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Islands, floras and history
An environmental history of plant introduction and extinction on
the Austral Islands, French Polynesia

by

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This thesis is the product of the author's research, and the results presented are, except where otherwise acknowledged, the original work of the author.

Matthew James Prebble
Abstract

Jared Diamond has recently suggested that the unique societal and floral attributes of Easter Island (Rapa Nui) and Tikopia may be a result of their geographical and historical isolation. In what Diamond proposes as the ‘orthodox’ understanding of these islands, I suggest that the discovery of material remains of the extinct Easter Island palm *cf. Paschalococcus disperta* and the introduced Tikopian tree crop *Canarium harveyi* can be seen to represent fundamentally different social strategies for alleviating problems of isolation. In developing a synthesis of evidence for plant introductions and extinctions from the Austral Islands in French Polynesia, I question whether the botanical discoveries on Easter Island and Tikopia allow for the establishment of a robust model of environmental transformation in the Pacific Islands following human colonization.

Despite the totality of explanation proposed in this orthodox picture of Pacific Islands, defining the course of events that led to the establishment and proliferation of human trans-located plant species or the extinction of indigenous plant species is by no means straightforward. There are geographical and historical biases that for many plant species render the relationship between human colonization and the geographic distribution of plants untenable particularly in relation to the downstream effects of human-generated disturbances. Just as some introduced taxa may become naturalized on islands once released, some indigenous taxa may decline or face extinction on their own accord in response to other environmental factors independently of human activity.

The relationship between human colonization and phytogeographic patterning on the Austral Islands is assessed through the examination of multiple lines of botanical evidence. These include historical documentation from early explorer or missionary accounts, oral traditions, sub-fossil archaeological and palaeobotanical remains and the assessment of molecular phylogeographic patterning. Each line of evidence has a different chronological representation and each is preserved differently in different geographical settings. In synthesizing this information I follow an historical method proposed by Fernand Braudel which first establishes the duration of each line of evidence then explores the overlap between their chronological and geographical representations. It is at these points of overlap that a more robust history is revealed.

By following this historical structure I argue that much of the Diamond’s ‘orthodox’ model has a weak foundation. Material evidence from the Austral Islands suggests that the cases of Easter Island and Tikopia are not unique and that the chronological interpretation of plant extinction or introduction events may be distorted. Palm trees (Arecaceae: Iguanurinae type) have also become extinct on the Austral Islands and palm forest decline appears to correspond to the establishment and expansion of introduced tuber and tree crops. The chronology of these extinctions and introductions
established from the examination of microfossil remains from sedimentary deposits on Rapa and Rimatara are generally synchronous. I suggest that changes in land-use following European contact directed the final extinction of some plant species including the Iguanurinae type palm on Rimatara. With the resolution of chronological evidence for the Austral Islands, particularly from palaeobotanical evidence, I suggest that most plant extinctions either occurred at the onset of human colonization or were delayed until after European contact.
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<td>Additional palynomorphs recorded from Tukou Cores 2-6 not recorded in Core 1</td>
<td></td>
</tr>
<tr>
<td>7.6</td>
<td>Palynomorphs from Rapa of introduced taxa</td>
<td></td>
</tr>
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<td>7.7</td>
<td>Sedimentation rates (cm/yr) based on linear age/depth interpolations (cal. yr B.P.) for each core from Tukou</td>
<td></td>
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<tr>
<td>7.8</td>
<td>Additional palynomorphs recorded from Maunutu not recorded in Core 1 Transect 1</td>
<td></td>
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<td>Palynomorphs of introduced taxa from Rimatara</td>
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<td>Theoretical plant categories (after Matthews, 1996)</td>
<td></td>
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<td>(Anacardiaceae to Malvaceae) Botanical source list of pre-contact introduced or indigenous trees and shrubs</td>
<td></td>
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<td>(Moraceae to Urticaceae) Botanical source list of pre-contact</td>
<td></td>
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<td>8.3</td>
<td>Botanical sources of probable herb introductions to the Austral Islands</td>
<td></td>
</tr>
<tr>
<td>8.4</td>
<td>Botanical sources of probable inadvertent plant introductions to the Austral Islands</td>
<td></td>
</tr>
</tbody>
</table>
Preface

Since the 18th century European explorations of the remote Pacific, oceanic islands have been integral for developing an understanding of the evolutionary history of floras and of phytogeographic patterns. They have also been integral to understanding how humans have impacted on environments, a major subject of archaeological and palaeoenvironmental research. Linking these two research areas is the causal relationship between human colonisation of islands and the concurrent introduction and/or extinction of plant species. Plants or animals may have been transported from one island to another for a variety of reasons, whether as items of social or economic importance, or as unintended stowaways. On colonised islands, some taxa may have become extinct or extirpated in response to human exploitation, or may have eventually been displaced by other introduced taxa once established.

Defining the course of events that led to the establishment and proliferation of human-translocated plant species or the extinction of indigenous plant species is by no means straightforward. There are geographical and historical biases that for many plant species render the relationship between the geographic distribution of plants and human colonisation untenable, particularly in relation to the downstream effects of human-generated disturbances. Just as some introduced taxa may become naturalised on islands after an interval, some indigenous taxa may decline or face extinction on their own accord in response to other environmental factors that take effect independently of human activity.

For the oceanic regions of the Pacific, changing ideas of 'natural' plant dispersal mechanisms and the role humans have played in translocating plants have influenced interpretations of phytogeographic patterns. The discoveries of rich archaeobotanical deposits as well as the development of additional techniques for identifying plants including phytolith and starch grain analysis have highlighted the potential antiquity and diversity of plant utility and agricultural production across the region. Molecular biology has provided phylogeographic information outlining the genetic lineages and probable movements of plants across the island. Also important is the growing body of palaeobotanical research that has provided an additional chronological framework for human impact on island environments and enabled the processes that may have led to plant extinctions to be inferred.

In this thesis an attempt is made to define the geographical and historical biases which define the flora of the Austral Islands in the southernmost part of French Polynesia in the central Pacific Ocean (Figure 1.1). These islands are distributed across the Tropic of Capricorn (23.5° S) along a marked tropical to subtropical climatic gradient. This gradient has some bearing on island type (atolls, makatea or high islands), size, topography, age and varying plant diversity. The
phytogeography of the Austral Islands, in particular, is of interest for their contrasting tropical and subtropical affinities but also their remoteness from other archipelagos.

Remoteness is another key factor that has influenced human colonisation of the Austral Islands. These islands are remote in that they are located ~600 km south of the Society Islands to the north and ~1400 km to the west of Easter Island (Chile), the most remote inhabited island of the Pacific. Although not in an equivalent remote position to Easter Island, inter-island contact and exchange between the Austral Islands society and other archipelagos prior to European contact may have been similar.

In Chapter 1 I outline how these islands provide an interesting case for assessing species translocation and extinction processes since human colonisation. I firstly outline the historic context for European colonisation of the islands and the historical relationships between the Austral Islands understood at first European contact. I then discuss Remote Oceania, the cultural and biological geographical sub-division of the oceanic Pacific to which the Austral Islands are aligned. I then broadly outline the modern phytogeography and cultural geography of the Austral Islands as established from the respective botanical survey and ethnographic data. I then provide an overview of archaeological and palaeoenvironmental research conducted on the Austral Islands in the context of Remote Oceania.

In Chapter 2 the characteristic interests that have privileged islands as exemplary locations for biological and anthropological interests are addressed in an historical overview. I question the notion of island insularity as defined by island isolation and size, as established in biogeographic theory as an essential feature of island environments. I see the lack of incorporation of disturbance and especially human disturbance in biogeography, specifically phytogeography, as a major discrepancy. I then expand on Chapter 1 by examining the cultural history and phytogeographic context of what I have termed Oceanic Island Remote Oceania. I specifically focus on the methodologies employed to characterise the disturbances associated with human colonisation of islands that maybe concurrent with the introduction and/or extinction of plant species of plants.

In Chapter 3 I outline what has been popularised as the ‘orthodox’ view of the relationship between island environments and human colonisation in Remote Oceania, exemplified by Jared Diamond (2005) in his book Collapse, how societies choose to fail or survive. I suggest that Diamond establishes Easter Island in the east Pacific and the Western Pacific island of Tikopia (see Figure 1.1) as two model systems that reflect the extremes of the human influence on phytogeographic patterning. There are two bodies of information that are fundamental to this relationship which have been distorted by geographical and historical biases in both ecological and archaeological studies of remote islands. Firstly, there is an apparent spatial discrepancy in the evidence that sets the ‘natural’ dispersal mechanisms and distribution of plants against the role that humans have played in plant translocation. Secondly, there is an assumed temporal discrepancy in
the response of island floras to 'novel' disturbances arising with the initial human colonisation of islands.

I then discuss the process of human colonisation as established in Diamond's interpretation of Pacific Island environmental history and archaeology. I argue that this interpretation rests in the assumption that geographic isolation is equivalent to social and historical isolation. By contrast, the Austral Islands have been equivalently or even more isolated from human influence than is reflected in their geographical isolation. From radiocarbon determinations of archaeological material, the earliest human colonisation of the Austral Islands may have taken place at a similar time to Easter Island. 18th century European contact, however, did not begin until 1769 when James Cook located Runutu, 52 years after Jacob Roggeveen sighted Easter Island, whereas it was not until 1812, 95 years after first contact at Easter Island, that Rimatara was recorded by any European. First European landfall on any of the Austral Islands did not take place until 1789 with the arrival of the HMS Bounty mutineers on Tubuai. More 19th century accounts of exploitation by beachcombers are available for Easter Island than for the collective Austral Islands.

In examining the influence of geographical and historical bias, the Annales historian, Fernand Braudel stressed the limitations on preservation of historical evidence with time and under certain geographical conditions. He emphasised a structural approach to history that explores the interaction of multiple lines of evidence along different temporal trajectories (longue durée, conjoncture and histoire événementielle). Braudel attempted to objectively pullout historical bias from different bodies of historical observations by defining each temporal trajectory with historical processes or events that have a specific duration. In this thesis, I utilise Braudel's structural approach to history in exploring the relationship between the process of human colonisation and phytogeographic patterning on the oceanic islands of the remote Pacific. I transpose Braudel's historical structure, more focused on modern Western history, to incorporate geological and archaeological time depths and temporal structures.

The inherent unevenness and diachrony in island histories appears to have necessitated such conceptions, a problem that has been recognised in a range of anthropological and historical theory emphasised in the Annales historical method. This is addressed further for Easter Island and Tikopia in Chapter 4. These islands have formed part of an island-laboratory perspective employed by Diamond (2005) in Collapse. The utility of botanical sources in the prevailing 'orthodox' perspectives upon these islands, implicit in Diamond's précis, is countered by a diachronic approach to history, exploring the range of botanical sources in structural detail. I examine the relationship between what are regarded as human introductions or human-induced extinction of plants on these islands. I suggest that much of the discussion of human-induced environmental degradation on Easter Island is bound in the interpretation of the processes that led to the extinction of the palm Paschalococcus disperta. As a counterpoint, the utilisation and potential introduction of
the arboricultural crop *Canarium harveyi* to Tikopia is bound in the idea that the success of this crop reflects the success of Tikopian society.

The potential for divergent opinions to develop within this overlap of methodological approaches is illustrated in the conflicting interpretations surrounding the historical, archaeobotanical and palaeobotanical evidence for an extinct palm (*cf.* *Paschalococcus disperta*) on Easter Island (Chile). The cause and timing of palm decline and eventual extinction is unclear. Palaeobotanical evidence suggests that palm representation in pollen records has fluctuated over at least the last 20,000 years and declined or disappeared within the last 2000 years. Archaeobotanical records reveal the use of palm fruits throughout radiocarbon-based human settlement period. Equivocal historical accounts of palms within the island's flora suggest that the tree may still have been present on the island in the 1860's. In recent syntheses there are two extreme interpretations, one that stresses the primary role of human agency in palm extinction, whereas at the other, climate change is seen as the main mechanism for palm decline.

The debate on the role of human agency in plant translocation or extinction goes to the heart of the problem created by the persistent dichotomy established between the 'natural' or 'wild' and the 'cultural' or 'human' relationship with plants. I suggest that the way time is conceptualised and interpreted through botanical sources is part of the same theoretical paradigm. Human agency also presents a problem for historically oriented disciplines where only fragments of information are available for analyses. For botanical research on islands, there has been a preoccupation with the indigenous (natural) status of plants, in which autonomous inter-island dispersal ability of plant propagules, although poorly defined, is accepted *a priori* as a feature of indigeneity. Outside of natural dispersal, plants are then presumed to be 'cultural' or human introductions.

Given the recent colonisation of the Pacific compared to the adjacent continents (e.g. Australia and New Guinea), anything that is perceived as cultural, in this view, must therefore be unequivocally young. In palaeobotanical research, a cultural environment is identifiable only after the temporal and spatial outline of an exclusive and pre-existing 'natural' environment is defined. In this way human activity must assume some form of unprecedented botanical change. In both research contexts, plants are envisaged outside of their potential biological and ecological responses. The idea that plants may have responded to both natural and cultural influences under a completely different impetus in the past is rarely discussed, but is pivotal for this thesis. The reliance on modern analogy, which assumes that comparative patterns in space can be used to understand changes in time, entrenches the paradigm embedded in the nature-culture dichotomy, by assuming that human perturbations on island environments must be not only relatively recent but also unprecedented. It should be recognised, however, that environmental history is filled with unprecedented change, and that human-induced change and environmental caused change are not mutually exclusive. I suggest that these points are wholly neglected in many of the macro-historical descriptions of islands without synchronicity, old or young, natural or cultural.
Using the diachronic framework alluded to by Braudel I explore the various structural components of Austral Island botanical history. In Chapter 5 accounts of Austral Island botany from the period between the eighteenth century European explorations of the islands through to the establishment of Christian mission stations are compiled with reference to the historically recognised human impacts on these island environments (e.g. sandalwood harvest, exotic faunal introductions etc.).

In Chapter 6 these historical accounts are placed in a longer-term view of botanical sources revealed in a palaeobotanical synthesis of the Austral Islands. The Tertiary geological origins of the Austral Islands are discussed in relation to the origin and antiquity of their floras. Molecular phylogenies of a number of plant lineages are presented in order to highlight the genetic routes of dispersal and their inferred timing set on the basis of island orogeny. The pronounced response of vegetation to long-term geological processes and sea-level change since the Tertiary is exhibited in more detail in Holocene-aged palaeoenvironmental records from Rapa and Rimatara. Within these records a series of late Holocene human settlement sequences are presented in Chapter 7, where I outline the conjuncture between the archaeological and palaeobotanical treatments. Human impact is discussed in relation to the archaeological synthesis provided for Rapa. Archaeobotanical material from the rockshelter excavations on Rapa is discussed and provides both an archaeological determination of the timing of human presence and supporting information on the botanical status of particular plant taxa.

In Chapter 8 information obtained from botanical sources for the Austral Islands are synthesised and then discussed in relation to the most critical environmental changes, particularly the adjustments that take place with human colonisation. The chronology of these critical changes is then placed in the context of the plant introduction and extinction models proposed for Easter Island, Tikopia and for other islands within Remote Oceania.

In conclusion I suggest that much of the orthodox model is misled by an historical legacy of speculation centred on loosely framed temporal and spatial botanical data. In reviewing these botanical and spatial data, particularly in relation to human-generated disturbances, I suggest that any model can only be robustly defined at particular points in time and in specific geographical settings. For many islands the relationship between human colonisation and phytogeographical patterns may remain ‘insoluble’, rarely defined in any robust way.
Figure 1.1 Map of the Pacific Ocean (from http://www.sopac.org/) with sites referred to in the text. The outline for Near and Remote Oceania and the continental/oceanic geological affinity defined by the Andesite Line are also shown (after Green, 1991). The lower map outlines the position of all of the islands within the Austral Islands.
Chapter 1
The Austral Islands

The Austral Islands consist of five populated islands namely Rapa, Ra'ivavae, Tubuai, Rurutu and Rimatara, and two smaller, outlying, uninhabited islands. The islands are known locally as the Tuhae Pae and span approximately 1200 km in a northwest-southeast direction from 27 to 21° S, crossing the Tropic of Capricorn (see Figure 1.1). The northern most outlying group is Maria or Hull consisting of two atolls less than 1 km² in area, positioned ~250 km northwest of Rimatara. The Austral Islanders use these atolls as seasonal refuges during fishing expeditions. Marotiri or Bass Rocks are a group of low lying volcanic islands less than 1 km² in area that consists of 10 sub-aerial peaks and are situated around 90 km east-southeast of Rapa (St. John, 1982). It is only occasionally visited by local fisherman and can be seen from Rapa on a clear day. Rapa, Ra’ivavae and Tubuai are between 9 and 45 km² in area and can all be described geographically as high basaltic islands (Nunn, 1994). Rimatara and Rurutu are also high islands but have been geologically defined as ‘makatea’ islands (Wood and Hay, 1970), a term that comes from the Cook Island word referring to the rugged, forested limestone areas of their islands.

The islands are separated by a distance of ~600 km from Tahiti in the Society Islands, the political centre of French Polynesia. In 1996 a population census of the Austral Islands recorded 6,500 inhabitants with a majority identifying themselves as of Polynesian/Pacific Island descent (Law, 2003-2005). The official languages spoken are French and Tahitian with the local Polynesian lexicons largely subsumed under Tahitian. The Austral Island economy is currently sustained by a small-scale fishing industry with some horticultural production and minor tourism. Many islanders are currently reliant on French government funded social security for income. Access to the islands has recently been developed to include commercial airline connections to all the populated islands except Rapa¹, where transport is restricted to bimonthly passenger and freight ships. Childhood education is limited on most of the islands with most students attending schools established in Tubuai with opportunities for higher education restricted to Tahiti.

Historical context for the Austral Islands post-European colonisation

The first European contact with the Austral Islands took place in 1769 at Rurutu with the HMS Endeavour under James Cook (see Table 1.1 for other first contact accounts). With the exception of Rimatara, the earliest contact in the Australs did not involve landfall. The HMS Bounty

¹It is expected that the current runway and airport development on Rimatara will be completed in 2006
mutineers under Fletcher Christian and James Morrison (in)famously landed for three months on Tubuai in 1789 (Morrison, 1931), representing the earliest European settlement of the island. Relatively late in the European contact chronology of the Pacific Islands was Rimatara where according to Maude and Crocombe (1962: 35) the beachcomber, Michael Foldger, on the brig *Daphne* was the first to make contact with the island in 1812, although earlier dates for this event or other first contact events have been cited (e.g. Guill, 2001). By that time all the inhabited islands of the Australs were noted as potential resource bases, trading posts and mission stations by the European colonial powers.

The size of populations at first European contact has remained a contentious but often critical subject to the cultural and environmental histories of islands (e.g. Bushnell, 1989). The population of the Austral Islands at first contact was probably equivalent to or greater than the contemporary population. George Vancouver (1803: 214-217) on the *HMS Discovery* estimated the population of Rapa at first contact in 1791 to be approximately 1500, around three times greater than the most recent census records.

<table>
<thead>
<tr>
<th>Island</th>
<th>Ship</th>
<th>Key observers</th>
<th>Name given</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rurutu</td>
<td><em>HMS Endeavour</em></td>
<td>James Cook, Joseph Banks, Daniel Solander</td>
<td><em>Ohoteroa</em></td>
<td>1769</td>
</tr>
<tr>
<td>Ra‘ivavae</td>
<td><em>Agulla, Jupiter</em></td>
<td>Tomás Gayangos</td>
<td><em>Santa Rosa</em></td>
<td>1775</td>
</tr>
<tr>
<td>Tubuai</td>
<td><em>HMS Resolution</em></td>
<td>James Cook, J ohanne Reynold Forster, Georg Forster</td>
<td><em>Toobouai</em></td>
<td>1777</td>
</tr>
<tr>
<td>Rapa</td>
<td><em>HMS Discovery</em></td>
<td>George Vancouver, Archibald Menzies</td>
<td><em>Oparo</em></td>
<td>1791</td>
</tr>
<tr>
<td>Rimatara</td>
<td><em>Endeavour</em></td>
<td>LMS Missionaries Rev. Lancelot Threlkeld and Rev. John Orsmond with Captaln Thomas Henry</td>
<td><em>Rimatara</em></td>
<td>1822</td>
</tr>
<tr>
<td>Maria</td>
<td><em>Maria</em> whaling ship</td>
<td>Gardner</td>
<td><em>Maria</em></td>
<td>1824</td>
</tr>
</tbody>
</table>

**Table 1.1** List of first recorded European contacts with the Austral Islands (see Chapter 5).

The first mission station in the Australs was established on Ra‘ivavae in 1819 by a self-anointed Tahitian missionary named Para, but more often described as a ‘political agent’ (Ellis, 1931: 377). Para joined an expedition led by King Pomare II of Tahiti in his attempt to gain political alliances in the region during a period of negotiated colonial rivalries between the French and British. It was not until 1822 when the first Christian mission stations under the auspices of the LMS were established on Tubuai, Rurutu and Rimatara (see Table 1.2). More precise estimates of congregation sizes given in the initial years of missionary contact indicate a marked decline in population of at least one half since first European contact. Such demographic changes appear to be the norm for many Pacific islands (Moorehead, 1966; MacArthur, 1968; Maude,
either as a function of poor first contact estimates or other causes including endemic warfare, “blackbirding”, introduced disease, and inter-island migration (see Chapter 5).

Between the first European contact and mission station establishment a number of critical events for the environmental history of the Austral Islands and more specifically for vegetation change occurred. During the early 1800s ‘beachcombers’ employed by trading companies largely based out of Sydney, Australia, harvested large quantities of the indigenous varieties of sandalwood (e.g. *Santalum insulare* var. *margaretae*) from the islands and other parts of the Pacific (Shineberg, 1967; Maude and Crocombe, 1981). Bèche de mer (dried *Holothuriodea*) were usually harvested during the same expeditions and required prolonged smoking utilising significant quantities of scarce firewood. A number of exotic animals including pigs and goats were probably introduced prior to the 1820s possibly as trade items for people or sandalwood (Maude, 1968a). The best record for such introductions to the Austral Islands comes from the 1789 HMS Bounty mutineer settlement on Tubuai depicted in Morrison’s (1935) account. Close to 460 pigs, 50 goats, chickens, dogs, cats and a solitary cow were introduced to the island during the mutineers’ three month long encampment. Such animal introductions represent an immediate but poorly documented historical impact on these island environments.

All of the Austral Islands were annexed by France before 1901 and now form part of the Territories of Polynésie française. A more detailed synopsis of the historical introductions and environmental disturbances for the Austral Islands up to 1825 is provided in Chapter 5. More detail on the social and political history of the Austral Islands since 1825 has been provided elsewhere (e.g. Danielsson and Danielsson, 1977; Toullelon, 1991; Guillin, 2001).

### The cultural geography and biogeographic context

The Austral Islands are positioned within a broad cultural and biogeographical affinity described as Remote Oceania (Green, 1991 see *Figure 1.1*). This includes the regions of ‘ethnicity’ commonly recognised as Polynesia and Island Melanesia. Based on an earlier linguistic and ethnological analysis (e.g. Pawley and Green, 1973), Green distinguishes between Near Oceania and Remote Oceania, representing to some degree a return to the ethnological and linguistic-based geography alluded to in J.R. Forster’s (1778) early geographic synthesis of the Polynesian Pacific. The boundary between Near and Remote Oceania lies to the west of the Temotu Province (e.g. Tikopia) of the Solomon Islands where Remote Oceania is characterised by decreasing intervisibility between islands with a separation of at least 350 km of ocean (Green, 1991, see *Figure 1.1*). Green also distinguishes between continental and oceanic island Remote Oceania (here termed OIRO) based on the Andesite line (*Figure 1.1*). The continental andesitic crust to the west of this line has a high SiAl ratio whereas the basaltic crust to the east is characterised by a high
SiMg. In reference to the plant geography of the oceanic islands of Remote Oceania, he suggests that east of Fiji, lowland rainforests were largely absent and annual herbs rare prior to the arrival of people. These oceanic islands tend to be smaller and possess a more attenuated biology with a predominantly Indo-Malayan and Near Oceania floral and faunal affinity, with minor South American elements (e.g. van Balgooy, 1971; Mueller-dombois and Fosberg, 1998).

<table>
<thead>
<tr>
<th>Island</th>
<th>Missionaries</th>
<th>Date of mission arrival</th>
<th>Congregation size</th>
<th>Date of first contact</th>
<th>Population at first contact</th>
<th>Years between first contact and mission</th>
<th>References (see primary sources for Chapter 5, Appendix 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tubuai</td>
<td>LMS missionary Rev. Henry Nott, Hapunia and Samuela from Tahiti</td>
<td>1822 600-800</td>
<td>1777</td>
<td>~2000</td>
<td>45</td>
<td></td>
<td>Ellis (1831-385-386), Morrison (1966: ?)</td>
</tr>
<tr>
<td>Rapa</td>
<td>Hota and Nene from Tahiti</td>
<td>1826 Jan</td>
<td>~500</td>
<td>1791</td>
<td>~1500</td>
<td>35</td>
<td>Davies (1827: 331), Ellis (1829: 47)</td>
</tr>
<tr>
<td>Rimatara</td>
<td>Two missionaries from Ra’iataa, Faarova and Oo (Borabora)</td>
<td>1823 200-300</td>
<td>1822</td>
<td>~1200</td>
<td>1</td>
<td></td>
<td>Davies (1961: 284-285), Ellis (1831-389-390)</td>
</tr>
</tbody>
</table>

Table 1.2 List of first mission stations established in the Austral Islands, French Polynesia

Oceanic Island Remote Oceania (OIRO) has also been described on the basis of oceanic isolation as a biogeographic barrier with island age as an additional determining factor. In this sense, an expanse of ocean beyond inter-island visibility is seen as a biogeographic filter for entities that lack long-distance dispersal capabilities, but also as a cultural marker distinguishing the voyaging capabilities of ancestral Pacific islanders who began occupying the region during the late Holocene. Green (1991) further distinguishes between oceanic island and continental Remote Oceania purely on geological criteria (as above). OIRO can be defined by the variety of physiographic island types (e.g. high islands, makatea, atolls), age (Miocene <100 Ma in age) and disconnection and distance from the larger landmasses of New Caledonia and New Zealand in continental Remote Oceania. Many cultural and biogeographic sub-regions have been described within Green’s Remote Oceania where the Austral Islands have generally been placed at the southernmost end of the East or Central Polynesia culture regions and the eastern or south-eastern
Polynesia botanical sub-regions of Polynesia (e.g. Brown, 1931a; 1935; Thorne, 1963; van Balgooy, 1971; Takhtajan, 1986).

Biogeography is the study of geographical patterns of species distribution where it is assumed that environmental conditions may change predictably along spatial gradients and species will vary in response to these changes (Lomolino, 2000). Stoddart (1992) suggests that for the Pacific islands, the spatial contiguity of species distributions, inferred from species histories or ecologies, has been given priority over disjunct or discontinuous distribution patterns. It has almost become conventional to assume that regional biogeographic schemes such as those described above connote regional hierarchies but these fail to 'comprehend the discontinuous nature of biogeographic insular distributions' (ibid: 281). Stoddart proposed a non-hierarchical scheme based on atolls (or low coral islands), raised limestone islands (makatea) and high (basaltic) islands as areal units. Because of the diversity of island types, such a scheme is useful when examining the phytogeography of the Austral Islands.

Austral Island phytogeography

The indigenous angiosperm floras of atolls remain relatively depauperate and homogenous throughout their distribution and may be recognisable from the Indian Ocean to the east Pacific (Fosberg, 1984). According to Raymond Fosberg, Maria atoll in the Australs shows 'the original vegetation of any moderately wet atoll investigated anywhere' (in Mueller-Dombois and Fosberg, 1998: 401). Representatives of the genera *Scaevola* (Goodeniaceae), *Pemphis* (Lythraceae), *Suriana* (Surianaceae), *Timonius* and *Guettarda* (Rubiaceae) are common to Maria and most other Pacific atolls and reef islands. On Maria, Fosberg and St John (1951) recorded in 1934 a total vascular flora of 30 species and suggest that 24 of these are probably indigenous (see Table 1.3).

Stoddart (1975) has noted that where high species numbers are recorded for atolls, this simply represents invasion by exotic weeds or on inhabited atolls replacement of the indigenous vegetation by introduced taxa. The character of atoll floras has been demonstrated to respond directly to drought, and this is well reflected in the distribution of *Cocos nucifera* (Areaceae) which remains unviable in areas or years with less than 1000 mm annual rainfall (Fosberg, 1956 in Stoddart, 1992). More generally the phytogeography of atoll floras is poorly reflected by atoll size or the long distance dispersal mechanisms of the representative species (Stoddart, 1992). It is expected that future botanical surveys of Maria will reveal a considerable increase in invasive and introduced species (Jean-Yves Meyer pers. comm. 2004).
<table>
<thead>
<tr>
<th>Islands</th>
<th>Indigenous vascular plant species</th>
<th>Endemic vascular plant species (%) endemicism</th>
<th>Indigenous angiosperm species</th>
<th>Endemic angiosperm species (%) endemicism</th>
<th>Naturalised exotic plant species (IS)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marotiri</td>
<td>12</td>
<td>1 (8%)</td>
<td>10</td>
<td>1 (10%)</td>
<td>2 (6)</td>
<td>Fosberg and St. John (m.s.)</td>
</tr>
<tr>
<td>Rapa</td>
<td>212</td>
<td>79 (37%)</td>
<td>136</td>
<td>61 (45%)</td>
<td>?</td>
<td>Meyer (2002a), Meyer (2002b)</td>
</tr>
<tr>
<td>Ra'ivavae</td>
<td>147</td>
<td>43 (29%)</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>Meyer (2002b)</td>
</tr>
<tr>
<td>Rurutu</td>
<td>126</td>
<td>17 (13%)</td>
<td>?</td>
<td>157 (0.80)</td>
<td>?</td>
<td>Florence (1993), Meyer et al. (2003), Meyer et al. (2004)</td>
</tr>
<tr>
<td>Rimatara</td>
<td>80</td>
<td>9 (11%)</td>
<td>63</td>
<td>178 (0.45)</td>
<td>?</td>
<td>Meyer (2002a), Meyer et al. (2003), Meyer et al. (2004)</td>
</tr>
<tr>
<td>Maria</td>
<td>26</td>
<td>0 (0%)</td>
<td>21</td>
<td>4 (8)</td>
<td>?</td>
<td>Fosberg and St John (m.s.; 1951)</td>
</tr>
</tbody>
</table>

Table I.3 Floral diversity and endemism for the Austral Islands. IS (index of secondarisation) = number of primary flora (indigenous plant species)/number of secondary flora (naturalized exotic plant species). \( ? \) = data currently unavailable.

Makatea islands consist, in geological terms, of an uplifted carbonate platform that either forms the greater part of the island (Wood and Hay, 1970), or where an annular limestone plateau surrounds a degraded volcanic bedrock core (Dickinson, 2001). Islands that fall strictly under the later definition are concentrated within the Cook Islands (Atiu, Mitiaro, Mauke, and Mangaia) and the Austral Islands in French Polynesia (Rimatara and Rurutu). The limestone area (% of total area of the islands) and emergence above modern sea level of the makatea is variable (23% and 11 m for Rimatara and 11% and 115 m for Rurutu; after Dickinson, 1998). Stoddart (1992) broadens this definition to include all raised reef limestone islands that lack the central volcanic bedrock core including, for example, Niue (New Zealand), Makatea (French Polynesia), Eua (Tonga) and Henderson in the Pitcairn Group (Britain). Many islands within continental Remote Oceania and Near Oceania also fit this definition. The destruction of many makatea by industrial phosphate mining (e.g. Nauru, Banaba, Marcus and Angaur) has limited phytogeographic reconstruction and comparative analyses (ibid). Recent botanical surveys of the rugged limestone makatea (locally called matô) on Rurutu (Meyer et al 2003) and Rimatara (Meyer et al 2004) has revealed a higher concentration of indigenous vascular species on these substrates in comparison to the volcanic soils and other substrates also present on the islands. Many genera found on the

\^This comes from the Cook Island Polynesian word for limestone outcrops. Makatea islands are discussed further in Chapter 6.
mato are common to Pacific atolls, but in some cases are represented by more species (e.g. *Canavalia, Hernandia* and *Peperomia*). The habitat heterogeneity on the mato surface is also thought to restrict the extent of exotic species invasion (Meyer et al. 2004), but is also likely to reflect the relative lack of agricultural disturbance.

The high Austral Islands (all the islands except Maria) are remnant late Miocene/Pliocene-aged volcanoes, the youngest of which (Marotiri, 3.75 ma) is deeply incised and the oldest (Rimatara and Maria have a tentative maximum K/Ar age of ~27-28 ma; Cloudard and Bonneville, 2001; Bonneville, 2002) deeply weathered and eroded (see Chapter 6 for discussion. The makatea islands of Rurutu and Rimatara are deeply weathered high islands that have been uplifted leaving a coral limestone periphery. Marotiri is mostly treeless but on the few gentle higher slopes a cover of shrubs and herbs can be found including the endemic species *Bidens saint-johnii* Sherff (St John, 1982; Mueller-Dombois and Fosberg, 1998: 402) and *Chamaesyce sparrmanii* (Boissier) Hurusawa ex Lin et al. (Florence, 1997: 51). On the lower slopes are a number of indigenous angiosperm taxa common to other high islands such as *Portulaca lutea* Solander ex Seemann (Florence, 2004: 344-346) and *Lycium carolinense* var. *sandwicense* (Mueller-Dombois and Fosberg, 1998: 402; see Chapter 8).

The remaining high islands, including the makatea islands, typically have a more highly diverse indigenous angiosperm flora that is essentially an attenuation of the Indo-Pacific and Malesian floras. Families with representative genera of this attenuation include Asteraceae (e.g. *Apostates, Bidens, Fitchia* and *Oparanthus*), Euphorbiaceae (e.g. *Acalypha, Chamaesyce, Claxylon, Glochidion, Macaranga*, and *Phyllanthus*), Rubiaceae (e.g. *Canthium, Coprosma, Cyclophyllum, Hedyotis* and *Psychotria*), Fabaceae (e.g. *Canavalia, Mucuna, Sophora* and *Vigna*), Myrsinaceae (*Myrsine* and *Rapanea*), Orchidaceae (e.g. *Oberonia*) and Urticaceae (e.g. *Boehmeria, Pilea, Pipturus* and *Prociris*).

American components within the Austral Island flora are rare although on Rapa, two endemic *Plantago* species (*P. rapensis, P. rupicola*) are more closely related to a Hawaiian species derived from an American lineage (Tim Motley pers. comm. 2005). Rapa is unique in having a strong floral affinity with New Zealand including representatives of the genera *Hebe* (Schrophulariaceae), *Olearia* (Asteraceae) and *Corokia* (Corokiacaeae). The Austral Islands also contain some ‘Old Pacific’ elements (Fosberg, 1984) that possess a disjunct distribution with no clear geographical origins (e.g. *Meryta, Abutilon* and *Apetalidia*). Most of the indigenous and endemic components of these islands seem to have remained relatively undisturbed by human impacts due to the inaccessible montane or makatea geography.

Florence (2003) has examined the propagule dispersal characteristics of the indigenous Austral Island flora (see Table 1.4) concluding that most taxa are wind dispersed (47%; anemochory) with a large proportion actively or passively dispersed by birds (37%). Both dispersal mechanisms attest to the long-distance dispersal abilities of the majority of taxa on these
islands. These data suggest that the most likely source area for plant propagules are the other tropical islands to the north and northwest, given that the northern tropical affinity of bird populations on the Austral Islands and the prevailing wind direction is from the northwest.

<table>
<thead>
<tr>
<th>Dispersal type</th>
<th>Indigenous vascular plant species</th>
<th>Percentage of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anemochory</td>
<td>145</td>
<td>47</td>
</tr>
<tr>
<td>Hydrochory</td>
<td>32</td>
<td>10</td>
</tr>
<tr>
<td>Active zoochory</td>
<td>83</td>
<td>27</td>
</tr>
<tr>
<td>Passive zoochory</td>
<td>31</td>
<td>10</td>
</tr>
<tr>
<td>Autochory</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Indeterminate</td>
<td>17</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>310</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Table 1.4 Dispersal modes of indigenous vascular plant species of the Austral Islands (after Florence, 2003: 132).

Archaeological and ethnographic context

The timing of first human colonisation of Remote Oceania is a contentious archaeological subject with various proponents backing different colonisation models and dispersal hypotheses. If it is accepted that it is the archaeological sites which contain faunal remains of taxa vulnerable to extinction that generally disclose the earliest radiocarbon dates for island colonisation, then an entry date of around 3,000 yr B.P. can be proposed for the western Remote Oceania (e.g. Fiji) generally (Anderson and Clark, 1999; Burley et al. 2001). Similar ages have been obtained from sites on Tonga (Burley et al. 2001) all possessing ceramic (Lapita) or other artefacts sourced and introduced within the earliest archaeological settlement period.

Based on evidence from the aceramic sites further east, a later date of around 1100 yr B.P. for colonisation has been proposed (Anderson, 1995; 1996; 2003b; Anderson and Sinoto, 2002). This punctuated model rests on a corpus of radiocarbon results gathered in the region over the last 15 years. Changes in the colonisation chronology for the Marquesas from around 2000 yr to 900 yr B.P. (Ottino, 1985; 1991; Leach et al. 1997; Anderson and Sinoto, 2002) provides one example of the effects of increased sampling in the construction of absolute chronologies. However, it has been suggested that the ‘aceramic’ islands of Remote Oceania may also demonstrate a sampling deficiency given the absence of the high visibility ceramic markers (Kirch and Hunt, 1988).

Peter Buck (1927) asserted in his ethnography of Aitutaki in the Cook Islands that the Society, Austral, and Cook Islands formed a common cultural affinity. Linguistics tends to support this evidence suggesting that the Austral Islands were settled from the Cook Islands, the Society Islands and the Marquesas based on Proto-Polynesian language reconstructions of a relatively poor lexicographic database (Pawley and Green, 1973; Pawley and Ross, 1993; Fischer.

3Throughout this thesis where possible radiocarbon ages are presented as re-calibrated age ranges determined using the calibration program OxCal version 3.9 (Bronk Ramsey, 2001). All ages are presented as 2σ 95% interval age ranges.
Researchers based at the B.P. Bishop Museum, Honolulu, like Buck, developed on this ethnographic analysis for Tubuai (Aitken, 1930) and Rurutu (Seabrook m.s. and later by Vérin, 1969) with a series of unpublished theses held at the Bishop by John F.G. Stokes (n.d.a; n.d.b) on Rapa (see Hanson, 1970), Ra'ivavae and Rimatara that were compiled during the 1920s and 30s.

Because of this potential cultural affinity it is useful to characterise the archaeological and palaeoenvironmental record of the Cook Islands for comparison. Bellwood (1978) suggested on the basis of a preliminary archaeological survey of the Cook Islands that these groups of islands were colonized by around 1000 yr B.P finding evidence of occupation on Rarotonga at the Ngati Tiare site as early as 730-530 cal. yr B.P (No lab number available). The earliest accepted radiocarbon age ranges on archaeological charcoal (cf. Spriggs and Anderson, 1993) are from Rakahanga at 1180-760 cal. yr B.P (Lab no. N-5874, Chikamori and Yoshida, 1988) and Aitutaki at 1170-760 cal. yr B.P (Ureia; Lab no. Beta-25250, Allen and Steadman, 1990; Allen, 1994).

Excavation undertaken in the Tangatatau Rockshelter on Mangaia by Kirch et al (1995) provided the earliest archaeological radiocarbon ages for the island at 1060-730 cal. yr B.P. (Lab no. Beta-32826). This excavation also revealed the most extensive stratified sequences of artefacts, faunal and botanical remains found in the Cook-Austral region. The rich assemblage of botanical remains is significant in that few excavations in the Pacific region have yielded such deposits. It also provides a useful comparison for the Tangarutu excavation from Rapa in the Australs discussed below.

Chronological inconsistencies within and between the designated stratigraphic zones, has meant that there is considerable overlap between the youngest and oldest sections when comparing the calibrated radiocarbon age ranges. The material selected for radiocarbon dating was in most cases a mixture of unidentified wood charcoal, carbonised *Aleurites moluccana* endocarps and *Pandanus* keys. The potential for inbuilt ages of wood charcoal could be considerable for some species and may be enough to create a significant age bias of many hundreds of years. This would be enough to explain, for example, the age difference between the youngest calibrated age of the basal stratigraphic zones (e.g. Lab no. Beta 52931, 660-510 cal. yr B.P.) and the oldest age of the overlying zones (e.g. Lab no. Beta 52934, 970-730 cal. yr B.P.). Aside from these constraints, which apply in part to any excavation in Remote Oceania, there appears to be considerable site disturbance and potential reworking of sediments in a large ‘soft disturbed zone’ overlying three excavation units and separating a number of stratigraphic zones (*ibid*: 51-53).

In the most recent account of the Tangatatau excavation, Kirch (1996) has noted the extinction or extirpation\(^4\) of thirteen terrestrial bird species represented exclusively in the oldest stratigraphic zones. Such ‘extinction chronologies’ have been documented for many islands

\(^4\)Steadman (1995: 1123) defines extinction as the ‘global loss of a species’ and extirpation as the ‘loss of a species from an island or region, with one or more populations surviving elsewhere’.
within Remote Oceania and this has been discussed at length elsewhere (see Steadman, 1995; Anderson, 2001; 2002). Extinct or extirpated terrestrial birds from Mangaia include examples of rails (Gallirallus, Porzana), pigeons (Ducula), doves (Gallicolumba and Ptilinopus), parrots (Vini), and passerines. These birds tend to sustain more species-level extinctions due to their higher rates of endemism on islands as opposed to sea birds that readily disperse between islands (Steadman, 1995). Martin and Steadman (1999) suggest that the rugged makatea terrain on Mangaia may have provided forest refuges for many terrestrial bird species allowing them to survive for a prolonged period after human arrival.

Anderson (2002) has argued that such claims are based on poorly constrained palaeoenvironmental evidence (see below) that Kirch and Ellison (1994 see below) suggest provide an additional 1000 years of human occupation preceding the archaeological chronology. Anderson instead suggests that for most islands, especially those in the sub-tropics, extinctions occurred rapidly, early and independently of human population density where even small groups of people could decimate vulnerable taxa.

The distribution and representation of the commensal Pacific rat (Rattus exulans) in the archaeological record is unequivocally related to human dispersal. This same interpretation applies to the archaeological evidence from Mangaia (Kirch et al. 1995). Evidence for the introduction of domesticated fauna including jungle fowl (Gallus gallus), pig (Sus scrofa) and dog (Canis familiaris) are generally discontinuous in archaeological records across island Remote Oceania. Remains of jungle fowl and dog are preserved throughout the Tangatatau sequence but in larger quantities in the younger sections. Pig bone is frequent in the older sections of the Tangatatau sequence but scarce or absent in many of the younger sections. Jungle fowl and dog are generally regarded as household scavengers and may have never been present in large numbers (Ball, 1933; Cassells, 1984). Pigs were probably integrated into agricultural systems where husbandry was conducted by the feeding of such staples as Cocos nucifera, Artocarpus altilis and Ipomoea batatas (Yen, 1973; Kirch, 2000a). Kirch (2000a) suggests that assuming pigs were fed on vegetable productions a ‘trophic conversion’ may have taken place where the energy cost of pig husbandry became too expensive and was instead substituted by greater plant cropping for human consumption.

A diversity of introduced plant cultigen material is preserved throughout the Tangatatau sequence and it is detailed in Table 1.5. It is interesting to note that no corm or tuberous crop cultigens (Colocasia esculenta, Cyrtosperma merkusii (Syn. C. chamissonis) and Ipomoea batatas) are preserved in the younger sections of the sequence. The earliest presence of these cultigens coincides with the extinction chronology suggested for endemic avifaunal species. If ideas of rapid extinction can be extended to Mangaia then onset of agricultural activity, albeit

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5 Robert Bollt of the University of Hawaii has recently identified Pteropus cf. tongamus from a Last Interglacial cave deposit on Rurutu.
potentially small in scale, is likely to have coincided with the harvest of endemic species. Kirch et al (1995) instead apply a model of delayed extinction where the association of plant cultigen and extinct avifauna fits the notion of progressive agricultural development, an idea often advocated by Kirch in his other commentaries on island settlement strategies in pre-contact Remote Oceania. Kirch et al (1995) propose that the presence of the introduced freshwater mollusc _Thiara_ sp., thought to have been brought into the site adhered to crop corms, may provide a potential proxy for irrigated pondfields and canals. In his view the increasing abundance of this mollusc in the upper stratum of the sequence suggests agricultural intensification.

Given the depth of archaeological research undertaken in other areas of Remote Oceania such as the Cook Islands, it is surprising that the cultural and environmental history of the Austral Islands has been minimal. The oldest radiocarbon dates indicative of the earliest human occupation of the Austral Islands have been obtained from archaeological charcoal fragments. The first radiocarbon dating exercise undertaken on Austral Island material provided a tentative age of 960-660 cal. yr B.P. from charcoal fragments found at the Tuituiaoa excavation on Rurutu (Verin, 1969: 307; no lab number available).

The oldest date obtained from the Austral Islands comes from a piece of wood charcoal identified as _Tournefortia argentea_ (Rod Wallace, unpublished data) from the Atiahara excavation at Mataura on Tubuai, dated to 1300-650 cal. yr B.P. (Lab no. ANU 11599). Radiocarbon dates from unidentified charcoal excavated from the Tangarutu rockshelter on Rapa revealed a maximum age of 770-540 cal. yr B.P. (Lab no. ANU 11848). The Tangarutu sequence also represents the most extensive stratified sequences of artefacts, faunal and floral remains for the Austral Islands (see Chapter 7).

A comparative list of the presence or absence of excavated faunal and floral remains of taxa, commonly regarded as pre-contact introductions, for the Tangataatau and Tangarutu excavations is provided in Table 1.5. Jungle fowl and pig are not consistently represented throughout island Remote Oceania and this is reflected in the Mangaia and Rapa comparison. The only certain pre-contact faunal introduction to the Australs inferred from studies of other Pacific islands and confirmed from the archaeological record of Rapa are rat (_Rattus exulans_) and dog. Pig and jungle fowl may have been introduced to Rapa, but it is possible that they were not taken into any husbandry system due to the lack of sufficient staples such as _Cocos nucifera_ and _Artocarpus altilis_ (see Kirch, 2000a). A scenario of inadequate staple production was also proposed for Mangaia where pig and jungle fowl are absent in the upper zones of the Tangataatau sequence and were reported to be absent on the island at first contact (Gill, 1894: 125 in Kirch et al. 1995).

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6Articles covering the artefact and other faunal remains of the Tangarutu and other excavations on Rapa are currently in preparation.
### Introduced fauna

<table>
<thead>
<tr>
<th>Introduced fauna</th>
<th>Tangataua</th>
<th>Tangarutu</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Presence or absence</td>
<td>Timing of introduction</td>
</tr>
<tr>
<td>Canis familiaris (dog)</td>
<td>+</td>
<td>Continuous</td>
</tr>
<tr>
<td>Gallus galus (jungle fowl)</td>
<td>+</td>
<td>Continuous</td>
</tr>
<tr>
<td>Thiaras sp. [Melania sp.] (pondfield mollusc)</td>
<td>+</td>
<td>Continuous</td>
</tr>
<tr>
<td>Pteropus tongensis (fruit bat)</td>
<td>+</td>
<td>Early</td>
</tr>
<tr>
<td>Rattus exulans (rat)</td>
<td>+</td>
<td>Continuous</td>
</tr>
<tr>
<td>Skink or gecko</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Sus scrofa (pig)</td>
<td>+</td>
<td>Early</td>
</tr>
</tbody>
</table>

### Introduced flora

<table>
<thead>
<tr>
<th>Introduced flora</th>
<th>Tangataua</th>
<th>Tangarutu</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Presence or absence</td>
<td>Timing of introduction</td>
</tr>
<tr>
<td>Aleurites moluccana (Euphorbiaceae) endocarp, endosperm, wood charcoal</td>
<td>+</td>
<td>Continuous</td>
</tr>
<tr>
<td>Cocos nucifera (Areaceae), endocarp, husk, leaf, bracts, wood charcoal</td>
<td>+</td>
<td>Continuous</td>
</tr>
<tr>
<td>Colocasia esculenta (Araceae) corm</td>
<td>+</td>
<td>Early</td>
</tr>
<tr>
<td>Cordyline fruticosa (Laxmanniaceae) root, leaf</td>
<td>+</td>
<td>Continuous</td>
</tr>
<tr>
<td>Cyrtosperma merkusii (Araceae) corm</td>
<td>+</td>
<td>Early</td>
</tr>
<tr>
<td>Ipomoea batatas (Convolvulaceae)</td>
<td>+</td>
<td>Early</td>
</tr>
<tr>
<td>Inocarpus fagifera (Fabaceae) wood charcoal</td>
<td>+</td>
<td>Late</td>
</tr>
<tr>
<td>Lagernia sicera (Cucurbitaceae) exocarp</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Musa sp. (Musaceae) leaf</td>
<td>+</td>
<td>Early</td>
</tr>
<tr>
<td>Saccharum officinarum (Poaceae) stem</td>
<td>+</td>
<td>Early</td>
</tr>
<tr>
<td>Schizostachyum glauophyllum (Poaceae) stem</td>
<td>+</td>
<td>Early</td>
</tr>
<tr>
<td>Syzygium malaccense (Myrtaceae) wood charcoal</td>
<td>+</td>
<td>?</td>
</tr>
</tbody>
</table>

**Table 1.5** A comparative list of the pre-contact introduced fauna and flora recorded in the Tangataua (Mangaia, Cook Islands after Kirch et al 1995 and Kirch, 1996) and Tangarutu (Rapa, Austral Islands, French Polynesia) excavations (see Chapter 7 for further discussion). Kirch et al (1995) suggested this fruit bat may be a pre-contact introduction from Tonga but this comment is later retracted in Kirch (1996). A recent discovery of Pteropus bones from a pre-human aged deposit on Rurutu by Robert Bolt suggests that this taxon may be indigenous to the Cook and Austral Islands. + = data currently unavailable.

Of the introduced plant taxa represented in these rockshelter deposits (Table 1.5) *Aleurites moluccana* endocarps have been recorded in the highest abundance for any archaeobotanical material identified from the Tangarutu excavation on Rapa. Kirch et al. (1995) do not verify the amount of endocarp identified from the Tangataua excavation but suggest that it is abundant. From both the Tangataua and Tangarutu excavations *A. moluccana* endocarp or endosperm are represented throughout. In island Remote Oceania, this plant has been identified from several archaeological sites from the Hawaiian Islands (e.g. Māhā'ulepū, Kaua'i; Burney et al 2001;
Mauna Kea, Hawai’i; Allen, 1981), Mangareva (Weisler, 1996, Conte and Kirch, 2005), Henderson Island (Weisler, 1995) and Pitcairn Island (Weisler, 1996). The pre-European contact distribution and introduction of A. moluccana may have extended to as far as Raoul Island in the Kermadec Group (New Zealand), although this may have been an historic introduction. Due to the inherently low in-built age, radiocarbon dates from A. moluccana endocarp potentially provide the most reliable chronology not only for the timing of this probable introduction, but also for the Tangarutu sequence as it is represented throughout almost all of the stratigraphic units. The earliest date from A. moluccana endocarp has an age range of 950-300 cal. yr B.P. (Lab no. ANU 12102) approximate to the age range of that provided from a piece of unidentified charcoal from the lower most unit of the excavation (770-540 cal. yr B.P., Lab no. ANU 11848).

**Palaeobotanical context**

T.H. Streets (1877) first recognised the potential for palaeobotanical research for island Remote Oceania in locating a 1-1.5 m deep buried deposit of organic debris ‘composed of the roots, trunks, and debris of the cocoanut and pandanus trees’ on Washington Island in the Line Islands. Olof Selling (1948) initiated systematic Quaternary palynological research in the region with his analysis of pollen assemblages from high elevation bog deposits from Kaua‘i, Moloka‘i and west Maui also in the Hawaiian Islands. Some of these records were later radiocarbon dated to the late glacial-Holocene transition (Stuiver et al. 1965). Selling identified three major vegetation transitions that were contemporaneous across these records suggesting changes from mesic forest during the last glacial to wet forest in the Holocene (see Hotchkiss and Juvik, 1999).

The epistemological framework of palynological research has always been geared towards providing palaeoclimatic information. Lucy Cranwell’s first palynological examination of Quaternary sediments in the Pacific was undertaken under such research objectives (Cranwell and von Post, 1936). From the 1970’s onwards a number of palynologists began to recognise the problematic nature of pollen source areas for interpreting vegetation and climate change where only small enclosed sedimentary basins were deemed suitable for palaeoclimate research (e.g. Jacobson and Bradshaw, 1981). In island Remote Oceania these ‘ideal’ sites are limited in number and include the high elevation bogs and volcanic caldera lakes from the Hawaiian Islands (Selling, 1948; Waiau, Hawai‘i in Massey, 1979; Kau‘a, O‘ahu in Athens and Ward, 1993), the Galápagos Islands (Colinvaux and Schofield, 1976a; 1976b) and Easter Island (Flenley, 1979; Flenley and King, 1984; Flenley et al. 1991; Dumont et al. 1998; Mann et al. 2003). In 1961, Selling (in Heyerdahl and Ferdon, 1961: 12) published some preliminary results of palynological examinations of the Rano Raraku crater-lake sediments demonstrating that forest vegetation, including a palm, formerly occurred on the island. From the pollen morphology data and
biogeographic inference, the palm represented was originally believed to be *Pritchardia*, characteristic of the Hawaiian Island flora.

Flenley and King (1984) later built on this finding, examining the palynology of a series of caldera lake records from the island including consistent abundant records of Arecales (Palmaceae) type pollen. Discoveries of macrobotanical palm endocarps, with gnaw marks from introduced rats (*Rattus exulans*), in an archaeological rock shelter deposit (Dransfield et al 1984) corroborated Flenley and King’s palynological findings and provided indications of the likely taxonomic status as either an endemic *Paschalococcus disperta* Dransfield, or, a close relative of the Chilean *Jubaea* palm (Grau, 2004). Because of the latitudinal restriction of the Arecales family, the climatic conditions indicated by this palm are thought to be warm climate forest environments characteristic of the Holocene. Flenley *et al* (1991) later suggested that fluctuations between this Arecales palm type and Asteraceae (Tubuliflorae) pollen provide a climatic index for changing temperature. For sediments dated to the Last Glacial Maximum at 18,000 to 16,000 yr B.P. from the Rano Raraku record (RRA 3, presented and discussed in Chapter 4), the index indicates cooler conditions than those exhibited for the Holocene that show a gradual warming. Within the same record a marked decline and eventual absence of Arecales pollen by around 1,000 yr B.P., coupled with the archaeobotanical record of Dransfield *et al* (1984) and modern absence, led Flenley *et al* (1991) to conclude that extinction took place within the timeframe of human settlement.

Criticism of the radiocarbon chronology and interpretation of the RRA 3 core by archaeologists (e.g. Kamminga and Cotterell, 1984) invigorated the debate that later included the Holocene sedimentary deposits used for the purposes of detailing human activity elsewhere in the Pacific (e.g. Anderson, 1995). Since the initial publication of the RRA 3 record, palaeobotanical records have been seen as an additional archaeological proxy for understanding past human interactions within island Remote Oceania (e.g. Flenley *et al* 1991; Ellison, 1994; Flenley, 1994; Kirch and Ellison, 1994; Athens and Ward, 1993; 1996; 2001; 2004; Parkes, 1997). Criticisms of the resulting interpretations revolve around the reliability of the generated chronologies, the equivocal representation of both natural and cultural disturbance, the lack of direct cultural indicators and taphonomic integrity as well as a variety of other issues intrinsic to the methodology (e.g. Anderson, 1994; 1995; 2001; 2002; 2003b). Palaeoenvironmental interpretations for fire, for example, are too readily complicated by the numerous potential ignition sources (e.g. lightning, volcanoes, burning by humans) that have an inherent capacity to clear forests, encourage soil instability and favour ruderal plant taxa to a degree that may be confused with human induced ignitions.

In a reappraisal of the RRA 3 radiocarbon chronology, Flenley *et al* (1991) contend that the dates indicate a steady accumulation rate for the organic sediments but may reflect contamination from younger soil washed in from above or older bedrock carbon beneath (cf. Pennington *et al*
This problem was recognised in more recent attempts at dating core deposits from Rano Raraku in an effort to improve the chronology of human impact events (Dumont et al. 1998; Mann et al. 2003). Flenley (1993) suggested that the poor radiocarbon chronology of the Rano Raraku cores may be a result of historical sedimentary deflation of the crater swamp during the late 1960s to early 1970s. Formerly around 2 m above its current average level, water was piped out via a large trench along the lowest western side of the crater (ibid).

Following the interpretive dilemma generated by the Rano Raraku palynological records of Flenley and King (1984), additional attention was placed on this site in an attempt to resolve the question of human agency in the decline and eventual extinction of the indigenous palm tree (Paschalococcus disperata). Little was achieved in this regard with the provision of additional radiocarbon ages (Flenley et al. 1991) or the retrieval and analysis (palaeolimnology, charcoal particle concentrations and magnetic susceptibility) of additional sedimentary cores (Dumont et al. 1993; Mann et al. 2003). McGlone and Wilmshurst (1999) have since shown that there appears to be a differential between the radiocarbon age ranges obtained by dating human disturbance signatures in New Zealand lake sequences as opposed to swamps or mires despite having comparable sedimentary horizons. The implications of the dating differential between adjacent closed and open sedimentary basins, has also been discussed in reference to the differing interpretations of past climatic and vegetation change (e.g. Anderson, 1993).

The lack of robust chronological detail for these volcanic caldera lake sites for approximating human activity led researchers to investigate sites deemed less suitable for palynological examination (i.e. open sedimentary basins). Based on sedimentary and palynological signatures from a number of palaeoenvironmental core sites on Mangaia, a more concentrated effort at identifying signals of human impact was attempted, but still within the framework of providing a background palaeoclimatic information (Lamont, 1990; Ellison, 1994; Kirch 1996; Kirch and Ellison, 1994; Kirch et al. 1991; 1992). Out of a total of 24 cores taken from the moat swamp and lake deposits, three were chosen for palynological examination as they were thought representative of the stratigraphy of the surrounding basins. Kirch and Ellison (1994) later proposed an initial settlement timeframe for the Cook Islands of around 2500 yr B.P. based on bulk sediment radiocarbon determinations from samples representing the earliest with palynological signatures of human activity. A critique of the palynological chronologies of these cores has been provided by Anderson (1995) who commented on the potential for dissolved carbonates from the surrounding makatea to contaminate bulk sediment dates to explain some chronological inconsistencies with the archaeological chronology established for the Cook Islands.

A number of features of the three examined cores from Tiriara (TIR 1) and Tamarua (TM7) and Veitatei (VT6) appear to be synchronous and are broadly consistent with the stratigraphic changes exhibited in the Rano Raraku cores. The primary anthropogenic signatures identified
across all records are, firstly, a decline in arboreal pollen representation including in representative Arecaceae pollen, and secondly, the associated increases in fern spore and grass pollen. For the TM7 and VT6 records a concurrent rise in charcoal particle signals provides a potential additional proxy for human activity. Palynological signatures for human activity worldwide have generally been built on such indirect indices as charcoal particle concentrations or changes in seral plant pollen or fern spores (e.g. Behre, 1986; Walker and Singh, 1993; Flenley, 1994; Haberle, 1994; Maloney, 1994). Records from island Remote Oceania are no different although they appear to present more pronounced fluctuations in pollen representation that may be interpreted as unprecedented vegetation change. The key problem cited for the archaeological application of palaeoenvironmental records has been the lack of direct palynological indicators either as the recovery of artefacts stratified within the core deposit or the recovery of cultigen pollen unequivocally introduced to the site.

It has become apparent from archaeological excavations of agricultural features that pre-contact agricultural development noted for the Hawaiian Islands and other islands in Remote Oceania (e.g. Kirch, 1982; 1984; Spriggs, 1982) has produced dramatic environmental modification should be detectable in the palynological record. Selling (1947: 339) earlier suggested that such significant agricultural species as *Colocasia esculenta* (Araceae) should be looked for in the pollen record ‘as a means of tracing the history of agriculture of the islands’. Cranwell (1964b: 43) also emphasised the potential of palynology for this purpose suggesting ‘in general it can be used in the Pacific to study the organic matter of old taro-fields, and specifically, to trace the spread and ultimate sources of such warmth-loving plants as the coconut.’ A number of palynologists have later concluded that *C. esculenta* pollen and a number of other cultigens in palynological records will remain relatively invisible due to their low pollen productivity and selection against flowering in the cultivation process where the corms are harvested prior to flowering (e.g. Haberle, 1994; Flenley, 1994).

Following the examination of a range of less conventional pollen depositional sites, within or directly adjacent to historically abandoned or active agricultural areas, tentative identifications of *C. esculenta* pollen were specified for three sites from the Hawaiian Islands (Ward in Hammatt et al 1990; Ward in Beggerly, 1990, Wickler and Ward, 1992; Athens and Ward, 1993). These claims were supported by other direct (associated pollen from other possible introduced taxa) and indirect indications of agricultural environments exhibited in the same palynological records including the replacement of forest vegetation by grass and herb taxa associated with an increased fire frequency and intensity indicated by charcoal particle concentrations. Subsequent systematic examinations of *C. esculenta* pollen by Haberle (1995) removed the previous ‘tentative’ status of pollen identified by Garrett-Jones (1979) from 8500 yr B.P. aged sediments from Lake Wanum in the Morobe Province of Papua New Guinea (see below). Following Haberle’s (1995) revision of *C. esculenta* pollen morphology a further five records from around the Indo-Pacific have been
documented by Athens and Ward (1997; 2004), Haberle (2005) and Prebble et al (in prep; this thesis). The range of other indigenous aroid taxa in island Remote Oceania appears to be limited, though some confusion exists over the indigenous status of the cultivated genus *Cyrtosperma* on the island of Palau (Federated States of Micronesia). Athens and Ward (2001) located *Cyrtosperma* pollen from 4,000 yr B.P. aged sediments from Ngerchau swamp on Palau and suggested that this may indicate the earliest presence of human occupation on the island around 1000 years prior to the settlement chronology provided by the archaeological record (Phear et al 2003; Anderson, 2005).

