygia*, is found in forests from the mountains to the coast, along tree-lined streams and also in areas of secondary growth, including clearings (Sibley and Monroe 1990). The reasons for the extinction of members of this genus on some Polynesian islands may be similar to *Gallicolumba*, though *Macropygia* may have been able to utilise the areas influenced by human activities, and thus have been less sensitive to habitat change.

Gallirallus is another genus frequently found extinct in Polynesia. It is fairly catholic in its requirements, inhabiting forests (from montane moss forests including the steeper parts to humid lowland forest), scrub, grassland, swamps, marshes and mangroves (Sibley and Monroe 1990). These birds are normally ground-dwelling, though some can fly, albeit awkwardly (Sibley and Monroe 1990; Watling 1982). Their diet comprises small insects, including larvae, molluscs and crustacea, as well as fruit and leaf and flower buds (Watling 1982). They nest in thick vegetation or under overhanging branches (Watling 1982). *Gallirallus philippensis* will sometimes cross roads from one thick stand of vegetation to another (Watling 1982). Another rail, sometimes found to be locally extinct, *Porzana tabuensis* is found in dense vegetation, usually near water, such as swamps, bogs, saltmarshes, mangroves and scrubland (Sibley and Monroe 1990; Watling 1982). It feeds on small aquatic animals and vegetation, and nests near water (Watling 1982).

These two rail taxa are much less reliant on the presence of primary forest, though there appears to be a requirement for the presence of wetland, especially *Porzana tabuensis* as an important component of its diet seems to be small aquatic animals. In an economy, such as that evidenced in the oral tradition and ethnographies (see 6.1.2, 6.3 and Appendix A.5), the practice of leaving parts of the swamplands and other cultivated areas fallow with grasses, sedges and even scrub may have left adequate habitat for such birds to survive, though they would no doubt have been reduced in number. It may be that the introduction of a cash crop economy with European practices of more intensive plantations with more fertilisers and less use of fallow, that the habitat of such rails was too far reduced for their long-term survival. Also, grasses, sedges and scrub, which formerly were regarded as economic resources, have been and are being superseded by the availability of commercially procurable products.

In this way, it can be seen that hunting should not necessarily be seen as a cover-all solution. Indeed, if hunting or even human presence, itself, were to be thought of as an acceptable unicausal explanation, then the fact that other members of these apparently extinction-prone genera survive to this day on other islands in the western Pacific, despite human presence and, no doubt, predation, would have to be ignored.

In New Zealand, it has been suggested that Moa were in some way unused to predators, despite evidence for two enormous birds of prey: one the largest bird of prey ever known, the eagle *Harpagornis moorei*, and the other, the largest goshawk ever known (*Accipiter eylesi* - eg. Anderson 1989b; Cassels 1984). In both these cases, it could be said that humans represented a new kind of predator that these birds were ill-equipped to deal with, though one might question why other large ratites like the ostrich and the emu have survived despite human presence. The answer is clearly more complex than simply "humans arrived and hunted the moa to extinction". More sophisticated ecological models need to be developed to explain such circumstances.

Alternatively, it was the permanent or seasonal occupation or alteration of land (such as by deforestation - Anderson 1989a; 1989b: 184-185) formerly used by such birds that was the greatest blow to their existence[54]. In tropical Polynesia, land birds may have required a certain amount of lowland space in order to survive and that human presence was not compatible with their continued preservation. Humans and birds would also have been in direct competition for resources, like fish, fruit and vegetables, wild or cultivated. In fact, humans and birds share other similarities in their ecological roles on such islands. Both are at the end of the food-chain and both are vectors of new organisms (for instance, Ellison 1990: 6).

Extirpation of the avifauna by hunting is not to be postulated every time Polynesians discovered a new island. 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.