Two sites have now been examined from the Austral Islands that mirror the stratigraphic palynological changes exhibited in the Mangaia and the Easter Islands records but provide more robust estimates for the timing of agricultural and environmental change (see Chapters 6 and 7). On Rapa, a marshland (Tukou) adjacent to a series of abandoned former terrace cultivations at the head of Ha’urei harbour was examined (Kennett et al in press; Prebble et al in prep). A moat swamp deposit (Maunutu) on Rimatara, similar to the swamp systems on Mangaia, was examined with cores taken from sites immediately adjacent to a series of active and recently abandoned *Colocasia esculenta* cultivations (Prebble, in prep). Both deposits have revealed stratified pollen of *Colocasia esculenta* with radiocarbon determinations on pollen concentrates suggesting the earliest presence of this pollen falls within the chronological framework for the Cook and Austral islands settlement established archaeologically. The palynological and archaeological chronologies for Rapa are directly comparable whereas the only radiocarbon ages for Rimatara that may be regarded as archaeological comes from the palaeoenvironmental investigation of Maunutu swamp. As for the Hawaiian sites mentioned the implications for *Colocasia esculenta* presence was supported by associated pollen from other possible introduced taxa and indirect indications of agricultural environments.

A multiple profile approach for both the Tukou and Maunutu sites was undertaken in an attempt to elucidate the range of taphonomic processes affecting the palynological assemblages (see Chapters 6 and 7). This revealed an uneven response of palynomorph deposition to sedimentary influxes whereby palynofacies could be identified but were represented in differing size units. What are more striking within these palynological records are the direct indications for post-contact introduction of a range of seral weed taxa. The initial presence of these taxa corresponds to distinctive palynofacies unit that extends into the modern marshland surface. On both islands the earliest anthropogenic palynofacies, described as a Polynesian phase, is characterised by *Colocasia esculenta* pollen, a suite of other potential introduced taxa (e.g. *Aleurites moluccana* and *Erythrina variegata*), the onset of high charcoal particle concentrations, declines in arboreal taxa including the extirpation or extinction of Arecaceae palm pollen, and an associated increase in fern, grass and other herb taxa. The upper European phase palynofacies are characterised by a decline of *C. esculenta* pollen, further local declines or extirpations of arboreal
taxa (e.g. *Pandanus tectorius*) and the initial presence and subsequent increase of a range of introduced weed taxa (e.g. *Ludwigia octovalvis*, *Commelina diffusa* and *Sonchus oleraceus*). In addition, high charcoal particle concentrations continue with a further increase in fern, grass and other herb taxa. Such a distinctive pattern of pollen and spore deposition has only been found in a few other sites in island Remote Oceania (e.g. Kawainui Marsh, O'ahu, Ward in Hammatt *et al.* 1990; Alenaio swamp, Hawai'i, Wickler and Ward, 1992; Maunawili swamp, O'ahu, Athens and Ward, 1997).

**Recent historical context**

The modern environment of the Austral Islands like many other archipelagos in Oceanic Island Remote Oceania (OIRO) can be characterized by widespread degradation. On most of the Austral Islands only remnant indigenous forest vegetation has survived the period of human occupation. The number of animal and plant species that have arrived through human introduction or natural dispersal has exceeded the population of indigenous species. Apart from a few terrestrial bird species (the rail *Porzana tabuensis* is the only extant species found on all of the Austral Islands; Jean Claude Thibault *pers. comm.*), most of the Austral Island fauna are either pan-tropical migrants or introduced species. As on most islands in Remote Oceania rats (*R. norvegicus*, and *R. rattus*, e.g. Neale, 1965), goats (*Capra hircus*, e.g. Hamann, 1975; Coblentz, 1978) and pigs (*Sus scrofa*, e.g. Maude, 1968b; Kirch, 2000a; Allen *et al.* 2001) have been introduced to the Austral Islands following first European contact and have subsequently become feral. On Rapa, cattle and horses could be regarded as feral as they are present in large numbers and are only partially managed. The historical consequences for such introductions has been only partly substantiated, but has clearly led to a decrease in indigenous vegetation and a subsequent reduction or loss of indigenous floral and fauna. On most islands, hill slope erosion is visible with substantial scarring from landslips caused primarily by a combination of vegetation clearance through burning practices by the local inhabitants and further vegetation browsing by feral domesticates.

The extent of garden cultivations on all of the islands has declined in recent years perhaps with the exception of the most populated island of Tubuai. The former extent *Colocasia* cultivation on Rapa is apparent with almost the entire north and east valleys possessing relic terrace features. Most of the remaining populated islands also have a large number of terrace features that appear to have been abandoned for many years outside of the usual fallow period for *Colocasia* cultivation (~2-3 years). On Rapa, the arboricultural species *Aleurites moluccana* formed a major forest component in the 1930s (Mueller-Dombois and Fosberg, 1998: 403) where the nuts were still used as a primary fuel for torch-lights up until the 1950s (Robinson, 1957: 35).
Presently only a few specimens remain around the two main villages of Ha’heurei and Area with only a few stands persisting in some of the more forested lowlands. In addition to *A. moluccana*, some formerly important garden cultigens are no longer cultivated on the islands including the tuberous crop *Tacca leontopetaloides* although it can be found in naturalised populations on some of the other islands within the Australs.

A recent biological survey of Rimatara has revealed that the number of naturalised plant species is now double the number of indigenous species (Meyer *et al* 2004). The most invasive of these include agricultural grasses (e.g. *Melinis minutiflora*), garden weeds (e.g *Passiflora foetida, P. maliformis*) and the invasive shrubs (*Eugenia uniflora, Falcataria moluccana, Psidium cattleianum, Syzygium jambos, S. cumini*). On Rapa some remnant high elevation forests between 300 and 635 m^2^ persist in the few areas that are mostly inaccessible to feral cattle and goats. A number of endemic plant species have been located in these areas (Motley, 2002; Meyer, 2002). Most of the summit ridgelines have been overgrazed and regularly burnt for access and are now covered with invasive grasses and shrubs. Ra’ivavae presents a similar picture with indigenous vegetation found only in the steep inaccessible valleys and a few surrounding areas below the summit ridgelines. Tubuai has similarly been denuded of much of its former indigenous vegetation and is now covered by extensive forestry plantations of *Pinus caribea* var. *hondurensis* (Pinaceae), *Melia azedarach* (Meliaceae) and *Leucaena leucocephala* (Fabaceae). Rurutu and Rimatara are both *makatea* (see Chapter 6) islands. In the case of Rimatara, the inland vegetation has almost no indigenous component. The rugged limestone substrate of the *makatea* (locally called *mato*) is thought to have restricted the extent of invasive species and retains, on both islands a number of endemic plant species.

Despite the potential for insular refuges to protect indigenous vegetation a number of species remain vulnerable with a few notable species documented as historical extinctions or extirpations. Rapa has only two remaining terrestrial bird species, a rail (*Porzana tabuensis*) and a fruit dove (*Ptilinopus huttonii*). Vulnerable angiosperm taxa include the indigenous sandalwood (*Santalum insulare*) that has formed island specific varieties. On Rapa *S. insulare* var. *margaritae* is known only from a few individuals on a small islet off the coast. Several other historical extirpations or extinctions recorded in recent botanical surveys include that for a population of *Exocarpos psilotiformis* from Rapa, also in the Santalaceae, and *Myoporum rimatarense* on Rimatara.

\[7\]The highest summit on Rapa is called Pera’u and at 635 m is also the highest in the Austral Islands.
Chapter 2
Islands of history: the floral origins of Oceanic Island Remote Oceania (OIRO)

Why islands?

Questions about the origins of island floras and faunas are intrinsic to ecological and evolutionary theory (Carlquist, 1965; 1974). Where and from which direction did many species immigrate from? When did their ancestors arrive? Did they displace any existing species? Have the present indigenous species formed under adaptive radiation in situ, or did they arrive essentially unchanged from a nearby geographic area that has since changed or disappeared? These questions have become fundamental to the overall construction of oceanic islands as 'island microcosms' of a continental biogeography. If geological and biotic processes worked in tandem, then a single underlying pattern could be envisaged that shapes all organisms. In fact, however, biogeographic research tends to illustrate that processes including dispersal, extinction and sympatric speciation outweigh geological constraints on biota, disrupting any diffusionist or linear pattern (Turner et al 2001: 227).

Distinguishing a priori factors or stable principles in biogeography is central to this island-for-continent approximation, where islands are seen to have more pronounced or attenuated features and processes that may be obscured or indistinguishable on continents. In Raymond Fosberg's view:

'Some of the more significant characteristics of the island ecosystem are relative isolation; limitation in size (space resource); limitation in, or even absence of certain other resources; limitation in organic diversity; reduced inter-species competition; protection from outside competition and consequent preservation of archaic, bizarre, or possible ill-adapted forms; tendency toward climatic equability; extreme vulnerability, or tendency toward great instability when isolation is broken down; and tendency toward rapid increase in entropy when change has set in.' (Fosberg, 1963: 5)

Simberloff (1974) has pointed out that islands are important for other significant reasons. He notes that 5% of the terrestrial surface of the earth is insular and if this island area includes South

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1 Both Darwin (1856) and Wallace (1869) made the distinction between oceanic islands and continental islands later defined separately in both geological (an island not situated on a continental shelf) and biogeographic terms (an island that has received its flora and fauna across the sea and not by way of land bridges) (cf Mayr 1976:604). See Brown and Lomolino (1998) and Whitaker (1998) for a review of island geography and island type terminology.

2 Non-vicariant
America, an island for much of its geological history, this figure would be boosted to 19%. The evolutionary histories of many biologically and economically important species have been recorded on islands (though not always on oceanic islands). I would add to this list the domestication histories of several island plants particularly from the spice islands of Southeast Asia and Island Melanesia including tuberous crops (e.g. Dioscorea nummularia and Cyrtosperma merkusii), shrubs (e.g. Piper methysticum) and arboricultural species (e.g. Metroxylon sagu, Canarium spp., Aleurites moluccana, Syzygium aromaticum and Myristica fragrans), although some of these histories are far from precise and perhaps tied to continental New Guinea. In regard to evolutionary histories, islands present a ‘diversity and stability paradox’ as they are species poor but have high rates of endemism that appear stable over long periods but have been susceptible in historic times to rapid change, notably through human impact (Cronk, 1997). Simberloff also remarked that if oceanic islands did not exist, the diversity of the world’s biota would be much reduced. This would have to include the high rates of species extinctions on islands, where for example 90% of all historically documented bird extinctions and a potentially similar margin in the zooarchaeological record, have taken place on islands (Vitousek, 1988; Steadman, 1995). Simberloff concluded that the focus on these aspects of islands has failed to inspire research on island biogeographic patterns, but instead it has been the paradigm that oceanic islands are accepted as ideal analogies or representations for other geographic entities and global biotic processes that have received the most attention.

Historically, the appeal of islands for interpreting larger continental phenomena extends back to the Enlightenment explorations⁵, but it was expressed most explicitly by Charles Darwin, the co-founder of island biogeography, in his Origin of species treatise, and in Voyage of the Beagle (1845: Chapter 17) where he states:

‘we see that a vast majority of all the land animals, and that more than half of the flowering plants are aboriginal productions. It was most striking to be surrounded by new birds, new reptiles, new shells, new insects, new plants ... to have the temperate plains of Patagonia, or the hot dry deserts of Northern Chile, vividly brought before my eyes. Why, on these small points of land, which within the late geological period ... differ in geological character from the American continent, and which are placed under a peculiar climate,—why were their aboriginal inhabitants, associated, I may add, in different proportions both in kind and number from those on the continent, and therefore acting on each other in a different manner—why were they created on American types of organisation?’

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⁵Enlightenment explorations in the history of biogeography commonly refer to those conducted with biologists trained in Linnaean systematics, epitomized by the explorations led by James Cook 1769-1778. Michel Foucault (1973: 310) refers to this as the ‘classical’ period set from the close of the Renaissance to the beginning of the nineteenth century.
It is apparent that Darwin followed the geologist Charles Lyell's (1842) earlier insistence that observable but small-scale geological changes can be extrapolated, under a reductionist guise, to encompass macro-phenomena. To Lyell this meant not only substituting small-scale for broad geological phenomenon, but also short temporal events to processes that operate over geological time scales. Darwin (1845: Chapter 17) 'felt near, both in space and time, to that great fact, that mystery of mysteries, the first appearance of new beings on the earth'. Darwin's (1859) Origin represents a synthesis of his observations of the Galápagos Islands as well as the collected observations of other naturalists working in the Pacific islands and elsewhere. This took the form of three main hypotheses that specifically relate to islands. Firstly, on oceanic islands the array of species are reduced compared to that on continental areas of an equal size. Secondly, although biological diversity is reduced on islands, the proportion of endemic species is often extremely large. Thirdly, the proportion and diversity of representatives from higher orders are comparatively reduced on islands and where some orders may be expected given their proximity to a continental system, they are more often absent.

At the same time, Alfred Russell Wallace (1869), the co-founder of the theoretical outline expressed in the Origin treatise (Berry, 2002), through his observations of contrasting Indo-Pacific biotas also stressed the acceptance of definite laws governing the evolutionary process. In Malay archipelago, Wallace (1869: Chapter 18) writes:

'The rule is, that just as the productions of adjacent areas usually resemble each other closely, so do the productions of successive periods in the same area; and as the productions of remote areas generally differ widely, so do the productions of the same area at remote epochs. We are therefore led irresistibly to the conclusion that change of species, still more of generic and of family form, is a matter of time. But time may have led to a change of species in one country, while in another the forms have been more permanent, or the change may have gone on at an equal rate but in a different manner in both. In either case, the amount of individuality in the productions of a district will be to some extent a measure of the time that a district has been isolated from those that surround it.'

Darwin emphasised the role of long-distance dispersal on oceanic islands, stating that if one species occurs on two isolated or widely separated islands, dispersal must be the primary factor if geological mechanisms are not involved. An alternative to this explanation, though it seemed unlikely to Darwin, included the possibility of the independent evolution of the same biological form that may arise on two different occasions or in two different locations (Carlquist, 1996: 154). The ecological attributes or adaptations of species on different oceanic islands led to the opinion that most speciation is allopatric⁴, taking place in the absence of continental land bridges,

⁴Vicariant or where some isolating mechanism influences the speciation process.
an idea supported by a number of Darwin’s contemporaries (e.g. Huxley, 1870). Darwin (1859: 437) regarded the lack of mammal diversity, as an example of the absence of entire classes of fauna and flora, as support for ‘the efficiency of occasional means of transport [of oceanic island animals], carried out during a long course of time, than with the belief in the former connection of oceanic islands.’ Wallace’s suggest for Indo-Pacific biogeography that different biotas originated in Asia and Australia, and they were subsequently shaped by differing mechanisms for species dispersal. His observations expressed in Malay Archipelago provided some clarity to the role of changing sea level and the probability of land bridge formation. This led to his initial biogeographic demarcation of the Sunda and Sahul continental regions (Wallace, 1860) by what was later called Wallace’s line.

Most of the material observations presented in the Origin and the Malay archipelago texts represent two attempts at substantiating the idea of descent or homology, not mechanisms governing evolutionary processes (Gould, 1986). Darwin suggested that the ordering of biological systems, realised in taxonomic orders, reflects an historical pathway that was heavily influenced by contingent factors. In reference to this, Ghiselin (1969) views Darwin as a methodologist who allowed for the interplay between the pronouncement of evolution processes as a foundation of biology and the implications of chance or contingency as opposed to metaphysical forces. Darwin (1859: 74) provided the image of an entangled bank to explain this interplay: ‘when we look at the plants and bushes clothing an entangled bank, we are attempting to attribute their proportional numbers and kinds to what we call chance. But how false this view is!’ He extends this idea of invariance of ecological process to include a cleared forest re-establishing in a linear succession to a state parallel with adjacent intact forest just as a ‘handful of feathers... fall to the ground according to definite laws.’ To Darwin, oceanic islands provided a useful situation for exploring this interplay as they enabled the testing of evolutionary constructs through the observation of isolated modern populations (Kay, 1994).

The legacy of equilibrium theory

MacArthur and Wilson (1967: 3), authors of The theory of island biogeography (equilibrium theory), stress the importance of Darwin’s island observations in stating that ‘many of the principles graphically displayed in the Galápagos Islands and other remote archipelagos apply in

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5 Thomas Huxley’s ideas were later taken to the extreme by James Churchward (1931) whose lost Pacific continent of Mu, as an adjunct to the Mediterranean Atlantis and the Indian Ocean’s Lemuria, provided a diluvium explanation for cultural and biological patterns in the region.

6 Mayr (1944) later showed that this line separates a continental Asian (Sunda) biota from a depauperate island biota (Sahul and adjacent islands) to the east.
lesser or greater degree to all natural habitats. In this quantitative theory, the vagility of species on islands is in dynamic equilibrium between extant species and the immigration of exotic species. The variety of taxa on oceanic islands is limited, both by the comparatively limited time frame for speciation (oceanic islands are younger than continents), and the limited dispersal ability of the small range of taxa that are vagile enough to cross oceanic barriers (Cox, 2001: 513). The use of oceanic islands as theoretical model systems of continents clearly draws on their geographical area and isolation. The defined geographical structure of an island, especially at the shoreline, allows for the examination of rates of colonization and extinction, and of the effects of island size and isolation (measured as distance) from their potential source populations.

At the core of equilibrium theory is a stochastic, simplified mathematical model of species turnover at equilibrium. It allows biogeographic patterns and processes influencing species richness to be quantified with island area or size and spatial isolation as critical variables. In some senses the concepts of island area and isolation are equivalent. The area or size of islands, in the perspective of global biogeography, lends itself to a reductionist perspective in that they are ‘the first unit that the mind can pick out and begin to comprehend’ (MacArthur and Wilson, 1967: 3). The most essential outcome associated with island area is that species richness increases with size, so that smaller islands are generally depauperate. Though this outcome seems intuitive, the main contribution of equilibrium theory was more to do with the prediction of changing rates of species immigration or extinction to equilibrium within a defined timescale and island area.

**Island isolation and equilibrium theory**

Ernst Mayr (1976) suggested that it is possible to apply the term isolation in two ways. Firstly, there is a modern geographic interpretation whereby a gene pool is divided into two independent subsets (vicariance – see below) through some external barrier mechanism (e.g. the ocean), and a second reproductive interpretation whereby an internal mechanism of some kind prevents gene flow within a population eventually eliminating compatibility between two or more subsets. The terms insularity and isolation are in some senses equivalent in biogeographic contexts. To MacArthur and Wilson (1967: 3) insularity ‘is moreover a universal feature of biogeography’ as it is exhibited in a wide range of ecological subsets (to use their examples: caves, streams, gallery forest and tide pools). Variation in any biological feature (ecological, genetic, morphological etc.) exists across many geographical dimensions such as distance between sites or along gradients of area and elevation. The most fundamental effect of island isolation, if quantified using distance, is that the chance of dispersal decreases with increasing distance from the source population. Like the effect of island area, this is an assumption embedded within equilibrium theory and crucial for

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7Ability to migrate/disperse
predicting the changing rates of species immigration or extinction in relation to changing equilibrium. In equilibrium theory the islands that are nearer have a greater equilibrium but also a greater species turnover rate than distant islands.

The utility of equilibrium theory for exploring the effect of distance was deemed unequivocal by Diamond (1972; 1974) in demonstrating the reduction of bird species from island New Guinea to Pitcairn Island in the East Pacific. When coupled with island area this reduction becomes logarithmic in scale. This principal tenet was extended to include ‘rescue’ and ‘commuter’ effects in which the less the distance to the source population, reduced the probability that an established population on the island would go extinct, mainly because of the effect of immigration population renewal and resource accessibility from other islands (Brown and Kodric-Brown, 1977). These observations are again all intuitive, but they do not employ the more abstruse theoretical insights of MacArthur and Wilson’s theory of island biogeography. In a sterile or biota-less island, for example an oceanic island formed from a volcanic eruption (e.g. Krakatau), equilibrium theory predicts that distant islands will take a disproportionately longer time to reach equilibrium through chance immigration than near islands.

Long distance dispersal and equilibrium theory

The validation of long-distance dispersal was essential to Darwin’s Origin treatise, because if the same two species occurred on two isolated or widely separated islands, then few other possible explanations including independent evolution seemed plausible. In Wallace’s (1880) Island life, one chapter is dedicated to long-distance dispersal in an attempt to understand the Asian and Australian biogeographic affinities, in which dispersal could explain the vicariant distributions of large mammals in contrast to non-vicariant avifauna. The high frequency of flightlessness found among many endemic birds and invertebrates, for example, posed a dilemma for early dispersal theory. Darwin instituted the idea that flightlessness was favoured on islands that arose through differential subsidence or by the inundation of former continents to form islands. This phenomenon was later explained by Darlington (1943) and Diamond (1972). They proposed that kinetic (energy) investment for flight or long-distance dispersal is reduced or relaxed on the more stable, inland, or mountainous areas of larger islands, whereas on more remote, low and small islands such dispersal mechanisms are still evident because the kinetic investment is necessarily high.

MacArthur and Wilson (1967) have discussed long distance dispersal theory in direct relation to island area and insularity (as above). They suggest that certain taxa are suited to remote island colonization because they either have long-distance dispersal or survival adaptations. Wilson’s (1959) earlier examination of the distribution and ecology of Melanesian
ant fauna, a study that foreshadowed equilibrium theory, highlighted the tendency for species to colonize islands through ecologically marginal or ‘weedy’ habitats. Wilson proposed the concept of ‘taxon cycles’ (Wilson, 1959; MacArthur and Wilson, 1967: 163-165); meaning that on larger islands such as New Guinea, various taxa occupying marginal habitats are more likely to disperse across oceanic barriers to colonize the equivalent environments of smaller and more isolated islands of Island Melanesia. Once colonised, some taxa failed to establish, especially within the island margins, while others successfully invaded inland areas forming new adaptations and potentially new species. A small proportion of the inland-adapted species may then radiate back to the island margins and subsequently colonize other islands.

**Critics of equilibrium theory**

Most critics of equilibrium theory accept that its greatest value has remained its position as a definite anchor for floating alternate theories of island biogeography (e.g. Sauer, 1969; Simberloff, 1974; Gilbert, 1980; Brown and Lomolino; Heaney, 2000; Lomolino, 2000; Whittaker, 2000; Walter, 2004). By and large, the concentration on biogeographical evidence has been part of ecological and evolutionary perspectives within a species-centred approach. Recent biogeographic research concentrating on molecular-based phylogenetic data and the increasingly detailed palaeobiogeographic data has allowed the competing long distance dispersal and vicariance hypotheses to be tested (Sanmartin and Ronquist, 2004). Taxa from different orders, both plant and animal, exhibiting the same phylogenetic and biogeographic pattern, are assumed to share a common ancestry based on the same geological isolation events. Molecular clock estimates indicate that the Cretaceous break-up of Gondwana was an important mechanism for speciation, especially in birds and mammals. Molecular data for post-Gondwanan floras suggests that long distance dispersal better accounts for biogeographic patterns of species in which the ancient vicariant patterns and recent dispersal events have formed hybrid lineages (e.g. Pole, 1994; Sanmartin and Ronquist, 2004).

Comparative molecular and long distance dispersal studies have been relevant for older continental landmasses such as Australia, New Zealand and South America where ecological processes may operate under an order completely different from that of oceanic islands. For the younger islands, molecular and palaeobiogeographic datasets are not yet of a sufficient resolution to provide concordance between phylogenetic and vicariant patterns. The avifaunal and mammal distributions on oceanic islands have little to do with the break-up of Gondwana and cannot be analysed within the same vicariance hypotheses. The same applies to island floras despite the high proportion of taxa with Gondwanan lineages. Geological isolation events, such as the
Gondwanan break-up that marked the beginning of the Cretaceous, are likely to be more frequent and important to vicariance hypotheses for oceanic islands.

Walter (2004) has questioned the application and validity of species-centred evolutionary concepts in island biogeography. Firstly, he suggests there is a taxonomic conundrum where a pattern or process may be highly visible for birds but not for other organisms (ibid: 190). For example, Rapa in the Austral Islands, has an area of 38 km² and there are 100 species of land snails⁸ (Solem, 1982; 1990), with species density an order of magnitude greater than for any continental land snail fauna. This same paradoxical trend applies to the species radiation of the Rapan flightless weevils (67 species of Miocalles and 13 species of Rhyncogonus; Paulay, 1985). This could exemplify one of Stephen Jay Gould’s ‘reversed established orders’ (Gould, 1995a), a counter-intuitive trend, at least in regard to equilibrium theory, where continents are deemed highly impoverished of land snails and weevils. Secondly, Walter highlights the tendency to generalise local and regional environments and to accord them universal validity or significance as discussed above. The foundation of equilibrium theory with the inherent bias towards taxon dispersal has been invalidated where species-centric concepts should be replaced by concepts that incorporate a wider range of geographical attributes of islands. Walter suggests that oceanic island taxa are functionally insular as a result of long-term island stability, confinement, and isolation as a protection from continental source invasion and disturbance such as predation, competition, and disease. He also distinguishes continental taxa on the basis that they persist in different, more complex and open spatial systems.

From a geographical perspective Walter (2004) suggests that the island biogeography paradigm has been developed without empirical data on historic, pre-human biodiversity and the geological timeframe of many tropical oceanic islands. He elaborates on the human-island component by stressing that island biogeography research has dealt only with small continental land-bridge islands with impoverished flora and fauna resulting from human modification (e.g. Island Southeast Asia and Melanesia). He adds that biogeographic studies of the land-bridge islands of the North and Baltic Sea, the eastern Atlantic and the Mediterranean are more often populated by mainland metapopulations⁹. These metapopulations are also more heavily modified through historic human influences than the mainland source populations.

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⁸This number has recently been increased to more than 150 species (Benoit Fontane and Olivier Gargominy of the Museum de Paris, pers. comm. 2004). Walter (2004), following Solem (1990) incorrectly cites Rapa’s area to be 14.2 km².

⁹Connected populations
Discrepancies in island biogeography

Disturbance and islands

The processes of species immigration, extinction and evolution are central to island biogeography (Lomolino, 2000). Evolutionary speciation is perhaps the most intractable, given the problems of examining the biology of long-lived species that may require extensive, long-term historical data. For equilibrium theory and its precursors, island immigration has essentially supplanted speciation as an equivalent process, given that the first successful colonisation of a species on an island represents a speciation event for that island. As Gould (1986) has emphasised, this does not demonstrate any evolutionary process. Speciation in the form of adaptive radiation, as one example, has clearly taken place but the processes that led to such events remain unsubstantiated. Generally any treatment of the evolutionary speciation process on islands has remained hypothetical. Disturbance may play a more pivotal role in the interpretation of these processes.

Levin (2004) suggests that speciation is likely to follow pronounced ecological shifts, in which species from an ancestral habitat may have radiated into numerous other habitats. Increasingly, the fossil record suggests that island environments have changed abruptly and/or periodically and it is the most disruptive points in these records that appear conducive to high rates of speciation. This may result from in situ speciation, or in the case of island biotas may be more a consequence of increased plant dispersal and colonisation as a mechanism for increasing genetic exchange. Levin suggests such speciation facilitated by disturbance relaxes pressures on competing taxa by either allowing for colonisation of an entirely new environment (e.g. an oceanic island) or a newly formed niche. On oceanic islands such disturbance-oriented ecological shifts may be quite pronounced, such as the extensive radiation that has been documented for colonising species of several plant genera (e.g. Hawaiian silver-swords in the Asteraceae). Levin points out that such plant speciation has also been noted for some continental silver-sword like genera including *Espeletia* (Asteraceae) in the cool Andean tropics (Monasterio and Sarmentio, 1991 in Levin 2004: 225), suggesting that the nature of disturbance, not insularity or isolation is the driving process behind such speciation.

Disturbance has long been seen as a facilitator of ecological change along a continuum ranging from the outright destruction of environments to local biological heterogeneity across an environment. Disturbance has been defined as ‘any relative discrete event in time that disrupts ecosystem, community or population structure and changes resources, substrate availability or the physical environment’ (White and Pickett, 1985: 7). A number of authors have examined the role of disturbance in either maintaining or increasing species diversity (e.g. Grime, 1973; Connell, 1979; Grubb, 1979). Connell (1979) suggests that in tropical environments diversity is increased...
and the highest diversity is maintained at intermediate scales of disturbance. The long-term historical investigation of the colonization of flora and fauna on Krakatau (Republic of Indonesia), following the volcanic eruption of 1883, has provided an abundance of data that do not fit MacArthur and Wilson’s equilibrium theory (Walter, 2004). The frequency and degree of disturbance, examined in conjunction with the ecology of many biotic elements, were important in defining the patterns of colonisation and species where a constant dynamic disequilibrium has existed for at least 100 years (e.g. Whittaker, 1995; Bush and Whitaker, 1993).

Human impact and islands

The impact of humans on oceanic islands is one subject that has been filled with ambiguity and contention. Prior to the publication of MacArthur and Wilson's equilibrium theory, Fosberg (1959; 1963) alluded to the potential influence of humans on island ecosystems not only in terms of direct impacts but also as dispersal agents. In 1961 he wrote:

'It is probable that no island ecosystem was ever completely stable. The limited size makes even relatively small changes capable of rather profound general effects; in other words, the buffering effects of great size and diversity are lacking. However, it is likely that, before the advent of man, many or most of the older island ecosystems had reached such relative stability that changes were mostly very slow. In most respects organisms present had evolved into an effective equilibrium with their environments. Closed biotic communities had developed that made difficult the unaided invasion of new organisms.' (Fosberg, 1963: 5)

The methodological priorities set by equilibrium theory such as the measurement of species turnover, have resulted in the comparative neglected of complex and contingent issues surrounding human impact (Walter, 2004). As one example, most avifaunal studies of species turnover ratios (e.g. Diamond and Jones, 1980) and kinetic relaxation times (e.g. Diamond, 1972) on islands that incorporate equilibrium concepts, appear to avoid datasets that reveal the direct and indirect nature of human impact and other environmental disturbance on colonisation and extinction processes. Some of the most important evidence for the eroding support of equilibrium theory has come from biological evidence for human impact on islands (e.g. Olsen, 1990; Woods and Sergile, 2001; Steadman et al 2002). The strongest records of avifaunal extinction on oceanic islands is that of the Pacific rails (Rallidae), with estimates of thousands of extinct species occurring within the period of human settlement (Steadman et al 2002). Since such discoveries it has been clear that the current biogeographic patterns of island flora and fauna have been heavily influenced by human impact. Olson (1990: 49) in commenting on these recent findings in the
island fossil record concludes that 'the only safe generalization in island biogeography is that it is not safe to make generalizations.'

The recent chronicling of species immigration and extinction, human impact and other ecological disturbance on islands with no record of human occupation prior to the European exploration of the Pacific, has expanded the temporal view of biogeographic analyses. Socorro Island (140 km\(^2\)), the largest of the four Revillagigedo Islands in the Mexican Pacific is thought to be one such example. It was not until 1869 when sheep were introduced to the island that any indirect human impact was recorded (Grayson, 1871 in Walter, 2004). No extinction or immigration of any bird species was documented on Socorro until the Mexican Navy established a base there in the 1950s. In the 1970s an endemic elf owl and pigeon became extinct, probably through feral cat predation or habitat degradation, with only 2 of 77 visiting terrestrial birds establishing breeding populations on the island since this time (Walter, 1998; 2004). Socorro's avifaunal history is thought similar to other islands including the Galápagos Islands (Equador), Cocos Island (Costa Rica) and the Tres Marias' Islands (Mexico) in having few historic records of human impact. On such islands, contrary to the predictions of equilibrium theory, the resident endemic bird populations appear to be stable with little species turnover except after historically recorded disturbance events. Recent documentation of human impact on islands has shown that species richness of vascular plants has approximately doubled on many oceanic islands (Sax et al 2002; Meyer, 2004). This has largely been a result of introduced exotic biota invading ecological niches opened up by severe species and habitat loss. Such pronounced disequilibrium has produced knock-on effects that escape the predictions of equilibrium theory.

Why island floras?

Modern island biogeography has been under the biased perspective of avifaunal and mammalian ecological and distributional studies. Equilibrium theory, the dominant paradigm in island biogeography, was established under the premise of such a bias but in many senses it failed to incorporate other elements of island biology. Island floras are interesting for a whole different set of reasons. The differing dispersal abilities and vagility of island floras when compared directly to the associated faunal constituents have generated an entirely different set of assumptions regarding species-area relationships, the core concept of equilibrium theory. Carson (1996: 7-8) suggests that island biogeography could not operate in the absence of floral analyses, as plant distributions are not only more stable than those of fauna, but also frequently serve as ‘specific determinant substrates’ for various animal species. Like their faunal counterparts, island floras also exhibit high rates of endemism, but demonstrate more effectively the influence of dispersal barriers and the consequences of long-distance dispersal mechanisms for insular biotas.
It has been suggested on the basis of fossil and historical evidence that plants seem to be more resistant to extinction than animals (James, 1995). This could be, in part, a function of the paucity and lack of resolution of the plant fossil data and may also be a function of the lack of empirical data on extinction processes *per se*. The mechanisms for both immigration and extinction have been traced for the historical development of the post-eruption flora of the Krakatau islands (e.g. Bush and Whitaker, 1993; Whitaker, 1995; Whitaker *et al* 2000). A number of authors examining this case study (e.g. Sauer, 1969; Whitaker *et al* 2000) suggest that the case history of Krakatau cited by MacArthur and Wilson (1967) may follow the predicted pattern of colonisation and extinction for avifauna but not for plants. Between the volcanic eruptions of 1883 and 1934 plant colonisation progressed at a steady rate whereas plant extinctions declined as vegetation succession continued (van Borssum Waalkes, 1960; Whittaker *et al* 2000).

*Long-distance dispersal and island floras*

The accumulation of evidence of long-distance dispersal by Darwin and Wallace was critical to their framework for understanding descent, but did not mark the beginning of island biogeography (Browne, 1983). The peculiarities and idiosyncratic nature of plant and animal distributions on islands became paramount after Charles de Buffon (1761) in his ninth volume of *Histoire naturelle* reported observations of the disjunct distribution of large mammals between continents. The distribution of oceanic island floras and the role of long-distance dispersal did not form a part of this initial biogeographic picture, yet they were critical to the contribution made by many Enlightenment naturalists. Johann Reinhold Forster (1778: 186-187), after his time on James Cook’s *Resolution* voyage, remarked that ‘the plants which grow on south-sea isles partly resemble those of America and partly those of Asia, with the resemblance to India becoming more apparent the further west.’ In Cook’s depiction of the flora of Palmerston Island on his third voyage (Beaglehole, 1967: 95), he stressed the likely role of long-distance dispersal suggesting ‘the plants that may have Vegetated from Cocoanuts, roots and seed, bought there by the wind, birds or thrown up by the sea.’

The German botanist Adelbert von Chamisso (1821: 365) noted, whilst on Otto von Kotzebue’s *Rurick* expedition to the Pacific between 1815 and 1818, that the region’s flora ‘seems to have become more scanty... from west towards the east.’ He also found that ‘the sea brings [to the Marshall islands]... the seeds and fruits of many trees, most of which have not yet grown there... many of them appearing... to have not yet lost their capability of growing’ (Kotzebue, 1821: 155). The French botanist Charles Gaudichaud (St John and Titcomb, 1983: 11) in his description of the Hawaiian Island flora in 1819 notes that the ‘littoral plants, so abundant
in the Moloques [Moluccas] and Mariannes [Mariannas], begin to desert the shores of the Sandwich Islands [Hawaiian Islands]. He also observed that it was 'more natural to attribute the plant life... to the air or marine currents, to the birds... than to search for the germs of all living things of these islands, within the center of the earth.' This was perhaps the first pre-Lyellian recognition that former continents may not have been involved in the distribution of oceanic island floras in the Pacific. At this same time Alexander von Humboldt (1816, 1820) expanded 'Buffon's law' to include other biological entities, whilst the French botanist, Augustin de Candolle (1820), proposed the first regionalised system of biogeography distinguished on biological (endemism), physiological (physical barriers including oceans, deserts, temperature clines and plant competition) and climatic criteria (Cox, 2001). Oceanic island floras did not figure highly in de Candolle's initial twenty 'areas of endemism' with only two oceanic areas designated, but in a later revision of these biogeographic regions islands made up six of forty areas of endemism (de Candolle, 1838 in Cox, 2001).

The importance of barriers to understanding plant distribution and dispersal became critical to the more detailed observations made by the growing body of professional naturalists in the Pacific. The American botanist Richard B. Hinds (1844) in 1829 began to substantiate the position of the peculiar plant species of the Pacific in stating that they were 'being chiefly fed by migration from other seas' and noting that increasing numbers of 'Indian' species were present on islands to the west of the Marquesas (after Kay, 1994: 56). In Darwin's (1937) earlier writing he remarked 'we find species few in proportion to the difficulty of transport', and though aware of the role of migrating birds as potential dispersers of plant propagules, saw seawater as the main dispersal medium.

As professional botanists began to develop systematic observations of plant collections from the oceanic islands of the Pacific, the disjunct nature of many plant distributions (phytogeographic) became apparent, raising plausible explanations for vicariant biogeography. Asa Gray (1854) examined collections of the Compositae (Asteraceae) silver-swords from the different Hawaiian Islands, noting their vicariant geographic distribution, a trend recognised by Joseph D. Hooker (1847) after examining Darwin's plant collections from the Galápagos Islands. These observations, particularly of the silversword alliance, confused dispersal theory but provided considerable stimuli for later adaptive radiation theory. In many senses these peculiarities were put aside as William Hillebrand (1888) in his *Flora of the Hawaiian Islands*, suggests that the flora was largely derived from seed dispersal in ocean drift. This was contrary to Darwin's ideas, suggesting such dispersal accounts for relatively little of the character of island floras. Hillebrand's flora gives recognition to historical and other factors in that they may also contribute the makeup of island floras outside of the strict physiographic and climatic parameters

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10 Witter and Carr (1988) provided molecular evidence supporting Carlquist's (1959) anatomical claim that the Hawaiian silver-sword alliance were derived from Californian tarweeds.
suggested earlier by de Candolle (1838). This was born out in Adolf Engler’s (1879-1882) incorporation of evolutionary and historical aspects of phytogeographic regions in a system he termed ‘realms’. Engler designated an ‘ancient ocean’ realm that incorporated the Tertiary floras from coastal Chile, the Capes of South America and Africa, most of Australia, including Tasmania, and the South Island of New Zealand. These were thought sufficiently adapted to long distance transport that they could extend their distribution to the islands of the southern Atlantic, Indian and Pacific Oceans (Cox, 2001).

The efficacy of long-distance dispersal has long been questioned on the basis of the rarity of successful establishments of plant propagules on islands (Croizat, 1952; Carlquist, 1996). Information from field collections following the publication of Darwin’s Origin appeared largely to support either the extension of a former southern continent\(^\text{11}\), or to support long-distance dispersal mechanisms, namely by ocean-currents. Hermann von Jhering (1882; 1907), Hans Hallier (1912) and Douglas H. Campbell (1928) followed the geological perspectives expressed by James D. Dana (1847) and Thomas H. Huxley (1870) who proposed the existence of either a Mesozoic continent or a series of land-bridges that connected all islands. Forest B.H. Brown, who later composed the Flora of Southeastern Polynesia (1931; 1935), argued that the Hawaiian island flora originated from a disturbed isthmus region of Central America beginning in the Jurassic. He proposed seed dispersal \textit{via} rafted Gymnosperm wood as the primary long-distance dispersal mechanism (Brown, 1921; 1922; 1928). Harold B. Guppy (1906) focused instead on seed buoyancy, concluding that plant propagules are heavily dependent on chance establishment. Like Darwin, he found that ocean current dispersal accounts for relatively little of the floras of the most remote islands including the Hawaiian Islands. It was not until James Small (1919) provided evidence for airborne seed and spore dispersal that wind was recognised as an effective carrier of plant propagules. The evidence for long distance plant dispersal challenged a developing view at that time that geographical isolation played a more important role in plant speciation (e.g. Abrams, 1905; Allen, 1905) as advocated in the case of certain land snails (e.g. Gulick, 1872) and Pacific fish species (e.g. Jordan, 1905; 1908).

More systematic surveys of plant dispersal mechanisms began with Carl Skottsberg (1925) who compared the floral origins of the Hawaiian and the Juan Fernandez islands. Henry N. Ridley (1930) attempted a general overview of the subject, later followed by Elmer D. Merrill in a number of publications (e.g. Merrill, 1946). Sherwin Carlquist (1967; 1974) presented the most detailed study to date on long distance plant propagule dispersal and remains its leading advocate for characterising the constituents and ecology of oceanic island floras. Carlquist (1996) later conceded that despite the overwhelming evidence for long distance dispersal, the rarity of successful establishment, allowed other mechanisms to be postulated (e.g. vicariance or pan-
biogeography). He earlier proposed that successful establishment of populations derived from
distant archipelagos would only occur in rare events operating over millions of years (Carlquist,
1980). To Carlquist:

‘The endemic nature of species on oceanic islands is indirect evidence of rarity of successful
establishment, a necessary correlation because frequent reintroduction of a species prevents
development of an endemic derivative.’ (1996: 153)

Nowhere in his examination of long distance dispersal has any other process been invoked that
makes the connection between prolonged establishment and eventual speciation. The vicariant or
isolating role of disturbance, so pronounced on oceanic islands, could equally account for the
endemic character of particular species. This does not deny the efficacy of long distance dispersal
but suggests other processes may have played an equivalent historical role.

Disturbance and island floras

Explanations for the indigenous character and dispersal origin of island floras are often based on
the assumption of a stable terrestrial and marine environment (Hope, 1996). Fosberg (1963: 5)
noted of most the Pacific island environments immediately prior to human settlement that ‘the
older island ecosystems had reached such relative stability that changes were mostly very slow’.
On the contrary, palaeoenvironmental data for the Quaternary suggest disturbance processes were
more pronounced on the oceanic Pacific islands than on the adjacent continents (e.g. Enright and
Gosden, 1992). Exposure to tectonic activity, fluctuating sea levels, tsunamis, cyclones and
volcanic ash fallout have produced an uneven array of geomorphic signatures across many
islands, some indicating entire removal of habitats suitable for particular vegetation types. Apart
from the plant fossil proxy indications for fluctuating sea level (e.g. mangrove sediments;
Woodroffe, 1987; Ellison, 1989) most of the aforementioned disturbances are generally poorly
exhibited in proxy records for floral or vegetation change (e.g. pollen, charcoal particles,
phytoliths and plant macrofossils). The taxonomic precision of fossil pollen records has allowed
some past climatic patterns to be inferred on the basis of referential indexes of modern climate
affinities of the plant taxa represented. Climatic variation, along with any marked pattern of
disturbance, has not been unequivocally detected in the pollen record. Fire signatures have been
recognised from many palaeoenvironmental records from the oceanic Pacific islands. Outside of
human-induced burning, fires could result from volcanic ash, lightning strikes or cyclones. The
extent to which such disturbances regimes have influenced the indigenous character of many
island floras has been blurred by the unprecedented environmental changes evident with human arrival (see Chapter 6 for further discussion).

Phytogeographers have tended to concentrate on historical distributional data for species as well as the comparison of complete island floras in search of vicariant and sympatric patterns or other geographical explanations for floral composition. The most comprehensive study of historical biogeography data on floral immigration and extinction comes from studies based on the post 1883 sterilisation event on the Krakatau islands. Whittaker et al (2000) found that the structure of the Krakatau flora could best be described on the basis of the establishment of viable populations by 1934\textsuperscript{12} within the first 50 years of the disturbance (volcanic sterilisation). Current records (1979-94) of population viability or extinction could be determined by considering whether these populations were on the increase or in decline, respectively, within those first 50 years. The current structure of the flora could not be attributed to stochastic causes and was only partly a function of species vagility.

Along longer time scales (over millions of years), it is thought that island geological diversity and centres of tectonic activity may provide a good indication of floral diversity and rates of endemism. Using a limited phytogeographical dataset of the continental island Malesian flora generated in 1971, Balgooy et al (1996) found that the biogeography of plant endemism in comparison with geological data suggests that a correlation exists between points of Tertiary or earlier plate tectonic activity and the proportions of endemic taxa in a given area. It is suggested that the collision of more than 30 tectonic plates in northern New Guinea probably initiated the most speciation. The geologically diverse islands of New Caledonia, for example, have the most (100) endemic genera and the highest rate of endemcity anywhere in the Pacific (Jaffré, 1993; Morat, 1993). By comparison the relatively uniform geology of the neighbouring Vanuatu and the Santa Cruz Islands is recognised with only one endemic genus (Balgooy et al 1996).

On islands such as Rapa, plant speciation events may have taken place within a shorter timeframe, both within and between the interceding glacial periods culminating in the Last Glacial Maximum (LGM; 22-16 ka) and the Penultimate glaciation (~150 ka). From the minimal amount of sea floor bathymetric data from off the coast of Rapa, with the sea-level at LGM approximately 120-110 m below present (Shackleton, 2000), the terrestrial area of Rapa would have at least been doubled. Satellite islets surrounding the main island were joined with the main island and the current disjunct cloud forest (>350 m) would have formed a continuous tract above a more extensive stretch of lowland vegetation. Around 200 km to the northwest/west of Rapa is Nielson Bank), a shallow submarine reef system that during the LGM may have represented a considerable island, perhaps up to 50 km\textsuperscript{2} in area. A similar but smaller terrestrial extension to Marotiri, 90 km to the southeast/east of Rapa, could also be inferred from current sea-floor

\textsuperscript{12}The final year of the initial survey period running from 1883-1834. This was summarised by W.M. Docters van Leeuwen (1936).
topographic data (e.g. McNutt et al. 1997). Increased species dispersal between the connected islets and the extended adjacent islands occurred during glacial sea-level regressions. This was followed by increased isolation or extirpation of populations on the outer islands, islets and the retracted cloud forests accompanying post-glacial sea-level rise. Such a sea-level driven mechanism for habitat heterogeneity and consequent allopatric speciation has been inferred for the few other oceanic islands with satellite islets or islands such as Tahiti and the Hawaiian Islands (e.g. Levin, 2000). These islands appear to have a disproportionate endemicty of both floras and faunas compared to islands without satellites.

In examining the characteristics of island strand floras of the Indo-Pacific, Andreas Schimper (1891) found that the capacity of these species for establishment is dependent on how frequently coastal habitats are disturbed by more immediate ocean events (e.g. storms, tidal surges and tsunami). Although not directly referring to island environments, Edgar Anderson (1948) suggested that disturbance has the capacity to create a more benign and heterogeneous environment where plants, particularly hybrids with recent adaptations, may more readily establish. Such habitat or niche differentiation as a primary cause of speciation in floras has been examined by a number of authors (Clausen, 1951, Grubb, 1977; Grant, 1981 in Levin, 2004: 225). More recently, the relationship between disturbance as a potential precursor to colonisation or invasion has been noted for many situations globally (e.g. Hobbs, 1989). Levin (2004: 225-227 after Hubble, 2000) proposes ‘long-term or repeated, episodic disturbance at the landscape level as the prerequisite for invasion.’ He notes that the removal of stresses placed on species may induce a similar response to that exhibited by disturbed species. He also suggests that the many documented cases of adaptive radiations and rapid diversification of plant species on oceanic islands ‘presumably occurred because of the ability of lineages to take advantage of ecological opportunities’ (i.e. creation of vacant niches by disturbance).

The extinction of plant species outside of the human impact sphere is typically attributed to contingent environmental and demographic effects or to environmental changes which have removed a particular habitat or rendered it uninhabitable (e.g. Harrison, 1991). Such changes may involve increases in disease, predation, or decline in a symbiotic mutualism, and for small populations may also involve inbreeding depression. Generally, it can be assumed that environmental and demographic factors will outweigh genetic constraints, particularly for small populations that are inherently more vulnerable to extinction than large populations (e.g. Lande, 1988), a factor that Darwin pointed out in Origin. Island floras are typically low in diversity especially at the genus level rendering them more prone to the effects of invasive species than continental floras (e.g. Vitousek, 1988; Mueller-Dombois and Loope, 1990). In many instances such invasive taxa actively displace indigenous species, resulting in extinctions, of which a growing number have been documented.
Long distance vagility of various plant taxa may account for the presence of plant propagules on islands but may in fact be a very poor predictor of successful plant establishment. For example, both viable and sterile tropical plant propagules of a large range of species can be found in beach drift along the coasts of temperate Australia (Smith and Kinnear, 1998). As few of these taxa have established viable populations, vagility may also have very little to do with the process of immigration or extinction that give rise to the endemic character of island floras. What now seems unequivocal is that disturbance plays a contingent role in the speciation (immigration included) or extinction processes on islands, perhaps more so than on continents. Gould, (1995a: 12-16) in reference to Darwin’s entangled bank, suggests that:

‘the same patterns do not always recur from adjacent starting points colonised by the same set of species. Even the most apparently predictable patterns of supposedly established orders may fail.’

A fertile plant propagule may successfully make it to an island shoreline through some long distance dispersal mechanism but establishment and proliferation is dependent on environmental and historical contingencies. It may be that historical contingencies control the influence of many environmental disturbance factors in propagule establishment. Long distance (dispersal) vagility has more often been offered as the only possible explanation beyond which all other influences are seen as entirely random. For many authors (e.g. Carlquist, 1974; Fosberg, 1984), long distance dispersal has been seen as a process of chance in itself. However, the production and proliferation of many large-seeded plant species in the Pacific islands, for example, despite seeds being recorded in long-distance drift, of which the seed viability is unknown, are more dependent on local dispersal and predation by fruit bats, crabs and rats for recruitment (e.g. Ash, 1987 for Pandanus tectorius on Fiji). Preferential intra-island dispersal and post-dispersal predation of these seeds by fauna, especially rats, has had a measurable impact on vegetation composition and ecological dynamics on islands such as Tonga where nearly 80% of the forest tree species and lianas are vertebrate dispersed (McConkey et al 2003). Historical changes in the types of seed dispersers and predators, with some documented species declines and extirpations recorded, has significantly changed species recruitment independently of long-distance dispersal vagility (McConkey and Drake, 2002). From such data it has become apparent that it is the quantity of seeds dispersed to a site and the factors influencing plant establishment at a site that provide a more measurable indication of vegetation composition. Disturbance events including light-gap creation after tree-

13To Gould (1995b: 8-15), contingency has a meaning distinct from chance or stochastic processes:

‘pure chance precludes any explanation of particulars, but contingency, while denying that predictions can be made with confidence at the outset, does assert the possibility of explanation after a particular history has unfolded. Contingency is the historian’s mode of knowability; pure chance denies the explication of particulars.’

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fall and limitations on seed dispersal are seen as equally important to plant establishment potential in tropical locations (Hubbell et al. 1999).

Cultural history and the origins of floras in OIRO

The differential dispersal and establishment of Pacific island faunas and floras have permeated discussions on the colonisation of this region by people since at least the Enlightenment voyages. J.R. Forster, who joined Cook on the HMS Resolution voyage in 1773, published a work centred on both the comparative biogeography and ethnology of the Pacific (Forster, 1778). His discussion of cultural geography focused on the disjunct distribution of languages in the Western Pacific, noting the unity of language distribution in the east. These observations inspired ideas of cultural diffusion and race later elaborated by Jules-Sébastien-César Dumont D’Urville (1832; 1841; 1987) who separated a Polynesian and Melanesian geography on the basis of a rigid classification of the physical appearances of people (see D’Arcy, 2003). While the physical distinctions were rigidly defined, the geographical distinction was more vague in the late eighteenth and early nineteenth centuries when Vanuatu and New Caledonia were often termed ‘Western Polynesia’ and later incorporated into the Melanesian geography (Thomas, 1989; 1996).

This Enlightenment cultural geography also entered discussions on the regional schemes of biogeographic patterning of the Pacific. Prior to the publication of Dumont D’Urville’s ideas of race distribution in the Pacific (1832; 1841), Joachim Frederik Schouw (1823) in Grundtræk til en almindelig plantegeografi sketched a regionalised plant geography that included a Polynesian region based on a limited floral database established from existing plant collections. Schouw never travelled to the Pacific but established his Polynesian plant geography in a form that appears to combine the systematic framework of de Candolle’s (1820) areas of endemism as well as the geographic implications of cultural diffusion stressed in Forster’s ethnological examination. Schouw’s 1823 publication is not clear about the role he affords humans in the distribution of various plant taxa, but this role is explicitly addressed in his more notable thesis The earth, plants and man first published in 1845. Here he expanded his ideas on plant geography to explore the problematic of the interaction between human society and the environment, something not explored in such detail by any of his more notable contemporaries (e.g. von Humboldt, 1816; 1820). Schouw writes:

‘can it be stated that the different characters of nations are determined by, or at least essentially dependent upon, the nature which surrounds them? ... Such a dependency is generally assumed by historians, philosophers, naturalists and poets; but, nevertheless, I dare assert that this opinion represents a great error, which has only become so general because conclusions have been drawn on the
subject with a superficiality which would not be endured in any other science.’ (1852: 240-246 in Olwig, 1980: 32)

Olwig (1980) describes Schouw as one of the founders of plant biogeography, but also as one of the originators of the hermeneutic tradition as applied to geography, seeing structure in the process of interaction among humans, other species and the environment in establishing their own design outside of any existing natural order. This was to some extent a response to the then prevailing ‘classical’ (cf. Foucault, 1973) notions of cultural diffusion determined from environmental constraints. Such classical ideas were introduced in regard to the Pacific region by Dumont D’Urville and later explored for Polynesia by a spate of authors (e.g. Fornander, 1878-1880; Fraser, 1895; Smith, 1898; 1921).

The inclusion of a human dimension in Schouw’s Polynesian plant geography is perhaps not surprising given the emphasis placed on economic plants in the Enlightenment accounts and the notable pre-Linnaean (cf. Linnaeus, 1758) *Herbarium Amboinense* of Rumphius (1747) with his Indo-Malayan collection of plant esculents. The naturalists on board Cook’s 1768-1779 voyages recorded at least 37 species of ‘weeds’ and plant cultivens that were regarded by a number of later authors as intentional or inadvertent human introductions (e.g. Guppy, 1906; Ridley, 1930; Merrill, 1954). The collectors themselves questioned the origin of many of these plants compiling lists of economic plants deemed unequivocal human introductions and mentioning the possibility for many other species (e.g. Forster, 1786). They also enumerated local plant vernacular as part of their record of the Pacific lexicon, and put forward the possibility that there was some generalised Indo-Malaysia to Polynesia distribution of cultures and floras within Polynesia (Banks, m.s.; Monkhouse, m.s.; Solander, m.s.; Forster, 1774 in Rensch, 1991).

With the establishment of mission stations and other colonial settlements on many of the islands in the early nineteenth century, many foreign residents began to elaborate on these ideas in their documentation of the traditional and economic use of plants (e.g. Ellis, 1831 –see Merlin, 2000 for a brief history). Some of the earliest lexicons compiled for Polynesia, largely completed by missionaries, are laden with descriptions of both economic and indigenous plants (e.g. Hale, 1846; Davies, 1851). From the late nineteenth onwards, the development of a Polynesian plant vernacular has been seen as an accessible form of enquiry for botanists, ethnologists and linguists alike, inspiring a number of explorers with little expertise in any one of the relevant disciplines to take up the pursuit (e.g. Powell, 1868; Pickering, 1879; Guppy, 1896; Christian, 1897; Cook, 1901; Safford, 1921). Plant vernacular began to form part of systematic linguistic examinations of cultural origins in the region. The linguist William Churchill (1911; 1912) proposed an eastern Southeast Asia origin, an opinion at odds with the prevailing linguistic and ethnohistoric synthesis centred on Eurasia (e.g. Tregear, 1891). He also suggested on linguistic grounds that people entered the region through two independent routes.
Systematic botanical interpretations of the distribution of ‘Polynesian’ plants often included commentaries on possible introductions and traditional plant use. Berthold Seemann (1865) was exceptional in his extensive commentary on the introduced element of the Polynesian flora, focusing more directly on Fiji. He also commented on the weeds of Fiji suggesting that their ability to spread was dependent on the amount of cultivated land or habitats otherwise disturbed by people. Comparable to Seemann’s treatment of Fiji, Hillebrand’s (1888) early synthesis of the Hawaiian island flora provided considerable detail on plant productions and introductions. Apparent in both botanists’ work was a lack of congruence between ethnographic and botanical data in differentiating plant dispersal by humans from other mechanisms.

Such botanical data did not rest easily with treatments of the subject by ethnographers. In his Origins of cultivated plants volume, Alphonse de Candolle (1886) outlined a number of asymmetric patterns and conflicting viewpoints on the west to east distribution of plant cultigens; as a primary example, the American origin of sweet potato (Ipomoea batatas- see Yen, 1974 and Chapter 8). This later contributed to the more complex problem of the human settlement and cultural origins of the eastern Polynesian islands that persisted up until Yen’s (1991a; 1998) recent syntheses on the subject. Polynesian ethnographers including S. Percy Smith (1898; 1921) amongst others (reviewed by Bellwood, 1978) rigidly pursued diffusionist ideas of racial distributions and physiognomy, in the vein of Dumont D’Urville’s earlier assertions.

By the 1920s, ethnographic research in the Polynesian region was driven by museum-based ethnography. Thomas (1996: 41-49) suggests that ethnography during this period gave equal standing to the concerns of natural and cultural history and emphasised collecting any empirical detail of island societies and environments. A series of ethnographic descriptions of Polynesian societies, mostly from the Bernice P. Bishop Museum in Honolulu, according to Buck (1945: 125 in Thomas, 1996: 44) were intended ‘to gain a picture of native culture as it existed before the changes due to foreign contact began to take place’. Thomas’s version of this museum ethnography emphasises the diachronic separation between the static ‘native cultures’, uncontaminated by foreign contact and the historical acculturation process set in place upon foreigner arrival:

‘What is native is simply in a process of fading away. It may be less visible, but it has not apparently changed through accommodation, reaction or adaptation to new conditions, nor does transformation seem to consist of anything more than displacement. Indigenous culture exists in a quantity which is reduced more or less according to the degree of foreign influence...’ (Thomas, 1996: 45)

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14This may have been in part a reflection of the growing awareness of human impacts on the environment as espoused by Joachim Schouw (1852), Thomas Huxley (1863) and George Perkins Marsh (1864).

15Thomas (1996: 42) lists a number of the key publications in this regard that were seen as authoritative texts by Buck (1945) and Goldman (1970). Ethnographies of this period relevant to this thesis include: Firth, 1936; Aitken, 1930; Metraux, 1940; Stokes, n.d.
Island floras and faunas were viewed in much the same way as people, again in a process of ‘fading away’. Many of these museum ethnographies provided extended commentaries on plant use, particularly agricultural production, material culture, medicinal uses and occasionally religious idolatry and symbolism. First contact narratives were employed simply as a demarcation point for assessing the impacts of foreign influences on the flora and fauna, but also foreign introductions. Some authors attributed the distribution of *I. batatas* in the Pacific to early Spanish explorers (e.g. Frederici, 1929). This view was countered on historical and ethnological grounds where a number museum ethnographers, including J.F.G. Stokes (1932), pushed for a Polynesian introduction into the Pacific based primarily on information drawn from Polynesian oral histories (see also Dixon, 1932; Hornell, 1946).

Museum-based botanists, who often relied on the field collection of herbarium specimens by ethnographers, were more often drawn upon in assessments of the antiquity of human disturbance. Alfred Metraux (1940), in his *Ethnology of Easter Island* quoted Skottsberg (1920) as an authority for his then contentious views about the pre-existence of forest vegetation on Easter Island prior to Polynesian arrival (see Chapter 4). Botanists began to create an image of what the indigenous or exotic characters of different plants might be. Plant species were characterised by some authors as being introduced by Polynesians if they were shown to have any ethnobotanical significance. Their status within cultivation systems or associations with habitation sites was often critical in defining human introductions. The distribution of economic plants also inspired some botanists to focus on specific cultigens (e.g. Wilder, 1928 on *Artocarpus altilis*).

In a number of articles, Merrill (1917; 1939; 1954) synthesised the growing body of information on the antiquity, origin, and dispersal of economic plants for the Indo-Pacific, following from Rumphius’s’ earlier descriptions of the cultivated plants of the Indo-Malayan region and de Candolle’s ideas on their origins. His study of the weeds and cultivated plants of Polynesia recorded at the time of Cook’s voyages provided an additional insight into the human settlement of the Pacific Islands from an Indo-Malayan origin (Merrill, 1954). At the same time, St John (1953) noted that the majority of ‘sustenance’ plants present in Polynesia prior to European contact could also be found cultivated in Indonesia and New Guinea, he thus proposed a migration route through Indonesia, New Guinea and Melanesia for Polynesians. Jacques Barrau (1955; 1956; Massal and Barrau, 1956) elaborated on this pattern of cultigen distribution but also

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16 e.g. Forest B.H. Brown, Carl Skottsberg and G.P. Wilder, who were all employed at the Bernice P. Bishop Museum during the 1920s.
17 Rumphius also contributed to the *Ipomoea batatas* debate, identifying the cultivated plant, from his Dutch East Indies collections, as a historic Spanish introduction (Yen, 1974b).
18 Both Harold St John and Elmer Drew Merrill were also based at the Bernice P. Bishop Museum for a period during the 1930s.
stressed the associated diversity of agricultural production systems, including a number of tree crop species restricted to New Guinea and the east Pacific (e.g. *Artocarpus* - breadfruit).

**Recent approaches to the origins and introduction of plant cultigens to OIRO**

To many botanists, and ethnobotanists alike, the plants that were seemingly incapable of dispersing long distances through ‘natural’ means, must have reached the islands as intentional or inadvertent human introductions. Skottsberg (1920-1956; 1925), who worked chiefly on the Juan Fernandez Islands, Easter Island and Hawaiian Islands, was a strong advocate for long-distance dispersal and suggested very few taxa aside from plant cultigens were human introductions. Brown (1931, 1935) expressed a contrary view in discussing the flora of Southeastern Polynesia that includes French Polynesia, the Pitcairn Islands and Easter Island. He suggested that prior to European arrival (i.e. of Medaña de Neyra in 1595), Polynesians were responsible for nearly half of the number of exotic species recorded on the islands during his botanical surveys from the 1920s-1930s. The apparent continuity between certain island chains in the presence or absence of particular economic plant species provided further impetus for ideas of cultural diffusion from Southeast Asia and cultural homology within Polynesia (cf. Merrill, 1954). Part of this floral origin dilemma was brought about by a lack of temporal controls and constraints on plant ecology fuelled by the debate centred on long-distance dispersal processes (e.g. Riley, 1930; Carlquist, 1967).

Nikolay Vavilov (1949-1950) developed the modern theoretical phytogeographic framework for examining the centres of origins of cultivated plants, utilizing taxonomic, genetic, biogeographic and historical forms of botanical analyses. He defined a number of origin centres for cultivated plants on the basis of a range of evidence, concentrating on the diversity of ‘basic varieties’ as revealed by the variability and composition of plant characters. A number of criticisms of this idea have been made, including that it fails to take into account the effect of hybridisation and introgression that may act to obscure a centre of origin. Nevertheless, such a theoretical framework has still found favour, particularly with the advent of cytological and later molecular analyses of cultigen phylogenies. Such systematic botanical treatments again threw into question the origins of a number of cultivated plants, most notably *I. batatas* (sweet potato), *Artocarpus altilis* (breadfruit) and *Colocasia esculenta* (taro) (see Chapter 8). These taxa are three iconic examples of clonally reproduced cultivated plants of Remote Oceania which also illustrate the three predominant directions of human introduction to the region from three probable Vavilovian centres of cultivated plant origin.

For the representatives of the Austral Island flora and OIRO floras in general, very few phylogenetic analyses (hypotheses) are available (see below and Chapter 8 for examples). Many
of the plant cultigen taxa of Remote Oceania are problematic given bias towards vegetative reproduction (Lebot, 2002). Some taxa are dioecious (having separate male and female plants, e.g. *Pandanus* spp. and *Broussonetia papyrifera*) whereby genetic signals presented within modern populations are often too weak to securely differentiate populations. The location of suitable molecular markers has been critical in the development of phylogenetic toolkit. For example, the Amplified Fragment Length Polymorphism (AFLP) technique has often been chosen for such examinations due to its ability to detect polymorphisms in closely related species and cultivars where in other techniques (e.g. isozyme analysis) they would remain identical.

In a recent molecular study using AFLPs, Zerega (2003; see also Zerega et al. 2004) showed that the Pacific cultigen, *Artocarpus altilis*, has a polyphyletic lineage derived from a number of monophyletic wild species, namely *A. camansi* (New Guinea) and *A. mariannensis* (Marianna Islands). The polyphyletic lineage of breadfruit populations from East Polynesian region that includes the Austral Islands, were more closely affiliated with *A. camansi* than *A. mariannensis* to which modern Micronesian region populations were closely related. The documented 19th century human introduction of *A. mariannensis* derived *A. altilis* cultivars from Micronesia to Tokelau, not recorded elsewhere in Polynesia, was detectable using AFLPs in measuring the diversity amongst these populations using the percentage of polymorphic loci as an index. Zerega’s study demonstrates the efficacy of AFLP based phylogeny to pinpoint origin centres of diversity for *A. altilis* populations. However, without knowledge of historical introduction of Micronesian cultivars to Tokelau and the east Pacific island population pool, the security of these claims would be weakened.

Zerega’s study illustrates the importance of historical factors in the interpretation of the genetic variability of plant introductions. Some populations that may have been introduced with the initial human colonization of Remote Oceania may have hybridised with wild relatives or with modern or post European contact introductions from markedly different genetic sources. These historical factors can really only be adequately assessed through the examination of archaeological and palaeobotanical material associated with human settlement period sedimentary deposits. Such data can rarely if ever account for multiple introductions from multiple genetic sources. Ethnobotanical and historic documentation can provide some indication of the introduced status of some plants, but equally rarely account for the possibility of multiple introductions from multiple genetic sources.

**Recent approaches to floral extinctions in OIRO**

As mentioned earlier in this chapter, plants appear to be more resistant to extinction than animals (James, 1995). This could be a function both of the paucity and lack of resolution of historical
and plant fossil data and perhaps of the lack of empirical data on extinction processes. By far the main focus for extinction ecologists has been megafaunal extinctions (e.g. MacPhee, 1999) and human impacts on island environments (e.g. Diamond and Case, 1986; Diamond, 1989). A number of anthropogenic extinction models including overkill, blitzkrieg (rapid overkill) and sitzkrieg (fire, habitat fragmentation, and the introduction of exotic diseases) have been considered (Diamond, 1989; Barnosky et al 2004). Megafloras on oceanic islands have rarely, if at all, been demonstrated to go extinct because of environmental causes without some anthropogenic influence (ibid). These same trends can be applied to island avifauna (Steadman et al 2002) and probably island plant species.

Modern ecological studies of extinction processes have been considered at two levels: (1) the extinction of local populations (extirpation), and (2) the near extinction of species (Levin, 2000). For plants, one of the best historic records of extirpation comes from a herbarium collection survey of a tropical rainforest fragment in the Singapore Botanical Garden since 1859. Turner et al (1996) found that of 448 historically documented species, 51 % (228) of species have been extirpated. Of the Hawaiian Island flora (Wagner et al 1990), consisting of ~1000 species, over 100 species are now presumed extinct or extirpated with 3-400 near extinction (Gemmill et al 1998).

Historic records of human impact have revealed a number of plant extinctions on several other islands. On St Helena Island in the mid-Atlantic a number of extinctions of endemic taxa have resulted from over-grazing by feral goats (Cronk, 1992). Several islands in the Pacific were known to have significant stands of sandalwood (Santalum spp. – some are endemic species or varieties) that were subsequently exploited in the 19th century sandalwood trade, later became extinct (e.g. Juan Fernandez Islands, see Wester, 1991). The effect of invasive species on the extinction processes of this type is clearly compounded by human disturbance, with the invasive species in question usually a direct result of human introduction. A primary example is the historical (1937) introduction of Miconia clavescens to Tahiti (French Polynesia) that has resulted in the possible extinction or at least extinction threat of a number of endemic species (Meyer and Florence, 1996; Meyer et al 2003).

Palynological studies, in conjunction with modern floral surveys, remain the primary means of detecting possible extinction events in the plant fossil record. Palynological records from throughout island Remote Oceania suggest that widespread habitat modification coincided with the timing of human settlement based on archaeological findings (e.g. Flenley, 1994). Such modification is thought to have induced a decline in fauna diversity with numerous avifaunal extinctions (e.g. Steadman, 2002). Few unequivocal plant extinctions have been documented in the region from the palynological record within the human settlement timeframe established from the archaeological record. The palynological record from Easter Island offers the clearest signal of plant extinctions that have taken place within the last 2000 years prior to European
colonisation (see Chapter 4). Eleven plant extinctions have been identified to at least the plant family level (Flenley et al 1991). Subsequent research on records of archaeological charcoal, radiocarbon dated to within the last 600 years, has revealed a further seven plant extinctions, some of which are possibly endemic taxa (Orliac and Orliac, 2002; see Chapter 4).

During the Holocene, prior to the human colonisation of island Remote Oceania, local extirpations and possible extinctions may have followed volcanic eruptions (e.g. Hawaiian Islands) or large-scale tsunami events. Floral sterilisation of Pleistocene atolls is likely to have occurred following complete inundation during the post-glacial marine transgression. A mid-Holocene (6,000-4,000 cal. yr B.P.) sea-level rise of up to ~2 m in the central Pacific (e.g. Dickinson, 2001) is known to have sterilised the Tuamotu Archipelago (Pirazzoli and Montaggioni, 1986). Direct evidence for species extinctions has not become available and is unlikely to be forthcoming.

A combination of phytogeographical and phylogenetic studies of the intraspecific genetic variation across island populations has been used to infer plant extinctions in the Pacific. Using chloroplast DNA microsatellite markers, Butaud et al (2005) assessed the distribution of molecular variation of the sandalwood species, Santalum insulare, an endangered tree species found only in French Polynesia, the Cook Islands and Pitcairn Island. This hemiparasitic tree grows on a wide range of habitats and on a diverse range of host species. The genetic relationships between island populations show that there is a closer relationship between populations on the Marquesas Islands and Rapa populations than for Rapa, Ra’ivavae, the Cook and Society Islands. Butaud et al (ibid) suggest that these genetic patterns may be a result of a combination of dispersion by birds and vicariance, but also as a consequence of the extinction of intermediary populations on the Tuamotu atoll islands that intercede the Marquesas Islands and Rapa. These islands were formerly highly elevated volcanic islands prior to their intermittent subsidence during periods of sea-level rise (e.g. during the post-glacial rise and mid-Holocene highstand). Extinction on these islands may also be due to recent impacts on the Tuamotus following human settlement.

A more difficult genetic relationship to document is the role of hybridisation of congeneric species (species of the same genus) in the extinction of insular and endemic species (Levin et al 1996). Insular species are more prone to interbreeding and hybridisation because they tend to be less genetically diverse and to have weaker barriers to crossing including poorly differentiated floral anatomy that may facilitate cross-pollination (Carlquist, 1974). Longer flowering seasons in tropical and subtropical islands coupled with greater proportions of generalist pollinators increase the likelihood of hybridisation (ibid). Any disturbance process that promotes habitat fragmentation may assist greater contact between endemic species and compatible congeners.

Disturbances that promote the establishment of congeneric species outside of human influences can be inferred from a number of basic assumptions. Firstly, during periods of elevated sea level
such contact is likely to have been reduced due to decreased habitat availability in the coastal lowlands of islands. The factors that may promote hybridisation are often compounded by human disturbance on islands (Levin et al 1996), but such an extinction process could equally apply to pre-human settlement island environments. Secondly, the degree to which congeneric hybridisation has caused species extinctions, however, is unlikely to be distinguishable in the fossil record and can only be speculated upon. In the Hawaiian Islands and other Pacific islands, historically introduced Gossypium barbadense has been found to hybridise with endemic species of the same genus, threatening the Hawaiian endemic G. tomentosum (DeJoode and Wendel, 1992).
Chapter 3

'500 leagues from Copiapo': macrohistories and the conception of time

In Chapter 2 I examined the role that distance between islands has played in the development of island phytogeography. The chapter also provided an overview of how the geographic or spatial patterns of plant species have been related to the human colonisation of Remote Oceania. I emphasized the importance of disturbance in the generation of phytogeographic patterning and how the role of human disturbance has been misrepresented in biogeographic theory. In this chapter, I concentrate on the role that the historical and temporal differences between islands have played in the reconstruction of island biogeography and how this may be related to cultural geography. I again emphasize disturbance, but concentrate on its role in generating historical pattern. I examine the way disturbance is perceived in island histories and how this is dependent on the construction of chronology and the conception of time. I focus on how phytogeography has been utilised in the 'orthodox' and 'macrohistorical' positions seemingly established for the archaeology and environment of the Pacific Islands.

The macrohistorical view of Easter Island’s environment

In 1687 Edward Davis on board the Batchelor's Delight sighted a low and sandy island around ‘500 leagues from Copiapo’ at 26° 56’S in latitude. His testimony was initially transcribed by William Dampier (1699) and later embellished in 1704 by Davis’ ship’s surgeon Lionel Wafer (Joyce, 1933). It was Wafer’s account that inspired Jacob Roggeveen’s exploration of the region, eventually sighting Easter Island at latitude 27° 07’S on April 6th 1722. The position of the island was enough to convince Roggeveen that this may have been Davis’ island, but Wafer’s description of a ‘Sandy Island’ contrasted so much with Roggeveen’s observations that he asserted that ‘the discoverers [Davis] must stand convicted of a whole bundle of lies in their reports, told by word of mouth as well as in writing’ (Gonzalez, 1908: 10). On initial observation, parts of the island appeared covered with ‘a soil of that arid nature’ that was originally mistaken for ‘parched-up grass, and hay or other scorched and charred brushwood...’ (Gonzalez, ibid)

1 The explorer Edward Davis provided this description for a ‘Sandy Island’ which Dampier (1699) believed could be uncharted land.
2 Métraux (1940:36) suggests Davis sighted Mangareva (23°1’S) not Easter Island. The description in Davis in many ways better describes Henderson Island given its predominantly calcareous coastline.
3 Other names for Easter Island include Paásch Eyland, Rapa Nui and Te Pito te Henua.
Roggeveen’s account marks the starting point for Easter Island’s contested past environment. Between the years 1727 and 1838, before Roggeveen’s own journal was first published (Roggeveen, 1838 in von Saher, 1993), the main sources of information regarding the 1722 sighting were ‘of a markedly corrupt and misleading character….‘ (Roggeveen, 1970: 14-15). Two anonymous authors published between 1727-28 spurious accounts of the voyage, in which they described, for example, Easter Island men as giants twelve feet in height (von Saher, 1993). Despite the refutation of these claims upon distribution of Roggeveen’s journal over 100 years after his death, the island environment and human society have remained the subject of popular speculation and contention. In 1859, Rev. William Ellis of the London Missionary Society surmised that:

‘Nothing can be more contradictory than the descriptions different voyagers have given of the appearance of this island. Some, as in Roggewein’s account, and that of La Perouse, representing it as rich and fertile; others, as Forster, describing it as parched and desolate. The population, which La Perouse estimated at about two thousand, is supposed by Kotzebue to have increased; by others they are said to have decreased, and not to exceed 1,200.’ (Ellis, 1859 Vol III: 325)

This constant speculation has been centred partly on its geography, unique in that it is isolated by nearly 3,000 km of ocean and that it presents a forestless ‘un-Pacific-island-like’ terrain. By far the most attention in the recent ‘orthodox’ narratives has been placed on the construction and transport of the carved moai stone-statues, and more recently on the fossil evidence for an extinct palm tree (Paschalococcus disperta; Zizka, 1991) thought to have covered much of the island’s surface (Mieth et al 2002; Bork and Mieth, 2003).

Bahn and Flennery’s (1992) Easter Island, Earth Island is the latest popular account of this ‘orthodox’ position. In their description, overpopulation of the island led to an environmental catastrophe that in turn fueled what has been termed a cultural devolution. The catastrophe was the loss of the palm through forest clearance that began with the arrival of people at ~1200 yr B.P. and was largely completed 200 to 300 years prior to Roggeveen’s arrival.

Apart from a few introduced coconut trees (Cocos nucifera) no indigenous palms remain on the island, but it is equally striking that no indigenous terrestrial birds survive. Bones of one species of heron, two rails, two parrots and an owl were identified from an archaeological deposit from Anakena dating to around 1,000 yr B.P. (Steadman et al 1994). Elsewhere in the Pacific such losses of island avifauna have commonly been used as measures of ‘ecodisaster’ extent (e.g. Martin and Steadman, 1999). Anderson (2002: 375-376) has suggested that they could equally be

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5 Erich von Däniken’s Chariots of the Gods (is perhaps the most extreme example of this Easter Island imaginary.
interpreted as an 'ecotriumph' or as an 'optimal strategy of initial survival... [that] got small colonizing populations of people past the demographic danger point as quickly as possible.' So why then are these palms accorded such significance in the orthodox scenario of Easter Island's collapsed society?

The removal of palms and other tree species is seen as a response to agricultural development, canoe building and house construction, but most importantly in Bahn and Flenley's reconstruction, palm trunks were removed for use as rollers for the transport of the famous moai statues from the quarries in the island's interior to platforms (ahu) at the coast. Palm clearance was compounded by the introduction of Pacific rats (Rattus exulans) by the early settlers, restricting regeneration by the consumption of palm fruits: gnaw marks have been found on a number of fossil palm endocarps (e.g. Dransfield et al 1984). The consequences of palm removal were increased soil erosion, habitat loss for endemic fauna and the gradual restriction of agricultural development and re-vegetation. The pressures on the island's society as a consequence of palm deforestation induced competition for resources and status amongst the various Matatoa chiefdoms, leading to further moai manufacture, periods of starvation, warfare, cannibalism and yet more social upheaval. By 'AD 1680', according to genealogical estimates, forty-two years prior to Roggeveen's first documented visit, most if not all of the palm forest was destroyed following the rise of the Orongo birdman cult who gained power as a result of this social decline. Cult followers toppled the moai and replaced these idols with their own tribal symbolism.

This story of Easter Island's environmental and social history has been repeatedly popularized by several authors over the last century (e.g. Routledge, 1919; Heyerdahl and Ferdon, 1961; Heyerdahl, 1958; 1971; 1978; 1989; Dos Passos, 1971; Porteus, 1981; Bahn and Flenley, 1992; Loret and Tancredi, 2003; Flenley and Bahn, 2002; Diamond, 2005) and 'has become a cause célèbre for many people who wish to see this island as a microcosm of a possible world environmental catastrophe' (Rainbird, 2002: 437). In Bahn and Flenley's (1992: 214) orthodox position, this message is taken from the image of the last palm tree:

'The person who felled the last tree could see it was the last tree. But he (or she) still felled it ... Humankind's covetousness is so boundless ... the islanders came unstuck in a big way, and we could do the same.'

In Jared Diamond's (2005: 82) recent magnum opus entitled Collapse he suggests that deforestation on Easter Island 'proves to be the closest approximation that we have to an ecological disaster unfolding in complete isolation'. Behind Collapse are the discursive but rarely addressed roles of human agency and social choice in the face of environmental crises indicated in the book's subtitle How societies choose to fail or survive. In an earlier macrohistory entitled
Guns, Germs and Steel: the fates of human societies (1997), Diamond traced the determining historical and environmental factors that led to the rise of civilizations over the last 13 000 years. In Collapse, Diamond (2005) applies these same constraining factors in reverse, to explicate the demise of certain societies. In both theses, Diamond (ibid: 17-18) employs what he calls the 'comparative method' familiar from many of his other books that deal primarily with evolutionary biology and physiology (e.g. Diamond, 1992). This methodology accepts that laboratory experiments are unfeasible for the examination of many social and environmental phenomena where a 'frequent solution ... is to compare natural situations differing with respect to the variable of interest' (Diamond, 2005: 17). Many of his macrohistorical case studies have involved Pacific island histories, which are commonly viewed, because of their size and isolation, as adequate microcosms or natural laboratories of the macro world (e.g. Burney, 1997; Kirch, 1997; Fitzhugh and Hunt, 1997; Vitousek, 2002).

In Collapse, the social and environmental histories of a number of Pacific Island societies are broadly compared. Rolett and Diamond (2004) attempt to assess anthropogenic impacts more directly by applying a quantitative model systems approach to oceanic islands. In their comparison of islands it is assumed that the responses of island societies to given environmental situations are measurable and can, if understood, inform as to the decision-making processes or human intentions that led to the survival or failure of these societies. This paradigm of a human-induced environmental disaster as the cause of societal collapse on Easter Island, with Bahn and Flenley (1992) and Diamond (2005) as leading advocates, has been questioned by a number of authors. Most responses have gone towards the other extreme, either climatic change (e.g. McCall, 1993; Hunter-Anderson, 1993; Orliac and Orliac, 1998b; Nunn, 2000) or post-European contact influences (Rainbird, 2002) being seen as a more plausible cause for the present environmental condition of the island. These contentious aspects of the island's past environment have inevitably built on a range of historical interpretations that pose a diametric opposition.

There have been surprisingly few attempts by historians or archaeologists to make clear the limitations of these interpretations at the extremes. Anderson (2002: 382-383) for example, in commenting on Flenley's (1998) interpretation of the AD 1650-1700 population decline, suggests this is a time interval too narrow to assess in archaeological terms:

'The social upheaval that toppled the statues occurred mainly in the late eighteenth century (statue toppling had probably occurred throughout prehistory as lineage competitions were won and lost). Recorded population decline occurred in the nineteenth century. All estimates of the peak size of the prehistoric population are entirely speculative, it might never have exceeded the 2000-3000 that can be estimated from early historical records. Warfare was endemic on most Polynesian islands and does not indicate demographic collapse.'
Pervading most of these interpretations, including those of Diamond, are sets of inherent assumptions about the intentions of Easter Islanders in shaping their island environment. Rainbird (2002) traces the pattern of human modification on other Pacific islands whose environments have been enhanced to allow for human subsistence and settlement, a scenario he also imputes for Easter Island. By contrast, Bahn and Flenley (1992) and Diamond (2005) suggest that it is inevitable that social competition and population collapse should develop, and that this is a feature of Easter Island's isolation. Rolett and Diamond (2004) have attempted to characterize Pacific island environments, by examining their different susceptibilities, independent of human actions. They conclude that Easter Island's collapse 'was not because its people were especially improvident but because they faced one of the Pacific's most fragile environments' (Rolett and Diamond, ibid: 445).

Clearly one key dilemma in establishing the history of remote islands is the separation between the intentional responses of humans (social/decision-making factors) and environmental influences (e.g. island isolation and fragility), an issue that pervades all historical perspectives of Easter Island. This is an epistemological problem central to the derivation of meaning from archaeological and environmental evidence.

The need for historical context

Binford (1983) has termed the relationship between understanding material remains and human behavior 'Middle Range Theory'. This implies that any historical or archaeological (long-term history) study should address both the retrieval of evidence and the epistemological foundation that establishes the questions posed about human action. Studies of remote islands, however, appear more often to have concentrated on empirical data to the exclusion of theoretical concerns, which have often been dismissed because it has been assumed a priori that islands are laboratory-like model systems. Such approaches concentrate on the spatial position of islands and the attributes of species in the frame of ecological and evolutionary processes as a substitute for the temporal and geographical character of islands (e.g. disturbance processes).

The theoretical and analytical basis for the universalism of the model system approach acts in the same way as the uneven retrieval of archaeological and historical information and temporal contingencies; they both mask context. Robin Collingwood (1961) saw this microcosm approach as a superficial arrangement of both cultural and environmental evidence, abstracted from its historical context. This model system approach assumes that islands provide a more precise record of human impact processes, because of the perception that they are more quantifiable in biological and geographic respects than continents with their more complicated human occupation histories and biology (e.g. Kirch, 1997; 2000b; Vitousek et al 1995; Vitousek, 1995;
Walter (2004: 183) suggests that such use of islands as model systems is an attempt to bind human impact into the ‘statistical straitjacket’ of equilibrium theory. Stephen Carpenter (1996) suggests that although microcosm-based studies can be used to examine ecosystem processes, they can fail to include organisms or processes that are crucial for ecosystem functioning.

In his book *Times arrow, time’s cycle* Gould (1987) explored this epistemological problem in his discussion of the dichotomy between time’s arrows (a linear Newtonian succession of unique events) and cycles (recursive patterns that re-appear unchanged). In this dichotomy, similar biological forms (e.g. flughted organisms) may be produced through the passive retention of characters in a lineage (time’s arrow, e.g. birds), or these same characters may develop within separate lineages through active transformation by cultural or environmental means through time (time’s cycle, e.g. bats and insects). Unless some theoretical framework is developed that focuses on the context for the retention of passive biological characters, or processes that enforce biological transformations through some external means, interpretations will remain superficial.

The need for exploring historical contexts of both environmental and social transformations in remote island antiquity is especially acute. The way in which humans in the past have been implicated in the translocation and extinction of remote island biotas is a prime example of how historical contexts have been neglected in favour of strictly environmental or social explanations. I believe that without the development of additional interpretive means for revealing historical contexts in more detail, the microcosm paradigm will leave us with many questions that remain untestable and insoluble within this framework.

There are three main characteristics of islands, however, that do allow greater interpretive precision and historical contextualization in the discussion of plant species introductions and extinctions. But these are heavily dependent on the theoretical construction of islands and only partly on the physical constitution of islands in time and space. Firstly, the biological attenuation of island biotas increases the precision with which introduced (translocated or exotic) or extinct species may be identified. The attenuation of higher order taxa (e.g. families and genera in Linnean taxonomy) of the older continental areas and adjacent islands in Near Oceania on the younger islands of Remote Oceania with an oceanic geology means that higher order taxa are more easily recognised and classified on these islands. This is dependent, however, on the set of assumptions of biogeographic patterning of islands (discussed in Chapter 2). Secondly, as an adjunct to the effects of biological attenuation, the taxonomic resolution of island biotas far exceeds that of other areas. The sensitivity of multiproxy fossil and historic evidence to enable introductions or extinctions to be recorded must therefore be greater. The third and most important characteristic of species translocations and extinctions in island antiquity is that these processes have operated along several distinct temporal trajectories, both dependent on and independent of human activity. Some of these processes may be perceptible to history in that they
have responded to historical environmental or biological transformations or disturbances, and some that may remain passive to any disturbance and hence remain entirely imperceptible.

While the model systems and macrohistorical approach to island history has assumed the role of disturbance *a priori*, in the absence of temporal constraints, an approach that emphasizes historical context enables disturbance to be expressed as visible historical transformation and also as a passive and constant force throughout the entire history of an island. I suggest that the effects of specific disturbances operate in a diachronic fashion and at specific points in history (conjunction), they may operate in a way that produces unequivocal social and environmental changes, at other points or periods in history changes may remain imperceptible and irresolvable. Identifying the cause and effect of each disturbance is dependent on the construction of an adequate chronology and a conception of time that can reveal the diachronic nature of disturbances, rather than mask it.

**Chronology and the environmental history of Easter Island**

That island environments have been continually and completely transformed in the time since first human settlement is undeniable. Every organism that was present on an island before human contact, is now oriented within an entirely different set of ecological relationships. For Easter Island, records of avifaunal and floral extinctions (e.g. Steadman *et al* 1994; Flenley *et al* 1991) support the idea that the modern biology of the island bears little resemblance to that of even the recent past. There is a growing body of evidence that suggests that this pattern is not unique to Easter Island and can be applied to many islands in Remote Oceania and indeed any island.

For the period from first European contact with island societies through to the establishment of mission stations, regarded by some as the most compounded form of disruptive occupation (e.g. Thomas, 1996), the historical, ethnographic and anthropological literatures of Pacific islands tend to be heavily contested, with few parallels to be drawn from modern society (e.g. for Easter Island see McCall, 1979; 1994). This may be seen as an almost insoluble problem: either existing methodological and heuristic frameworks are strictly derived from the understanding of the present, or where short-term events of a primarily social nature mask those that deal with more long-term concerns.

In Pacific island archaeology, many ideas of environmental transformation have been borrowed from disciplines concentrating on geological timescales such as evolutionary biology. Evolutionary archaeologists, for example, suggest that people will adapt to new environments in much the same way as any other organism. But such treatments may have distorted the picture of human relationships with islands. The process of evolution is often presented in polarity between slow, drawn out speciation in the form of natural selection, and a catastrophic event that induces
mass extinctions. Imputed processes of social or environmental change on small, isolated islands are often conflated by the interpretation of historical contingencies such that one set of past events or processes are set in opposition from one another. Ideas of social adaptation and environmental change are built on the assumption that these processes must operate within the same timeframe. But a simple correlation between human agency, demonstrated by interpretation of material remains, and environmental change does not always imply a causal relationship. This is a key point of attraction and contention for the history of islands.

Remote islands present methodological and theoretical problems that specifically relate to the construction of chronology and the conception of time. The geological, biological, and cultural attenuation of islands draw interpretations towards human caused environmental change without providing robust or testable explanations. This dilemma is reinforced by an assumption that has permeated historical treatments, that the closer an event is to the present, the clearer it’s meaning and appearance will become, like being in a canoe approaching the shore. But this increasing clarity does not apply for remote islands except perhaps for the post-industrial information age and where intergenerational oral histories may be supported by a developing literary tradition.

The chronology and conception of time in Easter Island’s history derive more from archaeological theory than history, albeit with its chronometric foundation (e.g. radiometric dating) embedded within the physical sciences. As I will later demonstrate in Chapter 5, the discontinuities presented within the uneven historical accounts dating from the first contact period, are more like archaeological than historiographic data in character with biases towards evidence that establish a sense of continuity from the past to the present. These biases are not unfamiliar in the historiography of any other environment or society, but on Easter Island the construction of chronology and time appears to have been dominated by a highly constructed historical narrative.

The earliest accounts of Easter Island from Roggeveen up until the arrival of the missionary Eugene Eyraud in 1863 (e.g. Altman and Schwartz, 2003), to an extent, are deficient in detail concerning the points of contention in Easter Island’s history. These points of contention appear to coincide with major episodes of social disruption and environmental disturbance and include records of population decline, the extent of deforestation, the state of agricultural production and the nature of social institutions. Understandably, historians and archaeologists alike have relied on the Polynesian derivation of Easter Islanders to explain by analogy the timeframe for island settlement (<1200 yr B.P.) as well as the potential for population expansion and the assumed structure of social institutions, by reference to Polynesian culture as understood by archaeology and ethnography. It is perhaps the cultural parallels revealed in the ethnographic boom period in Polynesia from the 1920s to the 1960s that has most strongly underwritten this regional delineation (discussed in Chapter 2). Archaeological research in Remote Oceania initiated by the
end of the 1950s with the advent of chronometric radiocarbon dating, has largely been and is still driven to extend this ethnographic corpus rather than to test it.

The perceived uniqueness and insularity of Easter Island’s environment prior to human settlement, and the succession of subsequent human impacts including European influences is important to this problem of chronology and the conception of time. I believe this preoccupation with uniqueness comes at the expense of environmental and contingent processes that have led to a greatly distorted historical picture of this island. For example, Diamond’s ‘comparative method’ with which Rolett and Diamond (2004) attempt to measure the susceptibilities of remote Pacific islands that predispose them towards deforestation almost entirely removes historical factors from the equation. They suggest (after Kirch, 1997) that on Tikopia (see Figure 1.1, Figure 4.1), a remote island in the Western Pacific first colonised around 3,500 cal. yr. B.P. (see Chapter 4), the society employed effective protective measures against deforestation, despite having an equally ‘susceptible’ environment, whereas on Easter Island social measures were ineffective. They explain that Easter Island’s low topography, porous soils, subtropical location and relatively low rainfall are key factors that distinguish the deforestation potential of this island from the predominant high elevation, tropical islands of most of the inhabited Pacific islands further west.

Rolett and Diamond (2004) do mention a number of caveats in their model, such as the influence of island age on biological evolution and accumulation, and the historical effects of reduced convection and rainfall associated with deforestation but make no attempt to incorporate them. In Diamond’s (2005) interpretation, the effective protective measures employed by Tikopian society were critical to their social success and vitality. After a period of destructive early slash and burn agriculture and pig husbandry, both were abandoned in favour of non-destructive arboricultural practices centred on the cultivation of the introduced almond tree Canarium harveyi (see Chapter 4).

This comparative approach of Rolett and Diamond (2004) is compounded by Diamond (2005) in Collapse who uncritically adopts the genealogical chronology based on Bahn and Flenley’s (1992) interpretation of the rise of the Orongo birdman cult in AD 1680, an apparent defining moment of societal collapse and environmental degradation. The historic record of social upheaval on the island is mentioned by Diamond (2005), including the abduction or “blackbirding” of the majority of the male population (~1500 men) in 1862-63 for the Peruvian guano mines, the impacts of these events are envisaged outside the context of the perceived societal collapse symbolised by the toppling of the moai. Radiocarbon dates from charcoal of a number of extinct tree species (Orliac, 2000) are incorporated into this genealogical framework, despite having calibrated age ranges that are poor calendar approximations, which could just as

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6 McCall (1976) suggests that they were in fact “black-birded” for the labour market at Callao, not strictly the Peruvian guano mines.
easily be interpreted as modern determinations (in Chapter 4, I explore some of the alternative views on this chronology).

Diamond (2005) has carefully selected a number of specific temporal representations that emphasise social meaning from the plethora of historical, environmental and social facts. Easter Island society chose to fail or survive on the basis that they had the opportunity to prevent an indigenous palm from becoming extinct. The extinct palm and its role in moai construction and collapse is undoubtedly a useful metaphor, for, like these, the palms are endemic features of Easter Island. But this interpretation may come at the expense of other features unique to Easter Island which may have similar importance. The replacement of palm forest with the extensive agricultural fields seen by Roggeveen in 1722, but later reported by Cook in 1774 as abandoned, is one example. The locally developed manavai or boulder gardens were employed as a barrier to moisture loss (e.g. Stevenson et al 1999; Wallin et al 2005).

**Structural history and the conception of time**

The derivation of meaning from historical and archaeological data has generally been discussed in terms of chronology and the conception of time as representation and process (Bailey, 1983: 166). Time as representation is explained in terms of the past, and the past in terms of macroscale processes whereas time as process is simply the past explained in terms of the present (Knapp, 1992: 12). This parallels Gould’s (1987) description of ‘time’s arrows’ as representation and ‘time’s cycles’ as process. In the context of Easter Island, I suggest that the orthodox and alternative views of societal collapse give more weight to time as process. In the development of archaeological conceptions of time, this is part of the diachronic polarity set up between cultural and environmental determinist views situating cultural time as marked by human experience with environmental/geological time as an abstracted but measured time (Shanks and Tilley, 1987). Inherent to both concepts of time is the utility of the geologically informed uniformitarian principles of Charles Lyell (1842). Uniformitarianism in its modern usage is more than just inferring past processes from the present, but is a belief that there are universal principles that apply irrespective of time and place. Bailey (1983: 174 following Trigger, 1978) suggests uniformitarian application in archaeological theory has had a stifling effect where theorists are faced with only two options. These are either to provide superficial generalizations about the past, or to concentrate on the contrasting features revealed between events and their contexts. Paradoxically, the application of uniformitarianism, originally devised to encourage the study of the past, has instead inhibited the exploration of processes that may not exist in the present. This is something that I believe is important when discussing the palaeoenvironment of Remote Oceania.

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A reassessment of the historiographic dimension of geological and environmental patterns has been viewed as a major stimulus to the development of archaeological theory. Niles Eldredge and Gould (1972) began by challenging the uniformitarian view that macro-evolutionary patterns in the palaeontological record can be explained in terms of micro-evolutionary principles. Under their theory of 'punctuated equilibria' new processes or causes of evolutionary change at the macro-scale are not opposed to those at the micro-scale, but may operate at a level that is entirely independent of them. The evolutionary quandary explored is the role of stasis that 'must be viewed as an active phenomenon, not a passive response to unaltered environments' (Gould and Eldredge, 1993: 223), in which organisms may adapt to biological pressures using behavioral response mechanisms that do not register physical or demographic changes in the palaeoentological record.

The philosophical significance of time has been taken up by Martin Heidegger in Being and Time (1962), his examination of the diachronic aspects of human perception. Gosden (1994) has attempted to apply Heidegger's multifaceted ideas to history and archaeology and the following summary is taken from Gosden. Heidegger asserts that there is a multiplicity of temporal rhythms that make up social life and these are created by the very practice of our being in its setting of social circumstance. He makes a distinction between public and personal time: for example, the individual's experience of the thought of death leads us to appreciate life as something ephemeral. This experience of death is distant from public life in its large, open and concrete character perpetuated by social institutions well beyond personal time (Gosden, 1994: 112). Time in this sense can be viewed not only as diachronic but also integral to our physical involvement with the world. For the historian and archaeologist this raises a set of perplexing issues.

Such diachronic principles as those approached by Gould and Heidegger have been a part of the discourse of historical sciences for some time. Fernand Braudel, in On History (1980) - a synthesis of his 1949 theoretical treatment of sixteenth century European social history The Mediterranean in the age of Philip II (Braudel, 1972) - continued the Annales multidisciplinary method earlier established by Marc Bloch and others during the 1920s. The Annales method has its roots in collective or sociological history rather than the individual histories of political figures. Bloch maintained that the actions or intentions of individuals could not be understood outside the context of society, which in turn is manifested in social institutions and material remains (Knapp, 1992: 3-4).

Braudel (1980) later proposed a hierarchical tripartite structure for history each representing a different set of processes and representations. At its centre are histories of conjoncture (socio-economic events) that are not reducible to histoire événementielle (fleeting socio-political events) or rigidly set within the structure of the longue durée (non-sociological

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7 See Bintliff (1991), Knapp (1992) and Smith (1992) for a detailed analysis of the Annales contribution to history and archaeology.
macro-histories or world-histories and environmental histories) but are diachronically attached to both. This represents a different take on universal structures of the human world from that advocated within structural anthropology (e.g. Lévi Strauss, 1966).

Braudel was more concerned with the environmental contexts of human action as opposed to the interaction between ahistorical contexts and the structure of the human mind and society (Knapp, 1992: 6). To many of his critics Braudel did not satisfactorily link the broader social forces of the longue durée with more ephemeral events that may disrupt more enduring trends of social change. They also claim that his structural history privileges biological, physical and historical factors over social factors (e.g. Kinser, 1981; Le Roy Ladurie, 1979; 1981; Ricouer, 1988). Braudel’s recognition of diachronic structures within history, parallels punctuated equilibria theory in that he suggests that within a temporal hierarchy, processes acting within one temporal structure have a distinctive rhythm and may have no causal relationship with the others.

If history can be generated by the perception of human practice within both social and environmental contexts then concentrating on environmental processes would mean that the longue durée and histoire événementielle would be operating under different impetuses (Gosden, 1994). This implies that the same question cannot be asked of the longue durée as of a narrated history, for example. Connecting the two would seem impossible when they are independent of each other and operate under differing environmental, cultural and historical constraints. Gosden (ibid) suggests that the lack of any explanation for the interaction between the longue durée and more short-term events in Braudel’s scheme may stem from his emphasis on the long-term. Braudel’s concentration on the longue durée, however, appears rather to be a considered response to the historical neglect of the relationship between humans and the environment, especially within geological timeframes.

The longue durée also represents a rejection of history as a Newtonian unilinear sequence of events marked by the activities of famous individuals, and instead sees history as being by nature serial. The need to incorporate a wider range of contextual information was paramount to Braudel’s methodology. His 1972 synthesis on sixteenth century Mediterranean history can now be seen as one of the earliest attempts at what is now termed macro or world history that focuses on the environmental context of historical change; a style of presentation made more familiar by authors such as Diamond.

**Absolute chronology and the conception of time**

Bradley (1991: 210) asserted that archaeologists use of chronometric techniques ‘lack the chronological precision that will permit them to investigate human intentions’ thus restricting their interpretations to Braudel’s *conjoncture* rather than *histoire événementielle*. Ingold (1984:
suggests that without such chronological precision, ‘the object of prehistory must be to elucidate cultural adaptation rather than social evolution’, again emphasizing the importance of conjuncture. Bradley *(ibid: 212)* highlights the potential for examining a form of contextual archaeology which observes the interplay between *conjoncture* (ritual) and *histoire événentielle* (mundane time) but also makes the assessment that the chronological precision does not yet permit the incorporation of these structures into the *longue durée*.

Bailey (1983: 165) states that:

‘It is only with the relatively recent development and widespread application of radiometric dating methods that archaeologists have begun to free themselves from technical preoccupations [i.e. stone tool typologies] and to concentrate more fully on problems of process.’

Over twenty years later, how wrong could this statement be! If anything, the concentration on process has never escaped the technical issues involved with radiocarbon dating, in either palaeoenvironmental or archaeological uses of radiometric dating. As Claude Lévi Strauss (1966: 258) has emphasized, ‘there is no history without dates’, but even in the construction of absolute chronologies ‘dates’ have many different representations, meanings and significance.

For the remote island Pacific, radiocarbon remains the predominant form of dating technology because most of the materials used for alternative dating techniques such as optical luminescence have yet to be developed to incorporate the decay rates of mineral substrates that make up the primary parent material east of the Andesite Line. Potassium argon (K/Ar) dating has primarily been used to assess the ages of islands operating at a >100,000 year time scale. Obsidian dating involving the measurement of hydration rates in the chemical composition has some potential in Remote Oceania (e.g. Stevenson, 1988; Stevenson *et al* 1993). This technique has had limited success. One problem is that the calibration of the rate of obsidian hydration has relied heavily on existing radiocarbon chronologies. Another is that the rate is affected by a large number of variables that are very difficult to assess (e.g. temperature, obsidian chemistry, soil chemistry, ablation rate etc (Wal Ambrose *pers. comm.* 2005). Other techniques such as lichenometry (measured growth rates of lichens) may yet prove to be useful in dating worked stone exposures while $^{210}$Pb dating is useful only in organic sediment accumulations developed since the industrial utilization of lead-rich fossil fuels (post-1920).

Dendrochronology has been essential for the calibration of the distribution of $^{14}$C in the troposphere, varying between the northern and southern hemispheres (McCormack *et al* 2004). For temperate regions where trees produce distinct-annual tree-rings with compartmentalised blocks of $^{14}$C, a chronology and calibration curve may be produced for the entire age of a tree. For the tropical and sub-tropical islands of Remote Oceania where most trees do not produce
distinct-annual rings and rarely have a longevity extending beyond 400 years, dendrochronology is of limited use for dating archaeological events.

Radiocarbon dating will remain for some time the major dating technique for sites east of the Andesite Line (see Figure 1). A number of warnings have been attached to the construction of radiocarbon chronologies and this has been spelt out most vividly in debates on the chronology of colonization in Remote Oceania (e.g. Spriggs and Anderson, 1993; Kirch and Ellison, 1994; Anderson, 1995; Anderson, 2002; Anderson, 2003). The focus for developing such a chronology has been on rockshelter sites with early archaeological deposits. In such settings, there remain irresolvable problems in dating marine shells associated with marine reservoir effects, whereby certain percentages of old carbon recycled in the global ocean circulation system influence the final radiocarbon determination (Stuiver et al 1998).

The bias towards dating charcoal has often failed to incorporate the potential ‘in-built’ ages of the parent tree species (Gavin, 2001). For most remote island tree floras, this can represent up to 300-400 years of additional error on top of the reported laboratory error of the radiocarbon age, for unidentified charcoal. Uncalibrated radiocarbon dates always have an uncertainty attached to them, typically between 30-100 years for Holocene aged organic material. Radiocarbon calibration curves established for the last 3,500 years cal. B.P., based on additional age-proxies such as dendrochronological markers (e.g. Stuiver et al 1986; Hogg et al 2002) identify a number of significant plateau’s that congregate around 900, 700 and 400 cal. yr B.P. (see Chapter 4). From a radiocarbon dates that fall close to the margins of these plateaus will when calibrated assume a larger uncertainty.

The construction of absolute chronologies is usually performed a priori, within a uniformitarian framework forming the basis for all comparisons and correlations of sedimentary or archaeological stratigraphic profiles. Currently, with the exception of varved (annually laminated) sediments, thus far only located in Remote Oceania from volcanic calderas deposits from northern New Zealand, the chronology of any sedimentary profile is based on radiocarbon dates. For archaeological stratigraphic settings where people may have actively modified a deposit, dates are given integrity on the basis of additional contextual information.

McGlade (1999:142) wrote that despite

‘the logic of absolute chronologies ... [there remains] the problem that the relational schemes constructed on the basis of a series of $^{14}$C dates, maybe dangerously misleading. The apparent objectivity of such an exercise can be severely undermined by the fact that events which are scientifically assigned to the same time may have little relationship to one another. By the same token, of two events which appear as abrupt and radically discontinuous, one may be the outcome of processes whose causality lies in the distant past, while the other may be the product of a short, almost instantaneous action.’
McGlade (*ibid:* 143) is dismissive of this ‘absolute time’ generated by radiocarbon dating, describing it as ‘no more than the time of organic decay – it is in fact statistical, probabilistic time with all its attendant uncertainties’. Most archaeologists and environmental historians accept these uncertainties as part of a scientific discourse, given that there are generally few alternatives for providing chronology in many environmental contexts.

One central problem has remained for archaeologists, especially, who too often refrain from explicitly expressing the inherent uncertainties of radiocarbon determinations. In many cases a determination will radically change if other ‘inbuilt’ statistical information and context-based evidence are integrated. This problem inspired Spriggs and Anderson (1993: 207-208) to establish a protocol for the acceptance or rejection of radiocarbon dates for East Polynesia, where the dates accepted were ‘those likely to be closest to calendrical ages of cultural events’ a process Spriggs (1989) has termed this process ‘chronometric hygiene’. One paradox revealed in this qualitative protocol is that at each selection step an additional set of probabilities must be incorporated. The identification of Spriggs and Anderson’s ‘cultural events’ is based on existing, acceptable, radiocarbon determinations.

The recent application of the Bayesian statistical paradigm to the construction of absolute chronologies has opened up a range of possibilities for integrating selection criteria that can be defined as a set of chronometric probabilities in what is defined as ‘risk analysis’ (e.g. Buck and Christen, 1998). The Bayesian paradigm is a statistical framework that describes the probabilities of a certain event or action on the basis of dependent events or actions that again can be defined in terms of a set of probabilities. This approach is especially useful in defining events within continuous stratigraphic deposits (e.g. varved sediments) or in dendrochronological applications. Such applications do not address McGlade’s disempowering view of the value of radiometric technology or resolve the problem that there is an inherent detraction of focus on the material remains in question. There may be some other relative correlations between material remains and their deposition that the physical isotopic features of the dated carbon-based material. Events represented in a stratigraphic sequence may have arisen independently (e.g. most archaeological deposits), and in this case the Bayesian approach is of limited utility and may radically distort the interpretation of these events.

The construction of absolute chronologies has, however, provided valuable ‘ball park’ figures for the examination of a range of temporal issues in archaeology and palaeoenvironmental research. In East Polynesia, the timing of island colonization has been, thus far, the most critical question of cultural adaptation, in which radiocarbon dating has been pivotal. But it is the interpretation of material evidence that may represent events or processes correlated with human activity on islands, that will remain dependent on other theoretical treatments to establish a robust temporal framework, as these events or processes may not always correspond with chronologies.
generated by absolute dating. The recognition that certain events or processes operate along
different impetuses and generate different contingent effects, an epistemological issue in
historical disciplines, suggests that the integration of absolute chronologies with the material
results of human agency must always rely on some \textit{a priori} conception of time.

For archaeological and palaeoenvironment research of Remote Oceania the interpretation of
the inherited social and environmental structures of islands upon initial human colonisation is
complex. The limited utility of radiometric dating given the short colonisation timeframe for
many islands (i.e. <1000 years) has meant that chronological issues are too often overshadowed
by an emphasis on isolation processes. In terms of social transformations, the divergence of social
interaction and material exchange between islands with increasing isolation is a fair assumption,
but the level to which it impacted on social institutions may not be crucial. Isolation processes
emphasised in evolutionary biology such as founder effects may have little bearing on the
retention of social structures formed prior to colonisation. The transformation of island
environments in Remote Oceania associated with human colonisation appears to be broadly
similar across islands and may have little correlation with isolation processes. However,
examination of the species diversity of vascular plants on the Austral Islands, colonised around
the same time, suggests there is such a relationship. The most isolated island (Rapa) retains
greater plant diversity than the other less isolated islands (see Table 1.3).

\textbf{Other diachronic approaches: the environment as time}

The complexity of interrelationships among time, chronology, and history is clarified in Ingold’s
exploration of human perceptions of the environment. Following the anthropological and
philosophical treatments of this subject (e.g. Heidegger, 1962; Bourdieu, 1977), many of his
essays have concentrated on the dichotomy between perceptions of environment as a sterile
backdrop to human activity and the culturally constructed view of the environment as a symbolic
structure (e.g. Ingold, 1992; 1993; 2000). He argues that recognizing temporality of the
environment\footnote{Ingold’s (1993) paper concentrates on ‘landscape’ but ‘for many purposes [landscape and environment] may be treated as practically synonyms’. My own preference is to discuss ‘environment’ as it is a less loaded term than ‘landscape’, with its etymology set within Renaissance art, but more recently adapted to artificially assimilate culture with the physical world. The environment appears more easily translatable as ‘nature organized by an organism’ (Lewontin (1982: 160) in Ingold, 1993: 156)} is essential in establishing a theoretical basis for breaking down the dichotomies
between human agency and environmental determinism. He is critical of the view that time and
history are complementary in that time is ‘the regular setting for the vagaries of history’ (Ingold,
2000: 194, after Kubler 1962: 72). More important for this discussion on diachronic structures is
that Ingold (1993: 163), like Braudel, equates time with rhythmic structures of the environment:
The rhythms of human activities resonate not only with those of other living things but also with a whole host of other rhythmic phenomena – the cycles of day and night and of the seasons, the winds, the tides, and so on... In many cases these natural rhythmic phenomena find their ultimate cause in the mechanics of planetary motion, but it is not of course to these that we resonate. Thus we resonate to the cycles of light and darkness, not to the rotation of the earth, even though the diurnal cycle is caused by the earth’s axial rotation. And we resonate to the cycles of vegetative growth and decay, not to the earth’s revolutions around the sun, even though the latter cause the cycle of the seasons. Moreover these resonances are embodied, in the sense that they are not only historically incorporated into the enduring features of the landscape [environment] but also developmentally incorporated into our very constitution as biological organisms... We do not consult these cycles, as we might consult a wrist-watch, in order to time our own activities, for the cycles are inherent in the rhythmic structure of activities themselves.

In applying these ideas to investigations of the past, Ingold makes the point that there is a need to examine the underlying cause behind the diachronic relationships between human activity and the temporal structures of anything that pertains to material remains. In addition to this, the potential range of contingent or consequential effects of these diachronic relationships should be thought through. For certain human activities there will be a particular rhythm or time signature attached, whether that be manifest in labour in the production of material remains (e.g. textiles or crops), or a human life-time as represented, for example, by mortuary remains. Each material, especially if it is biological, will have operated under its own rhythm or temporality, and adjusted under this impetus to human activity and other environmental factors.

Ingold’s description of human relationships with aspects of the environment provides some resonance with Braudel’s diachronic take on the rhythm of social life and the environment. He suggests that an adequate understanding of the social and environmental contexts of history is not just a matter of re-orienting the temporal and spatial scales from the present to the past, but instead requires adjustments of orientation in both theory and methodology. He proposes that archaeological evidence should be broken up into a series of components (e.g. evidence for topography, trees, short-lived plants, buildings and human remains etc.), each providing a different temporal and spatial orientation. For most environments Ingold (ibid: 167) suggests that it is possible to:

‘perceive the same topographic panorama, regardless of time of year, the weather conditions and the activities in which people may be engaged ... over centuries, perhaps even millennia , this basic topography has changed little. Set against the duration of human memory and experience, it may therefore establish a baseline of permanence’.
To Ingold (*ibid*: 166-167), this permanence remains relative and is entirely dependent on human orientation. Long-term changes in terrain may be independent of this orientation:

'Although the topography is invariant relative to the human life-cycle, it is not itself immune to change. Sea-levels rise and fall with global climatic cycles, and the present contours of the country are the cumulative outcome of a slow and long drawn out process of erosion and deposition. This process, moreover, was not confined to earlier geological epochs during which the landscape assumed its present topographic form'.

This apparently static topographic form may in time be successively altered by shifts in more mobile elements of the environment affected by various agencies including human action. Rivers and constructed pathways, for example, may rework the contours of the environment, at rates and scales of movement accessible to human experience. Over time these environmental contours behave like sediment accumulating or eroding but always with a potential for adjusting to human activity.

This conjuncture between human activity and long-term environmental change is brought into sharpest focus by the more transient components of the environment. In contrast to the topographic components of the environment, Ingold (*ibid*: 168) discusses the temporality of a cultivated fruit tree (a pear), suggesting that such trees manifestly have grown within living [human] memory' of people. Like any organism, however, a fruit tree has its own developmental history and form that have arisen from its ecological relationship with other components of the environment such as climate, pollination and other plants and animals. In the case of a fruit tree its development has also been influenced by the activity of the people who have cultivated (domesticated), pruned, picked fruit or slept under it. People 'are as much bound up in the life of the tree as is the tree in lives of the people' (Ingold, *ibid*). Ingold highlights the hierarchy of temporal rhythms embedded in a pear tree that range from 'the long cycle of its own germination, growth and eventual decay to the short, annual cycle of flowering, fruiting and foliation' (Ingold, *ibid*). As a Pacific example, the breadfruit tree *Artocarpus altilis*\(^9\) is generally less seasonal, and may yield fruit year-round. Like the pear, nevertheless, its occasional bursts of high fruit productivity over the short-term contrast with its long-life and large structure that often distinguish human dwellings on many Pacific Islands. Trees may thus represent both durable forms that persist for a number of human generations, and also the more transient cycles of the

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\(^9\) In Tahiti, the peak harvest period of *Artocarpus altilis* occurs from November to April with a secondary harvest between July and August (Wilder, 1928). Cultivation can allow for a few fruits to be gathered all year round. Also in Tahiti the main branches are sometimes extensively pruned to provide easier access to the fruit (Massal and Barrau, 1956). In some Pacific islands, the high seasonal production of breadfruit resulting in an excess of fruit for consumption is thought to have led to the development of a range of preservation practices including drying and fermentation.
environment such as the ‘life-cycles of insects, the seasonal migrations of birds, and the regular round of human agricultural activities’ (Ingold, ibid). To Ingold (ibid):

‘the tree bridges the gap between the apparently fixed and invariant forms of the landscape [environment] and the mobile and transient forms of animal life ... from the most permanent to the most ephemeral ...’

The temporality and biological development of a tree may not be entirely out of step with the development of human dwellings and other human constructions that encompass in time intergenerational social and environmental changes. Just as the ‘people’s ancestors’ are buried in the ground, the ‘roots [of the tree] may reach to approximately the same temporal depth’.

While trees establish a greater sense of duration in relation to human activity, annually or perennially cultivated crops establish a more vivid connection between ephemeral and enduring features of the environment. Cultivated annuals or perennials are more closely linked with life cycle of people, given that they may naturally decay or be harvested within a few seasons or less. These plants are more like the ephemeral features of a tree (fruits and leaves), but may require more human maintenance for their production. The cultivated forms of Cordyline fruticosa, for example, are nearly everywhere grown for a range of uses throughout the Pacific10, including the wrapping of fruits of cultivated Artocarpus altilis for cooking in earth ovens, or for fermentation (Wilder, 1928). Thus the tree and the perennial cultigen are interlocked in a synchronous temporality mediated by the seasonal harvest. Despite having independent life-cycles, conjuncture between tree, plant and people is provided in the activity of the harvest. To Ingold (2000: 198) it is this type of patterned activity that embodies the environment:

‘Human beings do not, in their movements, inscribe their life-histories upon the surface of nature as do writers on a page; rather, these histories are woven, along with the life-cycles of plants and animals, into the texture of the surface itself.’

In following a number of philosophical stances (e.g. Heidegger, 1971) as well as discussions of evolutionary psychology (e.g. Gibson, 1979), Ingold’s insistence upon mutual involvement of humans and environment contrasts sharply with approaches to history that posit one mode of change at the exclusion of complementary modes. For Easter Island, we are offered societal choice or climatic change, culture or environment. Ingold emphasizes that materials received in the historical or archaeological record must be viewed not only in terms of function but also in terms of form. The representation of certain material remains will capture a certain

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10 Uses include leaf fibre for clothing, sugar and starch production (from root tubers). The variegated and coloured varieties are known as track or pathway markers or as ornamentals in gardens (see Hinkle, 2004).
‘temporality’, for example, the presence of an arboricultural fruit represents an order of several years or more of maintenance within an agricultural system as opposed to a tuberous cultivigen (e.g. *Colocasia esculenta*) that represents only a few seasons of gardening activity.

Understanding this type of temporal representation has important ramifications for interpretations of the archaeological record on islands. The presence of material remains of translocated plants in archaeological contexts represents a greater order of human activity than is implied by its mere deposition. A cultivated plant was selected from an ancestral cultivation site and from a population of cultivated progenitors prior to translocation. For the successful reproduction of this plant a specific range of ecological conditions are required. Once successfully transported from the founder island to the discovered island, a particular environment must be selected and modified in order to continue successful plant production. Each step in this cycle requires interdependent adjustments on the part of both the plant and cultivator. At each step only certain features of this cycle may be available in the archaeological record. A seed of an introduced tree may represent several years of maintenance, while the pollen of a tuberous crop may entail only a few seasons of gardening activity. The multiplicity of potential outcomes is large, but clearly dependent on the material remains retrieved.

In summary, a strict functional representation of material remains as static entities acts to mask their temporality, whether long-lived or ephemeral. Failure to recognize this feature of material remains leaves the polarized interpretations embedded within over-simplified model systems and narrative approaches to history unchallenged. Restricting the interpretation of material remains to their temporal features opens up greater opportunities to contextualize human activity and environmental change, the ultimate aim of the historian.

**Botanical sources and history**

Botanical sources are any information sources, whether historical, archaeological or palaeoenvironmental that may identify a plant species according to Linnaean nomenclature. The types of botanical sources already discussed above have been critical to the construction of island histories, providing chronological information as well as direct evidence for human activity, but they represent historical structures in markedly different ways. As discussed in the preceding chapters, plants connect the more fixed and immobile elements of island environments with the more variable and transient forms of human and pre-human island biology. Some plant components obtained from material remains have, prior to deposition, operated in a range of contrasting temporal and spatial contexts, possessing ephemeral features that may occupy little space (e.g. flowers, pollen, leaves), as well as long-lived structures (e.g. trunk heartwood) that
also place a greater demand on space. Taphonomic constraints further limit the preservation qualities of some deposits favouring only durable structures (e.g. fruit endocarps).

Text-based botanical records from early European contact accounts add additional biases to what botanical information is available. The nature of these historic accounts is uneven, by virtue of the fact that Europeans arrived at these islands at different times and recorded information only selectively.

What is important to this thesis is that botanical sources enable recovered plant material and text-based information to be cross-referenced from different temporal contexts. It is not possible to achieve such detail for most other materials (e.g. faunal material and sediments). Plants not only formed the base resource for island economies but also constitute the majority of the biomass of islands prior as well as after human colonization. The ubiquity and near-universal constancy of plants within material and textual records of the past means that they may also provide a bridge for the diachronic gap between Braudel’s temporal rhythms and hierarchies.

This potential utility of botanical sources in the interpretation of world history has long been recognized. ‘Phytographical’ histories of plants that provide important commodities in the global market place, such as sugar (*Saccharum officinarum*) and coffee (*Coffea arabica*), have provided an index of social change in pre-industrial economies after their contact with the industrial European economy and subsequent incorporation in the global economy. For the Pacific, the historical exploitation of sandalwood (*Santalum* spp.) for the thriving Canton spice markets of the 19th century provides some clues as to the extent of early ‘beachcombing’ activity and the social and environmental impacts of first European contact (Maude and Crocombe, 1962; Shineberg, 1967). The usefulness of such economic plants to such macro-histories suggests that there is some transparent unity linking the history of each plant to its place in human history. Questions of the origins of early pre-industrial plant utility, however, do not form part of these historical enquiries. The breadfruit (*Artocarpus altilis*), for example, entered historical consciousness through its role in the saga of the HMS *Bounty* mutiny of 1789 (e.g. Morrison, 1966; Oliver, 1988; Bowman, 1989). William Bligh’s failed attempt at translocation of breadfruit from the Pacific to the Caribbean represented one of the earliest colonial economic enterprises in Remote Oceania. But what of the complex pre-contact translocation history of this plant and related forms that extended it from a likely origin centre of New Guinea to as far as Remote Oceania? The plant was successfully transported and cultivated as far east as Mangareva and the Hawaiian islands prior to European contact (Kirch *et al* 2005) and as far south as the Austral Islands (Tubuai and possibly Ra'ivavae).

The invisibility to history of Pacific island societies was encapsulated by Alan Moorehead in *The fatal impact* (1966), where he implied that European reformation of the Tahitian ‘arcadia’ and ‘noble savage’ better defined island societies than the islanders themselves. Similarly, the early presence of Spanish explorers in the Pacific during the 17th century provided fuel for the
debate on the pre-contact origins of the sweet potato (*Ipomoea batatas*), with recorded Spanish translocations of the cultigen elsewhere in the tropics during the 15th and 16th centuries (Barrau, 1957; Yen, 1974b). A number of authors (e.g. Langdon, 1991) have continued to promote Spanish translocation as the primary means of sweet potato introduction into the Pacific from South America, negating the overwhelming evidence for a much earlier Polynesian introduction. As the history of sweet potato illustrates, the history of European influences on Pacific island societies shows merely that the connection between plants and human activity, or particular groups of people, is not always clear-cut.

As the most renowned arboreal icon of the Pacific, the coconut presents another case where divergent viewpoints on origins and human agency have arisen, particularly given its strong historical association with the spread of people. From the perspective of world history the coconut has been described as the most important cultivated plant, predominantly for copra, but also for timber, thatch, beverage, oil, condiments and fibre (Anderson, 1952). Despite its ethnobotanical profile, compared to many cultivated Pacific plants, its origin and dispersal are poorly understood except to say that they are complicated by the dissemination of fruits both by floating and translocation by people because of the multiplicity of uses of its parts.

The question of the origin of the coconut was first raised in the 17th century. Based on his Moluccan collections, Rumphius (1633-1670) provided the first botanical determination of coconut, originally described as *Palma indica major calappa*. Linneaus later described *Cocos nucifera*, distinguished from a range of other palm specimens from the same collections. Although ascribing a plant to the palm family presents no problems, even to separate it from palm like families (e.g. Pandanaceae and Agavaceae) with superficial similarities (Tomlinson, 1979), distinguishing palm species from one another presents a greater systematic challenge. The diversity of palms recognized by Rumphius in his Moluccan collections was probably poorly reflected in the knowledge of traders, explorers and naturalists and even Linnean trained botanists entering the region during the 17th and 18th centuries. This was also a problem in the Pacific: Lionel Wafer's account of Cocos Island (Costa Rica), over 350 km to the southwest of Panama, described the island as having an abundance of coconut trees (Wafer, 1695). This observation was later countered in 1938 by reports of an endemic *Rooseveltia* palm having a close resemblance to *C. nucifera* (Cook, 1940).