Pre-European contact Polynesian spiritual beliefs may have exercised controls albeit of a limited nature on over-exploitation of the environment, such as ritual controls over resources like *ra`ui* on the Southern Cook Islands, preventing depletion and ensuring maintenance of adequate supplies. However, the extent and inclusivity of such controls is not clear, so this is only cautiously suggested. The ultimate purpose of these restrictions was ritual, religious and political, not necessarily to prevent extinctions of species. This also applies to arguments in the next three paragraphs. Indeed, as argued above (phase b in the model presented in section 9.2), this did not prevent extinctions taking place.

Some `totemic' or sacred animals and plants were not exploited (*cf.* the tradition about Te Aru-Tanga-Nuku - Tara`are 1917: part 6). Misuse of an animal in a kin-relationship with other people or deities was trouble (for example, Kae and the Tinirau's fish sons - Tara`are 1899). Some plants and animals were a *vaka*'s emblem, such as the *Spathoglottis plicata* orchid of Takitumu (McCormack - informed by the late Pa Ariki - pers. comm. 1990). In Tahiti, many trees had religious associations, being planted around or near a *marae* or used to construct religious buildings or artefacts (Eddowes 1991; Orliac 1990).

Religion required rituals and permission from the deity concerned when using a resource. In New Zealand (Grey 1956), natural resources were considered children of gods, punished for not assisting one brother against another by having their children harvested: for example, the forest was Tane's great sheltering forest, holding up the heavens (Walker 1981). In Rarotonga, Rata cut down a tree several times only to find it alive and standing the next day, because the tree belonged to a certain god (More-Taunga-O-Te-Tini 1910; Te Aipitaroi-A-Nui-A-Parara 1910 - Paumotu version).

Some animals were an especially important resource to Polynesians. For example, the peak of Oro`enga (Savage 1962: 210) above Karekare swamp was where people used to hunt birds whose feathers were necessary for making headdresses (Savage 1962). The *pare-kura*, a headdress made of red feathers, was a symbol of office of an ariki. Particular fish were tapu during particular seasons or from particular places, others were tapu for certain families, and some were regarded as tribal emblems in the Cook Islands (Mokoroa 1981).

The habits and ecology of the surviving relatives and surviving populations of birds now extinct in Eastern Polynesia suggest that other reasons, such as reduced and divided habitats, may have been at least as important in their demise as over-hunting. Also, some birds may have survived into later periods due to their ability to make use of secondary habitats. Cultural restrictions may have reduced the decline of indigenous plant and animal species, though how significant and to what extent this may have been is unclear.

9.3.2 *Alternative suggestions for other sites*

The author suggests that if forest was a significant part of Polynesian economies, they would not have been likely to create treeless wastelands, which might be the impression from a review of much of the past and current archaeological literature, which emphasises deforestation. Alternative interpretations are offered here for other sites to demonstrate the case for this alternative view, and not as an ultimate proof of the invalidity of those authors' views. It is the timing (Anderson 1991; Spriggs 1989; Spriggs 1990; Spriggs and Anderson 1993) and scale (Nunn 1990b; Nunn 1991) of human interference with the landscape that is at issue, prompted by recent critiques by Spriggs, Anderson and Nunn.

For Mangaia, Kirch *et al.* (1992) argued that people deforested the interior by means of shifting cultivation of crops like yams and aroids, so that the indigenous fauna dwindled, surviving in the makatea, where some of it was later hunted out. Finally, the population turned to the swamp lands, which had been enriched by the erosional material coming from the now deforested interior (whose basaltic soils declined in fertility), to plant taro, which became their main staple cultigen. The evidence for this came from the increase in fern spores, including *Dicranopteris linearis*, the main species in the interior fernlands, chemical and mineralogical analyses of the sediments, and from an increase in charcoal particles.

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54 Anderson (1989a and 1989b: 183) also mentions dogs, rats and introduced avian diseases as possible contributors to moa extinction.

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$\pm$80 BP and 1640$\pm$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.

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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 (tarolaroa) 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 $\pm$370, 5410 $\pm$100 and 5420 $\pm$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