The potential for dissemination of *C. nucifera* fruits by flotation was mentioned by James Cook who thought in 1777 that the palm groves on Palmerston Island (Cook Islands) might represent natural establishment (Beaglehole, 1967). De Candolle (1885) initially favoured an American origin for the palm but was later persuaded by Seemann's (1873) analysis, put forward in his *Flora Vitiensis*, of a Southeast Asian origin. O.F. Cook (1940) argued again for an American origin based on the grounds that many of the other species of Coccoideae sub-family were from Colombia. Merrill (1946: 34) suggested that coconut ‘normally occurs only where it
has been planted by man' and that it is likely to have an Indo-Pacific origin. Fosberg (1960) regarded *C. nucifera* as a cultivated species, domesticated in some tropical region where its wild relatives are presumably extinct. Sauer (1971) favoured the view that coconut populations may be wild and a product of natural dispersal. Arguments for the natural dispersal of *C. nucifera* (e.g. Ward and Brookfield, 1992) were to some degree confirmed by excavation of *C. nucifera* endocarp from Anawau Swamp on Aneityum in Vanuatu (Hope and Spriggs, 1983), dated to 6410-5950 cal. yr B.P. (No lab number available). This provided the first radiocarbon age outside of the expected age range for human occupation of a site in Remote Oceania. Palynological records from Atiu (Parkes 1997) and Mangaia (e.g. Ellison, 1994; Kirch et al 1992) in the Cook Islands indicate a prehuman presence of *C. nucifera* in this part of Remote Oceania.

The presence of *C. nucifera* in the Austral Islands presents an interesting case in the debate on the natural vagility and human translocation of plants. No palaeobotanical evidence for indigenous *C. nucifera* in the Austral Islands has been forthcoming. *C. nucifera* was noted in the early European contact accounts for Ra’ivavae, Tubuai and Rurutu but not for Rapa and Rimatara (see Chapter 5). *C. nucifera* has been introduced within the last sixty years to Rapa where it is located around Ha’urei village and as isolated trees found in some sheltered embayments on the island. On Rapa, these palms currently produce small fruits that do not develop to full maturity, probably as a result of the more sub-tropical climate of the island. On Rimatara, Rurutu and Tubuai, *C. nucifera* fruits do reach full maturity and the established plantations are used primarily for local consumption and as pig fodder.

**Insoluble problems**

The readiness of those who have explored this subject to either incorporate or exclude the human association with coconut dispersal presents an interesting dilemma. Corner (1966: 238) has suggested that because of its Cretaceous origins ‘the problem of the coconut palm [origins] is insoluble’. On the one hand, the assumed introduced status of *C. nucifera* to some islands (e.g. Corner believes that prior to the Enlightenment, Austronesian speaking people transported *C. nucifera* to Cocos Keeling Island (Australia) en route to Madagascar in the Indian Ocean) suggests an acceptance that there is some kind of dependency between palms and people. On the other hand, an indigenous determination of *C. nucifera* for other islands (e.g. Aneityum, Atiu and Mangaia) assumes that their current distribution is a result of flotation dispersal whereby human agency is of no consequence (see Ward and Brookfield, 1992 and Harries et al 2004 for discussion). Within this dichotomy the environment appears to play no role and remains a backdrop to human or natural palm dispersal entrenching the view that island environments are in constant stasis. This problem becomes more acute when we consider the possible role of humans
in the extinction of plant species. The divergent interpretations of the extinction of the *Paschalococcus disperta* palm on Easter Island, as driven by either anthropogenic factors or climate change, provide a case in point. Such explanations do not take into account the causal mechanisms underlying such a transformation. There is no discussion of whether humans, plants and the environment transformed under differing impetuses so that at some point in time, transformation might either have been coincidental or have had multiple causes. Plants have their own temporality and respond to environmental factors (e.g. climates, soils, herbivores and seed dispersers etc.) as well as to human activity, but also have their own inbuilt mechanisms for adaptation (e.g. genetic heritage) that may lie dormant until the right environmental conditions arrive where they can be expressed.

In order to define the historical and conjoint trajectories of plants and people, an environmental context at a particular point of conjuncture must be defined. To understand this conjuncture is to define some causal mechanism that may provide a sufficient explanation for the apparent chronological relationship between a set of events. For some phytographical histories defining a causal mechanism in this way, as Corner (1966) suggests, may remain ‘insoluble’ as there may be no means of providing context. Situating events in an overarching chronological framework is the primary method of contextualisation from which narrative structure emerges in most historical and ethnographic studies. In narratives, however, the chronological relationship between events is often subordinated to thematic concerns (Thomas, 1996). The more recent phytographical histories illustrate this substitution of context for theme, so that plants are seen more as static objects over which the narrative of human history is laid out. What becomes clear in narrative approaches is that there is an inevitable dichotomy set up between either cultural or environmental explanations. This is most apparent in the human agency or climate change oriented explanations for the extinction of the Easter Island palm. The proponents of each side of this debate have polarised human agency and climate influences to such an extent, that either of these explanations appears to subordinate or mask any evidence that may actually generate context.
Chapter 4

‘Opposite paths to success’¹: Easter Island or Tikopia?

Paschalococcus or Canarium?

‘... the historian can never get away from the question of time in history: time sticks to his thinking like soil to a gardener’s spade.’ (Fernand Braudel, On History 1980: 77)

A central interest in the study of Pacific island botany is the development of causal explanations for plant origins (speciation), translocation, cultivation and extinction (extirpation). To define the cause of these events or processes, multiple lines of evidence must be oriented in such a way that the chronological layout of the evidence can be correlated and scrutinized. Such correlation does not necessarily guarantee that a specific causal mechanism can be obtained with certainty, but it does allow for the development of a more robust explanation for how each plant may respond in time to specific disturbance events or processes, whether caused by environmental or human agency.

Characterising plant responses to disturbance

Interpretations of the response of plants to past disturbances are strongly limited by the available botanical sources and the ability to define a disturbance from correlated geomorphological, archaeological and historical evidence. When considering the plant fossil record, for example, soft-tissue plants are largely composed of a chemically reactive fraction, which is more often broken down in weeks or months, whereas a physically stable fraction, such as wood tissue may survive for thousands of years (Beck, 1989). Identifying the ecological and biological response of a single species to a single disturbance is dependent on identifying the normal responses of a plant before and/or after the disturbance event or process. The greater the magnitude of a single disturbance and the greater number of synchronous events or processes represented, the more likely the changes represented by preserved botanical evidence are related to these events or processes. This is at least a workable hypothesis. Distinguishing the contribution of each potential cause for disturbance or biological response, however, is limited further by the sensitivity of plant proxy evidence to specific disturbances over and above the normal measured ecological and

¹The title of Jared Diamond’s (2005) chapter in Collapse is taken from Kirch’s (1997) description of the societal approaches to environmental management on Tikopia that prevented environmental and social collapse perceived for Easter Island.
biological behaviour, but also the sensitivity of correlated geomorphological, archaeological and historical evidence in defining the magnitude of the disturbance event or process.

Even when viewed in controlled laboratory conditions, plants have only a limited number of response mechanisms or adaptations to an imposed stress or disturbance. Such responses are rarely observable, if at all, in the historical or palaeoenvironmental record. Plants may react to such disturbances as fire, for example, which has a variety of potential causes (e.g. lightning strikes, human ignition) indistinguishable in the observed changes in the geomorphological, archaeological and historical record. In environments where fire regimes have been the primary disturbance mechanism controlling plant distribution, adaptation and evolution, the influence of other causes of disturbances may be negligible. But in some environments, where the causes of disturbance may be evenly measured, the contribution of specific disturbances processes to plant responses, including fire, may be indistinguishable.

**Characterising disturbance on islands from botanical evidence**

If we accept the hypothesis supported by many authors (e.g. Whittaker, 1995; Levin, 2004; Walter, 2004) that the complexity of disturbance patterns occurring on islands exceeds that of other geographical areas, this presents a major dilemma for inferring plant responses from geomorphological, archaeological and historical evidence. If islands can be characterised by disturbance regimes, the same characterisation must be applied to the ecology and biology of island floras. Thus, we might accept, as is done here, that island floras *a priori* are disturbance-adapted compared to the floras of larger landmasses. Many islands possess a large number of taxa that would normally be regarded as secondary or disturbance taxa in continental regions. The relative scarcity of lower order (family or genera) taxa on islands suggests that most plants possess few specific adaptations to specific disturbances. For the interpretation of plant responses to disturbance on islands, this means that relatively few of the disturbances of any kind and of any magnitude that may occur on islands can be directly substantiated, even when calculated by inference of correlated geomorphological, archaeological and historical events or processes.

**Braudel, conjuncture and disturbance**

Braudel (1980: 3) alluded to Francois Simiand’s description of *histoire événementielle* or the history of events as a ‘surface disturbance’ or as ‘the waves stirred up by the powerful movement of tides’. Within Braudel’s tripartite structure of history, *histoire événementielle* is something that is superficial when compared to the *longue durée*. What is important about this view of historical structure is not that the causal mechanisms for historical change operating within the *longue*
durée are more vital than those operating as histoire événementielle. It is, instead, the normalising effect of the longue durée on the other historical structures that act to either mask or highlight their more ephemeral ‘surface disturbance’ events or processes. The pulse of the tide on a sandy beach, when viewed over the lunar cycle (longue durée), has the form of slow moving wave, but when the tidal movement of the ocean encounters winds or barriers such as islands, a freak wave may be produced that may subsequently form an impression upon the coastline different from that of the tide. Depending on the magnitude of the freak wave, the movement of the tide over its full lunar cycle, from neap to spring (springen) tides, might in time erode the impression formed by the freak wave.

Braudel placed conjuncture (conjuncture) as a central historical structure that is diachronically attached to both the longue durée and histoire événementielle but is in no way defined by either. Instead, conjuncture reflects the historian’s choice among the various ‘chronological realities according to more or less conscious preferences and exclusions’ (ibid: 27). Conjuncture may be a point of interaction or resonance between the longue durée of the cultural, biological and geological events or processes and is the historical structure in which coherency in history can be recognised outside of the historian’s bias. It may also be a point or period in history characterised by hiatus or the absence of evidence. It is an attempt at scientific history. To define conjuncture is to define the consequences of the interaction between long-term cultural, biological and geological events or processes.

**Conjuncture and island floras**

The interaction of long-term structures in historical conjuncture is likely to be recognised as some kind of novel disturbance as opposed to a superficial disturbance of the kind described for histoire événementielle. Braudel was primarily interested in the transformation of social structure, but there are also certain ecological and biological characteristics of island floras that can be viewed in this way, both in terms of their evolutionary development, but also in terms of their response to disturbance since human settlement.

There are a number of independent or interrelated disturbance events or processes that have operated synchronously at specific times on islands that may be accepted a priori as a characteristic of island environments. These disturbances are chronologically aligned into what I term ‘disturbance modes’ that can be defined by a number of pronounced geomorphological, archaeological and historical disturbance signatures. For OIRO, the most pronounced disturbance modes of any significant magnitude include post-glacial sea-level change, initial human colonisation and European colonisation (see Table 4.1). Although the timing and extent of the independent or interrelated disturbances represented within these modes may vary at each site, it
is important to recognise here that any one disturbance may be generated by multiple causes operating synchronously or diachronically but may register the same response in the available geomorphological, archaeological and historical evidence.

The various taphonomic constraints on the preservation of botanical-based disturbance signatures can usually be measured as a function of time, but this may also be compounded at the points of *conjuncture*: if the resolution of the geomorphological, archaeological and historical evidence increases or decreases with time, at the points of *conjuncture*, the evidence represented may have been selectively preserved or removed. Each of the disturbance modes may be also be characterised, chronologically and botanically, through a range of representations (e.g. absolute radiocarbon dating, archaeobotanical evidence). Again the precision of these representations will be either improved or weakened at the points of *conjuncture*.

Braudel’s structural model implies that there appears to be particular points of historical *conjuncture* where these disturbance modes will overlap and it is at these points where some coherency in history may be recognised. I suggest in the following sections that these points of overlap, for many islands in OIRO, have not yet been defined with adequate chronological precision, but it is even less clear how these disturbance modes interact to form *conjuncture*.

**Conjuncture on Easter Island and Tikopia**

The causal explanations for plant origins, cultivation, translocation and extinction appear critical to Diamond’s (2005) treatment of Easter Island and Tikopia in *Collapse*. As explained in Chapter 3, Diamond’s primary explanation for societal failure or success on these two islands centres on the demise of the *Paschalococcus disperta* palm on Easter Island and the localised domestication of *Canarium* on Tikopia, respectively. In this chapter, I question these explanations by addressing the likely responses of these and other plant taxa to the three disturbance modes discussed previously. I focus on the *conjuncture* between these modes and thus define the variation that may exist between island floras and their response to disturbance. The historical structures derived can then be compared directly in counterpoint with the macrohistoric treatment of the interpretations of plant origin, translocation, cultivation and extinction provided by Jared Diamond in his *Collapse* treatise. The disturbance responses of *Paschalococcus, Canarium* and a range of other plant species from these islands are addressed in the context of the available geomorphological, archaeological and historical evidence, including palaeobotany, archaeobotany, first European contact descriptions and modern phytographical treatments. With the current available evidence it should be possible to deduce what causal explanations for *Paschalococcus* extinction or *Canarium* cultivation are robust, or, what explanations will remain
speculative without further evidence established within a re-oriented theoretical and methodological framework.

<table>
<thead>
<tr>
<th>Geomorphological evidence for disturbance</th>
<th>Archaeological evidence for disturbance</th>
<th>Botanical evidence for disturbance</th>
<th>Absolute chronological representations</th>
<th>Chronological representations in palaeobotanical record</th>
<th>Chronological representations in archaeobotanical record</th>
<th>Taphonomic constraints on botanical evidence</th>
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<tr>
<td>Post glacial sea-level change</td>
<td>Initial human colonisation</td>
<td>European colonisation</td>
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<td>e.g. Coastal sediment progradation</td>
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<td>None</td>
<td>e.g. Faunal and floral utilisation, extirpation and introduction</td>
<td>Pollen, plant macro-remains, charcoal particles, ethnotropical sources</td>
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<td>Pollen, plant macro-remains, charcoal particles</td>
<td>Pollen, plant macro-remains, archaeobotanical remains, charcoal particles, ethnotropical sources</td>
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<td>Gram radiocarbon dates +/- 100-100 yrs on wood, seeds, charcoal or pollen concentrations</td>
<td>e.g. High charcoal particles, seed taxa and plant introductions, reduced endemic representation (or extinction)</td>
<td>e.g. Historic plant introductions, further reduced endemic representation (or extinction)</td>
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<td>E.g. Coastal swamp forest development; High plant endemism</td>
<td>e.g. Local economic plant resources; increasing introduced economic plant representation</td>
<td>E.g. Historic plant introductions, reduced local economic resources</td>
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<td>E.g. More preserved soft plant tissue and increasing resolution of sources</td>
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<td>E.g. Increasing diagenesis of soft and hard plant tissue</td>
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Table 4.1: The three disturbance modes mentioned in the text are placed in relation to the geomorphological, archaeological and botanical evidence for disturbance. *Conjuncture* is found at the shaded points where these disturbance modes overlap as indicated. The relevant palaeobotanical, archaeobotanical and chronological representations are presented. Some examples on the taphonomic constraints on botanical evidence are also presented. The arrows represent an increasing effect.

The macrohistoric view of Tikopia’s environment

Before discussing historical *conjuncture* on Easter Island and Tikopia it is necessary to outline Diamond’s macrohistoric treatment of Tikopia, which he contrasts with Easter Island. Of the societal and environmental collapse of Easter Island, Diamond (2005: 107) concludes:

‘The overall picture for Easter is the most extreme example of forest destruction in the Pacific, and among the most extreme in the world: the whole forest gone, and all of its tree species extinct. Immediate consequences for the islanders were losses of raw materials, losses of wild-caught foods, and decreased crop yields.’
To Diamond (ibid: 118) it is Easter Island’s isolation from attacks from neighbouring enemies or support from friendly island societies, as well as the lack of evidence for climatic mechanisms for environmental degradation that provide part of the explanation for societal collapse:

‘That leaves us with just two main set of factors behind Easter’s collapse: human environmental impacts, especially deforestation and destruction of bird populations; and the political, social, and religious factors behind the impacts, such as the impossibility of emigration as an escape valve because of Easter’s isolation.’

Diamond (ibid: 286-293) then offers Tikopia (12°16’S, 168°49’E; see Figure 4.1), a small (4.6 km²) isolated island around 360 km southeast of Santa Cruz in the Solomon Islands (Temotu Province), as an example of an island society who have chosen an ‘opposite path to success’ (ibid: 291, after Kirch 1997). Diamond (ibid: 292) suggests that on Tikopia a society-wide decision ‘taken consciously around A.D. 1600, and recorded in oral traditions but also tested archaeologically, was the killing of every pig on the island’. Pigs formerly the island’s primary protein source, were replaced by other food resources including fish, shellfish, turtles and probably vegetables. He continues:

‘their ancestors had made the decision because pigs raided and rooted up gardens, competed with humans for food, were an inefficient means to feed humans..., and had become a luxury food for many chiefs. With that elimination of pigs, and the transformation of Tikopia’s bay into a brackish lake around the same time, Tikopia’s economy achieved essentially the form in which it existed when Europeans first began to take up residence in the 1800s.’

The island is situated on the western, tropical edge of OIRO, a geographical area used to arbitrarily distinguish between both the dispersal abilities (vagility) of island biotas since island formation, and the voyaging capabilities of people who began occupying the region over the last 3500 years (Green, 1991). It is also on the edge of the ‘Andesite Line’ used to separate between the Gondwanaland continental geology over the predominantly Tertiary or younger oceanic island geology (see Figure 1.1). The nearest islands are Anuta (also in the Temotu Province) and Banks Island (Vanuatu), 137 km northeast and 210 km southwest respectively. In 1976 the island supported a population of around 1,856 people who are mostly speakers of the Tikopian Malay-Polynesian language (Grimes, 1996). The climate is humid tropical with mean temperatures ranging from 25-29°C and an average annual rainfall of 4,000 mm, receiving the heaviest rainfall between October and March (wet season).

The island was subject to a major archaeological investigation in 1976 run by Kirch and Yen, who compiled *Tikopia: the prehistory and ecology of a Polynesian outlier* (1982). Kirch and Yen concentrated on archaeological excavation but did not retrieve any palaeoenvironmental
records from the island. From the excavation data they suggest that the island was first occupied by about 3,000 yrs B.P. with the oldest deposits showing all the features of early settlement of a previously unmodified island ecosystem (Easter Island included).

Evidence for three extirpated bird species and an extinct megapode was found in midden deposits dating to between 3000 and 2100 yrs B.P. (Steadman et al 1990). A number of items of material culture were imported to the island in this 'Kiki Phase' including obsidian sources from West New Britain (around 2,200 km to the northwest) and Banks Island (around 300 km south). Locally manufactured pottery was produced at that time, mostly undecorated, with only a small proportion of the sherds identified exhibiting the dentate-stamped decoration characteristic of Lapita pottery. *Rattus exulans* and *R. praetor* and a full suite of domestic animals including pig, dog and fowl were introduced in this phase. No direct evidence of introduced plant cultigens or tree crops was located in these Kiki Phase deposits. Evidence for large-scale colluvial sedimentation associated with the deposition of fragments of charcoal is thought to indicate slash and burn (swiddening) agricultural practice.
The presence of *Canarium harveyi* mesocarp (see Plate 1) dated to between 2350-1700 cal. yr B.P. is consistent with the beginning of Kirch and Yen’s (1982) Sinapupu Phase (~2350-750 cal. yr B.P.), defined by the initial presence of incised and applied relief-decorated Mangaasi pottery sourced from northern Vanuatu. Evidence for the extirpation of a further two bird species was located from midden deposits (Steadman et al. 1990) and further extensive swiddening activity is dated to this Sinapupu phase. Diamond (2005) sees this phase of Tikopia’s environmental history as comparable to Easter Island. Diamond (2005: 292 after Kirch, 1997) suggests that:

‘Around 100 B.C. [Sinapupu Phase], the economy began to change as those initial food sources disappeared or were depleted. Over the course of the next thousand years, charcoal accumulation ceased, and remains of native almonds (*Canarium harveyi*) appeared, in archaeological sites, indicating that Tikopians were abandoning slash-and-burn agriculture in favour of maintaining orchards with nut trees.’

Kirch (1997: 37) believes this archaeological sequence represents a:

‘process of conversion from shifting cultivation to an arboricultural system [that] obviously took several hundreds of years and must have been built upon the accumulated trials and errors of many generations of gardeners.’

Kirch and Yen’s (1982) interest in Tikopia’s archaeology and environmental history stems from Raymond Firth’s anthropological investigations of the island’s social structure between 1928 and 1929. In a series of texts on the island, the earliest being *We the Tikopia* (*Matou nga Tikopia*) (1936) and *Primitive Polynesian economy* (1939), he portrays Tikopia as a cultural environment, most aspects of which are affected by human activity and interaction. Firth (1936: 374-375) showed that although the island could be characterised by dense forests with small cultivations interspersed between the scattered villages:

‘as one wanders abroad, ascends the ring of hills that encircles the lake, climbs the peak of Reani or skirts the rugged northern shore, it becomes evident that the whole place is in a high state of economic utilisation, that gardens are made right up in the mountain, and that what appears to be bush is really a collection of trees and shrubs, each having its own value to the people, either for its food or in their material arts’.

The closeness of human-environment relations on Tikopia was recognised by Firth who suggested that plant-use extended beyond simple subsistence value to include formal ritual
associations, in which plants are commonly drawn upon as metaphors for social relations and practice. For example, the tuberous crops *Colocasia esculenta* and *Dioscorea* spp., and the tree crops *Cocos nucifera* and *Artocarpus altilis* were totemic to specific clans. Some crops such as *Musa* spp. and *Cyrtosperma merkusii* (syn. *C. chamiissonis*) lacked such ritual associations. Analysing the economic significance of these relationships, Firth (1939) suggested that there was a distinct lack of correspondence among the relative economic importance of these crops (e.g. caloric value), the labour expenditure involved in production, and the relative social or ritual emphasis on them. Firth’s preferred explanation for this discordance emphasised the embedded social structure or in his words ‘institutional efflorescence’ (ibid: 65), or diffusion of distinctive social practices with a substantial historical basis. The ritual associations of plants provided symbols for action portrayed in oral histories, so that, for example, social measures of population control apparently fluctuated with the changing productivities of the various clan-associated crops.

It was Firth’s emphasis on the antiquity of these plant-human relationships that inspired Kirch and Yen (1982: 35) to approach ‘a complementary material explanation, based in the contrastive biological roles of the crop plants involved.’ This was part of a broader aim to map the human dimension of environmental change on the island. They were intrigued at the implications of the traditional, pre-European colonisation ritual cycle that encoded an ideology of marked human population control in response to changing agronomic productivity. Kirch (1997: 35) sees this mechanism of population control with its social implications for mitigating environmental change as ‘a model of the sustainable microcosm... perhaps unparalleled by other Pacific examples.’ He suggests that the island had a high resilience to human impact with highly nutrient-rich soils replenished through the rapid weathering of its geological parent material. He emphasised that this would not have been enough to avert the inevitable ecological disasters inferred from his other archaeological studies on other Pacific islands (e.g. Mangaia; see Kirch, 1996; Kirch et al 1991; Kirch et al 1995). To Kirch (1997: 38), ‘The final outcomes ... were ultimately the result of conscious choices made by successive generations of individual humans.’

**The macrohistoric island comparison**

A general summary and comparison of some of the main environmental characteristics of each island is provided in Table 4.2. At first glance many of these parameters are not comparable, rendering a comparison of any environmental aspect implausible given, for example, the disparity in island area (166 to 4.6 km²) and geological age (0.3 to 0.08 ma K/Ar). As I will illustrate later, this quickly comes into focus when the botanical sources for each island are assessed. Despite such contrasts, Barry Rolett and Diamond (2004) attempted to quantify the environmental
conditions for 81 islands that appeared ‘suitable for agriculture’ prior to European contact, in order to establish a classification of islands that are predisposed towards deforestation. They classified each island, including Easter and Tikopia, according to a range of environmental factors that may have contributed to their increased susceptibility to deforestation by humans, as estimated at the time of European contact with the islands (see Table 4.2). Statistically high values for island rainfall, elevation, area, volcanic ash fallout, Asian dust transport and uplifted reef terrain (makatea; see Chapter 1 and 6) are seen to have limited deforestation potential, whereas predisposition towards deforestation increased with latitude, age and isolation.

<table>
<thead>
<tr>
<th>Environmental factors</th>
<th>Easter Island</th>
<th>Tikopia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land area (km²)</td>
<td>166</td>
<td>4.6</td>
</tr>
<tr>
<td>Geological age (Ma)</td>
<td>0.3³</td>
<td>0.08⁵</td>
</tr>
<tr>
<td>Parent materials</td>
<td>Deeply weathered benmoreite and hawaiite lavas and scoria</td>
<td>Unweathered andesitic lavas capped by weathered breccia and tuff³</td>
</tr>
<tr>
<td>Annual rainfall at sea level (mm)</td>
<td>1200¹</td>
<td>4000²</td>
</tr>
<tr>
<td>Cyclone susceptibility</td>
<td>Low³</td>
<td>High²</td>
</tr>
<tr>
<td>Maximum elevation (m)</td>
<td>510 (Tere vaka)</td>
<td>360 (Reani)</td>
</tr>
<tr>
<td>Continental dust</td>
<td>3¹</td>
<td>370¹</td>
</tr>
<tr>
<td>Latitude</td>
<td>27° 07'S</td>
<td>12° 17'S</td>
</tr>
<tr>
<td>Longitude</td>
<td>109° 22'W</td>
<td>168° 48'E</td>
</tr>
<tr>
<td>Distance to nearest high island</td>
<td>140¹</td>
<td>1600¹</td>
</tr>
<tr>
<td>&gt;25% the size of homeland (km)</td>
<td>Limiting³</td>
<td>Non limiting³</td>
</tr>
<tr>
<td>Soil phosphorous</td>
<td>Low¹</td>
<td>High¹</td>
</tr>
<tr>
<td>Potential volcanic tephra fallout</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.2 Comparison of main environmental characteristics of Easter Island and Tikopia; ¹after Rolett and Diamond, 2004; ²after Kirch, 1997; ³my estimate; ⁴after Hasse et al 1997; ⁵after Fryer, 1974.

The statistical results of this survey were positively or negatively graded according to this deforestation potential. Tikopia is regarded as unusual given that at European contact (deforestation value of 2) the island is thought to have been well forested (e.g. Dillon, 1829) and has a high forest replacement value (4) and is, hence, predisposed towards deforestation. Easter Island is seen by Rolett and Diamond as the exemplar of an island with both complete deforestation (5) at European contact and the highest possible forest replacement value (5). Tikopia, Tonga and Kosrae (Federated States of Micronesia) all generated positive residuals requiring another explanation for why deforestation at European contact was limited. Kirch (1997) has explained that for Tikopia the island’s society effectively employed a set of protective measures against deforestation. Rolett and Diamond (following Kirch, 1997) suggest that such
effective human agency is the only plausible proposition given the apparent susceptibility of these islands to environmental degradation.

In *Collapse*, Diamond categorises each island society by their historically determined capacity to either solve or ignore environmental problems as causal to societal survival or demise. This dichotomy established between the ‘ecodisaster’ of Easter Island and the ‘sustainable’ productions of Tikopia is effectively employed to circumvent environmental information that is deemed redundant in order to highlight the role of human agency. As discussed in Chapter 3 the qualification of human impact on islands is dependent on a number of conceptions, namely the establishment of *conjoncture* between time and process within which human agency may be reflected. I maintain that it is unclear exactly where *conjoncture* exists, conceptually or chronologically, in this macrohistoric view of islands.

The emphasis that Diamond affords botanical sources in his brief outline of the environmental history of Easter Island and Tikopia is represented by two iconic species. For Easter Island it is the extinct palm tree (*Paschalococcus disperta*) that becomes a metaphor for societal collapse. For Tikopia, it is the development of the native almond (*Canarium harveyi*) as a tree crop that represents intentional and sustainable environmental practice. Here I provide a detailed critique of botanical utility in Diamond’s treatment of these island histories. In summarising the botanical sources for these islands, set within the diachronic structure proposed in Chapter 3, an additional means is provided for assessing the level at which botanical representations may reflect human agency in line or at odds with that proposed by Diamond and others. By considering how adequately botanical representations reflect historical structures, both durable and ephemeral, weaknesses in the varying interpretations may become more apparent. To reiterate, the methodology I have employed for this approach is aimed essentially at establishing what evidence and historical structures may be accepted *a priori*.

Given the pervasive human dimension of remote island histories and the ubiquity of botanical representation since and prior to human colonisation of these islands, it should be possible to record these changes using botanical sources. Human agency in the ‘orthodox’ scenario of Easter Island’s societal collapse has been constructed primarily from this relationship but, as I will demonstrate, is achieved in such a way that not only obscures the chronological detail but also the temporality of plants is obscured.
Easter Island and botanical sources

Modern flora

The flora of Easter Island has most recently been described by Georg Zizka (1991a; 1991b) recording 177 angiosperm species\(^2\). There are currently 43 extant indigenous vascular plants and 68 naturalised species along with an additional 66 exotic species introductions (Zizka, 1991b; Marticorena and Rodriguez, 1995). The island’s flora is exceptionally depauperate in woody species, considering the size, topography and the extent of deep soil horizons. Contention by botanists regarding the extent of the island’s flora began with Skottsberg’s (1956) remarks that the unusual character of the flora must be a result of its isolation. Balgooy (1960; 1971 in Flenley et al 1991) presented two diverging opinions on the issue originally disagreeing with Skottsberg in concluding that many species must have become extinct on the island as a result of human disturbance. It was not until the extent of palm pollen (Flenley and King, 1984) and macrofossils (Dransfield et al 1984) became clear that it was recognised that other angiosperm taxa may have been prevalent on the island. More recently Orliac and Orliac (1998) published their identification of archaeological charcoal assemblages indicating that a suite of large woody tree taxa formed a part of the island’s flora. Around 10 species extinctions are recorded in pollen records (e.g. Flenley et al 1991) with an additional 12 species extinctions recorded in macro-charcoal records (see Table 4.5 and discussion below) on top of the palynological findings (e.g. Orliac, 2000).

Through pressure of grazing, fire and invasion by exotic species, the island’s indigenous species are now restricted to marginal habitats. For example, two endemic grass species survive at higher elevation sites, *Axonopus paschalis* (Zizka, 1993) in large patches and *Danthonia paschalis* now rare. Most of the vegetation cover of the island consists of pastoral grasses and sedges (e.g. *Kyllinga brevifolia*), with grasses dominating areas at low elevation (see Plate 2). In 1891, W.J. Thomson commented on the historical effects of grazing by sheep and other domestic animals:

‘At various places throughout this land we found small clumps of *Edwardsia* [Sophora toromiro], *Broussonetia*, and *Hibiscus*, but all were dead, having been stripped of their bark by flocks of sheep, which roam at will over the island.’ (1891: 456)

The inner slopes of the craters are noted as being refuges for a number of indigenous plants species. The last remaining specimen of the endemic *Sophora toromiro* was located in 1935 along

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\(^2\)Zizka (1993: 46) notes that some of these species have only ephemeral records.
the slopes of Rano Kao. *Triumfetta semitriloba* and *Caesalpinia major*, rare on other parts of the island can still be found in the crater (Zizka, 1993: 47).

Plant taxa probably introduced prior to European contact include *Colocasia esculenta*, *Dioscorea* spp., *Ipomoea batatas*, *Broussonetia papyrifera*, *Cordyline fruticosa*, *Saccharum officinarum*, *Cucurma longa* and *Lagenaria siceraria*. Skottsberg (1956) earlier recognised a number of vascular plant species as having been ‘waifs and strays’ some introduced by the initial island inhabitants including *Triumfetta semitriloba* (*T. procumbens*), *Broussonetia papyrifera*, *Ipomoea batatas*, *Musa sapientum* (*M. acuminata*) and *Colocasia antiquorum* (*C. esculenta*). A number of other species are thought possible pre-European introductions including *Sapindus saponaria*. In 1911, Knoche (1925 in Zizka, 1993) recorded several cultivated varieties of *Dioscorea* spp. (42), *Ipomoea batatas* (25), *Colocasia esculenta* (14) and *Saccharum officinarum* (12). For some species including *Cocos nucifera* and *Solanum forsteri*, it is uncertain whether they were introduced prior to European contact (Brown, 1935).

**Botanical sources at first-European contact with Easter Island**

As discussed in Chapter 3, Jared Diamond has utilised Easter Island's first contact history, albeit in brief, as a means of measuring the extent of failure of this pre-European society:

‘Deforestation must have begun some time after human arrival by A.D. 900, and must have been completed by 1722, when Roggeveen arrived and saw no trees over ten feet tall’ (Diamond, 2005: 106-107).

Roggeveen’s perspective on this issue, however, is by no means clear. In his initial description of the island’s appearance we are led to believe the island is barren and treeless:

‘we have now come to the sandy island, at a distance of about two miles, which lie eastward (although ahead still out of sight) from the extent of the coast or tract of land, the discovering of which is part of our expedition; and since it was seen by us that smoke rose from various places, from which it may with reason be concluded that the said island, although it appears sandy and barren, nevertheless is inhabited by people’ (Corney, 1908: 7; also in Sharp, 1970)

Upon further observation of the island Roggeveen’s (*ibid*: 9-10) opinion changes:

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3 In 1955 Thor Heyerdahl collected and rescued seed from this *Sophora* specimen that died soon after. This seed was later propagated and successful attempts have been made to re-establish the plant on the island.

4 Diamond is actually referring to an observation made by Georg Forster 52 years later in 1774 ‘... there was not a tree upon the island which exceeded the height of ten feet’ (Cook and Forster, 1777: 566-569)
'The reason why at first, when at farther distance off, we regarded the said Easter Island as being of sandy nature is that we mistook the parched up grass, and hay or other scorched and charred brushwood for a soil of that arid nature, because from its outward appearance it suggested no other idea than that of an extraordinarily sparse and meagre vegetation; and the discoverers had consequently bestowed upon it the term sandy.'

On further reflection, Roggeveen (ibid: 21) portrays a considerably different picture:

'Nor can the aforementioned land be termed sandy, because we found it not only not sandy but on the contrary exceedingly fruitful, producing bananas, potatoes, sugarcane of remarkable thickness, and many other kinds of fruits of the earth, although destitute of large trees and domestic animals except poultry. This place, as far as its rich soil and good climate are concerned, is such that it might be made into an earthly Paradise, if it were properly worked and cultivated; which is now only done in so far as the Inhabitants are obliged to for the maintenance of life.'

In 1722, the island may have been 'destitute of large trees' but how this may reflect societal collapse in the terms described by Bahn and Flennley (1992) and Diamond (2005) is unclear. How could an island that appears 'exceedingly fruitful' also be indicative of an ecodisaster? One of Roggeveen’s party, C.F. Behrens (1739: 138) states that: ‘The whole [island] is cultivated and well kept, it is full of woods and forests’.

One feature of the island recognised in both Roggeveen’s and Behren’s account is the number of plants kept in agricultural production by the islanders. From a list of plants described by Roggeveen and other members of his crew including Cornelis Bouman (1994) and Behrens, a total of twelve cultigens may have been cultivated on the island in 1722 (see Table 4.3). In November 1771, Don Felipe Gonzalez y Haedo (1903) only mentions seven cultigens whereas three years later Cook and the HMS Resolution party noted ten (e.g. Cook, 1777). By 1786, Jean-Françoise de La Pérouse (1798; 1807) and crew on the Boussole and Astrolabe observed only five cultigens. This reduction in the number of listed cultigens is unlikely to represent an oversight by the later observers, but may reflect either seasonal changes in crop production, or an abandonment of certain crops. In March 1774 Cook observed:

'For the great part of the distance across the ground had but a barren appearance, being a dry hard clay, and everywhere covered by stones; but not withstanding this, there were several large tracks planted with potatoes, and some plantain walks, but they saw no fruit on any of the trees' (Cook, 1777: 277).

Cook’s party also found little evidence of active garden enclosures of the type described by Roggeveen. Instead, J.R. Forster found:
‘the country being strewed with volcanic cinders, and desolate all round us, though we found many remaining proofs of its having been formerly cultivated’ (J.R. Forster 1777 in von Saher, 1992: 38)

The inconsistency between these historical accounts of agricultural production on Easter Island from 1722 to 1774 is intriguing but not surprising. When considering the forty-nine years that had elapsed between Roggeveen’s and Gonzalez y Haedo’s account in terms of the probably social change that may take place in any small society, why should it be surprising? In forty-nine years, two generations of people would have passed away with only a few, if any, elderly people remaining alive who experienced the visit of Gonzalez’s crew and could also recall Roggeveen’s visit.

There is no information available to resolve either way the possible impacts that foreign visitors may have had on the social dynamic of the island. J.G. Forster on Cook’s expedition to the island in 1774 suggests that the islanders were well aware of the exploits of foreign visitors:

‘The people did not make the least unfriendly motion at our landing, but expressed a prodigious dread of our fire-arms, of which they seemed to know the deadly effects...’ (J.G. Forster in von Saher, 1992: 35)

Gonzalez y Haedo’s (in Corney, 1908) account from 1771 makes no mention of their use of firearms even when they were kept at hand in the presence of the islanders. It is not unlikely that European visitors utilised firearms.

The European impacts that were exhibited after Cook’s arrival are summarised by Diamond as follows:

‘The sad story of European impacts on Easter Islanders may be quickly summarised. After Captain Cook’s brief sojourn in 1774, there was a steady trickle of European visitors ... they must be assumed to have introduced European diseases and thereby to have killed many previously unexposed islanders, though our first specific mention of such an epidemic is of smallpox around 1836 [more likely 1838 after Du Petit-Thouars, 1841]. Again as on other Pacific islands, “black-birding”, the kidnapping of islanders to become labourers, began on Easter around 1805 [after the blackbirding vessel Kahu-Manu in 1806] and climaxed in 1862-63...’ (Diamond, 2005: 111-112)
<table>
<thead>
<tr>
<th>Year</th>
<th>Foreigner accounts</th>
<th>Duration of encounter and landfall</th>
<th>Exotic animal or plant introductions</th>
<th>Records of indigenous plants or pre-European plant introductions</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>6th April 1722</td>
<td>Myrheer Jacob Roggeveen, Cornelis Bouman and C.F. Behrens with the three ships Arend, Tienhoven and De Afrikaansche Galey;</td>
<td>4 nights landfall</td>
<td>None</td>
<td>Roggeveen in Corney (1908): - Saccharum officinarum. (sugar-cane) - Dioscorea spp.? (yams-ubaworteln, p. 13) - Musa spp. (bananas) - Cordyline fruticosa, Dioscorea spp. or Ipomea batatas? ('root of some vegetable... of good stout parsnips or carrots.' p. 14) - Ipomea batatas (potatoes) - Thepseria populnea, Broussonetia papyrifera or Cordyline fruiticosa? (Pret - p.18) - Psalchococcus disporta or Aleurites moluccana ('a large and hard nut, whose shell was thicker and more resisting than our peach stones.' p.15)</td>
<td>Bouman in von Saher (1994: 96) - Psalchococcus disporta or Cocos meiifera (small coconut palms) - Lagernaria siceraria (bottle gourd) - Dioscorea spp (ignames) - Schosonepectus californicus (reeds) Behrens (1739) - Ipomoea batata (sweet potato) - Colocasia esculenta (white root)</td>
</tr>
<tr>
<td>15th November 1711</td>
<td>Don Felipe Gonzalez y Haedo on the Santa Rosalia with the San Lorenzo</td>
<td>5 nights landfall</td>
<td>?</td>
<td>Gonzalez (in Conrey 1908: 7, 101, 123) - Cordyline fruticosa or Colocasia esculenta (ytca) - Dioscorea esculenta (yucca) - Musa spp. (plantain) - Saccharum officinarum (sugar-cane) - Cucumis longa ('a root which they chew and daub their body and limbs all over with; it is good for yielding a fine yellow dye.' 1908: 123) - palm leaf (ojas)-cf. - Ficus sp. (figs - gecoy) - cf. Sophora toromiro ('Its trees are very similar to mimosas and tanarinds.' 1903: 101) - Lagernaria siceraria (bottle-gourd)</td>
<td></td>
</tr>
</tbody>
</table>

*Metraux (1940:154-155) suggest yucca refers to Colocasia esculenta with ti (Cordyline fruticosa) first mentioned by Palmer in 1866, but yucca is a common word used to describe Cordyline in other explorer accounts.*

**Cont.**
<table>
<thead>
<tr>
<th>Year</th>
<th>Foreigner accounts</th>
<th>Duration of encounter and landfall</th>
<th>Exotic animal or plant introductions</th>
<th>Records of indigenous plants or pre-European plant introductions</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 1774</td>
<td>Captain James Cook and G. Forster and J.R. Forster on the HMS Resolution</td>
<td>2 night landfall</td>
<td>-Cocos nucifera (coconut) shells</td>
<td>-Musa spp. (bananas) -Saccharum officinarum (sugar-cane)</td>
<td>Cook and Forster (1777: 285, 288) Forster (1778: 556-559, 571, 573, 578)</td>
</tr>
<tr>
<td></td>
<td>Inland party: William Hodges, Johann Forster, Sparrman, Lieutenant Pickering and Edgecumbe</td>
<td></td>
<td></td>
<td>-Broussonetia papyrifera (Otaheitean cloth plant, paper mulberry) -Dioscorea spp. (yams) -Ipomoea batatas (sweet potato/potato, pouter-patoos) -Colocasia esculenta ('tara or eddy root' or 'eddoes') -Alocasia macrorrhiza -Lagenaria siceraria (gourd) -Solanum forsteri or S. americanum (night-shade, solanum) -Corcusa longa (turmeric root) -Sophora toromiro (mimosa) -Theopsea pudinefa? (hibiscus 'wood...dark-brown, like that of casuarina' Forster, 1778: 556-559) -grass</td>
<td></td>
</tr>
<tr>
<td>April 1786</td>
<td>J.F.G. de La Pérouse, Messr. de Langle, Messr. Berzin and on the Boussole and Astrolabe</td>
<td>?</td>
<td>? (beet) -Citrus spp. (orange, citron) -Gossypium sp. (cotton) -Brassica sp. (cabbage) -Daucus sp. (carrot) -Zea mays (corn) -Lagenaria siceraria (gourd) -goats, sheep, pigs</td>
<td>-Broussonetia papyrifera (mulbete?) -Musa spp. (bananas) -Solanum forsteri or S. americanum (night-shade) -Ipomoea batatas (sweet potato) -Saccharum officinarum (sugar-cane) -Dioscorea spp. (yams)</td>
<td>La Pérouse (1798: 73, 81, 178), La Pérouse (1807: 20-21, 25-26 vol. II), La Pérouse (1807: 187 vol. III)</td>
</tr>
<tr>
<td>1801</td>
<td>Amas Delano on the Pilgrim?</td>
<td>?</td>
<td>?</td>
<td>-Saccharum officinarum (sugar-cane) -Dioscorea spp. (yams)</td>
<td>Delano (1817)</td>
</tr>
<tr>
<td>16th -20th April 1804</td>
<td>Urey Lisiansky on the Neva</td>
<td>3 nights no landfall</td>
<td>?</td>
<td>-Musa spp. (bananas, plantain) -Saccharum officinarum (sugar-cane, toa) -Schoenoplectus californicus (balsam-root swimming) -Ipomoea batatas (sweet potato)</td>
<td>Lisiansky (1814), Barrett (1996: 34-38)</td>
</tr>
</tbody>
</table>

Cont.
<table>
<thead>
<tr>
<th>Year</th>
<th>Foreigner accounts</th>
<th>Duration of encounter and landfall</th>
<th>Exotic animal or plant introductions</th>
<th>Records of Indigenous plants or pre-European plant introductions</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1808</td>
<td>Armas Delano</td>
<td>?</td>
<td>no landfall</td>
<td>?</td>
<td>Delano (1817)</td>
</tr>
<tr>
<td>March 1815</td>
<td>Otto von Kotzebue, Aldalbert von Chamisso, Johann Friedrich Eschscholtz and Ludovik Choris on the Rurik</td>
<td>?</td>
<td>?</td>
<td>-Sophero toromiro (yellow blossoms) -Musca spp. (bananas) -Saccharum officinarum (sugar-cane) -Dioscorea spp. (yams) -Colocasia esculenta (taro) -Solanum americanum (pepino) -Cordyline fruticosa (ti) -Ipomoea batatas (sweet potato) -Brussensonia papyrifera</td>
<td>Kotzebue (1821), Chamisson, (1864), Choris (1826), Barratt (1996: 38-47), Eschscholtz (1829-1831)</td>
</tr>
<tr>
<td>1825</td>
<td>Frederick W. Beechey, George Peard and E. Belcher on the HMS Blossom</td>
<td>?</td>
<td>?</td>
<td>-Musca spp. (bananas) -Saccharum officinarum (sugar-cane) -Dioscorea spp. (yams) -Ipomoea batatas (sweet potato) or possibly -Solanum tuberosum (potato)</td>
<td>Beechey (1831), Gough (1973)</td>
</tr>
<tr>
<td>1826</td>
<td>Mr P.P. Blyth</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>Palmer (1868; 1870a)</td>
</tr>
<tr>
<td>27th Nov 1827</td>
<td>Hugh Cuming on his own schooner the Discoverer</td>
<td>1 night No landfall</td>
<td>?</td>
<td>-Ipomoea batatas (sweet potato) -Musca spp. (plantains) -Saccharum officinarum (sugar-cane) -Dioscorea spp. (yams) -Cocos nucifera (Cocos) Or Colocasia esculenta (&quot;a Root called Cocos in the West Indies&quot;)</td>
<td>Fischer (1991: Cuming (n.d.), McCall (1976: 91)</td>
</tr>
</tbody>
</table>

Cont.
<table>
<thead>
<tr>
<th>Year</th>
<th>Foreigner accounts</th>
<th>Duration of encounter and landfall</th>
<th>Exotic animal or plant introductions</th>
<th>Records of indigenous plants or pre-European plant introductions</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct 1828</td>
<td>Jacques Antoine Moerenhout on the Vénaise?</td>
<td>?</td>
<td>-No pig -chickens -rats</td>
<td>-Ipomoea batatas (sweet potato) -Musa spp. (bananas) -Saccharum officinarum (sugar-cane) - Dioscorea spp. (yams)</td>
<td>Moerenhout (1837)</td>
</tr>
<tr>
<td>1838</td>
<td>Admiral Aubert Du Petit-Thouars on the frigate La Venus</td>
<td>No landfall</td>
<td>?</td>
<td>?</td>
<td>Du Petit-Thouars (1841)</td>
</tr>
<tr>
<td>1843</td>
<td>Monsignor E. Rouchouze accompanied by 24 monks and nuns thought by Chauvet to have been massacred, although Altman and McLaughlin (2005) suggest there is no evidence of this group's arrival or massacre</td>
<td>Landfall ?</td>
<td>?</td>
<td>?</td>
<td>Altman and McLaughlin (2005)</td>
</tr>
<tr>
<td>1852</td>
<td>The English frigate Portland</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>Palmer (1868; 1870a)</td>
</tr>
<tr>
<td>14th Dec 1862</td>
<td>Captain Aiguurire of the “black-birding” ship Cora</td>
<td>?</td>
<td>~2000 people enslaved for Peruvian guano mining</td>
<td>None</td>
<td>Maude (1964; 1986)</td>
</tr>
</tbody>
</table>

Table 4.3 Preliminary list of accounts of first European contact for Easter Island from 1722 to 1864. Listed are the central characters involved in the visit and the vessel(s) they arrived on; whether landfall was made and the duration of their visit; the exotic animals or plants introduced to the island from the visiting vessel and the existing economic (and other) plants observed on the island. The most relevant references for these accounts are also listed with a bibliography of these primary and other sources provided in the Appendices. ? = information yet to be obtained or clarified. For a list of accounts of European contact after 1864; see McCall (1976). See Appendix I for primary and secondary sources references.
But it is not impossible that further encounters with European crews were made between 1722 and 1771 given the number of 'lost caravel' crews that failed to return from the Pacific (Langdon, 1988). Europeans had been immigrating to the Pacific as beachcombers and castaways ever since Magellan’s 1521 voyage to the region (Maude, 1964). Between the visit of La Pérouse in 1786 and the arrival of Otto von Kotzebue and Aldalbert von Chamisso on the Rurik in 1816, several foreign visits were made to the island but with no documented landfall or little noted interaction with the Easter Islanders (see Table 4.3). In the absence of landfall little reliable information on the status of the indigenous flora is available. Only items of trade, including vegetable productions, were noted on these encounters. The most common vegetable items noted in these accounts are sugarcane (Saccharum officinarum), yams (Dioscorea sp.), sweet potato (Ipomoea batatas) and banana/plantain (Musa spp.). Chamisso (1864) recorded several cultivated species as well as the Sophora toromiro (‘yellow blossoms’ - Fabaceae) and Solanum americanum (‘poporo’ - Solanaceae).

Between 1816 and 1862, from the dozen or so visits by European vessels, none of the crews the ventured onto land, or at least no accounts were recorded. In 1825, Frederick W. Beechey (1831) on the HMS Blossom noted, when anchored offshore, that the European introduced potato (Solanum tuberosum) was an item of production and trade. He observed that:

\[ \text{The hills, and exposed parts of earth, were overgrown with a short-burnt-up grass, which gave the} \]
\[ \text{surface a monotonous and arid aspect; but the valley were well cultivated, and showed that the island} \]
\[ \text{required only a due portion of moisture and labour to produce a luxuriant vegetation} \] (Beechey, 1831: 41)

In 1827 Hugh Cuming (n.d.; Fischer, 1991) on the schooner Discoverer noted the presence of the Cocos plant, a name that probably refers to the corm cultigen Colocasia esculenta not the Coconut palm Cocos nucifera. In 1862, Captain Aiguirre on the ship Cora “black-birded” around 2000 islanders from the Society Islands, Tuamotus and Easter Island for the slave labour market at Callao in Peru. The social toll of introduced European diseases and “black-birding” probably had their most far-reaching consequences by this time (see McCall, 1976 for further discussion).

*Paschalococcus disperta and first European contact*

In the earliest European accounts of Easter Island there are three descriptions of botanical interest that may allude to the presence of the extinct palm *Paschalococcus disperta* on the island. From his visit in 1722, Roggeveen records:

\[ ^5 \text{Although see Dr Stephen-Chauvet’s spurious account of a group of monks and nuns ‘massacred’ on the} \]
\[ \text{island upon arrival in 1843 (Aliman and McLaughlin, 2005)} \]
"These people have also snow-white teeth, with which they are exceptionally well provided, even the old and hoary, as was evidenced by the cracking of a large and hard nut, whose shell was thicker and more resisting than our peach stones." (Roggeveen, in 1908a: 15)

The only other nut that might fit this description is *Aleurites moluccana* (see Chapter 1 and 7), but no botanical description of this species has been found within any historical or archaeobotanical sources for the island.

Cornelis Bouman (1994: 96), also on Roggeveen's voyage, noted a 'small coconut palm' on the island, possibly indicating either *P. disperta* or *Cocos nucifera*. Bouman's coconut identification seems unlikely given the apparent lack of coconut shells on the island. The apparent absence of coconut palms or at least fruit bearing palms on the island was be alluded to in J.G. Forster's following remark:

"The most valuable item of trade on our part were empty coconut shells which we had received at the Society and Friendly Islands" (Forster, 1777 in von Saher, 1992: 36)

Later in 1771, Gonzalez y Haedo also alluded to the presence of a palm, observing that the women:

"...by way of distinguishing their sex, cover the head with a curious construction of palm-leaf [ojas] or fine rushes (Gonzalez y Haedo's, in Corney, 1908: 7)"

The surgeon J. Linton Palmer (1870) visited the island in 1868 on the H.M.S. *Topaze* and provided a brief but descriptive account of the island’s vegetation for the 19th century. He found that the north side of Rana Kao (Terano Kau) crater were well covered with *Hibiscus* (possibly *Thespesia populnea*) and *Broussonetia*. He notes that:

"There were boles of large trees, Edwardsia [Sophora toromiro], coco palm, and hibiscus [possibly *Thespesia populnea*], decaying in some places..." (Palmer, 1870a: 168)

He also observed that there were 'no coconut-palms now growing, but boles of large ones are to be found.' (ibid: 170).

None of Palmer’s descriptions provide any conclusive evidence that the *Paschalococcus disperta* still remained on the island in 1868, but neither do they confirm presence of *Cocos nucifera*. 'Boles' are the stumps of palm trees but cannot allow the easy determination of the
parent species. *C. nucifera* is now distributed on the island in small pockets around Hangaroa village or as isolated specimens along the island coastline.

**The geological context and the Rano Raraku microfossil record**

Poike Peninsula forms the eastern corner of Easter Island and represents the oldest volcanic formation, with one of the lava flows originally K-Ar aged to around 3 ma (Baker *et al* 1974), but more recently 0.5 ma (Hasse *et al* 1997). The surface of the island is largely composed of the younger lava flows from Tere Vaka and its satellite cones that link with the older flows of Poike and Rano Kao (Baker, 1967). The youngest flows form an exposed blocky surface with numerous lava tunnels with little soil (Flenley *et al* 1991) and may provide some index of the rate of soil development on the island. Clastic sediments available for soil development vary depending on the orogeny of the flows ranging from benmoreite lavas on Rano Kao, Hawaïite flows on Rano Raraku, to porphyritic flows on Rano Aroi. Recent radiocarbon dating of soils on these lava flows suggests that few soils are unlikely to exceed Holocene ages (Meith and Bork, 2003).

As the largest volcanic lake caldera, Rano Kao, forms the southwest corner of the island with flows K-Ar aged 0.3 ma (Hasse *et al* 1997). One of the oldest lava flows of Tere vaka also has a K-Ar age around 0.3 ma. Tere vaka possesses at least 70 satellite cones of ash, scoria and lava on its flanks including two lake calderas, Rano Aroi and Rano Raraku (Flenley *et al* 1991). The accommodation space provided by the volcanic calderas have allowed an index of Pleistocene-aged organic sedimentation to be constructed. The oldest calderas, Rano Aroi and Rano Raraku, yielded basal ages on a highly organic ‘sedge’ layer exceeding the radiocarbon calibration curve (>24,000 cal. yr B.P. Stuiver *et al* 1998).

Rano Raraku is the most intriguing of the volcanic caldera of Easter Island, as its southern rim is composed of lapilli tuff. Along the poorly consolidated bedding planes of this tuff, the majority of the *moai* figures were apparently sculpted *in situ* and transported to the Ahu ceremonial sites along the island’s coast. Many sculpted *moai* remain both within the caldera and on the outer edge. The western rim of the caldera is composed of Hawaïite lava that sits 15-90m above the lake floor (Flenley *et al* 1991). The crater’s lake and swamp periphery form a near perfect circle with a diameter of around 200 m. The lake was pumped out to its present low levels (around 2 m below former levels) during the late 1960s to early 1970s, for domestic stock. The modern vegetation of the caldera is very sparse, now dominated by pastoral grasses and sedges along the outer banks with sedges and *Schoenoplectus californicus* subsp. *tatora* along the lake edge (see Plate 2).

Flenley (1993) suggests that he chose Rano Raruku as an ideal site for palynological research (after Jacobson and Bradshaw, 1981) as the lake represented an enclosed sedimentary
basin with no hydrological inflows or outflows. In 1961, preliminary palynological examinations of the Rano-Raraku lake sediments by Olof Selling (in Heyerdahl and Ferdon 1961) were published, demonstrating that forest vegetation formerly occurred on the island, including the *Paschalococcus* palm (thought by Selling to be a relative of the *Pritchardia* palm characteristic of the Hawaiian Island flora). In 1983, Flenley hand-cored four sequences along a transect extending out from the south-eastern edge of the caldera, immediately below the *moai* quarries. The maximum depth of 18 m was reached in a core located around 210 m away from the south-eastern embankment (RRA4) with none of the cores reaching bedrock. The stratigraphy of each of these cores is described in Flenley et al (1991). Core RRA3, located approximately 50 m from embankment (see Plate 2) was chosen for palynological examination with 13 bulk sediment samples from cores RRA3 and RRA4 selected for radiocarbon dating.

The palynological data (after Flenley et al 1991) for the Holocene-aged section of the RRA3 core (top 310 cm) have been placed into stratigraphic diagrams using the program C2 (Juggins, 2003) and are presented in Figures 4.2 and 4.4. For this examination, the radiocarbon ages have been re-calibrated using the OxCal program version 3.10 (Bronk Ramsey, 2001; 2005). The radiocarbon dates from RRA3 were augmented by an assay of $^{210}$Pb from the top 0.7 m, suggesting a mean rate of sediment accumulation of 1 cm yr$^{-1}$ for this section of the core. Flenley et al (1991) regard the three early Holocene dates as a possible result of contamination by older soil or bedrock carbon in-washed with a bed of silt and sand at 1.10 m. Charcoal particle, pollen and spore concentration data and plant macrofossil data are not available for this core and were not presented in either Flenley and King (1984) or Flenley et al (1991).

All of the pollen sequences presented by Flenley et al (1991) are from caldera deposits, and little of the pollen is likely to originate from outside of these catchment areas. The abundance of palm (cf. *Paschalococcus disperata*) pollen throughout much of the RRA3 core suggests that palms once formed a major component of caldera vegetation on the island. The Pleistocene pollen sequence of the RRA3 core consists of major fluctuations between palm and Compositae-Tubuliflorae (an Asteraceae pollen type) representation, which Flenley et al (1991) suggest represents warmer or cooler climatic phases, respectively. The ratio between grass (Poaceae/Gramineae) and fern (Filices) is similar used to provide an index of drier or wetter climatic phases. The sections dominated by cooler and drier grass and Compositae appear to fit the corresponding global and relative chronology established for the Last Glacial Maximum and Late Glacial climate phases of the Pleistocene (Flenley et al 1991). Some major fluctuations in palm pollen are represented within the RRA3 sequence and other caldera pollen records (e.g. Rano Kao; see Flenley et al 1991), but the relationship between palm pollen fluctuations and any climatic or edaphic cause remains unclear.

From around 9,000 cal yrs B.P. onwards (pre-human Holocene phase), the lake environment at Rano Raraku was progressively encroached by the sedge *S. californicus* subsp.
There is no clear climatic or edaphic control on this hydroseral development except to say that wetter climatic conditions most likely prevailed. Between 9,000 and around 8,000 cal yrs B.P. (represented by only two pollen samples) *Paschalococcus disperta* along with *Triumfetta*, *Sophora* and Asteraceae-Tubuliflorae type pollen decline. Sometime between 8,000 and 700 cal yrs B.P. there is a rapid decline in organic accumulation and sedimentation in conjunction with a sharp change in palynomorph representation. An unprecedented peak in Monolete psilate fern spores combined with a substantial drop in *Schoenoplectus* type pollen suggests that some major sedimentary disturbance process was operating on the site by ~500 cal. yrs B.P.

After ~7000 cal. yrs B.P. the palynological signatures and chronology of the RRA3 core are poorly constrained by a single radiocarbon age of ~500 cal. yrs B.P. and a 210Pb analysis of the upper 80 cm of coarse detritus. Within this loose timeframe, a sedimentary wedge of silt, sand and gravel between the depths of 120 and 80 cm accumulated. This rapid shift in sedimentation, but apparent reduction in sediment accumulation with an apparent chronological gap of around 6,000 years, suggests that some form of sedimentary hiatus is present within the RRA3 sequence. Multiple core profiles presented in Flenley *et al* (1991) indicate that this sedimentary wedge began to accumulate uniformly across much of the surface of the lake between ~800-500 cal. yrs B.P.

Mann *et al* (2003) found this same sedimentary unit (dated to ~ AD 1200 – Lab number and radiocarbon determination not published) in a core taken in close proximity to the RRA3 core. They examined this unit finding large peaks of macrocharcoal (>125 microns), as well as peaks in magnetic susceptibility (an indicator of mineral content within the profile; see Chapter 6), suggesting that this sedimentary sequence represents in-wash from the surrounding slopes following forest clearance.

Dumont *et al* (1998) also obtained a core (South West core) containing this sedimentary unit (Zone 4, 130-85 cm) from the base of which they dated *Polygonum* stem tissue to 660-510 cal. yr B.P. (Lab no. GIF-9629; 588+/−60 yr B.P.; see Table 4.5). From the upper section of this unit between 115 and 85 cm they identified the chyadorid cladoceran species *Alona weinecki*, the Ostracod *Sarscypridopsis cf. elisabethae* and two types of chrysophyte cysts and two diatom species (*Achnanthes cf. abundans* and *Nitzchia cf. vidoviciii*). Dumont *et al* (ibid: 418) suggest that these microorganisms, some with a sub-antarctic biogeographic affinity, may have been introduced by Cook and the crew of the HMS Resolution voyage who contaminated the Easter Island water supply in the process of refilling their casks that were previously used for ‘collecting ice from floating icebergs’ in the sub-antarctic ocean. Thus, Dumont *et al* (ibid) suggest that these data provide a microfossil signature for historical contact and European biological introduction in the sedimentary record.

Dumont *et al* (ibid) and Vrydaghs *et al* (2004) also examined the pollen and phytolith assemblages of the South West core. Dumont *et al* (ibid) identified trace counts of Palmae
(Jubaea or Paschalococcus) type pollen from the historic phase Zone 4 and 5 sediments (above 115 cm in depth). Vrydaghs et al (ibid) have identified Palmae type phytoliths (B.3) from throughout the South West core including in the historic Zone 4 and 5 sediments. They also identified sheet irregular psilate phytoliths, indicative of Schoenoplectus californicus subsp. tatora, from a sample immediately below the charcoal rich sedimentary unit in Zone 3 dated to just prior to 660-510 cal. yr B.P. Like Dumont et al (1998), they question the palynological interpretation of Schoenoplectus type pollen by Flenley et al (1991), located in sediments dated to the early Holocene, and from the phytolith-based determinations suggest that this sedge was introduced to the island from South America.

The in-wash of this charcoal-rich sediment unit at around 800-500 cal. yrs B.P. is indicative of two possible interdependent processes. Firstly, if widespread burning occurred at the site, the coarse organic unit consisting of preserved Schoenoplectus californicus subsp. tatora and Polygonum acuminatum root, stem and leaf material may have been deflated, potentially by many metres in depth. Secondly, the accumulation of mineral sediments on top of the loose organic sediments potentially caused considerable compaction of many metres.

Apart from sedimentary hiatus and/or compaction, Kamminga and Cotterell (1984) suggest that the chronology provided from AMS radiocarbon dates is unusable given the potential influx of carbon of an infinite age from the surrounding slopes of the lake (see Chapter 1). Butler et al (2004) also found that the organic deposits situated on the lake caldera deposits of Easter Island (specifically from the Rano Kao lake caldera), representing accumulating organic matter from the decaying ‘floating mat’ vegetation on the lake surface, produce anomalous ages (inverted) when dated by both bulk sediment and pollen concentrate samples. They suggested that in such settings, both older (e.g. hard water and reworked sediments) and younger (e.g. ground water and bioturbation) organic components are incorporated into sediments contiguously, complicating any absolute age-determination using radiocarbon dating.
Figure 4.2 Percentage pollen diagram for RRA Core 3 (310 cm shown of a total of 12 m; see Flenley et al 1991). The following are presented in the diagram from left to right: core lithology, total $^{210}$Pb (pCi·g$^{-1}$ units; line and ticks), calibrated radiocarbon ages (line and ticks), taxa (pollen and spores: taxa with ≥5% of total palynomorph sum are presented as colour coded bars; samples with proportions <5% are presented as triangle symbols) and total pollen counts (Areceae P. disperta type is synonymous with Palmae Juba chilensis type). Three stratigraphic phases (I=Pre-human, II=Polynesian, III=European) are presented. The transparent horizontal red bar in Phase II indicates a likely sedimentary hiatus in the record, as discussed in the text.
Figure 4.3 Percentage pollen diagram for RRA Core 3 (310 cm shown of a total of 12 m; see Flenley et al 1991). The following are presented in the diagram from left to right: core lithology, total $^{210}$Pb (pCi/g units; line and ticks), calibrated radiocarbon ages (line and ticks), taxa (pollen and spores: taxa with $<$5% are presented as triangle symbols) and total pollen counts. Three stratigraphic phases (I=Pre-human, II=Polynesian, III=European) are presented. The transparent horizontal red bar in Phase II indicates a likely sedimentary hiatus in the record, as discussed in the text.
Interpretation of the *Paschalococcus* pollen record

The mechanisms controlling palm pollen and phytolith representation within these caldera deposits are complex. Throughout the RRA3 core, palm pollen reflects edaphic and autogenic changes in vegetation cover and sedimentation as opposed to climatic fluctuations. Changing patterns in vegetation may be climatically controlled by changing effective precipitation creating a more aquatic caldera environment, increasing the lake level encroaching upon palm habitat, but I would suggest that the dominance of sedges and grasses (more clearly represented in the pollen record) at the site creates a significant pollen bias, as these plants produce an order of magnitude more pollen per unit area than palm trees. It is clear that palm trees once grew on the surrounding slopes of the caldera (although no palm root impressions have been found along the caldera rim or along the inner slopes), but the changes in palm habitat may be poorly reflected by palm pollen representation.

Palm trees of a maximum age may produce a similar amount of pollen, per unit area, to young fertile trees (e.g. of ten years or more; for example the Chilean wine palm *Jubaea chilensis* may take up to 60 years to form fertile fruit - Grau, 2004). Without some intervening disturbance process, palms may form even-aged stands, and if a stand is of a maximum age, they may occupy more space than a younger cohort but produce significantly less pollen. This is one alternative hypothesis that may be used to interpret the palm pollen record outside of the wetter and warmer climate explanation proposed by Flenley et al. (1991). It states that the age of a palm forest stand and potential pollen production is dependent on the disturbance regime, whereby the more frequent the disturbance, the more pollen may be made available from younger trees for deposition.

Much of the debate surrounding palm pollen reflects a lack of empirical data on both the life history of *P. disperta* and the frequency and severity of disturbance on Easter Island. The interpretation of *P. disperta* is based on the ecology of its closest relative (at least in terms of endocarp morphology) *Jubaea chilensis* palm, assumed to be analogous by its geographical proximity to Easter Island. On mainland South America, however, *J. chilensis* may live up to 300 years or more and reach up to 30 m in height. For many Pacific island palms, tree longevity and height is considerably less. It is unclear what height, girth or age the Easter Island palm could have attained given the ecological constraints of Easter Island’s environment.
Table 4.4 Palynomorphs from Easter Island records from Flehney et al (1991). Listed are the presence or absence of palynomorphs in Pleistocene to mid-Holocene sediments and in sediments aged <2,000 cal. yr B.P., the botanical status and biogeographic affinity of taxa. \(^1\)Pollen type capable of long distance dispersal (Flehney et al 1991 after Close et al 1978); \(^2\)Scirpus californicus or S. riparius is synonymous with Schoenoplectus californicus var. tatora (Kunth) T. Koyama. Dumont et al (1998) and Vrydaghs et al (2004) have questioned the pollen-based determination of Schoenoplectus based on macrofossil and phytolith evidence respectively. \(^A\)Palynomorphs present in Austral Island pollen records.

<table>
<thead>
<tr>
<th>Pollen taxa</th>
<th>Family</th>
<th>Present in Pleistocene early mid Holocene</th>
<th>Present in last 2000 cal. yr B.P.</th>
<th>Botanical status</th>
<th>Biogeographic affinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia (^A)</td>
<td>Euphorbiaceae</td>
<td>Y</td>
<td>Y</td>
<td>Indigenous/Extinct</td>
<td>Indo-Pacific/Endemic?</td>
</tr>
<tr>
<td>Canavalia (^A)</td>
<td>Fabaceae</td>
<td>Y</td>
<td>Y</td>
<td>Indigenous/Extinct</td>
<td>Indo-Pacific/Endemic?</td>
</tr>
<tr>
<td>Capparis comp.</td>
<td>Capparaceae</td>
<td>N</td>
<td>Y</td>
<td>Indigenous/Extinct</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Caryophyllaceae</td>
<td>Caryophyllaceae</td>
<td>N</td>
<td>Y</td>
<td>Indigenous/Extinct</td>
<td>South America</td>
</tr>
<tr>
<td>Cassarina (^A)</td>
<td>Casuarinaceae</td>
<td>Y</td>
<td>Y</td>
<td>Indigenous/Extinct</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Astereaceae-Tubuliflorae (^A)</td>
<td>Asteraceae</td>
<td>Y</td>
<td>Y</td>
<td>Indigenous/Extinct</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Astereaceae-Liguliflorae (^A)</td>
<td>Asteraceae</td>
<td>N</td>
<td>Y</td>
<td>Indigenous/Extinct</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Coprosma (^A)</td>
<td>Rubiaceae</td>
<td>Y</td>
<td>Y</td>
<td>Indigenous/Extinct</td>
<td>Pacific/Endemic?</td>
</tr>
<tr>
<td>Cyperaceae-Schoenoplectus (^A)</td>
<td>Cyperaceae</td>
<td>Y</td>
<td>Y</td>
<td>Indigenous</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Cyperaceae-Cyperus</td>
<td>Cyperaceae</td>
<td>Y</td>
<td>Y</td>
<td>Indigenous</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Ephedra (^A)</td>
<td>Ephedraceae</td>
<td>N</td>
<td>Y</td>
<td>Indigenous</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Euphorbia comp. serpen</td>
<td>Euphorbiaceae</td>
<td>Y</td>
<td>Y</td>
<td>Indigenous</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Filices-monolet (^A)</td>
<td>All monolet</td>
<td>Y</td>
<td>Y</td>
<td>Indigenous</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Filices-monolet scabrate (^A)</td>
<td>All monolet</td>
<td>Y</td>
<td>Y</td>
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<td>Indo-Pacific</td>
</tr>
<tr>
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<td>Y</td>
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</tr>
<tr>
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<td>Y</td>
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<td>Y</td>
<td>Indigenous</td>
<td>Indo-Pacific</td>
</tr>
<tr>
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<tr>
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<td>Y</td>
<td>Indigenous</td>
<td>Indo-Pacific</td>
</tr>
<tr>
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<td>Lycopodiaceae</td>
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<td>Y</td>
<td>Indigenous/Extinct</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Lycopodium-foveolale (^A)</td>
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<td>Y</td>
<td>Indigenous/Extinct</td>
<td>Indo-Pacific</td>
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<td>Melia comp.</td>
<td>Meliaceae</td>
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<td>Y</td>
<td>Indigenous</td>
<td>Indo-Pacific</td>
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<td>N</td>
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<tr>
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<td>Y</td>
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<td>Indo-Pacific</td>
</tr>
<tr>
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<td>Y</td>
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<td>Indo-Pacific</td>
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<td>Ophioglossaceae</td>
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<td>Y</td>
<td>Indigenous</td>
<td>Indo-Pacific</td>
</tr>
<tr>
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<td>Y</td>
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<td>Indo-Pacific</td>
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<td>Indigenous/Extinct</td>
<td>Indo-Pacific</td>
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<tr>
<td>Paris comp. (^A)</td>
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<td>Y</td>
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<td>Indo-Pacific</td>
</tr>
<tr>
<td>Rubiaceae (^A)</td>
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<td>Y</td>
<td>Indigenous/Extinct</td>
<td>Indo-Pacific</td>
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<td>Rumex sim.</td>
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<td>Sapindaceae</td>
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<td>Y</td>
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<td>Indo-Pacific</td>
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<td>Sisymbrium</td>
<td>Sisymbriaceae</td>
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<td>Y</td>
<td>Indigenous</td>
<td>Indo-Pacific</td>
</tr>
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<td>Sophora (^A)</td>
<td>Fabaceae</td>
<td>Y</td>
<td>Y</td>
<td>Indigenous</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Tremata (^A)</td>
<td>Ulmaceae</td>
<td>Y</td>
<td>Y</td>
<td>Indigenous/Extinct</td>
<td>Indo-Pacific</td>
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<tr>
<td>Triumfetta comp.</td>
<td>Malvaceae</td>
<td>Y</td>
<td>Y</td>
<td>Indigenous/Extinct</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Typha angustifolia</td>
<td>Typhaceae</td>
<td>Y</td>
<td>N</td>
<td>Indigenous/Extinct</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Unbelliferes Apium comp.</td>
<td>Apiaceae</td>
<td>Y</td>
<td>Y</td>
<td>Indigenous</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Urticaceae/Moraceae (^A)</td>
<td>Urticaceae</td>
<td>Y</td>
<td>Y</td>
<td>Indigenous/Extinct/</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Endemic</td>
</tr>
</tbody>
</table>

Table 4.4 Palynomorphs from Easter Island records from Flehney et al (1991). Listed are the presence or absence of palynomorphs in Pleistocene to mid-Holocene sediments and in sediments aged <2,000 cal. yr B.P., the botanical status and biogeographic affinity of taxa. \(^1\)Pollen type capable of long distance dispersal (Flehney et al 1991 after Close et al 1978); \(^2\)Scirpus californicus or S. riparius is synonymous with Schoenoplectus californicus var. tatora (Kunth) T. Koyama. Dumont et al (1998) and Vrydaghs et al (2004) have questioned the pollen-based determination of Schoenoplectus based on macrofossil and phytolith evidence respectively. \(^A\)Palynomorphs present in Austral Island pollen records.

Plant introductions in the Easter Island pollen record

Palynological examinations of the Pleistocene (not presented) and Holocene sediments of this core (also presented in Flehney, 1979; Flehney and King, 1984 and Flehney et al 1991) identified 25 palynomorphs to taxa at least to the family level (Table 4.4). Interpretation of the biogeographic affinities of these taxa suggest that the island’s flora is closely aligned with the
subtropical/tropical floras of the Pacific islands to the west with a number of taxa having a floral affinity with South America to the east.

Questions of plant origins have been raised for a number of taxa that are not represented in any Pleistocene record from Easter Island. However, no plant introductions from the subtropical/tropical western Pacific have been determined with any certainty from the pollen record. Of particular note are Sapindus (cf. Sapindus saponaria\(^6\)), Caryophyllaceae and Schoenoplectus pollen types (cf. Scirpus californicus syn. Schoenoplectus californicus subsp. tatora\(^7\)) which are thought to have been introduced to Easter Island from South America since human settlement, either by Polynesians or in the historic period (see Langdon, 1996; Dumont et al 1998; Vrydaghs et al 2004; Green, 2005). Another South American taxon recorded in the pollen record, Psidium sim (including P. cattleianum) is known to be an historic introduction to many islands in the Pacific (Meyer, 2004).

Historic/European introductions are more apparent within the pollen record with a number of taxa known as European garden weed species common in the upper (historic?) sediment horizons of the Easter Island records. Pollen types representative of such introductions include Asteraceae-Liguliflorae (e.g. Sonchus oleraceus), Plantago comp. (including P. lanceolata and Rumex sim. (including R. acetosella).

The macrobotanical and archaeobotanical record of Easter Island

The environmental picture of Easter Island just prior to human arrival is very unclear. With the recent discoveries of palm root impressions located in many parts of the island (Plate 2), the palm is now thought to have covered an estimated 70% of the island’s terrestrial surface (Meith et al 2002, Bork and Meith, 2003). This forest was interspersed with a range of widespread Pacific taxa (Orliac, 1998; 2000; 2003; Orliac and Orliac, 1998) including small sub-canopy trees and shrub taxa of the Rubiaceae (e.g. Coprosma and Psydrax spp.). Orliac (2000) has identified Elaeocarpus cf. rarotongensis (Elaeocarpaceae) from excavated material from the Orongo and Akahanga archaeological sites, one example of many sub-canopy tree species not (yet) found in the palynological record. Species such as Elaeocarpus probably grew along the older soil surfaces whereas the younger, more-shallow alluvial coastal soils were probably dominated by a range of smaller shrub species such as Sophora toromiro (Fabaceae). Grasses persisted along the disturbed alluvial margins and areas where occasional lightning strikes ignited the organic accumulations built up within the sheltered volcanic calderas. The greatest diversity of woody taxa likely existed

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\(^6\)The biogeographical origin of this taxa is very unclear as are many species within the Sapindaceae family

\(^7\)Flenley et al. (1991) have tentatively identified this pollen type from Pleistocene sediments.
along cliff faces and numerous now extinct herbaceous taxa may have occupied a range of different niches within the forest environment.

The timing of extinction or extirpation of some of these tree species is very unclear. Radiocarbon dates on wood charcoal and other plant materials, for the most part identified to taxa by Orliac (2000; 2003) from a range of macrobotanical and archaeological sites are now available (Table 4.5), allow the respective earliest and latest interpolated or direct-age determinations to be compared. The age determination of wood charcoal is complicated by site stratigraphy and taphonomy, but also the differential in-built ages of the different plant species. For a number of extinct taxa, the radiocarbon age ranges cover the last 1000 years of the calibration curve (see below) and some taxa have high in-built age potential (e.g. Elaeocarpus, Myrsine and Alphitonia). For these taxa, these factors rule out the possibility that the chronology of extinction is more likely to be later rather than earlier. The outer percentiles of the age range histograms of some of the dates used to interpolate the timing of extinction overlaps with the historical period (post-1722 AD). This is more clearly illustrated for the dates provided for Paschalococcus material, as discussed below.

Diamond (2005: 104) suggests that some trees identified by Orliac can grow up to 17 m (50 ft), based on the size of close relatives present in the Cook Islands. The size of extant relatives observed on other Pacific islands may not provide adequate analogies for inferring the height of a number of the extinct sub-tropical tree species identified in the palynological (e.g. Flenley et al 1991) and charcoal records (Orliac, 2000). A number of common Pacific island genera (e.g. Metrosideros, Myoporum and Sophora) have prostrate as well as tall-tree representatives. Forster noted from his visit to Easter Island in 1774 that:

‘The hill was covered with a shrubbery of the mimosa [Sophora toromiro], which grew here to the height of eight or nine feet, and some of whose stems near the root, were about the thickness of a man’s thigh.’ (Forster, 1777 in von Saher, 1992:38)

S. toromiro maybe a close relative to the S. microphylla, a species found throughout the Pacific (Hurr et al 1999) reaching heights of more than 5 m, but also having close prostrate relatives (e.g. S. prostrata). It is possible that the S. toromiro are simply stunted variants of S. microphylla as part of a common syndrome amongst many Pacific plant genera.
<table>
<thead>
<tr>
<th>Charcoal or macrobotanical material identified to taxa</th>
<th>Family</th>
<th>Earliest $^{14}$C date cal. yr B.P.</th>
<th>Latest $^{14}$C date cal. yr B.P.</th>
<th>In-built age potential</th>
<th>Botanical status</th>
<th>Biogeographic affinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alphitonia cf. A. zeyheroides</td>
<td>Rhamnaceae</td>
<td>550-100</td>
<td>550-100</td>
<td>High</td>
<td>Indigenous/Extinct</td>
<td>Pacific/Endemic?</td>
</tr>
<tr>
<td>Broussonetia papyrifera</td>
<td>Malvaceae</td>
<td>690-500</td>
<td></td>
<td>Low</td>
<td>Introduction/Cultivated in past</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Caesalpина cf. C. major</td>
<td>Fabaceae</td>
<td>690-500</td>
<td>460-0</td>
<td>Medium</td>
<td>Introduction/Extinct</td>
<td>Pacific</td>
</tr>
<tr>
<td>cf. Paschalococcus dispersa charcoal</td>
<td>Areaceae</td>
<td>780-650</td>
<td>480-150</td>
<td>High</td>
<td>Indigenous/Extinct</td>
<td>South America/Endemic?</td>
</tr>
<tr>
<td>cf. Paschalococcus dispersa endocarp</td>
<td>Areaceae</td>
<td>930-750</td>
<td>460-300</td>
<td>Low</td>
<td>Indigenous/Extinct</td>
<td>South America/Endemic?</td>
</tr>
<tr>
<td>cf. Xylosma</td>
<td>Euphorbiaceae</td>
<td>690-500</td>
<td>460-0</td>
<td>Medium</td>
<td>Indigenous/Extinct</td>
<td>Indo-Pacific/Endemic?</td>
</tr>
<tr>
<td>Coprosma</td>
<td>Rubiaceae</td>
<td>690-500</td>
<td>690-500</td>
<td>Medium</td>
<td>Indigenous/Extinct</td>
<td>Pacific/Endemic?</td>
</tr>
<tr>
<td>Coremyline fruticosa</td>
<td>Laxmanniaceae</td>
<td>1550-650</td>
<td>1550-650</td>
<td>High</td>
<td>Introduction/Cultivated</td>
<td>Indo-Pacific</td>
</tr>
<tr>
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<td>Elaeocarpaceae</td>
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<td>460-0</td>
<td>High</td>
<td>Indigenous/Extinct</td>
<td>Indo-Pacific/Endemic?</td>
</tr>
<tr>
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<td>Convolvulaceae</td>
<td>600-400</td>
<td></td>
<td>Low</td>
<td>Introduction/Cultivated</td>
<td>South American</td>
</tr>
<tr>
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<td>Myrsinaceae</td>
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<td>470-0</td>
<td>High</td>
<td>Indigenous/Extinct</td>
<td>Pacific/Endemic?</td>
</tr>
<tr>
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<td>Pittosporaceae</td>
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<td>690-500</td>
<td>Medium</td>
<td>Indigenous/Extinct</td>
<td>Indo-Pacific/Endemic?</td>
</tr>
<tr>
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<td>Pan-tropical</td>
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<td>Rubiaceae</td>
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<td>280-0</td>
<td>Medium</td>
<td>Indigenous/Extinct</td>
<td>Pacific</td>
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<td>1550-650</td>
<td>High</td>
<td>Introduction/Cultivated in past</td>
<td>Pan-tropical</td>
</tr>
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<td>690-500</td>
<td>Medium</td>
<td>Introduction/Extinct</td>
<td>South America, Pacific?</td>
</tr>
<tr>
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<td>5260-4830</td>
<td></td>
<td>Low</td>
<td>Introduction?</td>
<td>South America, Pacific?</td>
</tr>
<tr>
<td>Sophora tonoriro</td>
<td>Fabaceae</td>
<td>690-500</td>
<td>280-0</td>
<td>Medium</td>
<td>Indigenous/Cultivated</td>
<td>Endemic</td>
</tr>
<tr>
<td>Sophora tonoriro - wood from moai kava kava</td>
<td>Fabaceae</td>
<td>650-500</td>
<td></td>
<td>Medium</td>
<td>Indigenous/Cultivated</td>
<td>Endemic</td>
</tr>
<tr>
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<td>Introduction/Cultivated in past</td>
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<td>280-0</td>
<td>Medium</td>
<td>Indigenous/Extinct</td>
<td>Pacific</td>
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</tbody>
</table>

Table 4.5 Earliest and latest interpolated and direct calibrated radiocarbon age ranges for plant macrofossils from Easter Island. Direct ages are marked in bold. These data are predominantly from Orliac (2000; 2003) with other references indexed in the table as follows: ¹Huyge and Cauwe (2002: 15); ²Meith and Bork (2002); ³Dumont et al (1998); ⁴McCoy (1973: 63), mixed sample isotopic fractionation; ⁵Mann et al (2003); ⁶Forment et al (2001); ⁷Wallin et al (2005 after Heyerdahl and Ferdon, 1961).

**Chronological interpretation of Paschalococcus endocarp and charcoal data**

The initial discovery and description of *Paschalococcus dispersa* palm endocarps published by Dransfield et al (1984), has since been supplemented by the location of several endocarps along
with palm wood-charcoal fragments from both archaeological excavations and soil profiles, and palm root impressions, across the island. Many of the endocarps are characterised by gnaw marks consistent with those of rodents. A preliminary list of published radiocarbon ages from palm endocarps and charcoal is provided in Table 4.6. A multiple plot of the age range histograms (produced in OxCal 3.10; see Figure 4.4) of the palm material shows a distinct alignment of age-range histograms centering around 1200 to 1450 AD and 1550 to 1700 AD. When these ages are aligned with the radiocarbon calibration curve (following Stuiver et al 1998) for the period after 1000 AD (see Figure 4.5), these ages cluster around three radiocarbon plateau at 1050 to 1150 AD (~900-800 cal. yr B.P.), 1300 to 1400 AD (650-550 cal. yr B.P.), and 1500 to 1650 AD (450-300 cal. yr B.P.) respectively.

As discussed in Chapter 3, radiocarbon calibration curves established for the last 3,500 years cal. B.P. (e.g. Stuiver et al 1986; Hogg et al 2002), reveal a number of significant plateaus; the three mentioned are significant for the archaeology of OIRO. From a radiocarbon date with an age range that falls close to, or within these plateaus, the date when calibrated will assume an uncertainty over and above the radiocarbon error generated in the laboratory. Radiocarbon is not uniformly distributed in time or throughout the troposphere, and this distribution can depend on a number of factors including temporal and geographic fluxes in atmospheric-ocean carbon dioxide exchange that may change due to global climate cycles (e.g. Milankovitch cycles) or more regional effects on radiocarbon decay (Hogg et al 2002).

A radiocarbon plateau can be envisaged as a kind of age vacuum, pulling the radiocarbon determinations to within the plateau age range. For dating early human impact on Pacific islands or historical impacts using radiocarbon, this vacuum effect is important, given that the majority of dates from palm material and other wood charcoal are centralised around the 650-550 cal. yr B.P. and 450-300 cal. yr B.P. plateau. Whether these determinations are real or a result of the calibration curve is a key point of contention and conjuncture in remote island archaeology. If these dates were taken as real, the greatest probability is that almost all the palm endocarps and charcoal was deposited between around 1300 and 1600 AD (700-400 cal. yr B.P.).

One interesting feature of the palm dating record is the lack of published modern/historic period determinations, despite the historic accounts of palm material from Roggeveen and Gonzalez y Haedo. This may either be due to a reluctance of archaeologists to publish modern determinations, or be a feature of the archaeological record itself. Is it possible that the between Diamond’s Collapse year of 1680 and 1722 AD the Easter Islanders were not occupying the sites later excavated for palm by Orliac and others? If we follow the Collapse scenario where macrobotanical remains are seen as indicative of the final human hand in palm utilisation and extinction, the deforestation of palms and consumption of palm nuts was complete by 1600 not 1680 AD. The probability that the final use of palm material based on the radiocarbon chronology occurred in 1680 AD (~25th percentile of the most recent radiocarbon determinations; see Figure
4.4) is marginally greater than that it occurred the date of Roggeveen’s arrival in 1722 AD. Based on the current radiocarbon chronology for Easter Island, the 1680 AD Collapse event is clearly insoluble from any of the available botanical evidence.

**Paschalococcus extinction and disturbance processes**

The discussion of palm height and ecology is pivotal to the ‘orthodox’ picture of Easter Island, given the interpretation that palm trunks were used as ‘rollers’ for the *moai* statues, but also whether these were growing at the height envisaged for *J. chilensis* at the time of Roggeveen’s arrival, or whether they were in fact extinct or extirpated by this time. For understanding *P. dispersa* height potential, the frequency and severity of disturbance may be important. John Harper (1977) suggests that the frequency of disturbances relative to a plant’s longevity is likely to influence adaptive and evolutionary change. It is intuitive that plants and other organisms may not adapt to disturbances that occur at frequencies longer than their reproductive cycle (Lytle, 2001). For tree species on Easter Island, what disturbances there had a frequency of 100 years or less and may have operated to reduce palm height?

One of the main disturbance scenarios proposed for palm extinction outside of the direct human use as rollers for the *moai* statues is the predation by introduced rodents. Gnaw marks have been found on many palm endocarps excavated from both macrobotanical and archaeological sites. Flenley et al. (1991) suggest that during the early phase of island colonisation, the introduced *Rattus exulans* may have contributed to the attrition of the palm by seed predation that consequently prevented of palm recruitment.

There is no consensus as to whether fire is a constant factor in the ecology of Easter Island. Mann et al. (2003) identified fragments of charcoal (>125 micron particles) from throughout a sediment core taken from Rano Raraku with a basal date of around 4500 cal. yr B.P. What is not indicated from these data is the likely severity of fire events. The very presence of charcoal from sediments unequivocally dated prior to human settlement opens up the question of what mechanism caused these fire events. In recent years there has been an emphasis on the oceanic climate variability connected with El Niño-Southern Oscillation (ENSO) activity (e.g. Hunter-Anderson, 1998; Genz and Hunt, 2003). Evidence for increased frequency and intensity of cyclonic activity in the Western Pacific may be associated with the onset of the ENSO system in the mid-Holocene (e.g. Hayne and Chappell, 2001). From a limited historical dataset, Genz and Hunt (2003) suggest that there is no empirical basis to suggest that the effects of ENSO activity are linked with climate variability on Easter Island. Although there is no historic record of any cyclone events occurring on Easter Island, this is seen as one possible factor that may have increased the likelihood of lightning strikes and fire but may only be a 1/100 year event or less.
Along with westerly systems, high intensity wind storms generated in southerly low pressure systems may have been sufficient to restrict the palm forest development.

<table>
<thead>
<tr>
<th>No.</th>
<th>Palm material</th>
<th>Site</th>
<th>14C age range cal. yr B.P.</th>
<th>In-built age potential</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Palm charcoal?</td>
<td>Poike</td>
<td>440-290</td>
<td>High</td>
<td>Meith and Bork, 2003</td>
</tr>
<tr>
<td>2</td>
<td>Endocarp</td>
<td>Poike</td>
<td>460-300</td>
<td>Low</td>
<td>Meith and Bork, 2003b</td>
</tr>
<tr>
<td>3</td>
<td>Palm charcoal?</td>
<td>Poike</td>
<td>460-300</td>
<td>High</td>
<td>Meith and Bork, 2003</td>
</tr>
<tr>
<td>4</td>
<td>Palm charcoal?</td>
<td>Poike</td>
<td>480-150</td>
<td>High</td>
<td>Meith and Bork, 2003</td>
</tr>
<tr>
<td>5</td>
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<td>Akaheanga</td>
<td>510-290</td>
<td>High</td>
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<td>Poike</td>
<td>544-502</td>
<td>High</td>
<td>Meith and Bork, 2003</td>
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<td>Low</td>
<td>Orliac, 2003</td>
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<td>8</td>
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<td>600-560</td>
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<tr>
<td>9</td>
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<td>620-330</td>
<td>Low</td>
<td>Martinsson-Wallin and Crockford, 2001</td>
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<tr>
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<td>620-710</td>
<td>Low</td>
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<tr>
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<td>Low</td>
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<td>660-550</td>
<td>High</td>
<td>Meith and Bork, 2003</td>
</tr>
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<td>670-550</td>
<td>Low</td>
<td>Orliac 2003</td>
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<td>Low</td>
<td>Orliac 2003</td>
</tr>
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<td>702-675</td>
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<td>Low</td>
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<td>23</td>
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<td>Te Poru</td>
<td>720-650</td>
<td>Low</td>
<td>Orliac 2003</td>
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<tr>
<td>24</td>
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<td>730-510</td>
<td>Low</td>
<td>Orliac 2003</td>
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<tr>
<td>26</td>
<td>Charcoal</td>
<td>Aho O Rongo</td>
<td>780-650</td>
<td>High</td>
<td>Huyge and Cauwe, 2002</td>
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<td>Low</td>
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<td>Low</td>
<td>Dansfield et al, 1984</td>
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<td>Te Poru</td>
<td>930-750</td>
<td>Low</td>
<td>Orliac, 2003</td>
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</table>

Table 4.6 Calibrated radiocarbon age ranges for cf. *Paschalococcus dispersa* macrofossils. Listed are the macrofossil type, collection location, age ranges (cal. yr B.P.; 2σ age range), the potential in-built age for each macrofossil and the relevant references.
Figure 4.4 Multiple calibrated radiocarbon age plot (generated from OxCal Version 3.10) of the direct calibrated ages (2σ age range) for *Paschalococcus disperta* (endocarps and charcoal) as for Table 4.6. The potential in-built age for the dates on possible palm charcoal have been given an offset age (see OxCal version 3.10) of 50 ±40 years. The dashed vertical lines indicate the years 1680 AD (for Diamond’s year of societal ‘Collapse’ on Easter Island) and 1722 AD (the arrival of Roggeveen). Most ages lie between 1000 and 1500 AD with 5 ages overlapping the historic ages mentioned.
Figure 4.5 Radiocarbon calibration curve (generated from OxCal Version 3.10) for the last 1200 yr. B.P. (1000 cal. AD) with box plots (2σ age range) of the direct calibrated ages for *Paschalococcus disperta* (endocarps and charcoal) as for Table 4.6 and Figure 4.4. The three boxes in bold encompass three clusters of dates that centre around three distinct radiocarbon plateaus as discussed in the text.
Were the Easter Island palms ever of a substantial height or were they maintained at a low stature by climate, edaphic factors, rat predation on seeds, or even human agency? If so, is it possible that palms persisted on the island in isolated stands (e.g. within the volcanic calderas) that were below ‘tree’ height upon the arrival of Roggeveen? The question of tree height may be insoluble given the available botanical evidence, but there are a number of indications in the historic record (e.g. Gonzalez y Haedo’s ‘small coconut palms’) as well as macrobotanical and archaeobotanical evidence.

The erection of the moai has been proposed as the most likely cause of island deforestation and especially the extinction of the Paschalococcus palm. Palm trunks are thought to have been the primary means of transporting the moai from the Rano Raraku quarry to the coastal platforms (Bahn and Flenley, 1992). A more likely scenario, given the growing archaeobotanical evidence-base for the Pacific is that palm habitat was displaced for the production of introduced root and tree crops. Both root and tree crops would require the following:

1. Clearing by fire of palms, given they are known to have occupied fertile and thick soil horizons suitable for agriculture.
2. Tilling of an area large enough to cater for root and tree crops, thus preventing any palm recruitment on the most fertile sites on the island.
3. The ongoing maintenance of the established root and tree crops and continual prevention of palm recruitment except in marginal habitat.

**Pre-European contact plant introductions to Easter Island**

A number of plant species not represented in the pollen record have been identified from the archaeobotanical record alone and for this reason are thought to be human introductions. The identified species include the tree crops Broussonetia papyrifera and Syzygium (cf. S. malaccense), and Cordyline fruticosa and Saccharum officinarum; these are noted as common introductions to islands elsewhere in OIRO (e.g. Whistler, 1991; Matthews, 1996; Hinkle, 2004). Orliac (2000) regards Caesalpinia (cf. C. major) and Thespesia populnea as two further tree crop introductions, but gives no reason for this status.

A probable South American connection is represented by the occurrence in the various botanical sources of plant species thought to have originated from this region, including the root crop Ipomoea batatas, house garden crop Lagenaria siceraria and possibly Sapindus saponaria (soapberry; a small shrub; see Langdon, 1996). I. batatas has been documented in the archaeobotanical deposits (Orliac and Orliac, 1998), recorded in oral histories (Metraux, 1940) and historic accounts (e.g. Roggeveen, 1908) for the island. Although the evidence for the South American origin of I. batatas is clear, a number of authors (Green, 1998; 2001; 2005; Yen, 1974;
Wallin, 1999; Wallin et al 2005) have discussed the possibility that the plant was introduced to Easter Island only after the cultigen was brought from South America to Central East Polynesia (Society Islands, Marquesas and Cook Islands) and spread in a wave of secondary introductions to the margins of East Polynesia that also includes the Hawaiian Islands and New Zealand.

**Tikopia and botanical sources**

*The modern flora of Tikopia*

In addition to their investigations of the Tikopia’s archaeological record, Kirch and Yen (1982) provided a concise but incomplete description of the island’s flora, recording a total of 78 angiosperm species. The flora of Tikopia has a strong affinity with the lowland floras of the Solomon Islands, as described by Walker (1962) and Whitmore (1966), and Vanuatu by Gowers (1976) (see Table 4.7). Generally, the flora reflects an eastward attenuation of the Indo-Pacific/Malesian flora as outlined by Balgooy et al (1996).

The most striking feature of the island’s flora is the lack of endemic species; however, this may be a feature of poor botanical survey data for both Tikopia and the Solomon Islands. Despite these limitations, Balgooy et al (1996) have identified 11 areas of endemism for the Pacific region that includes the largest adjacent landmasses to Tikopia. Of these areas, New Caledonia has the most endemic genera (100) with Vanuatu and the Santa Cruz Islands (also in the Solomon Islands) recognised with only one (the Arecaceae genus, *Carpoxylon*). This reduced endemism is attributed to island age, size and proximity to the Australasian/Indo-Pacific continental floras.

Kirch and Yen (1982) concentrated their botanical survey on the arboreal angiosperm taxa of Tikopia and discussed other taxa only in passing. *Ipomoea pes-caprae* and *Vigna marina* form a common component of the island’s sand dunes. The shrub *Capparis* is common on the limestone outcrops. Grass species such as *Setaria*, *Spinifex* and *Thaurea* are mentioned as well as the sedges *Cyperus* and *Elaeocharis* but little detail is provided on their ecology.

Arboreal taxa occupy much of the island environment from the Reani at only 360 m to the coast. In the coastal lowlands, the vegetation is typified by strand taxa familiar in Indo-Pacific floras. Through pressure from grazing, fire and invasion by exotic species including human introductions, any of the island’s indigenous species are probably restricted to marginal refuges. The effects of Cyclone Zoe in January of 2003 removed much of the canopy of the lowland forest environments, causing substantial sediment erosion across the island (see Plate 1).
Kirch and Yen (1982:25) elaborated on Firth’s observations on Tikopia, noting that the ‘... terrestrial environment of Tikopia is virtually its agricultural system’. This built on Rev. W.J. Durrad’s comments (in Rivers, 1914: 334), after visiting the island for two months in 1910, that the whole island was more or less entirely cultivated where no forest existed. Of the cultivations Kirch and Yen (1982) observed, the swampy margins of Ropera swamp and Lake Te Roto was under cultivation for Colocasia esculenta and Cyrtosperma merkusii. The dryland areas were under a root-crop cultivation complex of Dioscorea spp., C. esculenta, and the historical introductions of Ipomoea batatas and Manihot dulcis from the Americas.

Firth remarked on the emphasis that Tikopian society placed on arboricultural production in what he termed ‘orchard gardening’. Kirch and Yen (1982) contrasted the limited number of trees with little or no economic value, including such species as Diospyros and Kleinhovia, with the diversity of arboricultural species as evidence for the extension of the domestication of tree species familiar to the Solomon Islands. Some examples of probable indigenous tree species that have arboricultural utility include Calophyllum inophyllum, Terminalia catappa, Casuarina equisetifolia and Canarium harveyi. Kirch and Yen (1982: 28-29) distinguish Calophyllum, for example, as a case for adaptation, planted for both dune stabilisation, and at higher elevation to yield ‘wood of a higher quality for canoe making...’

Plant taxa probably introduced prior to European contact include almost all of those thought to have been introduced to Easter Island. These include Colocasia esculenta, Dioscorea spp., Musa spp., Cordyline fruticosa, Saccharum officinarum and Curcuma longa. This list is reduced when considering tree species, as Syzygium malaccense is the only introduction found in the botanical record for both islands. Because of the closer proximity to the likely biogeographic origin centres of many arboricultural tree species, understanding the introduction process on Tikopia is more complex.

Questions of the origin and antiquity of arboricultural production, in what Kirch and Yen (ibid: 31-34) regard as the process of tree domestication, are pivotal to understanding the Tikopian flora. They suggest that:

‘[S]ome conspicuous tree crops are believed to be earlier [domesticated species or human introductions] than others, especially breadfruit (Artocarpus altilis) and the Polynesian Chestnut (Inocarpus edulis [syn. I. vogifera]). Such posited temporal precedence is simply based on the fact that these trees reached the very margin of Polynesia [e.g. French Polynesia] in prehistoric times, while the Solomon Islands domesticates such as Pometia, Burckella, Canarium, and Barringtonia did not. The implication is that the domestication of these tree species was late, too late to be distributed by the early, easterly flows of human dispersal from which Polynesian culture derived.’
<table>
<thead>
<tr>
<th>Plant taxa</th>
<th>Plant family</th>
<th>Botanical status</th>
<th>Biogeographic affinity</th>
</tr>
</thead>
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<td>Indo-Pacific</td>
</tr>
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<td>Euphorbiaceae</td>
<td>Indigenous</td>
<td>Indo-Pacific</td>
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<td>Araceae</td>
<td>Introduction/Cultivated</td>
<td>Indo-Pacific</td>
</tr>
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<td>Antiaris toxicaria</td>
<td>Moraceae</td>
<td>Introduction?/Arboircultural</td>
<td>Indo-Pacific</td>
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Cont.
Table 4.7 Flora of Tikopia (after Kirch and Yen, 1982). Listed are the species and family names and botanical status (including cultivation status) and biogeographic affinity. Present in Austral Island botanical sources. Present from Easter Island sources. Status uncertain.

The question implied from this passage is whether or not arboreal species can be distinguished within the palaeobotanical or archaeobotanical record as introduced domesticates or domesticated indigenous species.

Botanical sources at first-European contact with Tikopia

Tikopia’s first contact history (see Table 4.8) began in 1606 with Pedro Fernández de Quiros, the captain of the Spanish ship San Pedro and flag ship San Pablo (Markham, 1904). The ships stopped for a single day, after anchoring overnight on course to Vanuatu (Espiritu Santo Island) from Duff Island, one of the Santa Cruz Islands. The crew did not make land-fall but the expedition’s second in command Luis Vaez de Torres and pilot González de Leza on board the ship’s launch (zabra) met with two islanders in a canoe. Some coconuts were exchanged along with ‘some bark of a tree which appeared like a very fine handkerchief’ (Markham, 1904: 461 in
Kirch and Yen, 1982: 47), which Kirch and Yen suggest may represent a form of bark-cloth no longer manufactured on the island.

Also on the 1606 expedition was Juan de Torquemada, who in observing the north-side of the island noted that ‘amidst the verdure of trees which were in front, were many palms and cultivations’ (Markham, 1904: 436). Quiros noted that the lowlands of the island were ‘thickly covered with trees and palms while in the slopes of the hills there were cultivated fields’ (Kelly, 1966: 193). Quiros also observes that Lake Te Roto was an open bay at the time of his visit. The journals of Quiros and other members of his crew contain a large amount of information regarding the local food productions of the Solomon Islands and Vanuatu (Yen, 1973b). Despite their awareness of food production systems elsewhere in the region, none were noted for Tikopia.

The Spanish accounts from the San Pedro voyage provide the only available information for the island, aside from oral histories recorded by Firth, up until the arrival of Peter Dillon in 1813 on the Hunter. Dillon was in search of the ill-fated voyage of La Pérouse, wrecked on Vanikoro Island, 228 km to the northwest. Dillon found a Prussian sailor, Martin Buchert (Burkhardt), his Fijian wife and an East Indian (Lascar) named Joe, settled on the island. Dillon provided little detail on food production except that the islanders were chewing betel nut (Areca catechu). To assist Buchert and his wife, Dillon provided them with pumpkin seeds and chickens from the ship’s stores.

On his second voyage to the island on board the St. Patrick in May of 1826, again in search of the La Pérouse shipwrecks, Dillon again met Buchert who recalled the visit of European whaling ships. Joe had since travelled to Vanikoro with some of the islanders, sighting the two shipwrecks of La Pérouse. Having brought this intelligence to Calcutta in that same year, Dillon was sent out by the East India Company on the Research to make further inquiries on the shipwrecks. In September of 1827, Dillon again visited Tikopia only en route to Vanikoro, noting the scarcity of food (including yams Dioscorea spp.) and the supply of freshwater. He did note that:

‘the soil is very luxuriant; yet there generally is a scarcity of provisions. They live chiefly on vegetable food, having neither hogs nor poultry, which are plentiful on the other islands. They at one time had both but they were voted common nuisances and exterminated by general consent. The hogs destroyed their plantations of yams, sweet potatoes, taras, and bananas. These, and the breadfruit and cocoa-nuts, with fish, are what they subsist on.’ (Dillon, 1829: 134)

He also observed that Lake Te Roto was separated from the sea by the active tombolo (Ravenga) on the south coastline.

8Modern measures have been taken to artificially stabilise the periodically open tombolo to prevent marine confluence by reinforcement with stone blocks.
Table 4.8 Preliminary list of accounts of first European contact for Tikopia from 1606 to 1858. Listed are the central characters involved in the visit and the vessel(s) they arrived on; whether landfall was made and the duration of their visit; the exotic animals or plants introduced to the island from the visiting vessel and the existing economic (and other) plants observed on the island. The most relevant references for these accounts are also listed with a bibliography of these primary and other sources provided in the Appendices. *?* information yet to be obtained or clarified. See Appendix I for primary and secondary sources references.

<table>
<thead>
<tr>
<th>Year</th>
<th>Foreigner accounts</th>
<th>Duration of encounter and landfall</th>
<th>Exotic animal or plant introductions</th>
<th>Records of indigenous plants or pre-European plant introductions</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1606</td>
<td>Pedro Fernandez de Quiros, Gonzalez de Leza, Juan de Torquemada, Luis Vazquez de Torres, Fray Martin de Munilla, and Don Diego de Prado on the San Pedro and San Pablo</td>
<td>1 night no landfall</td>
<td>None</td>
<td>-Cocos nucifera (cocoa nut) -Antiaris toxicaria ('some back of a tree which appeared like a very fine handkerchief, four yards long and three palms wide') Markham (1904: 461)</td>
<td>Markham (1904:4367), Kelly (1966: 193), Firth (1936:37), Kirch and Yen (1982: 47), Stevens and Farrow (1930: 119)</td>
</tr>
<tr>
<td>1813 Sept</td>
<td>Peter Dillon, Martin Buchert, on the Hunter or Elizabeth</td>
<td>Landfall Buchert his Fijian wife and Joe from East India lived on the island for 3 years</td>
<td>-Cucurbite sp. (pumpkins) -other seeds -chickens</td>
<td>-Areca catechu (betel-nut) -Cocos nucifera (cocoa nut) -Artocarpus altilis (breadfruit) -Colocasia esculenta (taro) -Musa spp. (bananas) -Ipomoa batatas (sweet potato)</td>
<td>Dillon (1829)</td>
</tr>
<tr>
<td>1826 May</td>
<td>Peter Dillon on the St. Patrick</td>
<td>?</td>
<td>-chickens -ducks -goats</td>
<td>-Discocereus spp. (yams −scarce)</td>
<td>Dillon (1829)</td>
</tr>
<tr>
<td>1858</td>
<td>Mission arrival</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Firth (1936)</td>
</tr>
</tbody>
</table>

In February of 1828, the Astrolabe with Dumont D’Urville and J.P. Gaimard arrived on the island en route to Vanikoro, again in search of La Pérouse. They noted that breadfruit (Artocarpus altilis) was cultivated to an even greater extent than found in the Polynesian islands to the east. They also commented on the abundance of ‘évis’ which probably refers to Inocarpus fagifera (Kirch and Yen, 1982: 52). Dumont D’Urville noted the presence of chickens, duck and pigs, which Kirch and Yen (ibid) suggest must have been sourced from Dillon’s ship or as a product of exchange with Vanikoro. Kirch and Yen (ibid) also suggest that the contrasting accounts from Dillon and Dumont D’Urville regarding the state of food production may reflect the seasonal nature of food production on the island, where in February Artocarpus altilis and Inocarpus fagifera fruit production may be high.
Tikopia represents the remains of a volcanic caldera (~80,000 yrs in age) that has subsided on the south side to form a slightly brackish lake (Te Roto) that lies at sea level. Because of its volcanic youth, the soils that have rapidly accumulated in the lowlands are rich and productive. The lowland plains are built upon calcareous substrates overlain by volcanic alluvial and colluvial soils. The most extensive lowland flat on the west of the island, Rotoaia, is dominated by a diverse range of arboricultural species. Lying upslope and adjoining Rotoaia is Rakisu (see Figure 4.1), an elongated mixed cultivation strip of both root and tree crops, bounded on the southern side by Ropera Swamp (0.08 km²), intensively cultivated for *Cyrtosperma merkusii*. Kirch and Yen suggest that Rakisu is the most intensively cultivated area on the island, dominated by short-fallow cultivations of *C. esculenta* and *Manihot dulcis*.

<table>
<thead>
<tr>
<th>Charcoal or macrobotanical material identified to taxa</th>
<th>Family</th>
<th>Interpolated or direct earliest ¹⁴C date cal. yr B.P., lab code, site, provenance and phase</th>
<th>Representatives in modern flora</th>
<th>Biogeographical affinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barringtonia sp. fruit</td>
<td>Barringtoniaceae</td>
<td>No date; Layer 1, Ravenga Test Pit 21 650-320 or modern; Muripera Trench F-2, Layer VI/VII</td>
<td>Indigenous?</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Calophyllum inophyllum bark</td>
<td>Clusiaceae</td>
<td>2350-1700 (Beta-1225); Faresia, Test Pit-2, Layer II, 80-110 cm, charcoal, Sinapupu phase B2</td>
<td>Introduction?</td>
<td>West Pacific</td>
</tr>
<tr>
<td>Conarum harveyi mesocarp'</td>
<td>Burseraceae</td>
<td>4000-3250 (UCR-965); Sinapupu, Test Pit-52, Layer IV, 110-145 cm, charcoal and Cocos endocarp, Kiki phase K2</td>
<td>Indigenous?</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Cocos meiifera endocarp</td>
<td>Areaceae</td>
<td>650-320 or Modern; Muripera Trench F-2, Layer VI/VII</td>
<td>Indigenous</td>
<td>West-Pacific</td>
</tr>
<tr>
<td>Metroxylon salomonense</td>
<td>Areaceae</td>
<td>650-320 or Modern; Muripera Trench F-2, Layer VI/VII</td>
<td>Indigenous</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Pandanus tectorius key</td>
<td>Pandanaceae</td>
<td>650-320 or Modern; Muripera Trench F-2, Layer VI/VII</td>
<td>Indigenous</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Spondias dulcis? fruit</td>
<td>Anacardiaceae</td>
<td>No date; Layer 1, Ravenga Test Pit 21</td>
<td>Indigenous</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Thalassia sp. leaf</td>
<td>Zostereaceae</td>
<td>650-320 (1-10754); Muripera Trench F-2, Layer VI/VII</td>
<td>Indigenous</td>
<td>Indo-Pacific</td>
</tr>
</tbody>
</table>

Table 4.9 Earliest interpolated or direct calibrated radiocarbon age ranges for plant macrofossils from Tikopia (following Kirch and Yen, 1982). Direct ages are marked in **bold**.

In an attempt to ascertain the history of crop cultivation on the island and to test their hypothesis of intensified colluvial erosion following human settlement, Kirch and Yen (1982) conducted a series of excavations at Rakisu. A number of trenches were excavated running along a series of altitudinal transects cutting across the agricultural zone separating Ropera swamp from...
the upland hill-slopes. They found that Rakisu during the Kiki phase (~3500-2350 cal. yr B.P.) had been a calcareous plain overlain by soil and sediment eroded off the higher elevation volcanic slopes. They suggest that Ropera Swamp was partially open to the sea at this time and that Rakisu was evidently unavailable for cultivation prior to the Sinapupu phase (2350-750 cal. yr B.P.), approximately 1000 years after the earliest available archaeobotanical evidence for island (4000-3250 cal. yr B.P. based on Cocos nucifera endocarp and charcoal; see Table 4.9). By the end of the Sinapupu phase, forest clearance resulted in increased sedimentation of volcanic colluvium from the upland catchment surrounding Rakisu. The calcareous lowland flats were overlain by thick deposits of this colluvium and the overall productive land area of Rotoaia was expanded three-fold. Colluvium deposition and lowland expansion slowed during the Tuakamali phase, but still enabled Ropera swamp to be filled with enough organic sediment to infill and close the marine confluence.

The lower Rakisu excavation at Muripera (trench F-2) yielded the richest archaeobotanical deposit, but with only five species determined (Thalassia sp., Cocos nucifera, Pandanus sp., Metroxylon salomonense and Calophyllum inophyllum), all dated to within the late Tuakamali phase. Test pits conducted at the Ravenga tombolo, Sinapupu and Fareata revealed some additional plant remains (Canarium harveyi, Spondias cf. dulcis and Barringtonia sp.).

**Palynological investigations of the Solomon Islands: the implications for Tikopia**

As no palynological investigations have been conducted on Tikopia, it is worth examining records from other sites in the Solomon Islands as a means of interpolating the response of the region’s vegetation to the last 3500 years of human settlement. The most detailed palynological investigation in the Solomon Islands has been conducted by Simon Haberle (1996) on the inland Laukutu and Mela Swamp complexes of Guadalcanal (9°30’S, 160°05’E). Archaeological evidence from the northern end of Solomon Island chain suggests that Guadalcanal may have been occupied at around 28,000 cal. yr B.P. (Wickler and Spriggs, 1988), with direct evidence from the island dating back to around 6,000 cal. yr B.P. However, the more remote islands to the south and east of Guadalcanal were occupied only after around 3500 cal. yr B.P. (Spriggs, 1997), a timeframe that concurs with Kirch and Yen’s (1982) record from Tikopia.

Haberle (1996) obtained two swamp cores with a maximum depth of between 6.5 and 5.5 m, with a maximum age of 3850-3150 cal. yr B.P. (ANU 6462; 3230 +/- 110). Increases in charcoal particle accumulation after 2950-2490 cal. yr B.P. (ANU 6464; 2650 +/- 70) are associated with an equivalent increase in secondary forest and non-arboreal taxa (e.g. Acalypha, Macaranga, Trema and Poaceae). These swamp records suggest an expanse in agricultural
activity after 3000 cal. yr B.P., with an unprecedented impact distinct from the previous 1000 cal. yr B.P. of vegetation change.

Powell (1976) conducted a series of palynological investigations of the eastern Solomon and Santa Cruz Islands, concluding that very few suitable sites for Quaternary palynology are available in this region. In a modern survey of the regrowth vegetation of recently cleared garden sites of the Santa Cruz Islands, Powell found that they were comprised of a number of indigenous secondary forest taxa familiar on Tikopia (e.g. Acalphya, Barringtonia spp., Pipturus, Macaranga, Ficus and Hibiscus tiliaceus).

One of the islands she investigated was the Tertiary volcanic island of Tōmotu Noi (10°48'S, 166°03'E, 22.5 km$^2$ in area). This island lies less than 1 km off the south-eastern coast of the Santa Cruz Islands and may provide the best analogue for the palaeoenvironment of Tikopia. Powell (ibid) obtained a 3.4 m sediment core from Lake Luendambu (~0.8 km$^2$ in area), separated from a coastal lagoon in the north-east of the island. This record, although lacking radiocarbon ages, shows an increase in secondary forest taxa associated with a build up of in-washed clays, woody detritus and charcoal particles within the last 3,500 years. This sequence is paralleled by another of Powell’s records from Pono’ohey Swamp on San Cristobal.

The archaeobotany of Canarium introduction and cultivation on Tikopia

In work done more recently than his Tikopia study, Yen (1990: 262; 1991: 88; 1995: 838-839) has suggested that Canarium spp., Pometia pinnata and Burckella obovata, and possibly Artocarpus spp. may have been transported to the eastern Solomon Islands from New Guinea, one of their assumed biogeographic centres of origin. As the evidence for vegetation change prior to human settlement is unavailable, the human introduction of Canarium harveyi, a species pivotal to both Kirch (1997) and Diamond’s (2005) idea of social success on Tikopia, remains an open question. Tikopian oral tradition firmly points to the human introduction of Canarium:

‘Firth’s account (1939: 84) of the tradition for the introduction of Canarium dates it to the time of Matakai II of the house of Taumako; on the genealogy of that line (Firth, 1936: 356), this would be at six generations ago, or approximately in the time period of Dillon’s voyages in the early 19$^{th}$ century. Its immediate provenience was through canoe contact with Vanikoro.’ (Kirch and Yen, 1982: 37)

However, this does not preclude the possibility that this tree already existed on the island.

Canarium (Burseraceae) is a genus of around 100 species whose origin centre extends from Malaysia at least as far east as New Guinea. Most species are primary or secondary lowland forest trees, many occupying coastal strand habitats. P.W. Leenhouts (1955; 1959) and more recently Yen (1996) have described the ecology and systematics of the genus for the Indo-Pacific.
region. Several Canarium species are cultivated throughout the geographic range of the genus. Plants are always propagated from seed and are not known to clonally reproduce whether from wild or cultivated specimens (Yen, 1985). For the Western Pacific, *C. indicum* (Section Canarium: Vulgare group) is cultivated throughout its range as far south as Vanuatu with *C. harveyi* (Section Canarium: Maluense group) cultivated as far east as Samoa where it is thought to be a recent introduction (Whistler, 1991). Other domesticated or cultivated species found in the Western Pacific include *C. lamii*, *C. salomonense* (both in the Maluense group) and *C. decumanum*. The taxonomic status of *C. decumanum* is unclear as it is recorded only for Manus Island (Papua New Guinea), east Maluku and Kalimantan (Indonesia). The ethnobotany of Canarium species has been revised by Kennedy and Clarke (2004).

The remains of the edible nuts have been found in a number of archaeological sites throughout the Western Pacific. Bernard Maloney (1996) collated the earliest archaeobotanical finds for these nuts from the Indo-Pacific, which has since been extended (Fairbairn and Swadling, 2005; Fairbairn, 2005). The earliest bracketed archaeological radiocarbon age for Canarium (*C. indicum* mesocarp) comes from the Pamwak Rockshelter on Manus Island (Admiralty Islands) at around 21,000 cal. yr B.P. (Ambrose, 2002). In the Solomon Islands, the earliest bracketed date for Canarium mesocarp comes from the Vatuluma Posovi Cave excavation, Guadalcanal at 6720-5721 cal. yr B.P. (ANU-6733; 5430 +/- 220; Roe, 1993). Wickler and Spriggs (1988) also identified Canarium mesocarp in the Kili Cave excavation on Buka, now dated to 5660-4970 cal. yr B.P. (ANU-6757; 4680 +/- 140; Spriggs, 2003). *C. harveyi* was also found in the 1977 excavations on Santa Cruz Island but without any radiocarbon ages provided (McCoy and Cleghorn, 1988). None of the aforementioned sites have palaeobotanical records prior to the period of human occupation, reducing any determination of the indigenous or introduced status of Canarium in the region to speculation.

Kirch (1997) and Diamond’s (2005) idea of social success on Tikopia is dependent on the assumption that *C. harveyi* is a local domesticate on the island. Following Kirch and Yen’s (1982) excavation of *C. harveyi* mesocarp from the Sinapupu site on Tikopia and Kirch’s (1989; 1997) appraisals of local domestication practices for Tikopia and other Pacific Islands (e.g. Mussau Islands, Papua New Guinea), Yen (1990: 268) suggests that archaeological excavations have since ‘tempered this view’. In a number of publications, Yen (1990; 1991; 1995; 1996) has repeatedly emphasised an early domestication practice that may have its origin in Northern New Guinea. Gosden (1992) has gone so far as to suggest that Canarium was domesticated in New Guinea during the Pleistocene and subsequently transported to the outer islands.

It is unlikely that the domestication status of Canarium can be determined by means of direct archaeological evidence. There is no unequivocal systematic basis for the separation between wild and domesticated plants of most tree crop species, including Canarium (Yen, 1985). A more secure means is to treat the various lines of evidence within a broader context of
domestication. This must respect the growing realization that plant domestication reflects a continuum of intensity and extent of human engagement with changing environments.

Despite the recent refinement of the biomolecular, archaeological and paleoenvironmental outline of the origins of many Indo-Pacific plants, the connection between the grinding of Canarium nut anvils, isolated from archaeological excavations in New Ireland (Downie and White, 1978) and Guadalcanal (Roe, 1993), and the management of arboricultural systems is imperfect. Such a connection might be explained by plant domestication, but again this is imperfect given uncertain ecological status and biogeographic distribution of the tree and the limited genetic differentiation between wild type and cultivated forms.

To understand Canarium plant domestication, there is a need for a more integrated approach that accepts that selection pressures on plants by humans are part of a broader domestication process that incorporates the entirety of influences on plant reproduction. In alluding to early plant selection practices, Yen (1989) suggests that instead of individual plants being domesticated, plants were instead targeted in aggregates as interbreeding units, a process he has termed ‘domestication of the environment’.

For Tikopia, the evidence may never become available that allows for the genetic and phenotypic separation between wild and domesticated forms. Since Kirch and Yen’s (1982) excavations, archaeobotanical assemblages including Canarium, Cocos nucifera, Metroxylon and Pandanus have been located in many sites across near Oceania and coastal New Guinea (e.g. Kirch, 1989; Matthews and Gosden, 1997; Fairbairn and Swadling, 2005). This simply implies some uniformity in plant utilisation, not a pattern that is localised to Tikopia.

Canarium and first European contact

Unlike the Easter Island first contact history, few accounts of European contact with Tikopian society are available. Thus, there is a limited evidence base from which to make any conclusions on the changing nature of Tikopian society since the arrival of Quiros in 1606. Diamond (2005) and Kirch’s (1997) interpretation of one oral tradition recorded by Firth (1936) dictates that in 1600 AD, Tikopian society decided to divert their limited resources away from pig husbandry towards sustainable Canarium arboriculture and forest management. Diamond (2005: 292) suggests pigs were an ‘inefficient means to feed humans..., and had become a luxury food for many chiefs’. In light of European contact is it possible that a different interpretation could be offered, one where pig husbandry was an inefficient means of food production not only for the predations on root crops, but because they were a favoured item of theft by the increasing number of marauding European beachcombers?
Canarium cultivation and disturbance processes

There is no tenable palaeoenvironmental and archaeobotanical evidence for the introduction of *Canarium* to Tikopia by people or its subsequent localised domestication. The lack of any palaeoenvironmental record preceding the archaeological timeframe for the island is the main limiting factor in providing any robust evidence base. If it is assumed that *Canarium* was introduced to the island with the initial colonists or later as indicated by the archaeobotanical evidence, what consequences would this have in terms of environmental disturbance on the island? In speculation, the consequences of the initial introduction of *Canarium* to Tikopia may have involved the following:

1. Clearing by fire of indigenous vegetation indicative of fertile and thick soil horizons.
2. Tilling an area large enough for fruit or timber trees that may reach 20 m or more in height.
3. The ongoing maintenance of the established trees for several seasons.

From their excavations of the colluvial/erosion surface slopes of Rakisu, Kirch and Yen (1982) suggest that clearing for agricultural production resulted in the accelerated colluvial erosion with increased sedimentation into the surrounding agricultural lowlands. They suggest that the lowland flats at colonisation (Kiki phase) constituted unproductive calcareous sands, but were overlain with volcanic soils from the upland erosion surface during the Sinapupu and Tuakamali phases. This, they believe, in conjunction with the botanical evidence, provides indirect evidence for an agricultural production strategy involving arboricultural production. Kirch (1997: 37) suggests that this represents a land-use ‘conversion from shifting cultivation to an arboricultural system [that] obviously took several hundreds of years’. In light of the building archaeobotanical evidence-base for New Guinea and Near Oceania, it appears that arboricultural development was not localised to Tikopia and was probably a land-use strategy employed by the initial settlers of most islands.

Possible plant extinctions on Tikopia

One of the results of *Canarium* introduction to Tikopia may have been the displacement of a number of large indigenous trees. T.C. Whitmore (1969; 1967b) was adamant that human impact on the forest ecosystems of the Solomon Islands may have led to the extinction of some species, especially on the smaller islands like Tikopia. Kirch and Yen (1982: 27) reiterated this point suggesting ‘some extinctions through time must have occurred’. Tikopia can be noted for its absence of the large indigenous gymnosperm tree *Agathis macrophylla* that once formed dense stands on Vanikoro, prior to its exploitation for timber (Whitmore, 1966; Yen, 1974; Whitmore
and Page, 1980). As a species of a Gondwanan genus, *A. macrophylla* has a modern distribution stretching from the Santa Cruz Islands to Fiji, including the southernmost and northernmost islands of Vanuatu. The species is largely restricted to volcanic soils with an altitudinal range of 100 to 500 m above sea level (Beveridge, 1975), although it has also been recorded on coastal calcareous outcrops in Vanuatu (Neil, 1991). Like Tikopia, islands within the geographical area of *A. macrophylla* distribution are of Tertiary or Quaternary age and do not have a Gondwanan geology. Despite the lack of vagility of other members of this genus, *A. macrophylla* appears capable of long distance dispersal.

Tikopia does have one gymnosperm representative species within the flora, the tree *Gnetum gnemon* L. (Gnetaceae), currently located at higher elevation sites on the island (Kirch and Yen, 1982). Kennedy and Clark (2004) suggest that this tree has had a long-term relationship with people in New Guinea and other Melanesian islands where it regularly co-occurs with *Metroxylon sagu* and *Artocarpus altilis*. These species have also been found in archaeological assemblages from Pleistocene contexts from New Guinea (Fairbairn, 2005). With such an antiquity of plant-use in New Guinea, translocation of this species cannot be discounted for Tikopia.

Although *A. macrophylla* may be bound to more mesic sites, the distribution of this Gymnosperm may indicate that habitat availability is not limiting. On the Santa Cruz Islands *A. macrophylla* readily invades open ground. Equally, on these same islands introduced rats have been found destroying young seedlings and may have had a profound effect on populations in the past (Whitmore and Page, 1980). Other gymnosperms that may have been present on Tikopia, that remain on some of the Santa Cruz Islands and Vanuatu include *Dacrydium* (2 species) and *Podocarpus* (6 species; see Enright, 1995).

Many islands in the Western Pacific are noted for having representatives of at least one endemic genus within the Arecaceae (Palmae). The palms may have the strongest endemic element in the flora of the Western Pacific where around 80 percent of species are endemic to the region (http://www.kew.org/data/monocotsRedirect.html). For the Arecoideae sub-family, Vanuatu has one species each in the genera *Carposylon* and *Kajewskia*, whereas Fiji has *Goniocladus* (1 species), *Neoveitchia* (1 species), *Taveunia* (1 species) and *Vitiphoenix* (8 species). Kirch and Yen (1982) located three palm species from Tikopia, one of which was undetermined and may be representative of the genera *Pritchardia*, *Hydriastele* or *Licuala*. From an analysis of the palm flora of the Solomon Islands, H.E. Moore (1969) found that by far the majority of the palms (8 or 9 genera) are derived from the New Guinea flora. Three palm genera are notably absent from Tikopia’s flora despite having a distribution that encompasses the island. *Clinostigma* and *Physokentia* have a distribution that extends from Guadalcanal south to Vanuatu and east to Fiji and are thought by Moore (ibid) to be extensions of the Fijian flora. The distribution of the Arecoideae (sub-family) species *Pelogodoxa henryana* has an unknown biogeography as it is currently known only in cultivation on San Cristobal (Corner in Moore,
1969; Dennis and McQueen, 1989), Fiji (Phillips, 1996), Vanuatu (Dowe and Cabalion, 1996) and the Marquesas Islands (French Polynesia) (Gillett, 1971).

**Key point of conjuncture**

In this chapter I have commented on the utility Jared Diamond has made of the origins, translocation, cultivation and extinction of the plant taxa of Easter Island and Tikopia, as a means of measuring the extent of failure of the pre-contact societies on these islands. I suggest that Diamond’s thesis of Easter Island and Tikopia rests on the environmental picture constructed for the islands at first European contact, particularly the status of indigenous or introduced plants. The resolution of botanical records used in the construction of this picture is sufficiently poor to warrant environmental reconstruction ‘insoluble’. For Easter Island the chronology of deforestation, culminating in Diamond’s view at AD 1680 cannot be accurately correlated with radiocarbon dating from archaeobotanical and palynological data. For Tikopia, the lack of early accounts of European contacts meant that Diamond reverted, by inference, to the archaeological record for the interpretation of historic events.

As the island environment at first contact appears critical for interpreting human-induced environmental change on Easter Island and Tikopia, especially the introduction or extinction of plant species, can this same interpretation be applied to other islands in the Pacific? In the following three chapters I follow the same diachronic framework utilised in this chapter in exploring the relationship between human colonisation and the flora of the Austral Islands.
Chapter 5
Papa’a fenua - the foreign land: early European accounts and the botany of the Austral Islands

‘The natives, not harassed by labour for daily bread, or as slaves, have abundant time for instruction. Everyman sitting under his cocoa or bread-fruit tree is at hand, and the very sound of a hammer, a saw, or a smith’s bellows will hardly ever fail to attract an audience.’ (Dr. Thomas Haweis, 1795 in Lovett, 1899: 120)

In the previous chapter, I used the early European accounts of Easter Island to outline the chronology of botanical observations made by naturalists during visits dating from between the arrival of Roggeveen and the establishment of Eugene Eyraud’s Catholic mission station. This provided an index of the possible plant productions of the island exhibited at first contact and the status of probable indigenous taxa. This analysis also allowed for the distinction to be made between plants potentially introduced before and after European contact. The initial chronology for both pre- and post European settlement plant-extinction events was used for later integration and calibration with the palaeoenvironmental and archaeobotanical records.

By building this chronological outline, any empirical claims for plant indigeneity, introduction or extinction can be assessed in terms of consistency or variability across a range of historical observations. Biases of certain botanical observations throughout the early European period can also be measured against the more secure determinations made by later observers as well as sub-fossil evidence. In essence, the value of early European botanical observations is dependent, as Braudel suggests, upon how well historical biases are resolved, given that early European period is a point of historical conjuncture, where in the case of Easter Island, bias in early European history are difficult to resolve and may remain ‘insoluble’ to history.

The earliest observations or determination of plants made in one expedition may not have been supported by later observations or vice versa. In some cases, particularly for cultivated plants, inconsistency across observations could be put down to the state of plant production during the period of observation, in which for example, some plants may not have been in season. Some crops may not have been in leaf (e.g. Ipomoea batatas) or fruit, while some indigenous species may not have been in flower. The incomplete observations of European visitors, most of whom never made landfall, counter any robust claim for plant indigeneity, introduction or extinction.

The awareness of many plant cultigens amongst European observers on Easter Island appears to have been universal, whether by Dutch, Spanish, English, or French observers. With the exception of Sophora toromiro, (described as Edwardsia, mimosa or yellow blossom see
Chapter 4), many early descriptions of indigenous plant species were imprecise. The earliest Linnaean determinations of indigenous plants were made by naturalists, such as the Forsters on Cook’s HMS Resolution voyage, well after their exploration, at a time when plant collections could be described and compared with the herbarium collections based in Europe. With the exception of Frederick Beechey and Hugh Cuming, visiting Easter Island between 1825 and 1827, first-contact explorers did not collect botanical specimens for herbaria. Awareness of the Forster’s botanical determinations from their Easter Island collections did not form part of any European scientific observation of the flora until the 20th century.

Also in Chapter 4, I used the early European accounts as a means of assessing the timing of *Paschalococcus disperta* extinction drawn from the archaeobotanical and palaeoenvironmental records of Easter Island. None of the historical descriptions of palms provide any conclusive evidence for the presence of *P. disperta*. Equally, no historical observation could establish the timing of *C. nucifera* introduction either pre-contact or later. As for many indigenous species, early naturalists were notorious for being unable to differentiate between the coconut palm (*Cocos nucifera*) and other palm species, especially if fruits were not in season. The early descriptions of the palm flora of Cocos Island (Costa Rica) provide a case in point (Cook, 1940). The historical conjuncture or bias lies in the absent or incomplete historical observations of early European visitors to the Easter Island and/or the poor chronological control of archaeobotanical and palaeobotanical records for the pre-contact extinction of *P. disperta*. The chronology of palm extinction is the most apparent insoluble feature of Easter Island’s botanical history and makes the various claims for cultural agency insecure given the absence of essential historical detail.

In this chapter, I will expand on my analysis of the historical biases that have influenced the collection of empirical botanical data and the interpretation of botanical status for island floras in Remote Oceania, particularly for Tahiti. I will then focus on the various biases that affect the interpretation of the botanical history of the Austral Islands, particularly in light of the human introduction and potential extinction of plant species. I will then address the major episodes of environmental disturbance that maybe related to these introductions and extinctions. I focus particularly on those disturbances, whether recorded historically or inferred from other island histories in Remote Oceania, that have implications for Austral Island environments since first contact, particularly associated with beachcombing activity. I also emphasise some of the corresponding historical events and processes shared between Tahiti, Easter Island and the Austral Islands, especially in reference to environmental disturbance processes that characterise the period of European colonisation. In this analysis I include an additional dataset listing the exotic animals and plants introduced and/or documented by the European visitors as a means of further characterising these disturbance processes. These data are then related to the archaeobotanical and palaeobotanical records of the Austral Islands in Chapters 6 and 7.
Recent perspectives on early European accounts and European impacts on islands

Historians of Remote Oceania have often treated the idea of ‘first contact’ as a founding moment in which the accounts composed largely by Europeans can be distinguished from islander oral histories and archaeology. In his outline of the impact of European colonialism in the Pacific entitled *The Fatal impact*, Alan Moorehead (1968: 4) suggests that first contact ‘was a momentous occasion, a sharp and irrevocable turn in the history of the Pacific’. In other historical syntheses (e.g. Sahlins, 1985), first contact has been treated, as it is here, as a successive wave of events rather than a single phenomenon characterised by the first moment of physical contact between people of different cultural backgrounds. Ultimately, the history of first contact is seen to epitomise historical perceptions in reconstructing the cultural interactions between explorers and island people.

Aside from the cultural context of early European contact, this period of island history represents a shift in the way island environments were transformed by different groups and also in the perception of this transformation. The results of early European intervention in the Pacific led the environmental historian, George Perkins Marsh (1864) to view the Pacific Islands as ‘a theatre where man is engaged, on a great scale, in transforming the face of nature’. Critical to this paradigm of human impact on island environments was the initiation of an historical discourse centred on the origin of island biota.

In Moorehead’s (1968) synthesis of the social ‘invasion’ of the Pacific he treats the island inhabitants as naïve victims of the actions of foreigners, particularly missionaries. The most transient theme in these recent discussions on early European contacts, as addressed for Easter Island in Chapter 3 and 4, has been the agency of indigenous islanders in political, social and environmental change. This ‘agency’ theme has been presented under a number of guises, the most prominent being the recent counterpoint to Moorehead (e.g. Sahlins, 1985, Obeysekere, 1992; Salmond, 1991, 2003). The interaction between foreigner and islander is not seen as a unidirectional cultural transformation, from a society of the ‘noble savage’ to one that is ‘nevermore’¹, instead, the local inhabitants are viewed as self-motivated and often instigators of cross-cultural alterations.

Like Moorehead’s (1968) treatment of cultural transformation of South Pacific societies, island environments have been viewed in similarly passive terms in so far as they have been termed ‘naïve lands’ to the impact of human settlement (e.g. Dodson, 1992). This view is most acutely expressed in recent syntheses of European impacts on island environments (e.g. Ward, 1972; Crosby, 1986; 1988; Nunn, 1990; Grove, 1995; McNeill, 1997; Kirch, 1997b). Alfred Crosby (1986) suggests that European contact formed an immediate and novel disturbance on the

¹Chapter titles of Moorehead’s (1968) *The Fatal Impact*
environment that occurred as part of the expansion of Europeans into the 'neo-Europe', a process he termed 'ecological imperialism'.

Crosby's *ibid* perspective fits with a number of biologists who have envisaged islands as fragile and vulnerable environments as a consequence of their biotas having evolved in isolation (e.g. Fosberg, 1963). He suggests that the mechanism behind such novel environmental change through 'European imperialism' was that it had both biological and ecological components. European imperialism not only involved an expansion of the political and social order of Europe, but also represented 'the biological expansion of Europe' (Crosby, 1986: 5). Islands were exposed to what Crosby defines as 'portmanteau biota', or the exotic flora and fauna that accompany human colonists and are able to displace indigenous taxa in an environment in which they did not evolve (see also Roy, 1990). He views exotic biota as representative of a particular process of environmental transformation, as with each introduction (e.g. European ungulates) comes the introduction of an additional biotic element (e.g. European pastoral grasses and weeds) which act to restrict the development of indigenous biota.

Crosby (1986) viewed European colonisation of the new world, the Pacific included, as a series of novel disturbances. In a more recent environmental history of islands colonised under 17th and 18th century European imperial regimes, Richard Grove (1995: 55) questions this assumption of novel or unprecedented change:

>'the ability of man to cause very marked ecological changes over wide areas of the globe and then to respond constructively to them has not been confined to the last three centuries.'

The recognition of unprecedented environmental change during the early European period may be more a function of the structure of history as alluded to by Braudel. First contact history is a history of *conjoncture* as it appears to produce unequivocal social and environmental change, but at the same time holds many imperceptible or insoluble historical events or processes.

**Early European Enlightenment accounts of Remote Oceania**

*The literary industry and the influence of romanticism*

The rich historical documentation of first contact produced by Europeans entering Oceania established its own literary industry. Publications resulting from the first European contact accounts of Enlightenment expeditions during the maritime expansion of the 17th and 18th centuries portray remarkable variation. European visitors to Remote Oceania did not all share the same vision of the world or motivations towards the island societies they encountered. Grove
suggests that their attentions were primarily focused on the representation of Pacific Islands in the context of European society and environment. In the two editions of his book *European vision and the South Pacific*, Smith (1960; 1985) traces those European explorers aligned with the Rousseauian romanticism and the Enlightenment philosophy of the ‘noble savage’ epitomised by Louis Antoine de Bougainville’s (1772) description of Tahiti in 1768 as an Arcadian ‘La Nouvelle Cythère’. From his visit in April 1768 on the ship *La Boudeuse*, Bougainville (ibid: 156) wrote:

> 'Several times I went on inland walks. I felt as though I had been transported to the Garden of Eden ... Everywhere reigned hospitality, peace, joy, and every appearance of happiness'.

In his book *Green Imperialism*, Grove (1995) suggests that discussions, such as Smith’s (1960), of the ‘Enlightenment’ and ‘Romantic’ philosophies tends to obscure the more significant and earlier transition in European attitudes towards nature and the environment. Grove sees the legacy of the oceanic island 'Eden' as a vehicle for new conceptions of nature in Europe, as part of the secular response to social and economic change culminating in the industrial revolution in the late 18th and early 19th centuries.

To Grove, it is not that such transformation of attitudes were not recognised in Europe, it is more that oceanic islands provided a more effective metaphor for these changing attitudes. According to Braudel (1981: 69-50) by the end of the 18th century, romanticists saw that:

> 'vast areas of the earth were still a garden of Eden for animal life. Man’s intrusion upon these paradises was a tragic innovation ... what was shattered in both China and Europe with the eighteenth century was a biological Ancien Régime, a set of restrictions, obstacles, structures and numerical relationships that hitherto had been the norm.' (Braudel in Grove, 1995: 55; italics my emphasis)

In this regard, Pacific island environments were appealing as they provided a more pronounced biological Ancien Régime, one that was unknown, easily romanticised and not formerly 'corrupted' by any introduced European regime.

Diamond’s (2005) recent environmental macrohistory appears to draw upon this legacy of an oceanic island ‘Eden’ by employing the islands as opposed to continents as environments more responsive to the activities of people. Diamond explains that the demise of certain societies is largely dependent on their island environments being more susceptible and responsive to human

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2Grove (1995: 237-238) translates: 'Bougainville was making a deliberate reference to classical visions of an idyllic island society. More specifically, he was alluding to the island dwelling of Aphrodite, Greek goddess of beauty'.
degradation in their ‘natural’ state. By contrast, the continued survival of other island societies, Diamond suggests, has been dependent on factors of social choice and future decision-making capacity. For Diamond, oceanic islands provide an effective metaphor for the need to change current conceptions of the environment towards an impending global environmental change.

Romanticism, cultural diffusion and the origin of island floras

Also blanketed by the apparent historical focus on the romanticism of Tahiti, but intertwined with attitudes towards nature, are questions of the origins of the Tahitian people and the insular biology of their island. A debate by naturalists regarding the origins of Tahiti’s society and biology was established between, either the idea of spontaneous generation and indigenous production, or, the diffusionist notions of migration or dispersal. For many Europeans entering the Pacific, Tahiti was one of the few remnants of an antediluvian Eden.

The first to really delve into this subject was the surgeon and naturalist of the La Boudese, Joseph-Philibert Commerson. He stated: ‘Tahitians may not be sprung from their own soil, I mean, descended from ancestors who have always been Tahitians...’ suggesting the Tahitians were genealogically linked to populations outside of Tahiti. Nevertheless, to Commerson, Tahitians appeared as a different but virtuous race. The ‘pristine’, non-European or non-corrupted state of the Tahitian society and environment was such that it appeared as an idealised Ancien Régime.

Commerson’s emphasis on migration and dispersal in understanding the variation in plant species and race differentiation is a critical starting point in this discussion. His views were typical of Enlightenment thinking in which there was a strong tendency to conflate ‘native’ or ‘indigenous’ people with ‘indigenous’ plants. With this conflation was attached an awareness of the potential implications of European colonisation of island societies. Commerson (Pasfield-Oliver, 1909: 201-203 in Grove, 1995: 243) states:

‘A society of men once corrupted cannot be regenerated in its entirety ... colonies take with them everywhere the vices of their metropolis’.

Grove (ibid) suggests that Commerson was aware of the potential alterations to both island societies and environments with European colonisation and hence promoted the protection of the ‘natural’ environment as a means of retaining the virtues of the island Utopia in an attempt at preventing the ‘inevitable’ cycle of social and environmental decline that Commerson perceived of European society.
To Grove, first European contact with Pacific island societies provided a basis for new ideas of environmentalism, in explicitly revealing how the limitations of local and global resources were being disguised in an increasingly industrialised continental Europe. First contact accounts reflect a general discourse amongst naturalists and other commentators of a growing dissatisfaction in the increasing social and environmental changes exhibited in industrial European society, more so than any commentary on the state of Tahitian society and environment. For Commerson and other French naturalists, it related to the environmental deprivation that came with European colonisation and the establishment of slave states on other island societies such as the Mauritius.

Although many naturalists arriving on Tahiti after Commerson demonstrate a similar idealisation of the Tahitian environment, the background to Commerson’s interpretation of the island’s flora is important. Grove (1995: 236) suggests that in Commerson’s mind there is:

’a connection between the discovery of an apparently innocent, uncomplicated society on Tahiti and the discovery of new plants by Commerson … plants in their unspoilt habitats stood as anthropocentric representations of a natural human order, one which had not been [in Rousseau’s words] ‘denatured … by the hand of man’.

The discovery of new island plants became empirical proof of indigenous production, but one developed through some kind of unexplored biological and social process. Grove suggests that a connection between plant species variation and ‘race differentiation’ was made from Commerson’s experience on other islands from which he proposed migration and dispersal over countless generations as an explanation for such race variation. In support of this migration hypothesis was the apparent natural equilibrium between human labour and food production, a balance between nature and culture. Commerson observed of Tahiti:

‘Everything in their homes manifests the greatest intelligence … their navigator is directed by observation of the stars … their fruit trees are so planted at judicious intervals that they have not the tiresome monotony of orchards, though retaining all that is agreeable and pleasant in the latter’. (Pasfield-Oliver, 1909: 126)

The concept of the Tahitian environment as ‘pristine’ and the use of certain cultivated plants as symbols of a ‘Garden of Eden’ continued well into the Enlightenment period. Commerson’s and also Bougainville’s descriptions and analyses of the Tahitian society and environment may have informed later explorers, including a number of Anglophones. James Cook (Beaglehole I: 121-122) concluded of the Tahitian environment that:
'the Earth almost spontaneously produces or at least they are rais’d with very little labour, in the article of food these people may almost be said to be exempt from the curse of our fore fathers; scarcely can it be said that they earn their bread with the sweat of their brow, benevolent nature hath not supply’d them with necessaries but with abundance of superfluities.'

Joseph Banks on Cook’s HMS *Endeavour* voyage arrived and registered in his journals the following corresponding view:

‘sarceely can it be said that they earn their bread with the sweat of their brow when their cheifest sustenance Breadfruit is procur’d with no more trouble than that of climbing a tree and pulling it down. Not that a tree grows here spontaneously but if a man should in the course of his life plant ten such trees, which if well done might take the labour of an hour or thereabouts, he would completely fulfil his duty to his own and future generations’

Writing in 1789, the HMS *Bounty* mutineer James Morrison (1935: 152), perhaps after reading the accounts of Cook’s crew, described the islands fertility in almost the exact same terms:

‘As every part of the Island produces food without the help of man, it may of this country be said that the curse of Eden has not reached it, no man having his bread to get by the sweat of his brow nor has he thorns in his path.’

Such paralleled comments can only represent the extent to which these early explorers were naïve of both the cultural origins of Tahitian society and the biogeographic origins of the island’s flora.

*Empirical botanical data from Enlightenment accounts*

Commerson was the earliest Linnaean trained botanist to enter the oceanic islands of Remote Oceania, specifically Tahiti. To his discredit, he never published any of his collections and only provided a cursory commentary on the status of the Tahitian flora (Smith, 1974). The level of detail provided for the Tahitian flora in the publications produced by the naturalists on Cook’s voyages, was exceptional. The European experience of Tahiti was also exceptional in the amount of time spent exploring the island and the number of naturalists who became partly versed in the Tahitian language where environmental information could be obtained directly from the Tahitians.

Between 1777 and 1778, Johann Reinhold and George Forster, who joined Cook on the HMS *Resolution* voyage, published compilations and analyses of comparative biological and ethnological data collected from the dozens of Pacific archipelagos. This represented the first
systematic attempt to define the geographic origins of plants and humans on Pacific islands. It became immediately apparent that they were not entirely synchronous. Clarence J. Glacken (1967) suggests that the Forsters were the first to recognise human modification of the environment beyond the cultivations of which most Europeans were aware (e.g. root crop cultivations and fruit orchards). For the origin of *Artocarpus altilis* breadfruit on Tahiti, Georg Forster (1777) raised the possibility that humans were probably responsible for its distribution as they were rare in ‘uncultivated’ places. He also proposed a Southeast Asian origin for *A. altilis* along with a number of other species. Johann Reinhold Forster (1778) also commented on the affinity of the flora of Tahiti and other islands with America and Asia.

Despite the fact that Pacific botany began in Tahiti with the observations of Commerson and Banks, the ecology of the flora at first contact is poorly known (Fosberg, 1992). Botanists including Commerson and Banks never ventured into the high elevation areas of the island where modern botanical surveys indicate that most (70%) of the endemic plants are located (Meyer, 2004). The concentration of early European botanists was instead on the heavily cultivated lowland areas where most of the food plant species were determined. Some historians have remarked on how little ecological and ethnobotanical detail was provided on the manner in which food was produced (e.g. Oliver, 1974; Lepofsky, 1999; 2003). Dana Lepofsky (1999: 4) suggests that:

‘Despite the early European interest in acquiring food for their ships’ crews, they wrote surprisingly little about the Maohi [Tahitian society] food production system... Since the European had no context for understanding other aspects of food and production, little information was recorded about them... neatly tended, fenced gardens, which were appealing to the European aesthetic, were praised and the details noted. On the other hand, arboricultural zones were not even recognized as cultivated gardens, and tree crops themselves were considered wild.’ (Lepofsky, 1999: 4)

With the exception of root and corn crop agriculture (e.g. *Colocasia esculenta, Ipomoea batatas*) and especially breadfruit (*A. altilis*) cultivation, the most orchard-like tree of a kind familiar to Europeans, few details were available on other cultivation practices. According to Lepofsky (ibid: 21):

‘In terms of cultivation, this manifests in the fact that the Europeans wrote at great length about gardening practices that were familiar to them but gave little attention to those that had no analogue in Europe.’

In an attempt to establish a broad definition of indigenous agricultural systems prior to European contact, Yen (1973b) highlighted this tendency in his appraisal of early European sources for the
eastern Solomon Islands in examining the translated journals of de Quiros, Leza (Markham, 1904) and Munilla (Kelly, 1966). Before the advent of the Linnaean taxonomy most of the island plant products recorded by the Spanish were named according to the similar appearance of existing European foods or those experienced in the New World colonies by appearance, smell and taste. For example, the fruit of *Spondias dulcis* (called the Pomme de Cythère or Apple of Eden by the early French explorers on Tahiti and the Tahitian apple by Cook) is referred to by Leza as having ‘the smell and taste of nectarine’ (Markham, 1904 in Yen, 1973b: 36) and the nuts of *Inocarpus fagifera* (Parkins) Fosberg are grown ‘within the shells like those of large carob beans’ (Kelly, 1966 in Yen, 1973b: 36) later called Tahitian chestnuts by Cook when first describing the taste of these nuts in the Society Islands.

**Early European missionary accounts of Remote Oceania**

The arrival of London Missionary Society (LMS) evangelists on board the *Duff* to Tahiti in March 1797 represented the introduction of a more defined set of ideas on the origin of plants. The Judaeo-Christian perception of plants in nature provided an image of religious truths, particular of expressing the relationship between wild and cultivated plants. There was an intimate connection between evangelism and cultivation that built on the relationship between nature and humans. Sujit Sivasundaram (2001) suggests that there were parallels in the way Evangelical missionaries and Enlightenment naturalists ordered nature. Just as the naturalists such as Commeraon and the Forsters named and classified plants, missionaries also classified the island societies they visited, often providing islanders with new European names, or classifying them as saved (converted) or lost (unconverted) souls. The closer the islanders were to nature, the further they had moved against the divine.

The representation of island floras was critical to their position as it provided a metaphor for the state from which the island environments and the islanders themselves could be improved. The duty of the Evangelical missionary was to bring the Pacific Islanders under their God and to tend to the islanders as if cultivating a crop. Sivasundaram (*ibid*) suggests that the stages of spiritual development were marked by the improvements to nature, represented by the extent and productivity of gardens. To this aim, Tahiti appeared already on this path with the abundance of coconut palms and breadfruit trees.

Tahiti was selected as the London Missionary Society’s first project as an experiment in evangelism. Rev. Thomas Haweis (1795 in Lovett, 1899: 120-121) noted in an early address entitled *The very possible success of a proper mission to the South Sea Islands*, that the climate of Tahiti was hospitable, food was easily obtained; the government seemed amenable to missionary practice, there appeared to be no prejudices against religious practice and the language was easy
to acquire. Such a perception relied heavily on earlier naturalist accounts, particularly of Joseph Banks to whom Hawes fostered a close relationship. Evidence of the practice of cannibalism, infanticide and general social neglect in Tahiti was portrayed in Cook’s and Bank’s journals, thus outlining the urgency of the missionary project. Equally, Bank’s descriptions of the presence and abundance of cultivated plants on islands became an evangelical metaphor for the potential of conversion. If cultivation practices were not observed on an island, the perception then arose that islanders would therefore lean towards hostility of missionary practices.

**Empirical botanical data from missionary accounts**

After the initial establishment of the missionary enterprise in the Society Islands, plants became part of the Evangelising package of all islands, a process Richard Drayton (2000) describes as ‘agrarian patriotism’. In cases where certain cultivated plants were not documented for an island either by early explorers or initial missionary contact, they were intentionally introduced, particularly those plants that allowed replication of the improvements made on Tahiti, the ‘Garden of Eden’. Common introductions were breadfruit (*Artocarpus altilis*), coconut (*Cocos nucifera*) and papaya (*Carica papaya*) but some European origin vegetables and ornamentals could also be successfully grown in tropical/sub-tropical climates (e.g. *Brassicaceae* and *Cucurbitaceae*).

Later missionaries were actively involved in the collection of botanical specimens, but also the publication of island lexicons for the primary aim of translating the Bible. Rev. John Davies first published *A grammar of the Tahitian dialect of the pre-Polynesian language* in 1823 as the first of such lexicons to include terms and glosses for plant names as well as some Linnean names. For example, *Uru* is described as:

> ‘the general name of the breadfruit tree and fruit (*artocarpus*); see *maioe*. There are at Tahiti between 20 and 30 species, and as many names’ (Davies, 1951: 303).

Rev. William Ellis continued to expand on this Polynesian grammar in first publishing his influential *Polynesian Researches* in 1829. Ellis compiled a considerable amount of ethnographic, linguistic, historical and biological material collected by his contemporaries and earlier missionaries who had arrived in the *Duff* including Rev. Charles Barff, Rev. John Orsmond and Rev. Lancelot Threlkeld (Gunson, 1994).
Beachcombing and the exploitation of island societies and environments

The term ‘beachcomber’ was first coined in 1847 by the author and beachcomber Herman Melville (Maude, 1964). Henry Maude (1964: 255) suggests that they were immigrants who:

‘were essentially integrated into, and dependent for their livelihood on, the indigenous communities ... supplemented by casual employment ... as agents and intermediaries for the captains or supercargos of visiting ships.’

Unfortunately, beachcomber accounts are conspicuous by their rarity partly because many of these immigrants were illiterate opportunists, convicts or mutineers, but more because written accounts and descriptions of islands were not their primary trade. Apart from the location of plant produce (e.g. sandalwood and vegetable supplies) botanical information rarely formed part of any reference to beachcombing activity. With some notable exceptions (e.g. Martin, 1817; Melville, 1846; Im Thurn and Whaton, 1925; Morrison, 1935), beachcombers rarely chronicled their exploits in the Pacific and provided little environmental information on the islands they visited. Their influence was more often noted in the accounts of missionaries or indirectly inferred from the amounts of various commodities recorded in ships journals or the cargo holdings from the various trading ports (e.g. Port Jackson; see Cumpston, 1964).

One of the most detailed beachcombing accounts comes from William Lockerby's journal of his time spent on Vanua Levu (then called Sandalwood Island), Fiji from 1808-1809 (Im Thurn and Wharton, 1925). Lockerby documented the exploitation of sandalwood from the islands but also highlighted the integral relationship between the indigenous communities and beachcombers. The most famous beachcomber account comes from the HMS Bounty mutineer James Morrison. Morrison (1935) describes in narrative form the nature of island life, particularly the complexity of islander and mutineer relations. Of limited value are his descriptions of the available resources on the islands visited (including Tubuai – see below).

Maude (1959; 1964) outlined the beginning of beachcombing proper, and thought it a consequence of the expanding penal colony at Port Jackson in the early 1800s, where whalers and sealers became engaged in a variety of commercial ventures in the Pacific including the Tahitian pork-trade, the sandalwood trade, pearling and *bêche de mer* harvesting for the lucrative Canton and Calcutta markets. Each of these trades were unreliable and haphazard business ventures in which a pearl-trader, for example, would be required to locate sandalwood in order to supplement their income in times of poor pearl harvests.

To Maude (*ibid*), beachcombers could be differentiated from other immigrants in that they were dependent on island resources and indigenous communities for their livelihood.
Missionaries, for example, were supported with resources supplied by the various evangelical societies based in Europe. Beachcombers lacked the labour force required to secure enough commodity to maintain their income. Islanders were often willingly employed to harvest sandalwood or recruited as pearl divers, but in some cases they were “black-birded” for distant human labour markets such as those in Callao.

_Inferred social and environmental impacts of beachcombing_

From 1793 until the mid 1820s, beachcombing activity centered on the Tahitian pork trade rapidly adjusted the social and environmental framework of the Society Islands. Tahitian pig husbandry, even on a small scale, was regarded as a reliable and necessary supply for the growing Port Jackson market. It enabled pork traders to supplement their profits with other valuable commodities including pearls and sandalwood and _bèche de mer._

The introduction of infectious diseases during this period produced the sharpest indigenous population decline, although this has remained a point of speculation and contention (e.g. McArthur, 1968; Bushnell, 1989; Stannard, 1989). From his visits to Tahiti from 1768 to 1775, Cook (1777) thought the population of Tahiti exceeded 20,000. It is likely that through infectious disease, “black-birding”, and other colonial mechanisms that the population fell to around 5000 by 1816 (Henry, 1928). Similar, population declines are noted for Easter Island where in 1786 the population was greater than 2000 (La Perouse, 1798), later declining to around 1000 following a recorded smallpox epidemic in 1838 (Du Petit-Thouars, 1841) and a wave of “blackbirding” in 1862 (see _Chapter 4_).

Depopulation of the islands from disease and “black-birding” had obvious ramifications for the coherency of the indigenous island societies. This social decline, however, was not a uniformly negative process. By working with beachcombers, islanders could obtain goods formerly unavailable to them, but influential in adjusting the social status of individuals or groups involved in beachcombing activity. The intensive production of pork, poultry and other food staples (root and tuber crops, breadfruit etc.), provided valuable trade for firearms and ammunition, metal tools, fishhooks, cloth as well as other rudimentary European goods (Maude, 1959; Ward, 1972). The rise in beachcombing ships in the region allowed for islanders to join crews or in the case of the Pomare dynasty, purchase beachcomber ships (e.g. _Governor Macquarie_ and the _Minerva_) for the purposes of forming alliances and trade networks across the archipelagos surrounding the Society Islands.

The environmental impact of beachcombing and other colonial activities on Tahiti during the height of the pork trade can be inferred from the changes in land-use associated with differing agricultural requirements. The immediate effects of depopulation following the introduction of
disease and “black-birding” were dramatic changes in land-use primarily with the abandonment of agricultural systems in the upland areas of islands and increased soil degradation in the lowlands. Certain trade items, particularly food items preferred by visiting crews may have been preferentially produced by islanders in place of more traditional foods that had no market value. For example, sweet potato (*Ipomoea batatas*) and yams (*Dioscorea* spp.) and European root crops (e.g. *Solanum tuberosum* and Cucurbitaceae spp.) were preferred trade items for Port Jackson-based ships over and above other vegetable crops (e.g. *Colocasia esculenta*) due to their better storage qualities. The influence of the Port Jackson market would have also changed the production of other cultural commodities (e.g. prestige artefacts).

Soil erosion may have increased following widespread clearance of primary and secondary forest for commercial agricultural ventures, including pig husbandry. Nunn (1990) suggests that since the main purpose of forest clearance was for commercial ventures rather than subsistence, much larger areas, formerly unsuitable for pre-contact indigenous production were burnt. The introduction of exotic farm animals that may become feral (e.g. goats and cattle), created an additional mechanism for soil erosion through vegetation browsing and soil trampling activity.

*The environmental impact of sandalwood and bêche de mer harvesting*

The sandalwood trade was at its height in the early 19th century where it became so lucrative that supplies were exhausted quickly whereby new sources from other islands were highly sort after. The white sandalwood (*Santalum album*) of the western Indo-Pacific was the first to attain industry notoriety with most or all of the other Pacific species having equivalent economic value (St John, 1947). Exploitation of sandalwood in Remote Oceania is best recorded for Fiji, Vanuatu and the Hawaiian Islands (Im Thurn and Wharton, 1925; Shineberg, 1967). There are seven species on the Hawaiian Islands and a number of undetermined forms and varieties (St John, 1973). From 1811 to around 1828 it became such a profitable industry that fourteen foreign ships amongst many other expensive European curios were purchased by Hawaiian chiefs turning their commoners to the harvest (Shineberg, 1967: 9). By 1817 sandalwood became the region’s most lucrative commodity over and above the *bêche de mer* and pearl trades.

Depending on the species, sandalwood trees in their mature state can reach a girth of ~30 cm (some specimens are known to reach ~60 cm) and a height of ~2 m in the more tropical islands (Butaud *et al* 2005). The harvest of these hemi-parasitic trees sparsely distributed throughout the forested areas of many Pacific Islands was a destructive process and probably involved extensive deforestation. The trees were often located by their burning scent after tracts of forest were set alight. The burnt stumps of the trees were then uprooted then stripped of their young branches lacking the valuable oil in order to procure the oil rich heartwood portion of the
At the peak of the Fijian sandalwood trade, the crew of the American ship the *Roscoe* harvested 74 shipping tons (1016 kg = 1 ton) from Mbaa Bay in 3 ½ months (Ward, 1972). Assuming that around 70 kilograms of heartwood may be procured from each mature tree (Butaud *pers. comm.* 2005), around 1000 trees were required for such a harvest.

*Bèche de mer* (dried *Holothurioidea*) were usually harvested during the same sandalwood expeditions (Ward, 1972). If extensive deforestation resulted from sandalwood harvesting, this was compounded by the demand for firewood for curing *bèche de mer*. Uncured harvests would quickly result in spoil, thus drying houses were required depending on the size of the operation. In parts of Remote Oceania that produced rich beds of *bèche de mer* (e.g. Fiji), curing took place in large purpose built drying houses. One Fijian operation recorded by Charles Wilkes (1852: iii. 231-234) employed hundreds of men either for harvesting of *bèche de mer* off the reefs or for collecting cords (−3.5 m³) of firewood as fuel for the drying houses. According to R. Gerard Ward (1972), the average drying house required the trunks of about 35 palms for construction and suggests that this process used up a significant portion of locally available palm groves. On the Fijian island of Ngaloa in 1832, J.H. Eagleston (in Ward, 1972: 117-118) at one time measured 110 cords (−385 m³) piled and awaiting burning by a *bèche de mer* drying house and suggested that the islands entire firewood supply was exhausted and most of the supply had been delivered from mainland Vanua Levu. Ward estimates that −1/2 a cord (−20 m³) was required for the drying of 1 picule (60.5 kg) of *bèche de mer* and that between 1827 and 1835 over 160,000 m³ of stacked wood was combusted in Fiji alone.

**Plant introductions to Remote Oceania during the early European period**

A large number of plants in Remote Oceania, particularly taxa associated with cultivation sites, are considered by some Pacific botanists to be indigenous or naturalised by others (see Whistler, 1990 as one example). For many of these species more detailed molecular phylogeographic data or the identification of subfossil material may yet resolve their botanical status. The current understanding of this subject, however, has to a degree been contingent upon the empirical botanical collection of Enlightenment explorers. Elmer Drew Merrill (1946; 1954a; 1954b) who first collated the herbarium collections obtained during the Cook voyages, suggested that such accounts provide an invaluable source of empirical data on the origins of the island flora, especially given the emphasis early naturalists placed on plant collection. Other Pacific botanists (e.g. Yen, 1973b; St. John, 1978; 1979b) have since expanded this analysis to incorporate other first contact enlightenment accounts.

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3 see Edmund Fanning’s (1838: 61-63) description of sandalwood harvesting in Fiji during the 1830s
<table>
<thead>
<tr>
<th>Botanical name</th>
<th>Family</th>
<th>Common name</th>
<th>Date of introduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albizia lebbeck</td>
<td>Fabaceae</td>
<td>Faifai popa’a</td>
<td>1845</td>
</tr>
<tr>
<td>Alhum sp.</td>
<td>Liliaceae</td>
<td>Onion</td>
<td>Before 1800</td>
</tr>
<tr>
<td>Anacardium occidentale</td>
<td>Anacardiaceae</td>
<td>Cashew</td>
<td>1875</td>
</tr>
<tr>
<td>Ananas comosus</td>
<td>Bromeliaceae</td>
<td>Pineapple</td>
<td>Before 1811</td>
</tr>
<tr>
<td>Arctocarpus altis</td>
<td>Moraceae</td>
<td>Breadfruit, ‘Uru</td>
<td>Before 1768 (POL)</td>
</tr>
<tr>
<td>Cananga odorata</td>
<td>Annonaceae</td>
<td>Y’lang y’lang, moto’i</td>
<td>1899</td>
</tr>
<tr>
<td>Carica papaya*</td>
<td>Caricaceae</td>
<td>Papaya, i’ita</td>
<td>Before 1817</td>
</tr>
<tr>
<td>Cecropia palma*</td>
<td>Moraceae</td>
<td>Snakewood</td>
<td>Before 1890</td>
</tr>
<tr>
<td>Citrus</td>
<td>Rutaceae</td>
<td>Lemons, limes, oranges</td>
<td>Before 1811</td>
</tr>
<tr>
<td>Cocos nucifera</td>
<td>Arecaaceae</td>
<td>Coconuts, niu</td>
<td>Before 1768 (POL)</td>
</tr>
<tr>
<td>Coffea arabica</td>
<td>Rubiaceae</td>
<td>Arabian coffee</td>
<td>1817</td>
</tr>
<tr>
<td>Cucurbitaceae</td>
<td>Cucurbitaceae</td>
<td>Pumpkins, melons etc.</td>
<td>Before 1811</td>
</tr>
<tr>
<td>Gossypium barbadense**</td>
<td>Malvaceae</td>
<td>Cotton, vavai</td>
<td>Before 1835</td>
</tr>
<tr>
<td>Lantana camara</td>
<td>Verbenaceae</td>
<td>Taratara hāmoa</td>
<td>1853</td>
</tr>
<tr>
<td>Leucaena leucocephala</td>
<td>Fabaceae</td>
<td>Leucaena</td>
<td>1845</td>
</tr>
<tr>
<td>Ludwigia octovalvis</td>
<td>Onagraceae</td>
<td>Willow primrose</td>
<td>Before 1847</td>
</tr>
<tr>
<td>Mangifera indica</td>
<td>Anacardiaceae</td>
<td>Mango, vī popa’a</td>
<td>1848</td>
</tr>
<tr>
<td>Nicotiana tabacum</td>
<td>Solanaceae</td>
<td>Tobacco</td>
<td>?</td>
</tr>
<tr>
<td>Persea americana</td>
<td>Lauraceae</td>
<td>Avocado, avoka</td>
<td>1846</td>
</tr>
<tr>
<td>Psidium guajava</td>
<td>Myrtaceae</td>
<td>Guava</td>
<td>1815</td>
</tr>
<tr>
<td>Saccharum officinarum</td>
<td>Poaceae</td>
<td>Sugar</td>
<td>1835</td>
</tr>
<tr>
<td>Solanum tuberosum</td>
<td>Solanaceae</td>
<td>Potatoes</td>
<td>Before 1811</td>
</tr>
<tr>
<td>Tecoma stans</td>
<td>Bigoniaceae</td>
<td>Piti</td>
<td>1845</td>
</tr>
<tr>
<td>Typha domingensis</td>
<td>Cyperaceae</td>
<td>‘Ōpaero</td>
<td>1830</td>
</tr>
<tr>
<td>Theobroma cacao</td>
<td>Sterculiaceae</td>
<td>Cocoa</td>
<td>1880</td>
</tr>
<tr>
<td>Vanilla sp.</td>
<td>Orchidaceae</td>
<td>Vanilla</td>
<td>1848</td>
</tr>
</tbody>
</table>

Table 5.1 Preliminary list of introduced plants to Tahiti during the early colonial period (after Barrau, 1959; 1960 and Florence, 1993; Richards, 2005). * Timing of this introduction has been contested by several authors (e.g. Brown, 1935; Merrill, 1954; Langdon, 1989) ** Also the indigenous species G. hirsutum var. taitense. POL= Polynesian introduction prior to first contact (1768).

Merrill (1949; see also Yen, 1973b) points out that Europeans began introducing plants to Remote Oceania as early as 1568 when Medana and de Quiros (in 1595) attempted to establish a European settlement in the Marquesas by sowing maize (*Zea mays*) seed (Merrill, 1949, Yen, 1973b)4. On the Juan Fernández Islands (Chile), discovered in 1574 by Juan Fernández, quince (*Cydonia oblonga*) and clover (*Trifolium repens*) were introduced by Le Hermite in 1624.

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4The Galápagos Islands (Ecuador) were sighted by Fray Tomás de Berlanga in 1535 (Markham, 1892). This represents the earliest recorded 16th century European sighting of an island in Remote Oceania, but no records of any plant introductions exist.
It seems that these early plant introductions all failed but an increasing number of attempts in the 18th century by European explorers, traders and missionaries began succeeded. By the 19th century introductions were widespread and an integral part of the colonial process.

The introduction and extent of plant cultivations and/or invasions for the 19th century is best recorded for Tahiti. Tahiti played a central political and economic role in the Pacific during the early colonial period. Along with the Hawaiian Islands, and less so the Fijian archipelago, it was one of the largest trading ports in the region with an amenable labour force and co-operative political elite in the form of the Pomare dynasty. Due to the political and economic ascendancy of Tahitian society and the Pomare dynasty, Tahiti became the primary colonial experiment, with both Europeans and Tahitians actively exploring new trading opportunities. The agents of these introductions included the island Polynesians, explorers and naturalists, crews on trading vessels and missionaries of both islander and European descent (Green, 2005). Numerous plant species whether economic plants or ornamentals were introduced from the onset of European colonialism. The large number of botanical collections carried out on Tahiti since the Cook expeditions (see Smith, 1974) has meant the island presents one of best available records of plant introductions for any island in Remote Oceania.

Jacques Barrau (1959, 1960) and Jacques Florence (1993; 1997; 2004) have traced the European introduction of a series of economic plants intended for large-scale production on Tahiti (see Table 5.1). Florence has also outlined the timing of introduction of a number of ornamental plants and some inadvertent introductions (weeds) that were naturalised early in the colonial history of Tahiti. Some of the large-scale plant productions were also noted by beachcombers such as John Child whilst stopping at the island in 1811 on the sandalwood harvest ship, the Hunter (Richards, 2005). Coffee (Coffea arabica) was introduced to Tahiti in 1817 with the intention of establishing large-scale crops as an alternative product to replace the failing sandalwood and Bèche de mer trade. Charles Darwin (1839) observed during his stay on Tahiti in 1835 extensive cotton (Gossypium barbadense) and sugarcane (Saccharum officinarum) plantations. Of the introductions listed a number are regarded as inadvertent introductions including Ludwigia octovalvis, introduced to Tahiti prior to 1847 (collected by Vesco, the surgeon of the Uranie; Drake del Castillo, 1893), probably introduced embedded in soil attached to corms of Colocasia esculenta and other aroids brought in for cultivation in pondfield systems from the Western Pacific. Captain F.W. Beechey on the Blossom collected this plant from other islands in Remote Oceania in 1826 (Hooker and Arnott, 1830-1841). Later inadvertent introductions of this kind include Commelina diffusa (Commelinaceae) introduced to Tahiti sometime prior to 1912 (Florence, 1993), but was not located by any botanists before this time. J.G.A. Forster (1786) collected C. diffusa (syn. C. nudiflora) from the Tongan archipelago whilst on the HMS Resolution voyage (1773-1777), suggesting this plant maybe indigenous or a Polynesian introduction to Tonga, but a later introduction to Tahiti.
Plant extinctions in Remote Oceania during the early European period

Evidence for plant extinctions in Remote Oceania are generally only available from discrete sub-fossil records radiocarbon dated to within the period of human settlement. Macrofossil, pollen and phytolith records of more than fifteen plant species extinctions from Easter Island (Flenley et al. 1991; Orliac, 2000) and a palm from Rapa and Rimatara in the Austral Islands (Prebble et al. in prep; see Chapter 7) have provided the most notable extinction records. Extinction events have also been inferred, prior to the time of human settlement, from the divergence of species lineages identified from molecular studies of modern species populations, but the precise timing and nature of these events remain inconclusive.

Post first-contact extinction records from Remote Oceania are rare. Despite the history of botanical observation in Tahiti no plant extinctions have been documented on the island (Jean-Yves Meyer Pers. Comm. 2005). This may be a function of a number of historical factors. Firstly, the earliest plant collections were concentrated in easily accessible areas near the coast and in the vicinity of settlements where few rare taxa may have been present (Merrill, 1949). A number of authors (e.g. Guppy, 1906; Ridley, 1930; Merrill, ibid) have noted that a large proportion of species collected by the naturalists on Cook’s voyages, for example, were either weed species associated with cultivated areas or beach strand taxa common on most archipelagos. Secondly, prior to first contact many taxa may have already been exterminated at these collection points by island populations in the expansion of agricultural and settlement areas.

First contact and the Austral Islands

The earliest European accounts of the Austral Islands

The earliest European contacts with the Austral Islands, with the exception of Rimatara, were all associated with the prolific late 18th century voyages of discovery. In Faddei Von Bellinghausen’s account of Rapa from his 1820 visit on the Vostok, however, he incorrectly proposed that Pedro Fernandez de Quiros made an earlier discovery of the island close to two hundred years before George Vancouver’s sighting in 1791. Marotiri (Bass Rocks) are situated in roughly the same latitude (27° 45’S) provided in the Arrowsmith Hydrographic Charts. Following Bass, Arrowsmith marked ‘Los Cuatro Coronadas’ on his chart as described by Quiros in February of 1606. Bellinghausen (1945: 225) suggested that Marotiri ‘presents four summits to a vessel approaching from the westward’. Bellinghausen (ibid) translated Quiros’s description of these rocks:
‘On February 5th of 1606, having proceeded about 25 miles from the land we had surveyed, we sighted in the evening four islands, forming a triangle, each of a size of 5 or 6 miles which were quite bare, uninhabited and in general resembling the island we had discovered.’ (Quiros in Bellinhsen, 1945: 225)

Barratt (1996) suggests that Quiros’s description more likely reflects the Actaeons in the Tuamotu Archipaleago after their survey of Ducie Island to the northeast.

The first European contact with the Austral Islands, in fact, took place on the 15th August 1769 at Rurutu with the HMS Endeavour under James Cook (see Table 5.6). To Cook, Rurutu (Oheteroa) was an island of ‘little consequence… 13 miles in circuit and tolerably high, it appears to be neither populous nor fertile’ (Beaglehole, 1955: 156). Joseph Banks attempted to land on the island but was prevented from making any detailed observations by virtue of an altercation between the islanders and the ship’s crew. As well as Rurutu James Cook on the HMS Resolution voyage also sighted Tubuai towards the end of their four-year Pacific expedition in 1777, three years after visiting Easter Island. Unfortunately, to Cook (Rickman, 1967: 131), Tubuai ‘appeared of little consequence’, as did Rurutu, and no landfall was made on the island with few observations noted in any of the Resolution journals.

Having experienced many of the Pacific Islands with James Cook on the HMS Resolution voyage of 1773, including Easter Island and Tahiti, George Vancouver was aware of many of the cultural and environmental traits of the Pacific Islands when he first sighted Rapa in 1791 as ship’s captain on the HMS Discovery. Vancouver’s (1798: I 214-215) account of Rapa from December 22nd 1791 highlights the limited but quintessential observations characteristic of 18th century Enlightenment discoveries:

‘Its principle character is a cluster of high craggy mountains, forming in several places, most romantic pinnacles, with perpendicular cliffs nearly from their summits to the sea; the vacancies between the mountains would more probably be termed chasms than vallies, in which there was no great appearance of plenty, fertility or cultivation… (Vancouver, 1798: I 214)

Archibald Menzies, the Discovery’s surgeon and botanist, also had previous experience working in the Northern Pacific (including the Hawaiian Islands) as a ships’ surgeon on the Prince of Wales between 1787 and 1788, related many of the same images, but in equally limited detail:

‘At noon we were within 6 leagues of the island & as we approachd nearer, it presented a most rugged appearance for the Shore on the western side rose here & there in high naked perpendicular cliffs & precipices that in some places overhung their base & appeard to be composed of
horizontal strata the summits of these presented picked rocks & rugged shivers, irregularly piled & forming broken ridges & deep chasms overed the whole island... About 3 in the afternoon several canoes were seen coming off from the shore which convinced us that this dreary looking island was inhabited & we now began to think that these strong-holds were no doubt what their appearance at first suggested to us – places of defence... At first we found it a very difficult task to bring any of the Canoes along side us with all the amicable signs & invitations we could think of...' (Shineberg, 1986: 65)

None of the earliest European contacts with the Austral Islands involved any landfall by ship crews. Discovered relatively late was Rimatara where the missionary transport ship under Thomas Henry, with two LMS missionaries, were probably the first Europeans to reach the island in 1822, although possible earlier dates for this event or other first contact events have been cited (e.g. Sharp, 1960: 192; Guillain, 2001). Maude and Crocombe (1962: 35) suggest that Michael Foldger [Folger] on the brig Daphne were the first to make contact with the island in 1812, although nothing of this altercation have been recorded. Rev. John Davies (1966: 95) writing in the 1820s suggests otherwise:

'I have not spoken of any of my visits to Rimatara, a beautiful little island, about seventy miles west of Rurutu. We first heard of it from Aaura; and Christianity being established at Rurutu, we succeeded in imparting the same blessings to the inhabitants of Rimatara. My esteemed colleagues, Messrs. Threlkeld and Orsmond, were the first Europeans who visited it.'

In an offshore exchange between a Rapan canoe party and the HMS Discovery crew, Vancouver (1798: I 214-215) found that:

'that it was impossible to gain from them any information. Their answers to almost every question were in the affirmative; and our enquiries as to the name of their island, &c were continually interrupted by incessant invitations to go on shore. At length, I had reason to believe the name of the island was, Oparo; and that their chief, Korie...'

Tooworero was on board the HMS Discovery, a Hawaiian returning home after spending the previous two years in England, but according to Vancouver (ibid) he ‘could understand very little of what they [the islanders] said’. Menzies (Shineberg, 1986: 69) reiterates this confusion:

...I think it is probable [on the basis of Tooworero’s poor understanding of the islands language] that OparoO may not be the real name of the Island, though it was often their answer to our interrogation on that head and therefore adopted.
The brevity of contact allowed by Vancouver with the islanders was mostly due to his likely anxiety toward finding news of their tender the *Chatham* under William Broughton with whom they lost contact after a storm on their departure from New Zealand. The wake of Cook's death 12 years earlier in 1779 probably entrenched their wariness of the benevolent potential of islanders that dissuaded them from leaving the ships confines to explore the island on foot.

Another factor preventing the prospect of landfall may have been the extent reef shoals encompassing much of the perimeter of the island making any attempts a perilous venture.

*The earliest European settlers on the Austral Islands*

The earliest documented European settlement on any of the Austral Islands was by the HMS *Bounty* mutineers. Led by Fletcher Christian and James Morrison, the mutineers landed on Tubuai for three months in 1789, 12 years after Cook's first sighting of the island. From Morrison's (1935) account they first arrived on the 25th May for three days then returned to Tahiti where they obtained additional supplies intended for the construction of a 'fort' on the island. Returning from Tahiti on the 23rd of June they stayed until the 17th September. Just under 460 pigs, 50 goats, chickens, dogs, cats and a solitary cow were introduced to the island. Morrison (1935) provided a clear description of the island and its inhabitants, including details on the plants and animals brought to the island on the HMS *Bounty* and the local food and other plant productions on the island.

By the early 19th century the influx of European visitors to the Austral Islands increased directly in response to the beachcombing industries and the activities of the LMS operating out of Port Jackson and Tahiti. According to Rev. John Davies (1961: 282), an American going by the name of Campbell lived on Rurutu between around 1806 and 1814, but gave no information as to the nature of his stay. Apart from these two long-term residencies, no Europeans resided on the island for a great length of time, with only the LMS trained teachers from the Society Islands.

*Missionaries on the Austral Islands*

Two brigs (*Queen Charlotte* and *Governor Macquarie*) and a cutter (*Snapper*) were employed directly by the LMS to transport missionaries and their supplies to the Austral Islands from the established missions in the Society Islands. Rev. William Henry, one of the heads of the Society in Tahiti, who himself provided one of the earliest first contact accounts of Rurutu whilst

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5The *Chatham* passed by Ra'ivavae during the same expedition on 2nd December 1791.

6Identifying these ships logs would be profitable for assessing the relevant introductions. The *Snapper* was brought by the Tahitian chief Taati (Ellis, 1831: 372; Davies, 1961) while the *Governor Macquarie* was brought by Pomare II (Ellis, 1831: 377)
travelling from Sydney en route to Tahiti in 1800, employed his son Samuel Henry as Captain on these two ships. Samuel Henry is thought to have been the first European to encounter Rimatara in 1821 on the Queen Charlotte (see Table 5.7).

After the HMS Discovery encounter with Rapa in 1791 it was not until 1817, 27 years later, that the Queen Charlotte then under John Powell allowed further exchange between Islanders and Europeans. Powell was forced to anchor off the coast of Rapa due to a lack of wind and seek additional supplies. Rev. William Ellis of the LMS was on board the ship and became the first missionary to make contact with any of the Austral Islands. Ellis's (1831: 371-377) description of the island and its inhabitants provides:

'...we saw several canoes put off from the land, and not less than thirty were afterwards seen paddling round our vessel. There were neither females nor children in any of the canoes. ...Not withstanding all our endeavours to induce them to approach the ship, they continued for a long time at some distance, viewing us with apparent surprise and suspicion. At length, one of the canoes, containing two men and a boy ventured alongside... The principal person [chief] in the canoe appearing willing to come on board, I pointed to the rope he was grasping, and put out my hand to assist him up the ship's side. He involuntarily laid hold of it, but could scarcely have felt my hand grasping his, when he instantly drew it back, and, raising it to his nostrils, smelt at it most significantly, as if to ascertain with what kind of a being he had come in contact.'

The first mission station was established on Ra’ivavae in 1819 by a self-anointed Tahitian missionary named Para, who has often been described as a 'political agent' of King Pomare II of Tahiti (e.g. Ellis, 1831: 377). Para joined an expedition led by Pomare in his attempt to gain political alliances in the region during a period of negotiated colonial rivalries between the French and British. It was not until 1822 when the first Christian mission stations under the auspices of the LMS were established on Tubuai, Rurutu and Rimatara (see Table 5.2). In contrast to most of the remote Pacific islands, the Austral Island stations, as in the Marquesas and Tuamotu Archipelago were not run by resident European missionaries, but were instead pioneered by 'native teachers' (Gunson, 1978). This experiment with 'native teachers' formed integral part of the evangelical mission in the region (Lovett, 1899; Davies, 1966). The expense for the Society in operating a station fit for a European missionary could not be justified unlike a trained Tahitian, for example who could quickly interpret and translate some basic ideas of Christianity, consume the same food and occupy inexpensive non-European housing. This represented an experiment for the Society, enabling cheaper and more rapid expansion and ultimately more conversions.

The advent of mission stations throughout the Austral Islands brought an immediate series of social and technological changes including the increased introduction of goods and technology. The most common assumption is that missionaries urged the islanders to move from their
dispersed inland and hilltop habitations in order to establish new communities by the shore adjacent to the newly-built churches and mission stations. The construction of piers adjacent to these coastal settlements facilitated trade and improved the delivery of supplies. Missionary presence with their inherent focus on conversion and education through translation aided communication between islanders and the growing number of traders. Few records are available that identify the specific items introduced by missionaries to the Austral Islands.

Population decline following first contact on the Austral Islands

Vancouver (1803: 214-217) estimated the population of Rapa at first contact in 1791 to be approximately 1500, around three times greater than the most recent census records. No firm estimates of population size were provided for the remaining inhabited Austral Islands, but early missionary estimates suggest similar pre-contact population sizes. Ellis (1831) suggested that Rurutu had the greatest pre-contact population size of around 3000. With the first Christian mission stations in the Australs established between 1819 and 1822 under the auspices of the LMS, precise estimates of population sizes from early congregation census indicate a marked decline in population of at least one half since first European contact (see Table 5.2). The earliest congregation census undertaken on Rapa in 1822 suggests that its population had dropped to more than one third of its pre-contact size (Davies, 1827). Between first contact and the establishment of the first mission stations, estimates of population decline for each of the Austral Islands between (see Table 5.2) show that, like Easter Island, the island populations all declined by at least one half, with Rurutu the worst affected.

Although population estimates are generally imprecise, such demographic changes appear to be the norm for many Pacific islands (Moorehead, 1966; MacArthur, 1968; Maude, 1982), and may have been due to a number of factors. With the increased trade of guns with the beachcombing trade, endemic warfare may have increased, as has been inferred for many island societies (e.g. Easter Island). Events of “black-birding” took place on the Australs (see below) and with the advent of the beachcombing trade islanders may have taken the opportunity to migrate to other islands on board trader’s ships. By far the most likely cause of population decline appears to be introduced disease from earlier European contacts.

After sighting Ra'ivavae on January 28th 1775, the Spaniard Tomás Gayangos and the Aguila returned to Tahiti apparently introducing the first case of gastric influenza to the island (Moorehead, 1968: 55). It is possible that some of the crew of the Aguila also introduced this disease whilst at Ra’ivavae given that some contact was made between islanders coming on board the ship whilst anchored overnight. Rev. Pritchard and Rev. Simpson noted a ‘malignant fever’ that had passed through Ra’ivavae originally brought from Tubuai (Ellis, 1831: 378).
recorded case of tuberculosis on the Austral Islands was in 1831 by D.R. Darling (1835) who found that the Tahitian missionary, Nene, ‘was very ill of a consumption’ and understood that his wife had died of the disease about 18 months previous. Disease seems the most likely explanation for the dramatic population decline seen on Rimatara between 1812 and 1822 dropping from around 1200 to around 300 in just eleven years.

<table>
<thead>
<tr>
<th>Island</th>
<th>Missionaries</th>
<th>Date of mission arrival</th>
<th>Congregation size</th>
<th>Date of first contact</th>
<th>Population at first contact</th>
<th>Years after first European contact</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tubuai</td>
<td>LMS missionary Rev. Henry Nott, Hapunia and Saruana from Tahiti</td>
<td>1822 Oct</td>
<td>600-800</td>
<td>1777</td>
<td>~2000</td>
<td>45</td>
<td>Davies (1827: 331), Ellis (1831)</td>
</tr>
<tr>
<td>Rapa</td>
<td>Hota and Nene from Tahiti</td>
<td>1826 Jan</td>
<td>~500</td>
<td>1791</td>
<td>~1500</td>
<td>35</td>
<td>Davies (1961: 284-285), Ellis (1831: 389-390)</td>
</tr>
<tr>
<td>Rimatara</td>
<td>Two missionaries from Ra’iatea, Faarava and Oo (Borabora)</td>
<td>1823</td>
<td>200-300</td>
<td>1812</td>
<td>~1200</td>
<td>11</td>
<td>Davies (1961: 284-285), Ellis (1831: 389-390),</td>
</tr>
</tbody>
</table>

Table 5.2 List of first mission stations established in the Austral Islands, French Polynesia. See Appendix II for primary and secondary sources references.

“Black-birding” on the Austral Islands

As discussed in Chapter 4 ‘black-birding’, the kidnapping of islanders for slave labour began on Easter Island by around 1805 and continued through the remainder of the 19th century. “Black-birding” of Austral Islanders probably began in 1812 with the exploits of Michael Foldger on the brig *Daphne* at Rimatara, Tubuai and Raivavae in 1812. Based out of Port Jackson, Foldger was a notorious “black-birder” and prominent pork and sandalwood trader. Foldger departed with the *Daphne* from Port Jackson on September 26th, 1812 en route to Calcutta via the East Pacific where he hoped to obtain cargo of sandalwood, pearls, *bêche de mer* and other produce for the Bengal marketplace (Maude and Crocombe, 1962).

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Towards the end of 1812, Foldger managed to locate Rimatara (Hendrike, 1813 in Maude and Crocombe, 1962) where it is unclear whether landfall was made. This event represented the first recorded sighting of Rimatara by any European crew. He had a reputation for his harsh treatment of islanders, where on Rimatara, according to Hendrike (ibid), fourteen of the eighteen islanders who visited the ship were apparently driven overboard to their deaths under Foldger’s orders. Rev. John Davies (1961: 273), in referring to Ra’ivavae, states that Foldger ‘ill used the friendly natives in several instances’ suggesting his notoriety was known even amongst Europeans. Foldger ultimately came to his death upon revolt of a group of captive islanders in 1815 (Maude, 1968a: 196).

Given the extent of “Black-birding” recorded on many of the Pacific archipelago throughout the beachcombing period, it is likely that a number of unrecorded “black-birding” episodes took place on the Austral Islands. A number of records exist for ships that passed through the Austral Islands without their activities or intentions recorded. On Rapa, for example, two ships are known to have docked at the island between 1791 and 1835. This does not take into account the likely number of ships that visited the island without record.

**Empirical botanical observations of the Austral Islands**

The richest botanical record of early European accounts, surprisingly, comes from Rapa, the most isolated of the main inhabited Austral Islands. From the initial sighting of Vancouver on the HMS Discovery in 1791 to the establishment of the first mission station on the island in 1826 eight visits are listed in Table 5.1. A further ten visits were recorded between 1826 and 1834 when Jacques Antoine Moerenhout visited the island, the first European to observe all of the Austral Islands. Most of the encounters were brief and rarely exceeded one night stays, and until October 1825, when the cutter Snapper made landfall with two Tahitian missionaries (Hota and Nene), all observations were made within one league (<3 nautical miles) of the island’s coastline. In addition, most of the accounts were written retrospectively, not in ships logs or in journal form, and were all published a number of years after the encounter.

*Botanical observations of the Austral Islands by Enlightenment naturalists*

The infrequent landfall and the brief encounters that characterise first voyages to the Austral Islands limited European observations to the few available visual cues seen from offshore. The relative lateness of the European discovery of the Austral Islands, post 1769, meant that most explorers were aware of a large component of island floras, especially economic plants and strand taxa. The description of the environment of Rapa by Vancouver and Menzies on the HMS
**Discovery**, taking place within 6 leagues (~30 kms) from the shore highlights the limitations of offshore botanical observation. To Vancouver, Rapa was conspicuous by the lack of *Cocos nucifera* (described as the ‘cocoa-nut’ palm; see Table 5.3). Even with his experience of extensive travel throughout the Pacific, he failed to identify any *Colocasia esculenta* pondfield production systems, perhaps because the views of the inland valleys were obscured by thick shrubby vegetation along the coastline.

The most informative botanical observations both Vancouver and Menzies made concerned the contact with the islanders coming out from the shore on canoes. In the absence of adequate communication during such encounters, items of material culture were observed including clothing, canoes and vegetable produce intended for trade. Vancouver (1798: I 215) found that:

‘... they [the islands] were chiefly clothed with shrubs and dwarf trees. Neither the plantain [*Musa* spp.] nor other spontaneous vegetable productions common to the inhabited tropical islands, presented themselves.’ (Vancouver, 1798: I 215)

Menzies (Shineberg, 1986: 65-66) made some more technical observations of clothing items and canoe construction:

‘The only clothing they wore were a narrow slip of cloth made from the bark of a tree [prob. *Hibiscus tiliaceus* but potentially *Broussonetia papyrifera*] which passed round their waist & between their legs, this cloth appeared to be a very scarce article amongst them as many of them had not sufficient of it to cover their nakedness, it was evident however that they generally wore something for that purpose, as some of them had bunches of leaves of a species of *Dracena* [prob. *Cordyline fruticosa*] suspended to a girdle round their middle for that intention. Their Canoes were small & narrow but neatly formed, rising a little at each end to a sharp point with out riggers fitted to them – similar to the generality of Canoes in this Ocean. They had also double canoes with Sails constructed in the same manner, & though we observd no wood or timber on the Island of a size capable of making their canoes yet they did not seem to be a scarce article among the Natives, for at one time we counted no less than 30 canoes about the Ship & between us & the Shore, eight or nine of them were double ones each of which had upwards of 20 men, & few of the single Canoes had less than five men, many of them had more, so that we estimated...’

Only three or four plant species may be inferred from the descriptions provided in both accounts (see Table 5.3). More general comments were made regarding the status of the island’s vegetation, including the impoverished state of the forests and absence of coconut palms as summarised here by Menzies (*Ibid*: 67-68):

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3 Misprinted as ‘plantation’ in the second edition.
'The valley round the bottom of the Bay is tolerably pleasant when compared with other parts of the Island being scattered over with Bushes among which we could perceive the habitations of the Natives & some little signs of Cultivation, the hills behind & on the South Side of it appeared thinly covered with some verdure & here & there wooded with some scrubby Trees particularly in the hollow places between the hills, but they seemed of no great magnitude. Towards the North end the hills are not so rugged & rocky but ascend with a smooth surface covered with grass & destitute of Trees or bushes of any kind. We observed no Cocoa Nut Trees [Cocos nucifera] anywhere on the Island.' (Shineberg, 1986: 67-68)

Botanical observations of the remaining inhabited Austral Islands made by other Enlightenment naturalists are comparatively poor. Banks (1969: 331) noted the colouring of clothing items on a canoe party encountered whilst at Rurutu, suggesting the use of dyed bark cloth using either Hibiscus tiliaceus or Broussonetia papyrifera, but was only able to make the following botanical observations of the island’s vegetation (see Table 5.6):

‘The Island to all appearance that we saw was more barren than anything we have seen in these seas, the chief produce seeming to be Etóa (the wood of which make their weapons) [Casuarina equisetifolia]; indeed every where along shore where we saw plantations they were coverd by trees of this kind between them and the sea’:

The few comments that James Cook made of Tubuai (see Table 5.5) were concentrated on a canoe party that came out to meet the HMS Resolution on August 4th 1777. Cook (Rickman, 1967: 131) observed that:

‘their heads ornamented with shells, feathers and flowers, and their canoes elegantly carved, and neatly constructed... They appeared timid; but by their waving green boughs, and exhibiting other signs of peace, they gave us reason to believe that they were friendly. They exchanged some fish and coconuts [Cocos nucifera], for nails and Middleburgh cloth [Tongan tapa cloth – Broussonetia papyrifera]. The appearance of the inland was lofty, but small...’

In 1775 Tomás Gayangos and José de Andia y Varela’s led a Spanish expedition to Ra’ivavae on the Aguila and provided useful descriptions of plants allowing for some botanical determinations to be made. Unlike the Cook expeditions, no one on board was trained in Linnean botany, however, the Aguila carried two Tahitians on board who could identify some of trees present using their own vernacular and were able to converse to a limited extent with some of the islanders who visited the ship. None of the crew made landfall, although the Aguila was anchored only ~270 m (½ cable lengths offshore; Andia y Varela in Corney, 1913-1919: 311). Both Gayangos and Andia y Varela provided very brief descriptions of the island and instead
concentrated on the altercations had with some of the islanders on board the ship. In their accounts Gayangos and Andia y Varela’s use of Tahitian plant vernacular, and other descriptions of plants observed on Ra’ivavae, permits the identification several species (see Table 5.4). Apart from these plant identifications, few other observations of the island environment were made in their one-day visit. Gayangos (in Corney, 1913-1919: 179) states:

'It is hilly, but not very rugged, well timbered, and surrounded by a reef within which is a broad lagoon. Its verdure and reddish-coloured soil make it appear very fertile, to the view: euru [Artocarpus altilis], plantains [Musa spp.], and other fruit-bearing trees could be distinguished.'

Andia y Varela’s (in Corney, 1913-1919: 312) description is similar but lists some additional plant names and indicates the extent of palm groves:

'The reigning Chief in the island is called “Teraberobari”; his country is hilly, but wears a fairly fertile aspect. The trees that are called in Otahiti Euru, Etoa, Eihi, Purau, Aiti, Tuhuy, [see Table 5.4 for botanical names] and several others, extend halfway up the slopes of the island; and there are several groves of coco-nut palms along its beaches.'

Morrison’s botanical observations of Tubuai

Not only did the HMS Bounty settlement on Tubuai in 1789 represent the earliest European settlement of the island, but also the first record of animal and plant introductions by Europeans to the Austral Islands. As mentioned, 460 pigs, 50 goats, chickens, dogs, cats and a cow were introduced to the island upon their return from Tahiti. But on their initial arrival at Tubuai, exactly one month after the Captain Bligh mutiny, the mutineers offloaded a cargo of mostly spoiled breadfruit plants intended for the Caribbean. It is unknown whether these plants were ever recovered by any of the islanders for planting in their own breadfruit groves. Morrison (1935: 68) does indicate that breadfruit (Artocarpus altilis) was an already established crop on the island and was used along with Calophyllum inophyllum, called ‘Tummanno’, for canoe construction.

Morrison (ibid: 61) also managed to make several botanical and ethnobotanical observations of island. Of the cultivated plants observed on Tubuai, he found that ‘Almost everything Common to the Society Islands...’ was successfully grown. He suggests that ‘The cloth tree here [on Tubuai] grows to a larger size then in the Society isles, though they do not Cultivate it’ (ibid: 66). He also found that the ripe seeds and flowers of Pandanus tectorius, called the palm apple, were used to make necklaces (ibid: 61).
Later naturalist observations of the botany of the Austral Islands

The final European expedition to the Austral Islands that could be aligned within the Enlightenment period was the Russian led *Vostok* expedition. The ship’s captain, Faddei Von Bellingshausen (1820) led this naval and scientific expedition but focused on the ethnography of the Pacific Islands. No botanist naturalist joined the expedition although a ship’s artist, Pavell Nikolaevich Mikhailov and astronomer, Ivan Mikhailovich Siminov, were employed to make broader observations of the islands. The *Vostok* only visited Rapa on 29th June 1820 for two nights where in an encounter with several canoe parties offshore descriptions of a number of economic plants were made (see Table 5.3) allowing for botanical determinations to be inferred. Their descriptions included a potato like plant (*Colocasia esculenta* or *Ipomoea batatas*), possibly yams (*Dioscorea* spp.), bark sashes (*Hibiscus tiliaceus* or *Broussonetia papyrifera*) and dried pumpkin (*Lagenaria siceraria*).

Hugh Cuming, a privately funded naturalist voyaged to Easter Island, Rapa, Ra’ivavae, Tubuai and Rurutu on his owner-built ship the *Discovery* in 1827. His observations of the environment and cultures of the Austral Islands were minimal as he only ever stayed on each island for a few nights or less, never landing on Ra’ivavae due to rough seas. Cuming was an avid plant collector but concentrated his collecting on shells and other items. Being the first naturalist to make landfall on Rapa (also on Tubuai and Rurutu), Cuming managed to obtain ‘a number of botanical specimens new to me, amongst which several species of Laurels and some beautiful Mosses & Ferns’ (Cuming, n.d.: 122 in Gunson, 1994: 290-291). He later collected ‘several Cryptogamia, of much interest to the Botanist’ from Rurutu (Cuming, n.d.: 106). During his brief stay on the island, Cuming employed the resident Tahitian missionaries to assist him in his collecting, greatly increasing the extent of his collections (Gunson, 1994: 290). He has since been regarded as perhaps the greatest of the collecting naturalists of his time, although he was criticised for providing inexact provenances for his specimens. Much of his Pacific herbarium collection was sold in Britain to private collectors, but replicates are held by a number of European herbaria including the Royal Botanic Gardens, Kew (Gunson, 1994).

Jacques Antoine Moerenhout (1837), a wealthy Belgian pearl-trader, wrote extensively on Easter and all of the Austral Islands during his visits between 1828 and 1834 (see also de Deckker, 1997). He provided few details of his own exploits as a pearl trader and burgeoning politician based in Tahiti, perhaps given the precariousness of his trade. Later becoming the U.S. Consulate General to the Oceanic Islands from 1835, he states that his visits were primarily

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8Some contradictory accounts suggest Cuming was travelling throughout the Pacific in 1832.
conducted in order to ascertain their geography, culture and ‘general considerations of their commerce’ (Moerenhout, 1983: 12).

Moerenhout’s interests were primarily in the colonial and resource potential of the islands. But with this interest came an understanding of the agricultural systems and economic plants of the islands. From his overnight stay on Rapa in February 1834, Moerenhout (1983: 64) suggests that:

‘The vegetation of Rapa is much less rich than in most of the other islands. You scarcely see any large trees there. The largest is the tiairi (aleurites triloba) [Aleurites moluccana], which the natives use the trunk of in building of their dugouts and the nut as a form of light, as in all of the islands. There is also sandalwood there.’

Contrary to this description of Rapa, modern botanical surveys of the island suggest that the vegetation of Rapa is in fact the richest and most diverse of the Austral Islands (e.g. Meyer 2002a; 2002b). Moerenhout’s focus on agricultural productivity suggests his description may only address the lack of arboricultural species including fruit, nut and canoe building trees.

Moerenhout’s knowledge of the flora was limited to his experience of the Tahitian flora and the plant vernacular recognised for the main economic species. He was aware of the botanical names for some species as his following description of Colocasia cultivation on Ra’ivavae reveals:

‘Products of Laivavae [Ra’ivavae] differ already considerably from those of the tropics. There is almost no breadfruit and, as at Rapa, one finds only fish, taro (caladium esculentum) [Colocasia esculenta] and ti (dracaenae species) [Cordyline fruticosa]. Taro is cultivated on a kind of isthmus which separates a small part of the island from the principal part. Since this isthmus is very low, it has to be protected by dikes against the force of the sea, which in very bad weather had often broken these barriers, and the inhabitants of Laivavae hold in their memory frightful famines caused by these floods.’ (Moerenhout, 1983: 66)

Moerenhout spent fourteen days on Tubuai, where like Morrison, he found despite the island being ‘situated ... so exactly at the end of the tropics’, most of the products of Tahiti were grown there:

‘The road along the shore is pleasant and picturesque, covered with aito (casuarina equisetifolia), with tomana (calophyllum inophyllum), with miro (thespesia populnea), with bourrau (hibiscus tiliaceus), all magnificent trees, the first of which is often up to a hundred feet high. You walk there in the shade; the air is generally fresh and always scented with pandanus flowers [Pandanus tectorius], which abound in this place...’
Moerenhout (1983) also noted the successful cultivation of cabbages and onions on the island as he also found on Rapa. He did not indicate how long he spent on both Rurutu (Rouroutu) and Rimatara, but the brevity of his description of these islands suggests that he may have only stayed for a very short time.

<table>
<thead>
<tr>
<th>Year(s)</th>
<th>Foreigner accounts</th>
<th>Duration of encounter and landfall</th>
<th>Exotic animal or plant introductions</th>
<th>Records of indigenous plants or pre-European plant introductions</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1791 22nd Dec</td>
<td>George Vancouver &amp; Archibald Menzies on the HMS Discovery</td>
<td>1 night No landfall</td>
<td>- Cordyline fruticosa or Pandanus tectorius (dracena);</td>
<td>- Hibiscus tiliaeae or Broussonetia papyrifera! (bark cloth);</td>
<td>Vancouver (1803: 216-217), Shineberg (1986:59-69)</td>
</tr>
<tr>
<td>1815 20th July</td>
<td>John Powell and the brig Endeavour of Port Jackson</td>
<td>1 night No landfall</td>
<td>?</td>
<td>None</td>
<td>Richards (2004: 4); Barden (1999: 23); Ellis (1831: 371)</td>
</tr>
<tr>
<td>1817 26th Jan</td>
<td>Rev. William Ellis on the brig Queen Charlotte under John Powell</td>
<td>1 night No landfall</td>
<td>- Cordyline fruticosa (i)</td>
<td>- Sanaulum insularum (sandalwood)</td>
<td>Ellis (1831: 364-367)</td>
</tr>
<tr>
<td>1825 July</td>
<td>Shout on the cutter Snapper</td>
<td>1 night? No landfall</td>
<td>None</td>
<td>None</td>
<td>Pritchard (1929), Branagan (1996: 99)</td>
</tr>
<tr>
<td>1825 Oct</td>
<td>Hota and Nene on the cutter Snapper probably under Thomas Ebrill or Shout</td>
<td>1 night first landfall</td>
<td>- Colocasia esculenta (taro) - a few tons of Sanaulum insularum (sandalwood) procured</td>
<td>- Colocasia esculenta (taro)</td>
<td>Davies (1827: 331), Hanson (1970: 27-31); Ellis (1831: 373)</td>
</tr>
<tr>
<td>1826 Jan</td>
<td>Rev. John Davies on the brig Governor Macquarie under Samuel Henry accompanied by the Tahitian missionaries Hota and Nene and their wives and two other men, Mahana and Paaro. -Thomas Ebrill on the Minerva (owned by Pomare III) and Elley on the Active (owned by the LMS)</td>
<td>1 week landfall missionaries resident</td>
<td>- Carica papaya (papaya)</td>
<td>- twenty tons of Sanaulum insularum (sandalwood) procured</td>
<td>Davies (1825-1826; 1827: 331; 1961: 280); Branagan (1996: 71-72)</td>
</tr>
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<tbody>
<tr>
<td>1826 Jan and 8th April</td>
<td>Thomas Ebrill on the Minerva (owned by Pomare III) and Elley on the Active (owned by the LMS) a return trip; also the Snapper owned by Tusi</td>
<td>1 day landfall</td>
<td>?</td>
<td>-probably harvested Santalum insularum (sandalwood)</td>
<td>Braungan (1996: 71-72), Richards (2004: 5)</td>
</tr>
<tr>
<td>1826 25th June</td>
<td>Hamish Paulding Travelling on the schooner Dolphin on route to Chile from 'Teoufousi' (Tubuai) in pursuit of the mutineers of the Globe. A party of English beachcombers (one called Young) were present on the island apparently sent on the Active by the Richard Charlton, the English Consul based at Honolulu to obtain bêche de mer and sandalwood</td>
<td>2 nights landfall</td>
<td>None</td>
<td>-Colocasia esculenta (taro) -Santalum insularum (sandalwood, Eauh) -Artocarpus altilis (breadfruit) -Cordyline fruticosa or Piperaceae spp. (ti, 'they also have the ti root of which the Tahitians formerly made an intoxicating drink called ava' p. 72)</td>
<td>Paulding (1970: 251-255), Richards (2004: 5)</td>
</tr>
<tr>
<td>1826</td>
<td>Benjamin Saies</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>Saies (1826)</td>
</tr>
<tr>
<td>1829 12th April</td>
<td>LMS missionaries Rev. Pritchard and Rev. Simpson probably on the Snapper under Samuel Henry</td>
<td>?</td>
<td>Introstations listed as from Tahiti: fowl, pigs, kumara, pumpkins, melons, papau (Carica papaya), cabbages, onions, pineapples, potatoes (?) -Cocos nucifera ('did not appear to thrive') -Artocarpus altilis (breadfruit) -Apium sp. ? ('an abundance of wild celery') -Syzygium malaccense (Ahia) -Colocasia esculenta (taro) -Musa spp. (mountain plantain-possibly introduced)</td>
<td>-Cocos nucifera 'One coconut palm was reported as present from a drift and was not recognized by the local natives.' (Stokes ms Grp 2 Box 7.1)</td>
<td>Pritchard and Simpson (1830 in Stokes ms)</td>
</tr>
<tr>
<td>1831</td>
<td>LMS missionary Rev. Darling on the Rakotonga</td>
<td>?</td>
<td>landfall</td>
<td>?</td>
<td>Darling (1835), Davis (1861: 279-282)</td>
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</table>
| 1832 13th May or 1827 13th May | Hugh Cuming on his own schooner the *Discoverer* | 4 nights landfall | ? | - *Cordyline fruticosa* (Te Plant)  
- *Hibiscus tiliaceus* or *Broussonetia papyrifera*? ("made of a large bush with a rind taken off...")  
- *Colocasia esculenta* (taro and tara)  
- *Schoenoplectus* sp.? (rushes)  
- *Saccharum officinarum* (sugar cane)  
- *Cassyshe* spp., *Barringtonia* spp. ("several species of laurels") (Cuming, n.d.)  
- 'Mosses & Ferns' (Cuming, n.d.) | Richards (2004: 6-8),  
St John (1940)  
Cuming (n.d.: 122),  
Gunson (1994: 290-291),  
Fischer (1991) |
| 1834 Feb | Jacques Antoine Moerenhout on the *Volador*, a pearl trader | 1 night | -pigs,  
-chickens  
-*Brassica* sp. (cabbage)  
-*Allium* sp. (onion) | - *Santalum* sp. (sandalwood)  
- *Aleurites moluccana* (tintir)  
- *Cordyline fruticosa* (tl)  

**Table 5.3** Early European accounts of Rapa from 1791 to 1834 with first landfall recorded in 1825 and the first mission station established in 1826. Listed are the central characters involved in the visit and the vessel(s) they arrived on; whether landfall was made and the duration of their visit; the exotic animals or plants introduced to the island from the visiting vessel and the existing economic (and other) plants observed on the island. ?= information yet to be obtained or clarified. See Appendix II for primary and secondary sources references.
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<tbody>
<tr>
<td>1775 28th Jun</td>
<td>Tomas Gayangos and Jose de Andias y Vara on the Aguila with the Jupiter</td>
<td>1 night No landfall</td>
<td>None</td>
<td>- Artocarpus altiss (breadfruit, Eru)</td>
<td>Gayangos (1776: 126), Corney (1913-1919: 179, 312)</td>
</tr>
<tr>
<td>1791 2nd Dec</td>
<td>William Broughton on the brig HMS Chatham</td>
<td>No landfall</td>
<td>None</td>
<td>None</td>
<td>Vancouver (1803: 245)</td>
</tr>
<tr>
<td>1812</td>
<td>Michael Foldger on the brig Daphne probably with the Tryal, a blackbirder and sandalwood trader</td>
<td>? landfall</td>
<td>-pig?</td>
<td>- 1½ tons of Santalum insularum (sandalwood) procured</td>
<td>Minde (1906a: 196), Davies (1961: 273)</td>
</tr>
<tr>
<td>1819 5th Oct</td>
<td>Lewis of the whaling and sandalwood trade ship the Arab with Ponnare II. Para a 'political agent' and missionary was left on the island</td>
<td>? landfall</td>
<td>-pig (brought out to the ship)</td>
<td>- Santalum insularum (Sandal wood) - Musa spp. (banana) - Colocasia esculenta ('taro-roots and taro greens') (Ponnare II in Gimson, 1966: 202) - Artocarpus altiss</td>
<td>Massall (1969), Ellis (1831: 377), Gunson (1966), Edwards (2003: 18)</td>
</tr>
<tr>
<td>1821 Feb</td>
<td>Samuel Henry on the brig Governor Macquarie (a ship owned by Ponnare II or Eager &amp; Co.)</td>
<td>? landfall</td>
<td>?</td>
<td>?</td>
<td>Ellis (1831: 377), Maule (1966a: 227-231)</td>
</tr>
<tr>
<td>1823-1824</td>
<td>LMS missionary depedition on the Queen Charlotte under Samuel Henry</td>
<td>1 month? landfall</td>
<td>?</td>
<td>- Colocasia esculenta (taro)</td>
<td>Davies (1961: 275), Threlkeld and Williams (1823)</td>
</tr>
<tr>
<td>1825</td>
<td>LMS missionary Rev. Daniel Tyerman sent as LMS deputation probably on the Queen Charlotte under Samuel Henry; surgeon and naturalist George Bennett was on board</td>
<td>? landfall</td>
<td>?</td>
<td>?</td>
<td>Ellis (1831: 378), Montgomery (1831), Tyerman and Bennett (1832)</td>
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<tbody>
<tr>
<td>1832 5th or 9th May or 1827</td>
<td>Hugh Cuming on his own schooner the Discoverer Sea too rough to land</td>
<td>? No landfall</td>
<td>None</td>
<td>None</td>
<td>St John (1940), Fischer (1991)</td>
</tr>
<tr>
<td>1830 &amp; Mar 1834</td>
<td>Jacques Antoine; Moorishout on the Volador; a pearl trader</td>
<td>? None</td>
<td>-Colocasia esculenta (taro)</td>
<td>-Artocarpus altilis (breadfruit, almost none)</td>
<td>Moerenhout (1837: 66-67)</td>
</tr>
</tbody>
</table>

Table 5.4 Early European accounts of Ra’ivavae from 1775 to 1834 with first landfall recorded in 1812 and the first mission station established in 1822. Listed are the central characters involved in the visit and the vessel(s) they arrived on; whether landfall was made and the duration of their visit; the exotic animals or plants introduced to the island from the visiting vessel and the existing economic (and other) plants observed on the island. ? = information yet to be obtained or clarified. See Appendix II for primary and secondary sources references.
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<th>Records of indigenous plants or pre-European plant introductions</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1789 25th to the 26th May, return from Tahiti 23rd June stay until the 17th September</td>
<td>James Morrison, Fletcher Christian on the Bounty</td>
<td>~3 months, No landfall</td>
<td>-460 pigs (four lost during voyage), -50 goats (1 lost during voyage), -chickens, dogs, cats, -1 cow, -rats, -Artocarpus altilis breadfruit</td>
<td>-Pandanus tectorius (swarm), -Cassava esquirofolia (shining blackwood, toa), -Cocos nucifera (Cocoa-Nuts), -Musa spp. (plantain), -Cocos nucifera (Coco Nuts), -Amansia papaya (papaya), -Pandanus altissimus (breadfruit, Mahe, intoxicating pepper), -Curcuma longa (turmeric), -Bouassonetta papyrifera (Chinese paper mulberry, cloth plant), -Calophyllum inophyllum (hamunnoo), -prynose, -Cordyline fruticosa (tree, sweet root), -Ficus prolifera (roa), -grass, ferns, reeds, -Miscanthus floridulus (bamboo)?</td>
<td>Morrison (1935: 48-73), Davies (1961: 276)</td>
</tr>
<tr>
<td>1789 9th August</td>
<td>John Cox and George Mortimer on the brig Mercury</td>
<td>No landfall, anchored at night</td>
<td>-</td>
<td>-</td>
<td>Mortimer (1791: 22), Maud (1958: 117-118)</td>
</tr>
<tr>
<td>1797 22nd Feb</td>
<td>James Wilson on the Duff</td>
<td>No landfall</td>
<td>-</td>
<td>-</td>
<td>Wilson (1799: 51-52)</td>
</tr>
<tr>
<td>1812</td>
<td>Michael Foldger on the brig Daphne and probably with the Trial – sandalwood trader</td>
<td>? landfall</td>
<td>-</td>
<td>-</td>
<td>Davies (1961: 277), Maud (1968a: 196)</td>
</tr>
<tr>
<td>1817</td>
<td>Rev. William Ellis on the brig Queen Charlotte under John Powell</td>
<td>? landfall</td>
<td>-pigs, -chickens (fowl)</td>
<td>-Artocarpus altissimus (breadfruit), -Musa spp. (mountain plantain), -Pandanus spp. ('necklaces of nuts of pandanus'), -Coecosia esculenta (taro)</td>
<td>Ellis (1831: 385)</td>
</tr>
<tr>
<td>1819 2nd Oct</td>
<td>Captain Lewis of the American whaling ship Arab with Pomare II</td>
<td>No landfall</td>
<td>None</td>
<td>-</td>
<td>Massall (1969)</td>
</tr>
<tr>
<td>1822 June</td>
<td>LMS missionary Rev. Henry Nott with missionaries Haapuna and Samuela from Tahiti on the Queen Charlotte under Samuel Henry</td>
<td>? landfall, missionaires resident</td>
<td>None</td>
<td>-</td>
<td>Ellis (1831: 386-388)</td>
</tr>
<tr>
<td>1826 10th Feb</td>
<td>LMS missionary Rev. John Davies probably on the Minerva under Thomas Ebrill</td>
<td>? landfall</td>
<td>None</td>
<td>-</td>
<td>Davies (1961: 276)</td>
</tr>
<tr>
<td>Year(s)</td>
<td>Foreigner accounts</td>
<td>Duration of encounter and landfall</td>
<td>Exotic animal or plant introductions</td>
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</tr>
<tr>
<td>1826 25th April</td>
<td>Samuel Stutchbury on the pearl trading ships Sir George Osbourne and Rotia</td>
<td>1 night*</td>
<td>None</td>
<td>-Artocarpus altilis (breadfruit) -Musa spp. (plantain) -Colocasia esculenta (taro) -Tacca leontopetaloides (arrowroot, pig)</td>
<td>Brunaigan (1996: 72)</td>
</tr>
<tr>
<td>1826 13th June</td>
<td>Hiram Paulding on the schooner Dolphin on route to Chile from 'Toutouai' (Tubuai) in pursuit of the матерн of the Globe.</td>
<td>2 nights landfall</td>
<td>-pigs (hogs) for Port Jackson trade -chicken (fowl) -Carica papaya? (papayas) -Citrus spp. (citron and lemon)</td>
<td>-Cocos nucifera (Coconuts) -Artocarpus altilis (breadfruit) -Tocca leontopetaloides (arrowroot) -Colocasia esculenta (taro) -Musa spp. (plantain) -Hibiscus tiliaceus ('there is a tree, the bark of which, makes excellent cordage' p. 250)</td>
<td>Paulding (1970: 251-255)</td>
</tr>
<tr>
<td>1832 2nd May or 1827 3rd May</td>
<td>Hugh Cuming on his own schooner the Discoverer</td>
<td>2 nights landfall</td>
<td>?</td>
<td>-Casuarina equisetifolia (iron wood)</td>
<td>St.John (1940), Cuming (n.d.), Fischer (1981)</td>
</tr>
<tr>
<td>1830 and 1834</td>
<td>Jacques Antoine Moerenhout on the Venus(?), a pearl trader</td>
<td>14 days in 1830</td>
<td>-pigs -chickens -Brassica sp. (cabbage) -Allium sp. (onion)</td>
<td>-Calophyllum inophyllum (tonana) -Theopsea populnea (miro) -Casuarina equisetifolia (tano) -Hibiscus tiliaceus (bouma) -Pandanus tectorius (pandanus) -Ipomoea batatas (sweet potato) -Colocasia esculenta (taro)</td>
<td>Moerenhout (1837: 67-71)</td>
</tr>
</tbody>
</table>

Table 5.5 Early European accounts of Tubuai from 1775 to 1834 with first landfall recorded in 1789 with the HMS Bounty mutiny and the first LMS mission station established in 1822. Listed are the central characters involved in the visit and the vessel(s) they arrived on; whether landfall was made and the duration of their visit; the exotic animals or plants introduced to the island from the visiting vessel and the existing economic (and other) plants observed on the island. *= information yet to be obtained or clarified. See Appendix II for primary and secondary sources references.
<table>
<thead>
<tr>
<th>Year(s)</th>
<th>Foreigner accounts</th>
<th>Duration of encounter and landfall</th>
<th>Exotic animal or plant introductions</th>
<th>Records of indigenous plants or pre-European plant introductions</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1769 Aug</td>
<td>James Cook, Joseph Banks and Daniel Solander on the HMS Endeavour</td>
<td>1 night</td>
<td>None</td>
<td>-Casuarina (Elída) -Broussonetia papyrifera or Hibiscus tiliaceus 'materials... generally died of a very bright and deep yellow' (Banks, 1969: 331)</td>
<td>Cook (1955: 156), Banks (1969: 329-332)</td>
</tr>
<tr>
<td>1800 Jan</td>
<td>LMS Missionary Rev. William Henry on the Eliza under Captain Swain</td>
<td>No landfall</td>
<td>None</td>
<td>None</td>
<td>Davies (1961: 282)</td>
</tr>
<tr>
<td>1814</td>
<td>An American possibly by the name of Campbell continued to live on Rurutu until 1822</td>
<td>Resident for eight years</td>
<td>?</td>
<td>?</td>
<td>Ellis and Teyman (1822), Davies (1961: 282)</td>
</tr>
<tr>
<td>1821</td>
<td>Azura voyage from Rurutu to Raiatea</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Davies (1961: 282-283)</td>
</tr>
<tr>
<td>1822 Oct</td>
<td>LMS missionary Rev. William Ellis and an LMS deputation Queen Charlotte under Samuel Henry</td>
<td>2 days with -pigs (hogs) -chickens (fowl)</td>
<td>-Cordyline fruticosa (dracana) -Casuarina equisetifolia ('their spears, which were made of the hard dark wood' (Ellis) -Barringtonia 'the trunk of the latter frequently exceeding four feet in diameter' (Ellis)</td>
<td>Ellis and Teyman (1822), Ellis (1831: 395, 401, 403), Davies (1961: 283), Threlkeld and Williams (1823)</td>
<td></td>
</tr>
<tr>
<td>1824 Nov</td>
<td>LMS missionary Rev. William Ellis</td>
<td>?</td>
<td>?</td>
<td>None</td>
<td>Ellis (1831: 401)</td>
</tr>
</tbody>
</table>

Cont.
<table>
<thead>
<tr>
<th>Year(s)</th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Ipomoea batatas (sweet potato, umera)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Amana spp. (bananas, melon)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Saccharum officinarum (sugar cane, to)</td>
<td></td>
</tr>
<tr>
<td>1832 1st May or 1828 1st May</td>
<td>Hugh Cunning on his own schooner the Discoverer</td>
<td>1 day or 1 week? landfall</td>
<td>?</td>
<td>?</td>
<td>St John (1940), Fischer (1991)</td>
</tr>
<tr>
<td>-1830</td>
<td>Jacques Antoine Moerenhout on the Volador, a pearl trader</td>
<td>?</td>
<td>-pigs</td>
<td>-Dioscorea spp. (yams)</td>
<td>Moerenhout (1837: 71)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Ipomoea batatas or Solanum tuberosum (potatoes)</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.6 Early European accounts of Rurutu from 1769 to 1830 with first landfall taking place in 1814 and the first mission station established in 1822. Listed are the central characters involved in the visit and the vessel(s) they arrived on; whether landfall was made and the duration of their visit; the exotic animals or plants introduced to the island from the visiting vessel and the existing economic (and other) plants observed on the island. ?= information yet to be obtained or clarified. See Appendix II for primary and secondary sources references.
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<tr>
<th>Year(s)</th>
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<th>Duration of encounter and landfall</th>
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<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1812</td>
<td>Michael Foldge r on the brig Daphne sandalwood trader</td>
<td>No landfall</td>
<td>?</td>
<td>?</td>
<td>Maude and Crocombe (1962: 35)</td>
</tr>
<tr>
<td>1821</td>
<td>Samuel Henry on the Queen Charlotte</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>Cailet (1889)</td>
</tr>
<tr>
<td>1830 and/or 1834</td>
<td>Jacques Antoine Moerenhout on the Votador, a pearl trader</td>
<td>?</td>
<td>None</td>
<td>None</td>
<td>Moerenhout (1837: 71-72)</td>
</tr>
</tbody>
</table>

Table 5.7 Early European accounts of Rimatara from 1811 or 1821 to 1830 with first recorded landfall taking place in 1814 and the first mission station established between 1821 and 1822. Listed are the central characters involved in the visit and the vessel(s) they arrived on; whether landfall was made and the duration of their visit; the exotic animals or plants introduced to the island from the visiting vessel and the existing economic (and other) plants observed on the island. ? = information yet to be obtained or clarified. See Appendix II for primary and secondary sources references.
**Botanical observations and plant introductions of missionaries on the Austral Islands**

Of all the missionaries who visited the Austral islands Rev. William Ellis (1831) of the LMS made the most incisive comments on the vegetation and plant use of the islanders in his book *Polynesian Researchers*. During Ellis’s (1831: 370-372) brief encounter with a canoe party whilst anchoring at Rapa on board the *Queen Charlotte* on the 26th January 1817 he noted that:

> ‘The higher parts of the mountains seemed barren, but the lower hills, with many of the valleys, and the shores, were covered with verdure, and enriched with trees and bushes... The men were not tattooed [tattooed], and wore only a girdle of yellow *ti* (*Cordyline fruticosa*) leaves round their waists...’

In the same year the *Queen Charlotte* anchored at Tubuai where Ellis (1831: 382) and others of the crew made landfall for at least one day. Ellis explains:

> ‘the people were friendly, and readily bartered fowls, taro (*Colocasia esculenta*), and mountain plantains (*Musa* spp.) for articles of cutlery and fish-hooks. Their gardens were unfenced, and the few pigs they had were kept in holes or wide pits four or five feet deep, and fed with bread-fruit (*Artocarpus altilis*) and other vegetables.’

Rev. Pritchard and Rev. Simpson (1830 in Stokes ms), also of the LMS, visited Rapa on the 12th April 1829 on the Societies own brig, the *Snapper* under Samuel Henry. They listed several plant species already in cultivation on the island (see Table 5.3) and suggested that they were all introductions from Tahiti. It is probable that all of these plants were introduced by the Tahitian missionaries, Hota and Nene accompanied by Rev. John Davies in January 1826, although Davies makes no reference to this in any of his publications (e.g. Davies 1827; 1961). Davies (1827) did note that *Carica papaya* was in cultivation on the island, but there is no previous European contact account that registered this introduction. Pritchard and Simpson also visited Ru’ivavae in the same month, but provide few references to the vegetation of the island.

**Sandalwood harvesting on the Austral Islands**

By 1811 around 300 or more whaling ships were operating in the East Pacific (Maude and Crocombe, 1981) within the vicinity of the Austral Islands. Many ships were probably engaged in “black-birding” and beachcombing activities including the indigenous varieties of sandalwood (e.g. *Santalum insulare* var. *margaritae* from Rapa) and *béche de mer* harvesting for the thriving Canton and Calcutta markets (Shineberg, 1967; Maude and Crocombe, 1981). No records are
available which provide any indication of the amount of bêche de mer harvested from the Austral Islands or the extent of smoking house construction. The first record from the Austral Islands of sandalwood exploitation comes from Ra’ivavae in 1812 where Michael Foldger commanding the two Port Jackson (Sydney) based brigs, the Daphne and the Trial, (see Table 5.4) procured around of 1½ tons of sandalwood (Maude, 1968a) and probably “black-birded” many of the islanders in the process.

After Foldger’s demise in 1815, John Powell took on the captaincy of the Daphne and the Endeavour, a Port Jackson-based pork-trading brig that first sailed to Tahiti in 1811 (Richards, 2005: 115). Like Foldger, travelled extensively throughout the Pacific in search of island’s to exploit. On the Endeavour in 1815, Powell stopped at Rapa but reported nothing of the island (Richards, 2004: 4). In 1817 he was employed by the LMS to transport Rev. William Ellis from Port Jackson to the Society Islands on the brig Queen Charlotte. En route they stopped at Rapa on the 26th January after being becalmed passing through the Austral Islands. In an offshore encounter with one of the islanders who came on board the brig Ellis (1831: 364-367) recalled that:

“Our captain [John Powell] had been desirous to have the chief on board that he might ascertain from him whether the island produced sandal-wood, as he was bound to the Marquesas in search of this article. A piece was therefore procured and shewn to him, with the qualities of which he appeared familiar; for, after smelling it, he called it by some name [possibly a‘i; see Stokes, 1959:331], and pointed to the shore.”

The crew of the Queen Charlotte did not make landfall hence no sandalwood was procured.

The first recorded landfall of any Europeans on Rapa was by the crew of the Snapper under Thomas Ebril9 in October 1825. Davies (1827: 331) recorded in an extract from the journal of his week visit to the island on the Governor Macquarie under Samuel Henry in January 1826 that ‘a few tons of sandalwood were procured’ in the previous year. During that same month two other ships arrived at the island, the Pomare III owned Minerva captained by Ebril and the LMS owned Active under Elley. Davies (1961; Branagan, 1996: 71-72) recorded a sandalwood harvest of twenty tons.

On the 22nd April 1826 The Pacific Pearl Company’s two ships, the George Osborne and Rolla under Samuel Stutchbury arrived on Rapa. The Tahitian missionary came out to meet the party and informed Stutchbury (Branagan, 1996: 71-72) of the presence of sandalwood on the island:

---

9There is some confusion over whether the Snapper was then under Ebril (Abrill) or Captain Shout who sighted the island on the Snapper in July of the same year (Branagan, 1996).
which he described as being very large and fine, was the only produce of the Island worthy of notice, but three vessels had lately been there and obtained the whole that the island produced.'

Stutchbury noted that the *Snapper*, then belonging to the Tahitian Tati, and the *Minerva* had only 14 days earlier departed for Tahiti. Stutchbury (ibid) concluded that 'there is little doubt but it would answer well to bring down a party, and land them for a time, to cut Sandal Wood, (the native name *Eahi*).'

Both pearl trading vessels returned to Rapa on the 11th June where they met an employee of the English Consul, Young, who informed Stutchbury that he had been left on the island six months earlier in charge of a party of Tuamotu men to cut sandalwood. Presumably, Stutchbury’s intention was to collect sandalwood, but no mention of the amount of wood obtained was made.

The United States Navy schooner, the *Dolphin* under Hiram Paulding was employed to pursue the mutineers of the *Globe* whaling ship abandoned in the previous year. While spending two nights on Tubuai in June 1826, he met an American by the name of Strong who had spent some time on the island but whose activities he did not ascertain. Paulding also made some useful observations of the cultivation of a number of tree and vegetable crops. Later on the 26th of June the *Dolphin* stopped at Rapa in search of yam and taro supplies. Paulding noted the presence of the party of beachcombers apparently sent by the English Consul to obtain sandalwood and *bèche de mer* for trade in Canton. Paulding (1831: 251-255) found that the Englishman, Young was:

‘In charge of a party which had been left there by the English Consul at the Sandwich Islands to collect beach la mer, a valuable article of commerce at Canton. The collection of sandalwood was also to be an object of their attention; but they told us that both were scarce and difficult to obtain a statement we considered of doubtful veracity.’

*Inferred environmental impacts from the sandalwood trade on the Austral Islands*

From my calculations of tree harvests from Mbuá noted earlier in this chapter, if around 70 kilograms of heartwood may be procured from each sandalwood tree (Jean-Francois Butaud *pers. comm.*), a harvest of ‘a few tons’ may have involved a harvest of ~50 or more trees. The 1826 harvest of twenty tons from Rapa would require in the realm of 400 trees. A sandalwood harvest of this magnitude may have resulted in unprecedented deforestation on Rapa, perhaps of a number of the formerly forested valleys. Given that several ships stopped at the island in that same year, but failed to record the amount of wood harvested, the probability that certain areas of the island were heavily deforested seems high.

One oral history alludes to the summit of Ta’amora peninsula on Ra’ivavae being covered in sandalwood (Stokes in Edwards, 2003:5), indicating that this period of sandalwood harvests
may have decimated some large stands. Local extinctions of *Santalum* spp. and other scented woody trees (e.g. *Myoporum* spp.) have since been recorded on a number of islands in the Pacific (e.g. Juan Fernandez Islands, see Wester, 1991; French Polynesia - Jean-Francois Butaud pers. comm.).

A number of exotic animals including pigs and goats were probably introduced prior to the 1820s possibly as trade items for people or sandalwood (Maude, 1968a). From Ellis’s description of Ra’iavave pigs were introduced there prior to 1819 and may have been used as a trade item by Foldger during his 1812 visit. Some tree and vegetable crops may also have been introduced at this time and required substantially different agricultural land-management practices. As previously mentioned, these crops were most likely dry-field produced sweet potatoes (*Ipomoea batatas*) and yams (*Dioscorea* spp.), replacing wet-field *Colocasia esculenta* as the preferred trade produce. Such land-use changes may have resulted in the abandonment of traditional agricultural systems, but also the increasing environmental degradation resulting from feral goats and pigs.

The increasing traffic of ships, particularly on Rapa during 1826, meant that the number of plant and animal introductions increased accordingly. This is especially true of ship-bound rodents. Whilst on Rapa in April 1826, Stutchbury (Branagan, 1996: 71-72) noted that rats (probably ship rats) ‘appeared innumerable and exceeding bold, scarcely getting out of the way of our feet’. The influence of growing rat populations on the local flora including increased predation of plant seeds and flowers inhibiting regeneration of certain species, eventually permanently altering the vegetation structure of the islands. Evidence for pre-European contact rat seed predation of the Easter Island palm (e.g. Dransfield *et al* 1984) and a range of seed types from New Zealand (Wilmshurst and Higham, 2004) provide some insights into the potential impact of rodents on island ecosystems including the Australs. The ecological influence of rodents on the seed dispersal and plant recruitment of certain tree species on Tonga has been recently assessed by McKonkey *et al* (2003). They suggest that the forest structure has been permanently altered by rat predation through preferential seed predation resulting in the demise of some species (e.g. *Elaeocarpus* sp.), however, in some instances seed caching by rats has assisted tree recruitment (e.g. *Pandanus tectorius*).
Table 5.8 Examples of plants introduced to the Austral Islands based on the list composed by Florence (1993) for French Polynesia for the early colonial period (after Barrau, 1959; 1960 and Florence, 1993).* Known introductions to the Australs cited by Jacques-Antoine Moerenhout. ** Known introductions to the Australs cited by Rev. John Davies in 1826 (Davies, 1825-1827). *** From St. John and Fosberg (1934).

Plant introductions to the Austral Islands during the early European period

During the early 19th century, the Austral Islands rapidly became an extension of the Tahiti colonial experiment in which both Europeans and islanders actively explored new trading opportunities. With the increasing traffic of ships in the region, both intentional and inadvertent plants became common in the Austral Islands. Few of the early European period plant
introductions recorded for Tahiti have been recorded prior to 1921\(^{10}\). Of the list of plant species introduced to Tahiti during the early European period (see Table 5.1) the cultigens, papaya (*Carica papaya*), pineapples (*Ananas canorus*) and potatoes (*Solanum tuberosum*) were introduced to the Austral Islands at a similar time (between 1811 and 1829; see Table 5.8). If the assumption that plants were introduced to Tahiti prior to the Austral Islands is followed, then the dates provided in Table 5.1 can provide a minimum date for an Austral Island introduction.

Onions (*Allium* sp.) and cabbages (*Brassica oleracea*) were introduced by Europeans to most of the Austral Islands between 1830-1834 (Moerenhout, 1837). The historical status of breadfruit (*Artocarpus altilis*) introduction to the Austral islands is uncertain as it may have been introduced and cultivated by Polynesians on all of the islands except Rapa. The botanical status of coconut (*Cocos nucifera*) is uncertain for the Austral Islands, especially for Rapa. Most early European accounts, including from Vancouver and Menzies, suggest that coconut palms were absent until their introduction sometime before 1829 when Pritchard and Simpson (1830) located some specimens in poor health. J.F.G. Stokes (m.s.) reported in 1924 that ‘One coconut palm was reported as present from a drift and was not recognized by the local natives.’

\(^{10}\) Following Brown (1931a; 1931b; 1935) based on J.F.G. and E. Stokes’s collections from the Australs Fosberg and St. John (m.s) who provided the earliest and most comprehensive survey of the flora of the Austral Islands conducted in 1934 as a benchmark for the latest date of introduction.
Chapter 6
The longue durée: the palaeobotany and phytogeography of the Austral Islands prior to human settlement

In Chapter 5, I examined the first contact historical record as a means of providing an historical baseline for interpreting the post-European introduction of plants and the associated environmental transformation of the Austral Islands. These records also outline which taxa have or may have been introduced by Europeans or by Polynesians. In this chapter, the palaeobotanical context of these introductions is explored by distinguishing the timing of plant dispersals since the orogeny of the islands.

I focus on the geological epochs (mid-Miocene to Holocene) in which different plant lineages expanded into Oceanic Island Remote Oceania (OIRO). These periods are discussed in the context of the available sub-fossil records and environmental proxies for processes (e.g. glaciation and sea level fluctuation) that may influence plant migration to the islands and subsequent evolutionary processes. I also examine the phylogeographic (the study of the distribution of genetic diversity) evidence for the derivation of OIRO floras based on the recent research on taxa represented in the Austral Island flora.

A series of Holocene-aged palaeoenvironmental records from Rapa and Rimatara are then presented to provide an outline of the pre-human flora of these islands. An attempt is made to establish the main disturbance processes operating on the islands prior to human colonisation, later presented in Chapter 7.

Chronology of Austral Islands orogeny

The Austral islands are geographically distributed along a 1500 km transect that trends southeast to northwest in the southern part of French Polynesia (see Figure 6.1). This orientation roughly reflects the northwest movement of the Pacific plate over what corresponds to the South Pacific Isotopic and Thermal Anomaly (SOPITA; Staudigel, 1991). The islands are also are positioned on the western side of the South Pacific Superswell (see Figure 6.2) that forms a complex of overlapping volcanism (McNutt, 1997). The Austral Islands are composed of a diverse range of basalts including basanite (the most common), tholeiite and nephelinite, all characteristic of the HIMU (high µ [high $^{238}\text{U}/^{204}\text{Pb}$ ratios]) radiogenic isotopic composition (see Table 6.1). The ongoing debate of the origin and nature of these components attests to the geological complexity of the region.
Figure 6.1 Map of the Pacific Ocean (from http://www.sopac.org/) with sites referred to in the text. The outline for Near and Remote Oceania and the continental/oceanic geological affinity defined by the Andesite Line are also shown (after Green, 1991). The lower map outlines the position of all of the islands within the Australs.
Rapa and Marotiri are the youngest (see Figure 6.3 and Table 6.1 for ages) of the Austral Islands and are situated in a volcanic alignment that originated over the active MacDonald Seamount approximately 345 km southeast of Marotiri\(^1\). The extent of the island alignment runs more than 1500 km to the northwest incorporating Neilson Bank (a submarine volcanic chain) and Mangaia with a K-Ar age of 19 million years (Bonneville, 2002). Recent ocean floor surveys of the northwest region of the Australs have isolated a seamount (Arago) located around 120 km southeast of Rurutu, now thought to be the origin for the development of a second volcanic alignment including Rimatara and Rurutu with a K-Ar age range between 6.5 and possibly 27 million years (ibid). Previous models of the Cook-Austral-seamount chain thought to be derived from three eastern seamounts (Taukina, Ngatemato and MacDonald) have now had to be revised with a satisfactory synthesis of these data, in regard to their geomorphological implications yet to be drawn (Dickinson, 1998; Bill Dickinson pers. comm., 2004). The divergence between these two volcanic alignments is supported by the differing isotopic composition found between the basalts of Rapa and Ra'ivavae. It remains uncertain whether the Austral Islands fit the classic ‘hotspot’ plume hypothesis (McNutt et al 1997) of island chain orogeny as classically proposed for the Hawaiian Islands (Wilson, 1973; McDougall and Duncan, 1980), Lord Howe Island (McDougall et al, 1981) and Norfolk Island (Jones and McDougall, 1973).

**Late Miocene and Pliocene (-10-1.8 ma) phytogeography of the Austral Islands**

For the study of phytogeography, the Austral Islands are interesting as their floras had to arrive across the Pacific Ocean by long distance dispersal (Carlquist, 1974; 1996). If the hotspot models and K/Ar ages (see Table 6.1) are accepted, the original floral colonists had to disperse from the adjacent, but older seamount islands ‘downstream’. Given that all of the islands are of late Miocene to Pliocene (10-1.8 ma) age, but derived from two or possibly three different seamounts the direction of plant dispersal is unclear but can generally be assumed to follow a northwest (Rimatara and Rurutu are the oldest islands) to southeast direction (Rapa and Marotiri are the youngest islands).

\(^1\text{Eruptive activity of this seamount was last observed in 1987}\)
Figure 6.2 from Alain Bonneville’s website [http://www.mantleplumes.org/Cook-Austral.html](http://www.mantleplumes.org/Cook-Austral.html). The figure shows the position of the South Pacific Superswell and the adjacent Darwin Rise.
Figure 6.3 from Alain Bonneville’s website http://www.mantleplumes.org/Cook-Austral.html. The upper figure shows a shaded view of seafloor topography for the Cook-Austral region (see upper inset for location). Map projection is made along direction of present motion of Pacific plate (from right to left). White lines correspond to crustal magnetic anomalies, and their corresponding ages are in white numerals. Black diamonds represent places where K-Ar or Ar/Ar ages are known. These ages, in Ma, are printed in black. The lower figure is a three dimensional view of the Austral Islands.

Following the break-up of the Gondwanan supercontinent in the late Cretaceous, the largest southern continents (South America, Australia and New Zealand) moved northwards. For a prolonged period during the Miocene, New Zealand entered the warm-temperate zone shifting over 20 northwards while Australia moved into the warm-temperate and tropical climatic zones by the mid-Miocene (Markgraf et al 1995). This northward drift allowed for the expansion of warm-temperate and tropical florals from the north. Sub-fossil evidence for Australian genera such as *Eucalyptus* in New Zealand during early to mid-Miocene attests to the warm-temperate expansion (Pole, 1993). The northward drift also provided a greater floral source area of potential colonists for the mid-Miocene or older Pacific Islands (e.g. Fijian Archipelago).

If this interpretation holds, island orogeny and age may only have minor consequences for phytogeography, except that these islands have had, at a minimum, only 3.8 million years (based on the K-Ar age of Marotiri) of above sea level existence to accumulate and evolve endemic floras. The question remains whether the Austral Islands floras including endemic species arose during the late Miocene or later epochs.
<table>
<thead>
<tr>
<th>Island</th>
<th>Island type</th>
<th>Reef type</th>
<th>Area (km²)</th>
<th>Highest elevation (m)</th>
<th>K-Ar age (ma)</th>
<th>Basalt type</th>
<th>References</th>
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<tbody>
<tr>
<td>Maria</td>
<td>atolls</td>
<td>atoll</td>
<td>&lt;1</td>
<td>3</td>
<td>4.8-28.6?</td>
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<td>barrier &amp; offshore</td>
<td>9</td>
<td>92</td>
<td>27?</td>
<td>basanite?</td>
<td>5</td>
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<tr>
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<td>none</td>
<td>0</td>
<td>&gt;-27</td>
<td>0.23</td>
<td>nephelinite</td>
<td>5</td>
</tr>
<tr>
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<td>389</td>
<td>12</td>
<td>basanite</td>
<td>1,2,3,4,6</td>
</tr>
<tr>
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<td>barrier</td>
<td>45</td>
<td>422</td>
<td>9</td>
<td>basanite, nephelinite, tholeiite</td>
<td>1,3,4,6</td>
</tr>
<tr>
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<td>volcanic</td>
<td>barrier</td>
<td>20.3</td>
<td>437</td>
<td>6.5</td>
<td>basanite, nephelinite, tholeiite</td>
<td>1,3,4,5,6</td>
</tr>
<tr>
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<td>shoal</td>
<td>40.6</td>
<td>635</td>
<td>5.1</td>
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<tr>
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<td>&gt;-50</td>
<td>0.44</td>
<td>basanite, tholeiite</td>
<td>5,6,8</td>
</tr>
</tbody>
</table>

1=Morhange (1990); 2=Pinzolli (1992); 3=Spencer (1988); 4=Stoddart (1987); 5=Bonneville (2002); 6=Dostal (1998); 7=Cloudard and Bonneville (2001); 8=Johnson (1971).

Table 6.1 Geology and genetic morphology of the Austral Islands after Dickinson (1998). Note that some of the references listed in Dickinson (1998) have given inaccurate figures for island areas and elevations — these have been adjusted. Additional references to those listed by Dickinson (1998) are also provided.

The climate of the late Miocene (10-5.3 ma) was characteristically cooler and more variable than the preceding period as a function of the increasing periodicity of sea level fluctuations driven by an intensified succession of glacial periods extending the polar ice shelves. These fluctuations are thought to have altered species distributions by hindering or enhancing speciation or ultimately causing extinction (Macphail et al 1993). Winkworth et al (2002) suggest that the environmental instability of this led to the development of more open habitat that allowed more opportunities for the establishment of widely dispersed lineages.

Palaeobotanical evidence and late Miocene-Pliocene phytogeography

Unambiguous sub-fossil data on the influence of marine transgressions and regressions are difficult to obtain given the paucity of coastal or marine fossil records from the late Miocene-Pliocene (Jablonski, 1980), especially in the Pacific region. The only Pliocene deposit of value for a palaeobotanical interpretation of the Austral Islands is a shallow lignite seam located at Arahu at the northeast head of Ha’urei Harbour on Rapa at around 200 m in elevation (Figure 6.4; see Plate 3). This represents one of only two lignite deposits in OIRO, the other located at Babeldaob in Palau (Federated States of Micronesia). This Arahu deposit, like the Babeldaob deposit, formed prior to the erosional dissection of a former lake caldera that now forms the
harbour on the southeast side of the island. The earliest description of this lacustrine deposit dates to 1865 when John Vine Hall on the S.S. Ruahine *en route* from New Zealand to Panama stopped on the island in light of it being a suitable prospect for a steam ship depot. Hall (1869a: 132-133) noted that ‘Coal of a very inferior quality, has been found in the interior; the natives use it occasionally for cooking etc., but it is useless for steam [ship] purposes’.

The geologist Lawrence Chubb (1927) collected some material whilst on the St. George Pacific Expedition of 1924-25 and submitted some samples to the Natural History Museum (London). He described the deposit as lignite, ‘intercalated between lava flows’ and at points a few metres thick. He found an outcrop immediately below Mt Taga overlying parent rock consisting of clays interbedded with fine laminae of lignite. In 1939, Cranwell (1964b) examined some Arahu lignite collected by Raymond Fosberg whilst on Rapa as part the Bernice P. Bishop Museum Mangareva Expedition of the 1934. She suggests from Stokes (m.s.) description of the lignite outcrop that ‘it can be inferred that the deposit lay partly in a calderon which was emptied when later breached by the sea’ (Cranwell, 1964b: 45-46).

Cranwell located *Cyathea* tree fern type and other ferns spores, algal (e.g. *Phycopeltis*) and fungal (Microthryriaceae) fruiting bodies and a range of pollen types. Characteristic of the pollen assemblages examined are high proportions of sedges (Cyperaceae) indicative of ‘nutrient-rich waters’. Other Monocotyledon taxa include: Zingiberaceae, Taccaceae and some ‘palmoid’ grains (probably of Arecaceae or Liliaceae type). Of the Dicotyledon taxa identified, the following are represented: Myrtaceae, Piperaceae, Sapindaceae, and Rubiaceae of a type comparable to the endemic *Coprosma rapensis*. Cranwell also identified a few grains of the Gymnosperm genus *Dacrydium* (not of the New Zealand species *D. cupressinum* where the samples were processed), which she considered to be a contaminant. This could also have been derived from a wind blown dispersal during the late Miocene following the pacific expansion of *Dacrydium* into areas such as New Zealand (Pole, 2001) and potentially the Fijian Archipelago or islands further west (Mike Macphail *pers. comm.*).
The presence of a *Coprosma* type pollen grain within the pollen sample examined by Cranwell (1964b) suggests that the floral affinity of Rapa with New Zealand ascribed for the modern flora of the island may have a late Miocene/Pliocene origin. *Coprosma* is regarded by as one of a number of New Zealand genera that make up the flora of Rapa including *Hebe* (Scrophulariaceae), *Olearia* (Asteraceae) and *Corokia* (Corokiaceae), not found on any of the other Austral Islands or in the tropical Pacific.
In order to test this hypothesis some additional samples were required. In August of 2002, the author collected some material from the Arahu lignite deposit with the intention of processing some material for pollen analysis. The site is heavily eroded across the whole outcrop and is only exposed in a few places below the Taga ridgeline (see Plate 3). In a number of places the lignite is overlain by recently eroded clay. I was unable to locate any of the banded clay that Chubb described suitable for palynological examination and K/Ar dating. Some of this lignite was processed by Mike Macphail at the Australian National University who identified a similar, but less diverse assemblage consisting of Cyperaceae, Poaceae, Cyathea tree fern type and monolette fern spores, Dodonaea (Sapindaceae) and Rubiaceae type grains (see Table 6.3 for list). Like Cranwell, Macphail and the author did not identify any pre-Quaternary fossil taxa that may specify further the likely age of the deposit, although the K/Ar ages provided by Morhange (1990) and Dostal et al. (1998) now confine the age of this deposit to 5.1 ma or younger. The palynological record remains only partial, but provides no evidence to suggest that the age of this deposit is pre-Quaternary where the former southeast ridge of caldera may have only been breached by marine transgression within the late Quaternary interglacial phases.

Phylogeographic evidence and late Miocene-Pliocene phytogeography

Fossil data do not always allow for a precise or complete interpretation of phytogeographical patterning. For pollen and fern spore assemblages there tends to be a bias towards wind pollinated and peat swamp species preserved in Tertiary lignites. The very lack of late Miocene-Pliocene sub-fossil deposits from OIRO limits phytogeographical interpretation. The recent application of phylogenetic and phylogeographic methods has enabled historical events of genetic differentiation to be inferred. These inferences are established on the basis that the geological age of island orogeny provides the earliest timeframe in which newly established are given the evolutionary potential to speciate (Avise, 2000). For many Pacific plant lineages, phylogenetic studies have confirmed the importance of an eastward dispersal route in which Western Pacific species are basal to eastern species.

The timing of dispersal events can also be inferred by molecular dating in which the level of molecular divergence between taxa is examined. There are, however, a number of problems that may arise in interpreting these ‘molecular clocks’ including the genetic influence of multiple colonisation events, hybridisation and polyphyletic lineages. Despite these pitfalls, broad molecular estimates from many Austral Island floral lineages suggest that most dispersal events took place during the late Miocene-Pliocene with extant island taxa derived from this diversification. Most taxa are derived from the tropical west-east dispersal routes (see examples

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2A collection of this lignite and reference pollen slides are held by the Department of Archaeology and Natural history, The Australian National University.
below) with some taxa following a southerly route from New Zealand (e.g. *Sophora tomentosa* and *Hebe rapensis*; see below) and American lineages (e.g. two Plantago species (Plantaginaceae) from Rapa; Hoggard *et al* 2003; Tim Motley, unpublished data).

Tronchet *et al* (2005; also Tim Motley, unpublished data) used two nuclear-encoder spacer regions from the ribosomal RNA to resolve the genetic relationships between the Pacific populations of the Araliaceae genus *Meryta*, of which two extant species (*M. chloristantha* and *M. brachypoda*) are found on the Austral Islands (see Chapter 8). The spacer region data showed that the Austral Island populations are derived from the diverse New Caledonian lineages. The ancestral New Caledonian species may be derived from populations from either Fiji (*M. tenuifolia*) or New Zealand (*M. sinclairii*), although this relationship remains unclear. Tronchet *et al* (2005) suggest that the east Pacific populations, including from the Austral Islands would have arisen after the late Miocene-Pliocene island orogeny from long-distance dispersal events.

The phylogenetic relationship of some Austral Island taxa to late Miocene-Pliocene dispersals from New Zealand has received more attention. Using sequences from an intergene region (atpB-rbcL) of chloroplast DNA, Hurr *et al* (1999) found that the *Edwardsia* section of the genus *Sophora*, distributed across the southern Pacific from New Zealand to Chile, is monophyletic but from a distant non-*Edwardsia* lineage from the north-west Pacific. These data suggest that this section of *Sophora* initially dispersed to New Zealand from the northwest Pacific along an Antarctic route by the late Miocene, then dispersed across the South Pacific and to all of the Austral Islands. Based on molecular clock estimates and fossil pollen dates from ancestral New Zealand species, the derived *S. tomentosa*, represented on all of the Austral Islands (Meyer, unpublished data) and *S. toromiro*, found only on Easter Island (Zizka, 1991b), are late Miocene to Pliocene in age. Dispersal of the buoyant *Sophora* seeds to these islands from New Zealand is seen as the most likely explanation for this distribution.

Nuclear ribosomal internal transcribed spacers (nrITS) from species in the genus *Hebe*, represented on Rapa by *H. rapensis*, indicate dispersal eastward from New Zealand to South America probably during the late Miocene (Wagstaff and Garnock-Jones, 2000; Winkworth *et al* 2002; Michael Bayly and Phil Garnock-Jones, unpublished data). Winkworth *et al* (2002) suggest that the Sub-Antarctic Islands and the Antarctic may have provided a stepping-stone for dispersal from New Zealand to South America. It is possible that Rapa may have also served as a stepping-stone for this dispersal.

Few other high-resolution phylogeographic studies have been completed for representatives of the Austral Island flora. Florence (1997) has found from an analysis of the floral affinities of other Pacific regions with the flora of subtropical Rapa, that over 45% of genera are shared with the tropical Western Pacific. For the remaining Austral Islands, this percentage is greater given their more tropical position. Limited phylogeographic studies are also available for a number of pan-tropical genera including *Scaevola* (Goodeniaceae; including *S. taccada* found on most of the
Austral Islands; Howarth et al 2003), *Hibiscus* (Malvaceae: Hibisceae; including *H. tiliaceus* represented on most islands; Pfeil et al 2002) and *Erythina* (Fabaceae; Phaseoleae *Erthraster*; represented by *E. variegata* in most of the Austral Islands; Bruneau, 1996) with representatives with long distance dispersal capacities. These phylogenetic analyses suggest that most pantropical taxa had arrived in the Pacific region prior to Austral Island orogeny.

**Pleistocene (last 1.8 ma – 10,000 yr B.P.) phytogeography of the Austral Islands**

The dynamics of Quaternary vegetation change for OIRO are still little known but are best described for the Late Quaternary. By the Pleistocene the configuration of islands in the Pacific Basin was essentially the same as today. The geology of OIRO remained tectonically stable throughout this period relative to the regions adjacent to the continental plate boundaries to the west. Few terrestrial catchments in the region have accumulated sediment with palynological records for the Pleistocene. The lack of large sedimentary basins in this region dictates that continuous terrestrial records of an age exceeding the Holocene will remain elusive (Hope, 1996). Inferences of vegetation change for the Pleistocene in OIRO tend to rely on indirect proxies such as glacial or sea level signatures to determine constraints on vegetation.

**Pleistocene sea level fluctuations**

The influence of eustatic and regional hydro-isostatic sea level fluctuations (see Dickinson, 2001) on vegetation change in the Pacific are better understood for the Quaternary given the preservation of marine (e.g. coral reefs and marine sediments) and coastal sedimentary deposits (e.g. mangrove sediments) and other geomorphological indicators (e.g. coastal caves and uplifted coral terraces). Eustatic sea levels in the last 1.8 million years have fluctuated by up to 140 m on a time scale of about 100,000 years. The time spent at the lowest levels is similar to that spent at their highest, about 10-15,000 years or 10% of the time with intermediate levels achieved at other times (Chappell, 1987; Shackleton, 2000). Bathymetric data from much of OIRO does suggest that almost all existing island groups throughout the region remained separated even during glacial lowstand sea levels.

The regional hydro-isostatic response of the earth’s mantle to ice volume fluctuations is ocean depth-dependent and spatially variable (Dickinson, 2001; Lambeck and Chappell, 2001). These changes are related to earth mantle deformation upon the transfer of mass (H₂O) from expanded polar ice sheets at peak glaciation to the more even distribution during interglaciations. Chappell (1974) showed that islands in equatorial regions experience this adjustment far from glaciated regions due to this meltwater mass transfer. Hydro-isostatic adjustments during
interglacial periods of the Pleistocene are not well defined for the OIRO region due to the limited number and integrity of palaeoshoreline signatures (e.g. tide-line indicators including wave cut notches, see Dickinson, 2001) that are common along Holocene shorelines (see below).

Estimates of interglacial and interstadial sea levels are known for the late Pleistocene Pacific from a series of dated uplifted-coral terraces in the Huon Peninsula, Papua New Guinea (Chappell et al. 1996). The closest series of uplifted terraces to OIRO that provide any indication of Pleistocene sea level come from the Fijian Archipelago (e.g. Nunn and Omura, 1999). Uplifted Pleistocene reefs are common in many parts of OIRO including on Rurutu (Stoddart and Spencer, 1987; Pirazzoli and Salvat, 1992) and Tubuai (Pirazzoli and Salvat, ibid) where emergence by volcanic loading of the Arago Seamount (Bonneville et al. 2002) has left Last Interglacial shoreline signatures from a time when sea level was approximately 5 m above present level (e.g. Chappell and Shackleton, 1983). The impact of volcanic loading Last Interglacial hydro-isostatic drawdown on the Austral Islands has yet to be calculated.

Sea levels have also been estimated from oxygen isotope ratios in foraminifera from deep ocean-floor cores (e.g. V19-30 cores off the Huon coast). No marine cores have been obtained from anywhere within the South Pacific Superswell (Figure 6.2) as these are usually focused on the periphery of continental shelves and/or where tectonic activity has created large sedimentary basins along the sea floor. Those cores available from the OIRO region and those that are available tend to be shallow, intermittent deposits affected by organic dissolution (e.g. Ontong Java Plateau; see Figure 6.2; Kawahata, 1999; Lea et al. 2000).

Lower sea levels during glacial periods had the effect of increasing land area and therefore reducing migration distances between islands. For the Austral Islands this would have had a marginal effect given the large distances between islands. Based on limited bathymetric data and with the estimated sea level decline for the LGM, Rapa for example, would potentially have expanded its terrestrial area up to around 200 km². The ocean floor immediately surrounding these islands lies at a depth varying between 2 and 4.7 km. All of the surrounding satellite islets off the coast would have been joined with the main island allowed continuous tracts of vegetation to form between them. Given the rise in altitude of the island with lowering sea-level, orographic precipitation concentrated on windward flanks of the island may have increased leading to increasing valley dissection and sediment erosion, as has been proposed for most Pacific high islands (e.g. Gavenda, 1992). Paulay (1985) suggests that the montane cloud forest of Rapa would have extended down in elevation to encompass a greater area, potentially connecting the previously disjunct forest tracts.

Lower sea levels also had the effect of creating erosion dominated fluvial systems by increasing river gradients. This increased valley incision and sediment mobilisation limiting

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3The author surveyed the Rimatara raised limestone coastline for similar signatures but was unable to locate any wave-notch features at a height above the modern notches.
accommodation space for sediment deposition and organic accumulation and subsequently sub-
fossil preservation. Vegetation development particular at the outlets of rivers and in coastal areas 
was likely to have been greatly restricted. Coastal swamp forest or mangrove environments would 
have been either restricted to small refugia, or were entirely absent during these periods.

Evidence for Pleistocene glaciation

The generally low elevation and tropical orientation of OIRO has meant that few islands are 
likely to have been ever directly influenced by glaciation. During the Late Quaternary glacial 
phases, a succession of ice caps formed at the crest of Mauna Kea (below 4200 m), the highest 
volcano of Hawai‘i and the only known glaciated peak in OIRO. Mauna Kea now lacks perennial 
ice cover, but glacial moraine deposits stratified between lava flows and tephra layers, indicative 
of three glacial episodes $\text{K/Ar, } {^{36}}\text{Cl and }$radiocarbon dated to marine isotope stages 2, 4, and 6 
($\text{Porter et al. 1977; Porter, 1979; 2005}$), known periods of increased global ice volume. Evidence 
of glacial moraines extends down from the Mauna Kea summit to as far as 3500 m. Porter (1979) 
estimates that the tree line was depressed to as far as 2000 m during the Last Glacial Maximum, 
but no palaeobotanical information directly confirms this hypothesis. With this treeline 
depression cooler temperatures (perhaps 6-7 °C cooler) have been inferred for the height of the 
Last Glacial Maximum 18,000 yr B.P. The degree and timing of this cooling is similar to that 
known from temperate and continental glacial moraines, and can be taken as evidence that the 
Quaternary has been marked by similar fluctuations in the Pacific as elsewhere.

Palaeobotanical evidence and Pleistocene phytogeography

Lyon (1930) identified Pleistocene-aged macro-botanical remains of fifteen tree species from a 
tuff deposited in a salt lake at Moanalua, O‘ahu, Hawaiian Islands. Amongst the species 
identified were the endemic $\text{Pritchardia spp. (Areccaceae), Metrosideros polymorpha (Myrtaceae)}$ 
and $\text{Acacia koa (Fabaceae)}$ indicative of a mesic interglacial environment (Ruhe, 1964 in 
Gavenda, 1992). By contrast, Hay and Iijima (1968 in Gavenda, 1992) later examined the 
geomorphology of the site and interpreted the deposit to be from a glacial period at ~350,000 yr 
B.P. providing evidence for the long-term presence of at least three endemic species.

Some relatively continuous Pleistocene palynological records are available from 
continental sites in Remote Oceania (see Figure 6.1) including the Grande Terre, New Caledonia 
(Stevenson et al. 2001; Stevenson and Hope, 2005) and in New Zealand where there are numerous 
records (e.g. Prebble et al. in prep., Vandergoes et al. 2005, Newnham et al. 2004). Only one record 
has been located from the Fijian Archipelago at Lake Tagimaucia on Taveuni (Southern, 1986;
Hope, 1996). Discrete Pleistocene units have also been located along the Plaine des Lacs, New Caledonia (Hope and Pask, 1998), Nadrau Plateau on Viti Levu, Fiji (Southern, 1986) and from several sites in New Zealand (e.g. Moar, 1973; Moar and Suggate, 1996). Most interpretations of these records imply cooler and drier conditions with an increase in montane and herbaceous taxa in lowland areas in response to a decrease in forested environments.

Only three island groups in OIRO have provided palynological records extending back to the Pleistocene, including Easter Island (Rano Kao, Rano Raraku and Rano Aroi in Flenley, 1979; Flenley and King, 1984 and Flenley et al 1991), O’ahu, Hawaiian Islands (Selling, 1948; Athens and Ward, 1993; Hotchkiss and Juvik, 1999) and San Cristobal, Galápagos Islands (Colinvaux, 1972; Colinvaux and Schofield, 1976). All of these sites are located in either high elevation bogs (Hawaiian sites) or remnant volcanic caldera lakes, but are rare in the region.

Flenley et al (1991) proposed that fluctuations between an extinct Arecaceae palm type (see Chapter 4) and Asteraceae (Tubuliflorae) pollen provide a climatic index for changing temperature. For sediments dated to the Last Glacial Maximum (LGM) at 18,000 to 16,000 yr B.P. from the Rano Raraku record (RRA 3, presented and discussed in Chapter 4), the index indicates cooler and drier conditions than those exhibited for the Holocene. The palynological record of Ka’au Crater indicates that the dry to mesic forest vegetation just prior to the LGM with more open forest vegetation indicative of cooler and drier conditions dominating the LGM (Hotchkiss and Juvik, 1999). Colinvaux and Schofield (1976) suggest from sedimentary signatures that the Galápagos Islands environment was extremely arid during the Pleistocene due to intensified upwelling of the currents off the coast of South America (Humboldt current) and the consequent generation of strong westerly winds.

Palaeoclimatic influences on Pleistocene phytogeography

Studies of Mg/Ca and 18O ratios in foraminifera from ocean floor cores in the OIRO region have revealed equivocal changes in sea surface temperature and productivity during the Pleistocene glacial periods (e.g. Kawahata, 1999; Lea et al 2000). Records from sites further west within the Indo-Pacific Warm Pool indicate that sea surface temperatures may have been only 0-3°C below present levels (Gagan et al 2004). This counters estimates developed from temperature inferences gained from equatorial Pacific records of glacial extent (e.g. Hope, 1976; Porter, 1979; Seltzer, 2001).

Ocean floor core records from along the coast of South America (e.g. Calvo et al 2001) suggest that ocean circulation was relaxed during the Pliocene but intensified during the late Pleistocene glacial cycles particularly with the general locking of global thermohaline circulation (e.g. Broecker, 1991). This pattern is likely to have been similar in the Western Pacific, but is
only well defined for the Late Quaternary (e.g. Barrows et al 2000; Gagan et al 2004). With the
intensification of ocean circulation trade winds also strengthened. Such circulation patterns may
have had a major influence on the migration of plants that disperse via floating propagules. At
present, the prevailing circulation system in the OIRO region delivers plant propagules from
South America with the eastern equatorial current, while the counter equatorial current and the
eastern boundary currents provide a migration path for Western Pacific taxa upwind into OIRO.
The southeast trade winds bring airborne taxa from as far as New Zealand to OIRO. These wind
patterns and ocean currents intensified during glacial sea levels providing additional opportunity
for plants to establish via long distance dispersal.

There are few direct measures of palaeoprecipitation available for the equatorial Pacific and
OIRO. Large phosphate deposits on a number of Pacific islands (including some islands in the
OIRO region (e.g. Makatea, French Polynesia) are thought to have developed during the
Pleistocene from seabird guano that accreted in response to reduced precipitation. Nunn (1997)
suggests that phosphate may not have developed on these islands recently because the guano
supplied by the seabirds has been leached before decomposition. Pleistocene phosphate formation
may represent conditions drier than present and such conditions may be correlated with glacial
maxima. Aridity around the LGM in the Pacific islands has been inferred from a number of other
studies, such as dolomite formation on Niue (Schofield and Nelson, 1978). It is unclear how such
reduced precipitation may have influenced Pleistocene floras in OIRO.

Phylogeographic evidence and Pleistocene phytogeography

Most plant dispersals to the Austral Islands took place either soon after island orogeny in the late
Miocene/Pliocene or periodically in later periods. Additional dispersals of established Austral
Island taxa, particularly of taxa with long-distance dispersal mechanisms (avian dispersed,
floating propagules) continued to occur. Wright et al (2000) examined the nuclear ribosomal
DNA of the Metrosideros subgenus Metrosideros that includes ~ 26 anemophilous species found
throughout the Pacific. They identified three monophyletic clades, two of Miocene age with one
thought to be derived from a Pleistocene dispersal of a species identical to the New Zealand
species Metrosideros excelsa, only separated by a single nucleotide change. Varieties of M.
collina are now found throughout OIRO and are found on all of the populated Austral Islands
except Rimatara. Wright et al (ibid) attribute this late dispersal to a change in late Pleistocene
wind patterns, namely an intensification of the southeast trades.

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Holocene phytogeography of the Austral Islands

The phytogeography of the Austral Islands prior to human colonisation is discussed here for the Holocene (see Chapter 7) with particular reference to the geodynamic processes influenced by eustatic and hydro-isostatic sea level fluctuations. The post-glacial marine transgression of the early Holocene had the regional effect of enhancing the sediment budget, especially behind accreting river levees, boulder beach-ridges, and coral reef systems. This increase in sediment accumulation allowed formerly restricted coastal vegetation to establish. On most islands in OIRO this usually did not take place until eustatic sea level reached near modern levels by ~8,000 cal. yr B.P. when coastal sediment accumulation reached its peak behind reef bound lagoons that restricted wave-induced sediment erosion. Palynological sequences obtained from anaerobic, organic rich depositional contexts in the OIRO region that have accumulated since the post-glacial marine transgression in the early Holocene are available in most island archipelagos (see Chapter 1) and the Austral Islands.

‘Ideal’ contexts for pollen preservation described by Jacobson and Bradshaw (1981) such as large closed lake basins or Sphagnum peat deposits are rare in OIRO and are absent in the Austral Islands. The lack of closed volcanic lake calderas and peat bogs in the Austral Islands has meant that most sedimentary catchments preserving Holocene palaeobotanical remains are located on levee-backed marshlands (Rapa and Ra’ivavae), beach-backed swamps (Rapa, Ra’ivavae, Tubuai, Rurutu) and makatea moat swamps (Rurutu and Rimatara; see below). Aside from shallow soil horizon and wet-field agricultural terraces, upland sedimentary deposits are entirely absent from all of the Austral Islands.

Coastal marshland deposits on the islands can be characterised on the basis of sedimentary basin size and morphology, structure of the alluvial/marine interface and the morphology of offshore reefs. The largest coastal sedimentary catchment is found at the head of Ha’urei harbour on Rapa (see below). Smaller sedimentary catchments (see Chapter 7) are located at the base of windward boulder and leeward sandy beach embayments of the island (Figure 6.5). The more deeply incised windward embayments are characterised by higher energy fluvial/alluvial systems, but highly organic fine-grained sediment deposits preserving botanical remains tend to be of late Holocene age and often directly associated with human-induced sedimentation (see Chapter 7). Similar size boulder and sandy beach embayments are found on Ra’ivavae and Tubuai.
Dickinson (1998: 1051 after Scott and Rotondo, 1983) suggests that islands such as the Australs distributed “downstream” from hotspot volcanoes (i.e. the MacDonald and Arago seamounts) are expected to display the following successive coastal morphologies and reef development as a response to island subsidence due to volcanic loading: (1) volcanic islands without offshore reef development e.g. Marotiri (2) volcanic islands with fringing reefs, (3) volcanic islands within lagoons enclosed by barrier reefs, and finally (4) atolls (see Table 6.1). Reef development on Rapa is restricted with shallow (0-5 m or more below low-tide line) shoals along the coastal fringe. Only one small reef at the harbour entrance is exposed at low tide (~0.4 m below mean sea-level). Limited reef development is probably due to both subsidence from volcanic loading and restricted reef growth from the island’s cooler sub-tropical position. Shoal depth governs the extent of wave-induced sediment erosion at the marine/terrestrial interface. The coasts of Ra’ivavae and Tubuai are enclosed by a barrier reef that has allowed the development of an extensive prograding coastal plain.

Ha’urei harbour on Rapa represents the remnant of one of the original volcanic calderas formed during island orogeny and opened to the coast sometime in the Pliocene. The shallow bathymetry of the harbour suggests that the entire area was exposed during glacial lowstand sea levels. The exposed reef at the harbour entrance, backed by calcareous reef shoals along the interior, currently restricts wave-action from the sea, to the degree that the harbour could be
described as a lagoon. At low tide fine-grained sediments of a mixture of alluvial sediments, shell
and coral detritus are exposed to reveal three prominent birds-foot river deltas and tidal flats
extending out from the high-tide shoreline (see Plate 4 and 5). Water depth surrounding the
Tapuki (Tapu’i) basaltic islet in the centre of harbour is no more than 1.5 m below low tide level.

Shoreward of the exposed deltaic sediments are a series of levee-backed marshes
positioned at Tukou, Matataa and Aitoke (see Plate 3). All of these sites have been heavily
modified by human activity and grazing by cattle, horses and goats. A map of Ha’urei harbour
sketched in 1864 by Captain John Vine Hall (1869a) shows the position of a number of coastal
pondfield systems that were used for Colocasia esculenta cultivation (Figure 6.6). Remnant dry
stonewall terrace features are now interspersed within many of the levee-backed marshes, along
the margins of riverbeds or situated along the present shoreline. At certain points, these
marshlands extend over 100 m inland and rise to an elevation of over 2 metres. On the most
inland side, these marshes are bound either by river levees or steeply rising embankments of the
surrounding hill slopes that appear to have been cut by a previous, probably mid-Holocene, sea-
level high stand (see Figure 6.7 and below for further discussion).

![Figure 6.6](image-url)
Figure 6.7 Approximate position of highstand maximum marine incursion after sea-level stabilization at Tukou (blue line). Up to ~3 m of organic rich sediment has been accommodated at the site above present high tide/spring tide line marked by the interface between the marsh and the tidal flats.

**Palaeoenvironmental examination of Tukou Marsh, Rapa**

*The modern marsh: geography, climate and vegetation*

Tukou marsh lies on the south side of the broadest river delta and associated tidal flats of Ha’urei Harbour. The marsh is banked and divided by two smaller prograding river channels forming two waterlogged depressions. The central most marsh depression was chosen for palaeoenvironmental analysis (Figures 6.8; see Plate 4 and 5) and sediment cores were taken in 2002 (June-August). The modern marsh appears to have developed behind the southern levee of the main river and the northern levee of the smaller river bounded the marsh to the south. The marsh extends from the estuarine shoreline, marked at high tide (~0.4 m above mean sea level) by driftwood and estuarine detritus, ~135 m to the embankment of the surrounding hill slope. Below the embankment the marsh reaches a maximum elevation, based on laser transit measurements, of 3
m above the high tide mark. The topography of the remnant agricultural terrace features lie an additional 50 cm or more above the marsh surface.

Overall the climate on Rapa is subtropical/temperate. Tukou receives around 2500-3000 mm annual rainfall based on measurements taken from Ha'urei village, also at sea-level (Rapa Meteo, unpublished data). Tukou is fed by two permanent streams that drain the eastern catchment of the Per'a'u-Namuere range with water flow gradients averaging above 30 degrees. Hydrological data are unavailable for this catchment. From readings taken in 2002, both rainfall and wind are greatest from June to August with the average temperature minimums fluctuating around 15°C reaching as low as 10°C in August 2002 (Rapa Meteo, unpublished data). Thunder and lightning occur infrequently at any time of the year with only two storms recorded from February to March 2002.

The vegetation of the waterlogged marsh surface is currently dominated by introduced agricultural grasses (e.g. Paspalum subjugatum) and adventive herbs (e.g. Commelina diffusa and Ludwigia octovalvis) with some indigenous sedges (e.g. Carex spp.) and rushes (e.g. Schoenoplectus subulatus subsp. subulatus; some authors suggest that this may have been introduced to French Polynesia). The embankment on the periphery of the marsh is largely open grass with some naturalised Syzygium jambos and Psidium spp. trees (both in the Myrtaceae). Some indigenous tree taxa are found at the site including Hibiscus tiliaceus (Malvaceae) and Metrosideros collina (Myrtaceae). Hall's (1868a) sketch of the site indicates that stone-wall terraces lined the upper portion of the marsh and were focused along the banks of the adjacent river channels. Some of these terrace features remain but in a degraded state. Only one feral C. esculenta specimen was located at Tukou with no other cultigens identified. The marsh is currently left for cattle grazing.

Field methodology

In regard to the vegetation history of Rapa, Tukou marsh was examined for three main purposes. Firstly, to outline the extent of Holocene vegetation on Rapa; and secondly to assess the influence of fluctuating Holocene sea levels on vegetation and coastal sedimentation (see section below). The site was also examined for human impact signatures and this is discussed in Chapter 7.

In order to assess changes in vegetation throughout the Holocene, an attempt was made to obtain the oldest and most continuous section from the marsh. Cores were attempted in the Ha'urei lagoon at different intervals between Tukou Marsh and Tapuki Islet using both Russian D-Section and Livingston corers. The texture of the lagoon sediments was such that no core was retained with sufficient integrity for palynological analysis. After initial probing, the longest profile was located at the marsh/lagoon interface (Tukou Core 1; see Figure 6.8). This 6.5 m
sediment profile was taken 5 m inland of the shoreline using a 50 mm Russian D-Section corer down to 5 m below the marsh surface, with the remaining 1.5 m extracted using a 35 mm diameter Livingston piston corer.

![Figure 6.8 Satellite image of Tukou showing the position of Core 1 (red dot), the multiple profile transect (red line) and the position of the upper, central and lower marshes and other surrounding features.](image)

Given the dominant representation of exotic vegetation at the site, modern pollen and spore rain study was not conducted on Rapa. Pollen traps were erected on the island, but these have yet to be analysed. The dispersal characteristics and representation of identified pollen and spore taxa are instead inferred from modern pollen rain studies from other sites in the OIRO region (e.g. Flenley et al 1996) and from surface samples from the Tukou swamp.

**Laboratory and numerical methods**

Each extracted core was taken back to the laboratory for further analyses including radiocarbon dating, sedimentary, faunal and palynological analyses. Five samples were submitted for Accelerator Mass Spectrometry (AMS) radiocarbon dating and these are listed in Table 6.2. The
calibrations provided were calculated using the OxCal program version 3.10 with the IntCal04 calibration data set (Bronk Ramsey, 2001; 2005). Of these radiocarbon samples, one leaf sample was submitted along with three macro-charcoal particles. The remaining sample was submitted as a pre-treated pollen concentrate, processed using standard pollen protocols without the addition of carbon-based acids.

One cubic centimetre (cm$^3$) samples in volume were taken at approximately 0.10 m intervals throughout each core. Pollen analysis of sediment samples was conducted using the standard preparation techniques outlined by Faegri and Iversen (1989). To enable the calculation of pollen concentrations, Lycopodium clavatum marker spores of a known number were added (Stockmarr, 1971). Palynomorph counts generally amounted to 300. Microscopic charcoal fragments were also counted for each sample using the point count method (Clark, 1982). Foraminifera (rotalids indicative of estuarine/intertidal conditions; Jessica Reeves pers. comm.) and calcareous dinoflagellates (indicative of estuarine conditions; Marty Young pers. comm. 2004) within the pollen concentrates were counted as broad indicators of estuarine/intertidal environments but were not identified to taxa due to dissolution during pollen processing.

Pollen and spore identification was assisted by reference material collected in the field by the author and regional reference collections held at the Australian National University. All pollen taxa names refer to the family or genera of extant plant taxa with the exception of the fossil classification Arecaceae: Iguanurinae type which is derived from an extinct palm of that sub-tribe (see Chapter 7 for a more detailed description). Mineral magnetic susceptibility analysis was used to detect coarse changes in mineralogy down the cores. Each core was scanned by using a MS/2 Bartington Susceptibility Meter and core loop at 2 cm intervals in order to identify peaks in magnetic mineral concentration.

Sixteen samples from all sedimentary units of Tukou Core 1 were processed for biogenic silica including phytoliths and diatoms. Phytolith extraction follows the method described by Carter (2000). A further set of samples selected from sedimentary units were analysed for phytoliths and diatoms using a microwave digestion method described by Parr (2002).

All pollen and spores were counted as a ratio to added exotic Lycopodium spores (per cm$^3$). The concentration (per cm$^3$) data for pollen, spores and microcharcoal particles, foraminifera and dinoflagellate counts as well as percentage pollen and spore data were placed into stratigraphic diagrams (Figures 6.9a and 6.9b) using the program C2 Data Analysis version 1.4 (Juggins, 2005). Radiocarbon ages, linear age models and magnetic susceptibility data were also placed in these diagrams. This program was also used to numerically examine the relationship between samples using correspondence analysis (CA).
Holocene vegetation change: Tukou Core 1

Core stratigraphy, chronology and eustatic sea levels

The basal sediments (650-600 cm) of the core consist primarily of compacted reddish-brown basaltic clays with minimal organic content (<10%). Above these clays, a large unit (600-120 cm) encompassing much of the core consists of fine to coarse estuarine sands, silts and differing proportions of shell and coral debris and other calcareous material. Magnetic susceptibility measurements (K units) correspond to increasing proportions of inorganic (basaltic) mineral sands. Above this unit lies a predominantly organic unit (120-0 cm) with differing degrees of silt and clay, but lacking any calcareous material. The upper 22 cm of the core lie above the high-tide line and consist of sedge (Cyperaceae) and grass (Paspalum conjugatum) roots.

Five AMS dates were obtained for Tukou Core 1 at different intervals throughout the core (Table 6.2) and these are presented as linear-age models in stratigraphic diagrams (Figures 6.9a and 6.9b). The most basal sample submitted for dating located at 624 cm in depth obtained an age of 8,300 - 7,450 cal. yr B.P. (see Table 6.2). Dated from pollen concentrates this sample represents the most basal age for the Tukou deposit, but may as discussed below stem from reworked material. The estuarine sedimentary unit with calcareous material was dated to between ~8,000 and 2,000 cal. yr B.P. No radiocarbon dates were obtained from the upper organic unit, thus the chronology remains uncertain and is discussed below in the context of palynological markers.

The most detailed chronological measurements for eustatic sea level change in OIRO come from an analysis of barrier reef coral cores from coastal Tahiti (Bard et al 1996). These have provided comparable rates of sea level change for the late Glacial-Holocene period and a linear age model of this record is presented alongside the age model for the Tukou Core 1 sequence (Figures 6.9a and 6.9b). The three most basal ages dating from 7,450 - 8,300 cal. yr B.P. are all situated at depths deemed to lie above eustatic sea level at that time. All of these ages have been taken from depths associated with counts of foraminifera and dinoflagellates representative of intertidal or estuarine conditions. From the Tahiti coral record, Bard (ibid) estimates the level of eustatic sea level to lie at this time between around -20 and -12 m below current mean sea level, at least 6 m below the Tukou levels. Either sea level rose more rapidly on Rapa, or older organic material at the base of Tukou Core 1 have been reworked. The later explanation is followed here. By 6,500 cal. yr B.P., the Tahiti record indicates that sea levels reached levels represented at the Tukou Core 1 site. Ages obtained from this core that are younger than 6,500 cal. yr B.P are assumed to be consistent with the timing of sediment deposition and not a product of post-depositional processes.
Silicious particles, possibly fragments of biogenic microfossils, were found within the samples processed for phytoliths and diatoms but these appeared to be influenced by dissolution processes and could not be identified to any plant group or diatom species.

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Table 6.2: List of AMS radiocarbon dates obtained from the Tukou marsh sediment profiles. Presented are the sample depths, radiocarbon laboratory (ANU= Australian National University; California=University of California, Irvine; ANSTO=Australian Nuclear Science and Technology Organisation), material dated (distinguished by colour), pollen concentrations/cc, laboratory sample codes, uncalibrated determinations and calibrated ages to 2σ and 2σ central point estimates. Dates from two samples were replicated at 240-242 cm (Core 3) and 210-212 cm (Core 6) and calibrated using the combine algorithm in the OxCal program version 3.10. Post-European contact interpolated date estimates are referred to in Chapter 7.
Direct indications of estuarine or littoral conditions are available from the shell macro-remains of bivalves, gastropods and other fauna (e.g. crabs). The highest concentrations (10-15%) of shell remains are found at differing depths between 250-150 cm along with whole pieces of coral debris. Taxa recorded in this section of the core include bivalves in the Veneridae (Galarranium pectinatum; Clypeomorus sp.) and Mytilidae (Saccostrea sp.), Tellinidae (Tellina cf. staurella) families (Katherine Szabo pers. comm.). In the basal sediments of the core between 540-250 cm shell concentrations lie below 5% with all of the above taxa recorded in different sections. Saccostrea sp. and crab remains were recorded throughout this section. Until further analyses of these bivalve remains including isotopic analyses are undertaken, no definitive interpretation of the littoral or estuarine environment can be made.

Palynological analysis

The different palynomorphs identified from Tukou Core 1 are listed in Table 6.3. along with their presence or absence in Tertiary, mid-Holocene and <2000 cal. yr B.P. aged sediments and their biogeographic affinity. Proportional palynological data are also presented in stratigraphic diagrams according to the occurrence of taxa throughout the core in proportions of either >5% (Figure 6.9a) or <5% (Figure 6.9b). Taxa are grouped from left to right according trees and shrub, herb, fern and fern ally groups. Taxa are sorted within these groups in stratigraphic succession using the sort function in C2 Data Analysis program (Juggins, 2005). The core is divided into four palynological zones on the basis of the major vegetation changes.

Zone I (650 to 245 cm; ~6,500 - 4,000 cal. yr B.P.)

Trilete fern spores including Cyathea tree fern and Angiopteris types dominate this Zone. Palynomorph concentrations remain low until ~6,500 cal. yr B.P. after which time concentrations reach their highest in the early Holocene until 5,000 cal. yr B.P. Tree and shrub taxa are only preserved in low percentages or trace counts or percentages. Pandanus cf. tectorius type pollen does not enter the record in percentages >5% until after 6,000 cal. yr. B.P. Triumfetta (probably T. procumbens), Euphorbiaceae and Myrtaceae pollen are the most consistently represented tree and shrub taxa found in this Zone. Both foraminifera and dinoflagellates are found in trace counts at the base of this Zone but were not located after around 5,000 cal. yr B.P. From 6,500 cal. B.P. the Areceae: Iguanurinae type pollen appears in the record.
<table>
<thead>
<tr>
<th>Pollen taxa</th>
<th>Family</th>
<th>Present in Tertiary</th>
<th>Present in early – mid Holocene</th>
<th>Present in last 2000 years</th>
<th>Indigenous representatives in modern flora</th>
<th>Biogeographic affinity</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acalypha</em></td>
<td>Euphorbiaceae</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td><em>Acalypha</em> spp.</td>
<td>Indo-Pacific/Endemic?</td>
</tr>
<tr>
<td><em>Angiopteris</em></td>
<td>Angiopteridaceae</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td><em>Angiopteris rapensis, A. longifolia</em></td>
<td>Indo-Pacific/Endemic</td>
</tr>
<tr>
<td><em>Arecaceae: Iguanurinae Type</em></td>
<td>Arecoideae, Tribe Iguanurinae</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Extinct</td>
<td></td>
</tr>
<tr>
<td><em>Asteraceae - Tubuliflorae</em></td>
<td>Asteraceae</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td><em>Asteraceae - Liguliflorae</em></td>
<td>Asteraceae</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td><em>Cassarina</em></td>
<td><em>Cassurinae</em></td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td><em>Cassarina esquifolius</em></td>
<td>Indo-Pacific, probably extinct/contamination</td>
</tr>
<tr>
<td><em>Celtis</em></td>
<td>Ulmaceae</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td><em>Celtis pacifica</em></td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Coprosma</em></td>
<td>Rubiaceae</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td><em>Coprosma segetalis, C. rapensis</em></td>
<td>Pacifi/Endemic</td>
</tr>
<tr>
<td><em>Cyatheaceae</em></td>
<td>Cyatheaceae</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td><em>Cyatheaphyllum, C. mediterranea, C. rapensis, C. stokesii</em></td>
<td>Indo-Pacific/Endemic</td>
</tr>
<tr>
<td><em>Cyperaceae</em></td>
<td>Cyperaceae</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Numerous species</td>
<td>Pan-tropical, cosmopolitan</td>
</tr>
<tr>
<td><em>Davalliales</em></td>
<td>Davalliales/ Dennstaedtiaceae</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Numerous species</td>
<td>Pan-tropical, cosmopolitan</td>
</tr>
<tr>
<td><em>Dryopteridaceae</em></td>
<td>Dryopteridaceae</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Numerous species</td>
<td>Pan-tropical</td>
</tr>
<tr>
<td><em>Euphorbiaceae</em></td>
<td>Euphorbiaceae</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Numerous species</td>
<td>?</td>
</tr>
<tr>
<td><em>Freylinia</em></td>
<td>Pa شأنiaceae</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td><em>Freylinia arborea</em></td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Glochidia</em></td>
<td>Euphorbiaceae</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td><em>Glochidia longifolia, G. rapaense, G. socotrentis</em></td>
<td>?</td>
</tr>
<tr>
<td><em>Haloragaceae</em></td>
<td>Haloragaceae</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td><em>Haloragis stokesii</em></td>
<td>Indo-Pacific/Endemic</td>
</tr>
<tr>
<td><em>Hebe rapensis</em></td>
<td>Scrophulariaceae</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td><em>Hebe rapensis</em></td>
<td>New Zealand/Endemic</td>
</tr>
<tr>
<td><em>Hibiscus tiliae</em></td>
<td>Malvaceae</td>
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<td>Y</td>
<td>Y</td>
<td><em>Hibiscus tiliae</em></td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Hypochoerus</em></td>
<td>Dennstaedtiaenceae</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td><em>Hypochoerus punica</em></td>
<td>Indo-Pacific/Pan-tropical</td>
</tr>
<tr>
<td><em>Lycoctonum sp.</em></td>
<td>Lycoperidaceae</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Numerous species</td>
<td>?</td>
</tr>
<tr>
<td><em>Malvaceae undifferentiated</em></td>
<td>Malvaceae</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Numerous species</td>
<td>?</td>
</tr>
<tr>
<td><em>Meryta</em></td>
<td>Araliaceae</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td><em>M. chloristantha, M. breviflora</em></td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Monolete Psilata</em></td>
<td>?</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Numerous species</td>
<td>?</td>
</tr>
<tr>
<td><em>Monolete undiff.</em></td>
<td>?</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Numerous species</td>
<td>?</td>
</tr>
<tr>
<td><em>Myrtaceae undiff.</em></td>
<td>?</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Numerous species</td>
<td>?</td>
</tr>
<tr>
<td><em>Omalanthus</em></td>
<td><em>Umbilicaria</em></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td><em>Omalanthus minor, O. stokesi</em></td>
<td>Indo-Pacific/Endemic</td>
</tr>
<tr>
<td><em>Pandanus cf. tectorius</em></td>
<td><em>Pandanus</em></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td><em>Pandanus tectorius</em></td>
<td>Indo-Pacific/Endemic</td>
</tr>
<tr>
<td><em>Pactaceae</em></td>
<td><em>Pactaceae</em></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Numerous species</td>
<td>?</td>
</tr>
<tr>
<td><em>Peripus</em></td>
<td><em>Peripodotaceae</em></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Numerous species</td>
<td>?</td>
</tr>
<tr>
<td><em>Polyodotaceae</em></td>
<td><em>Polyodotaceae</em></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Numerous species</td>
<td>?</td>
</tr>
<tr>
<td><em>Rubusaceae</em></td>
<td><em>Rubusaceae</em></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Numerous species</td>
<td>?</td>
</tr>
<tr>
<td><em>Sophora</em></td>
<td><em>Fabaceae</em></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td><em>Sophora tomentosa</em></td>
<td>Pacific</td>
</tr>
<tr>
<td><em>Trialete Psilata</em></td>
<td>?</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Numerous species</td>
<td>?</td>
</tr>
<tr>
<td><em>Trialete undiff.</em></td>
<td>?</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Numerous species</td>
<td>?</td>
</tr>
<tr>
<td><em>Triumphetes comp.</em></td>
<td><em>Urticaceae</em></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td><em>Triumphetes procumbens</em></td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Urticaceae/Moraceae</em></td>
<td><em>Urticaceae/Moraceae</em></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Numerous species</td>
<td>?</td>
</tr>
</tbody>
</table>

**Table 6.3** Palynomorphs from Tukou Core 1. Listed are the presence or absence of palynomorphs in Tertiary and mid-Holocene sediments or from sediments <2,000 cal. yr B.P. in age. Also listed are the possible representatives of the palynomorphs found in the modern flora and the biogeographic affinity of taxa. 1 Pollen or spore type wind blown. 2 pollen or spore type capable of long distance dispersal (after Close et al 1978)
Figure 6.9a Percentage pollen diagram for Tukou Core 1 (total of 6.55 m). The following are presented in the diagram from left to right: Core lithology (>0= increasingly coarse), magnetic susceptibility values (k), calibrated radiocarbon ages (line and ticks with the Tahitian sea-level curved overlayed in green after Bard et al 1996), taxa (pollen and spores: taxa with ≥5% of total palynomorph sum are presented as colour coded bars; samples with proportions <5% are presented as triangle symbols) and total palynomorph concentrations (per cm²), microcharcoal particle concentrations (per cm²), foraminifera and dinoflagellate counts, palynomorph richness (number of taxa), Correspondence Analysis scores (CA score 1) and palynological zones. Four palynological zones (Early Holocene Marine Transgression Zone I; Mid-Holocene highstand Zone II; Late Holocene swamp forest Zone III; Human impact Zone IV) are presented. The dashed black line indicates the position of the high tide line. The horizontal transparent red bar indicates the section of the core where the sedimentary unit associated with palynological signatures of human impact (namely micro-charcoal particles) are poorly constrained by radiocarbon ages as shown in Figure 6.9b and discussed in Chapter 7.
Figure 6.9b Percentage pollen diagram for Tukou Core 1 (total of 6.55 m). The following are presented in the diagram from left to right: Core lithology (>0= increasingly coarse), magnetic susceptibility values (k), calibrated radiocarbon ages (line and ticks with the Tahitian sea-level curved overlayed in green after Bard et al. 1996), (pollen and spores: taxa with <5% are presented as coloured triangle symbols) and total palynomorph concentrations (per cm³), microcharcoal particle concentrations (per cm³), foraminifera and dinoflagellate counts, palynomorph richness (number of taxa), Correspondence Analysis scores (CA score 1) and palynological zones. Four palynological zones (Early Holocene Marine Transgression Zone I; Mid-Holocene highstand Zone II; Late Holocene swamp forest Zone III; Human impact Zone IV) are presented. The dashed black line indicates the position of the high tide line. The horizontal transparent red bar indicates the section of the core where the sedimentary unit associated with palynological signatures of human impact (namely micro-charcoal particles) are poorly constrained by radiocarbon ages as shown in Figure 6.9a and discussed in Chapter 7.
Zone II (255 to 145 cm; −4,000 - 1,500 cal. yr B.P.)

Ferns spores continue to dominate the early part of this Zone but in fluctuating proportions and decrease by 3,000 cal. yr B.P. in response to increasing Pandanus cf. tectorius and Cyperaceae pollen. Palynomorph concentrations decline from the base of this Zone to the lowest recorded concentrations recorded at the top of the zone from 3,000 - 2,000 cal. yr B.P. Both foraminifera and dinoflagellates reappear in the early part of this Zone from 4,000 to 3,000 cal. yr B.P. (see below for further discussion of this Zone)

Zone III (145 to 85 cm; −1,500 - 1,000 cal. yr B.P.)

Pandanus cf. tectorius pollen along with palynomorph concentrations increase from the base of this Zone. Trilete fern spores including Cyathea tree fern and Angiopteris types decline in this Zone. Celtis (probably C. pacifica) and Arecaceae: Iguanurinae type pollen become more consistently represented in this Zone.

Zone IV (85 to 0 cm; −1,000 cal. yr B.P. to present)

Apart from Myrtaceae (undifferentiated to species) pollen, all tree and shrub taxa and trilete type fern spores decline or are absent in this Zone. Charcoal particles first appear in high concentrations at the base of this zone. Pandanus cf. tectorius type peaks to its highest recorded levels at the base of this Zone. Charcoal concentrations and Pandanus proportions decline to low levels in association with a sedimentary change at around 50 cm below the marsh surface. Cyperaceae and Poaceae (both <40 and >40µm size classes) and palynomorph concentrations increase to their highest levels at the top of this Zone.

Correspondence analysis (CA)

Correspondence analysis was performed on the percentage data all pollen and spore taxa identified in Tukou Core 1. Eigenvalues (Axis I) generated for each sample are presented as proportions of the total variation in the dataset in each of the two stratigraphic diagrams (Figures 6.9a and 6.9b). These values account for 36 % of the variation in the entire dataset. These values are primarily controlled by the proportions of Pandanus cf. tectorius type pollen within each sample. The greatest variation that exhibited in this core occurs in the basal section of Zone I from −6,500 - 6,000 cal. yr B.P. and in Zones II and IV.
Vegetation history

Early Holocene marine transgression Zone I (~6500 - 4000 cal. yr B.P.)

The dominance of ferns (e.g. *Angiopteris*) and *Cyathea* tree ferns from ~6,500 cal. yr B.P. indicate a waterlogged swamp setting characterised by prominent alluvial sedimentation infilling an intertidal embayment indicated by the presence of foraminifera, dinoflagellates and littoral/intertidal shell remains. Some tree and shrubs including *Pandanus* and *Triumfetta* (a coastal strand taxon) were located along the coastal surrounding the throughout this Zone. The extinct Arecaceae: Iguanurinae type palm became prominent on the coastline after around 6,500 cal. yr B.P.

Mid-Holocene highstand Zone II (~4,000 - 1,500 cal. yr B.P.)

Fluctuation in the estuarine hydrology of the waterlogged fern swamp from 4,000 - 3,000 cal. yr B.P. is indicated by traces of both foraminifera and dinoflagellates as well as differing proportions of littoral/intertidal shell remains at irregular depths. A coastal *Pandanus* forest with a sedge (Cyperaceae) understorey is represented but is restricted to the brackish/freshwater periphery of the fern swamp and estuary after 3,000 cal. yr B.P. This swamp forest is restricted from expanding by high sediment mobility from both transgressive and regressive hydrological influences inferred from extremely low palynomorph concentrations (see below for further discussion).

Late Holocene swamp forest Zone III (~1,500 to 1,000 cal. yr B.P.)

After around 1,500 cal. yr B.P. the *Pandanus* coastal forest expanded behind a prograding tidal-river levee indicated by a magnetic susceptibility peak (high mineral sedimentation) and the absence of calcareous shell remains. This restricted any tidal influence on the site and allowed the predominantly freshwater swamp to develop. Other taxa including *Celtis* and the Arecaceae: Iguanurinae type palm become established within this developing swamp forest.

Human impact Zone IV (~1,000 cal. yr B.P. to present; see Chapter 7 for discussion)

This Zone, divided into two parts, is characterised by palaeoenvironmental human impact signatures including swamp forest decline in response to burning indicated by peaks in
microcharcoal particles. From the presence of charcoal particles radiocarbon dated from Zone I it is clear that burning was part of the pre-human island ecosystem. An interpretation of charcoal particles present in Zone IV may therefore remain equivocal in the absence of other human impact indicators. This problem is illustrated by the peaks in charcoal particles in the first part of this Zone (highlighted in Figures 6.9a and 6.9b) that are followed by an increase in Pandanus cf. tectorius representation. Peaks in Pandanus pollen may be representative of one of the following: sediment compaction in the early part of this Zone allowing for pollen to accumulate and become more concentrated with depth; the opening of forest conditions allowing for more pollen deposition; or the possibility that Pandanus responds to burning by increased flowering and pollen production.

The abrupt decline in Pandanus in the later part of this Zone (above 50 cm below marsh surface) appears to represent a more precise indication of human activity. This palynological signature of coastal swamp forest clearance appears similar in extent to that represented by the modern marsh at Tukou. The decline in charcoal signals in this later part may represent a decreased in the amount of available fuel available for burning at Tukou after an initial peak in human-induced fires. This Zone is discussed in more detail in Chapter 7.

Regional mid-Holocene high stand signatures in Oceanic Island Remote Oceania

As discussed earlier in this chapter, hydro-isostatic adjustments during interglacial periods of the Pleistocene are not well defined for OIRO. Definition of geodynamic theories surrounding hydro-isostatic adjustments has been largely constructed from Holocene evidence. Emergent palaeoshoreline notches in limestone seacllifs provide the most distinct signatures for palaeo-high-tide levels and emergent palaeoreefs provide robust indications of former low tide levels (Dickinson, 2001). The most frequently observed pattern of relative sea level is of a uniform rise in eustatic sea level followed by a regionally variable late Holocene sea level regression (ibid). These emergent palaeoshoreline signatures have been dated to the mid-Holocene and have become critical to understanding how modern shorelines have been conditioned.

An increasing number of alternative geomorphological signatures for mid-Holocene shorelines have been recognised that indicate 1 to 5 m fluctuations in sea level from around 5,000 to 2,000 cal. yr B.P. (see Grossman et al 1998; Dickinson, 2001 and Long, 2001 for reviews). Heights of these palaeoshoreline signatures above their modern counterparts are thought to be dependent on local lithospheric conditions whether by thermal subsidence of the lithosphere (mantle rheology) or thermal uplift from recent or active hotspot volcanism. Other factors may also be involved.

For much of Remote Oceania interpretations of mid- to late Holocene sea level fluctuations may have had an impact on human colonisation of the region. Dickinson et al (1994; 1999);
Dickinson and Green (1998) and Dickinson (2001; 2003) have examined these signatures for some archipelagos in an attempt to interpret the environments of early human colonisation sites for OIRO. For much of OIRO, human colonisation closely followed a mid-Holocene highstand, in some cases with a delay of around 1500 years after highstand conditions waned. Dickinson (2003) has put forward one hypothesis, suggesting the length of this delay in colonisation may have been regionally determined by the development of attractive coastal environments. Alternative hypotheses have been proposed such as climate change (Bridgeman, 1983); a lack of archaeological evidence for early occupation sites (Kirch, 1996) maritime technology and El Niño-Southern Oscillation forcing (Anderson, 2003b; Anderson et al 2006) and other cultural reasons (e.g. Irwin, 2000).

Signatures for mid-Holocene hydro-isostatic sea level fluctuations have been explored for the anomalous SPS/SOPITA region (Figure 6.2) that encompasses the Austral Islands, by Pirazzoli and Montaggioni (1988), Mitrovica and Peltier (1991) and more recently by Dickinson (1998; 2000; 2001). Palaeoshoreline signatures from this region indicate a prolonged mid-Holocene highstand within the region, especially in the Tuamotu Archipelago where the positions of palaeo reef flats (at the maximum elevation points of these islands) above modern counterparts vary in age from ~5,000 cal. yr B.P. to as late as 1,250 cal. yr B.P. Pirazzoli and Montaggioni (1986). Dickinson (2001; 2003 after Pirazzoli and Montaggioni, ibid) points out that human colonisation of many of the Tuamotu atolls would not have been possible until after around 1,200 cal. yr B.P. when the islands were exposed. Present archaeological data from these atolls is insufficient to assess the timing of initial colonisation of these islands (Chazine, 2003).

Dickinson’s (2003) analysis and hypothesis of regarding the influence of a prolonged mid-Holocene highstand not only enables the characterisation of island environments immediately preceding human colonisation but also outlines some important features of coastal evolution that may be important for the establishment of coastal floras. A late Holocene expansion of coastal swamp forests and marshes on OIRO sites between 4,000 and 1,000 cal. yr B.P. has been documented for the Hawaiian Islands (e.g. Athens and Ward, 1993; Athens, 1997) and Rapa (see below). Similar records have been found in Micronesia (e.g. Athens and Ward, 1995; 2001; 2004) and Tonga (Fall, 2005), although late Holocene human impact is thought to have distorted the initiation of coastal swamp vegetation development at these sites.

Mangrove sediments and palynological records of sea level change

Records of coastal vegetation development in OIRO following mid-Holocene sea level change are available from mangrove pollen studies in Micronesia (e.g. Ward, 1988; Kawana et al 1995) and Tonga (Ellison, 1989). The term ‘mangrove’ applies to any woody species that inhabit coastal environments regularly inundated by salt or brackish water (Grindrod, 1988). The composition of
mangrove vegetation is such that species tend to be zonally distributed along saline and tidal gradients. Modern pollen studies of mangrove vegetation suggest that both pollen and macro-botanical remains of most mangroves are deposited immediately adjacent to the mangrove species zone (e.g. Grindrod, 1985; 1988; Woodroffe et al. 1985), although sediment mixing from tides and bioturbation may alter this pattern (Chappell and Grindrod, 1985). Sediment is often accreted immediately behind the prop roots and pneumatophores of mangroves creating an autogenic environment allowing for further establishment of mangrove species.

The capacity of lagoonal-marsh sediments to preserve pollen in concentrations suitable for pollen analysis varies widely. Optimal conditions are most likely along muddy, low energy shores which supports vegetation containing high pollen producers and where sediment accumulation is not excessive (Grindrod, 1988). Muller (1959 in Grindrod, 1988) estimates pollen concentrations in deltaic mangrove sediments are highest where organic and mineral accumulation is slow but this also varies as a function of distance from high pollen producers.

In a study of mangrove sedimentation in Northern Queensland, Grindrod (1985) found that pollen concentrations in sediments from Rhizophoraceae-dominated forest generally lie between 4,000 and 10,000 pollen grains per cubic centimetre of sample to greater than 100,000 pollen grains per cubic centimeter for high tide mud facies. The high concentrations in the latter instance are a result of slow sedimentation rates, and/or localized deposition of pollen from salt marsh plants which produce large amounts of pollen.

**Mangroves in the Austral Islands**

The most widespread 'true' mangrove species in OIRO, *Rhizophora mangle*, was originally believed to be indigenous to islands west of Samoa. Ellison (1991) located what she believed to be *Rhizophora mangle* pollen from moat swamp deposits on Mangaia in the Cook Islands dating to ~4000 cal. yr B.P. (Ellison, 1994 see below). No longer found on Mangaia, this species was recently introduced to the Society Islands. Non-mangrove species of the Rhizophoraceae (e.g. *Crossostylis biflora* an inland species) are found in the OIRO region distributed east as far as the Society Islands but are limited to only a few high islands (Setoguchi et al. 1998). No 'true' mangrove taxa are presently known from the Austral Islands or in the sub-fossil record, but some of the specialised growth forms and life-histories that characterises the mangrove habit, namely aerial prop or stilt root growth phases are found on a few coastal strand species (e.g. *Ficus* and *Pandanus* species).

Prop roots are found on many species of *Pandanus* (Pandanaceae), notably on the most widespread species, *P. tectorius* (Stone, 1976; 1988; St. John, 1979c). Tomlinson (1986) regards them as a stabilising feature of older trunked trees. *P. tectorius* is found throughout the tropical and subtropical Indian and Pacific Oceans in substrates ranging from freshwater swamps to
coastal rocky beaches and seasonally brackish periphery of the tidal zone. For their ability to establish on these wide-ranging environments some Pandanus species have been described as ‘freshwater mangroves’.

The prop root species *P. tectorius* is a common swamp and dry land forest tree found on all of the Austral Islands and as on other islands in OIRO, it commonly forms monospecific stands with a sedge/herb dominated understorey (Ash and Ash, 1984). As no ‘true’ mangrove species occur on the Australs, *P. tectorius* appears to assume a mangrove type habit, forming dense stands along the few margins of tidal flats where human activity has not been prominent.

Other Pandanus species may be indigenous to the Australs, for example St. John (in Fosberg and St. John) recorded 13 species of *Pandanus* on Rapa in 1934. St. John made a similar to the number of *Pandanus* species determined for many Pacific Islands (e.g. Fiji; St. John, 1976) although Stone (1988) and Smith (1981) suggest many of these are simply varieties of *P. tectorius*. In examining the genus on Tahiti, Stone (1988) could not discount the human introduction of additional of *Pandanus* species or *P. tectorius* varieties.

The tree has an unusual life history rarely found in perennial plants (Hallé et al 1978) that may be an adaptation to coastal strand environments. From a study of Fijian populations, Ash (1987) found that *P. tectorius* prop roots usually do not develop until 5-12 years after a semi-prostrate growth and trunk growth phase. Prop root growths coincide with a flowering phase that may last for up to 40 years. Like ‘true’ mangrove species this growth form allows these trees to adjust to mobile sediment regimes, but also to accrete sediment immediately behind the prop roots, creating an autogenic environment suitable for *P. tectorius* but also pollen preservation.

The Pandanus pollen record

*P. tectorius* is a species which produces vast amounts of pollen, a strategy not often exhibited in perennial dioecious taxa. *Pandanus* pollen grains are generally dispersed by wind (anemophily) or small invertebrates (entomophily) (Meilleur et al 1997). Modern pollen studies of *Pandanus* suggest it is only locally dispersed, though one case of long distance dispersal, presumably by river transport, to deep-sea sediments has been recorded by Van der Kaars (1991). One study from a series of lowland swamp forest sites in Southeast Asia (Anderson and Muller 1975) found that pollen representation may be poor from sites dominant in *Pandanus*, but this may be due to differential pollen production of species other than *P. tectorius*.

The Tukou Core 1 palynological record (Figures 6.9a and 6.9b) described in this chapter outlines the coastal significance of *P. tectorius* from the early Holocene. The morphological variability of pollen located in this core and other cores from Rapa and Rimatara (see below) is such that *P. tectorius* seems the most likely species ascribed to this pollen. It is likely that for this reason no other species will be discernable with any certainty. From Zone III of the Tukou Core 1
I suggest that *Pandanus tectorius* swamp forest expanded behind a prograding tidal-river levee after around 2000 cal. yr B.P. This levee probably appeared due to accreting sediments built up behind developing *Pandanus* prop roots during a period of stable sea level. This autogenic process acted to restrict any tidal influence on the site and allowed the predominantly freshwater swamp to develop. Other taxa including *Celitis* and the Arecaceae: Iguanurinae type palm become established within this developing swamp forest.

This swamp forest expansion described may have allowed many plant taxa to establish on the island in a formerly restricted or unavailable environment. For this reason I thought it worthwhile to outline the timing and development of this swamp forest in more detail given that the stratigraphic profile in Tukou Core 1 appears to not only record vegetation responses to sea level fluctuations but also sharp responses to human activity. In the following section I will outline the vegetation response to fluctuating sea levels, focusing on the mid-Holocene highstand and then the chronological development of swamp forest in the late Holocene.

### The mid-Holocene highstand and late Holocene vegetation change on the Austral Islands

In order to chronologically define the response of vegetation to mid-late Holocene fluctuations in sea level, geomorphic indicators of regional relative sea levels must be outlined. Hydro-isosastic and observed emergence data for mid-Holocene palaeoshorelines have been outlined for Rurutu and Tubuai (Table 6.4) from limestone notches, emergent microatolls and palaeo-beach rock on reef islets by Dickinson (1997; 1998; 2001). Some measurements were originally taken by Pirazzoli and Montaggioni (1988) but later re-examined by Dickinson. Such signatures have either not been measured in the case of Ra’ivavae, or, are unavailable for Rimatara and Rapa.

According to Dickinson, the especially high Last Interglacial palaeoshoreline indicators from Rurutu (~11 m) are anomalous, however, he did not take into account the recent discovery of the Arago hotspot (Bonneville *et al* 2002) to the southwest of the island. This is currently being re-examined (Bill Dickinson pers. comm. 2004 see below for further discussion). From the author’s own survey of the island, no palaeonotch surfaces of probable mid-Holocene age were located on Rimatara above the modern notch system. Despite these discrepancies it appears that from around 5000 to 3000 cal. years B.P., a highstand of less than 2 m in magnitude occurred regionally.
Mid-late Holocene vegetation change at Tukou using multiple profiling

In order to determine the position of relative Holocene sea level at Tukou from palynological and sedimentary proxies, a multiple profile approach was chosen that allows for direct pollen stratigraphic correlation (sensu Clark et al. 1986). Due to the complexities of palynological analyses, multiple profiles are rarely analysed for palynological signatures. Instead, palynologists tend to either increase the temporal resolution of a single profile, or take single profiles in order to compare between individual depositional settings within a region. The multiple profile approach allows local or extralocal spatial variations in pollen representation to be examined in more detail (Dumayne-Peaty and Barber, 1998). If a reliable absolute chronology is obtained, it also allows palynological signatures to be more precisely linked to stratigraphic processes both spatially and chronologically.

<table>
<thead>
<tr>
<th>Island</th>
<th>Hydro-isostatic emergence (m)</th>
<th>Sea level proxy</th>
<th>Observed emergence (m) [mean]</th>
<th>Observed emergence (m) [range]</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rimatara</td>
<td>2.0-2.6?</td>
<td>Absence of palaeo-shoreline notches</td>
<td>0</td>
<td>0</td>
<td>1,3; this thesis</td>
</tr>
<tr>
<td>Rurutu</td>
<td>2.0-2.6?</td>
<td>Palaeo-shoreline limestone notches</td>
<td>1.2-1.7</td>
<td>1.2-1.7</td>
<td>1,2</td>
</tr>
<tr>
<td>Tubuai</td>
<td>2.0-2.6?</td>
<td>Emergent microatolls; Palaeo-beach rock on reef islets</td>
<td>0.8-0.9</td>
<td>0.5-1.0</td>
<td>1,2</td>
</tr>
<tr>
<td>Ra’ivavae</td>
<td>&lt;2.0-2.6 from volcanic loading?</td>
<td>Palaeo-beach rock on reef islets</td>
<td>?</td>
<td>?</td>
<td>1</td>
</tr>
<tr>
<td>Rapa</td>
<td>&lt;2.0-2.6 from volcanic loading?</td>
<td>Sediment and palynological record</td>
<td>0.34</td>
<td>Three data points between 0.20 and 0.60 m</td>
<td>4, this thesis</td>
</tr>
</tbody>
</table>


Table 6.4 Comparison of post-mid-Holocene hydro-isostatic emergence and observed emergence (mean and range) of palaeo-shoreline indicators for the Austral Islands. For each of the islands the influence of the SPS-SOPITA is not significant (Dickinson, 2001). The observations for Rapa are described in the text.

Multiple pollen profile studies from the same lakes or mires (e.g. Turner, 1975; Edwards, 1983; Boyd, 1988; Simmons and Innes, 1996; Turner et al. 1989) have demonstrated that there are often broad stratigraphic similarities between profiles. Within such ‘ideal’ depositional settings, however, differences in pollen representation over distances of less than 10 m have been observed.
(Turner et al 1989). Such studies have highlighted the importance of localised spatial variation in pollen deposition and reproducibility of palynological results (Dumayne-Peaty and Barber, 1998).

Because lake and mire settings are more easily assessed in terms of sedimentary deposition and post-depositional processes, the relationship between pollen representation and stratigraphic units is better defined for these sites. For depositional settings that are not ‘ideal’ such as coastal marshes (e.g. Tukou), sedimentary, edaphic and taphonomic influences can often obscure patterns of pollen representation. Multiple profiles studies of coastal marsh deposits, particularly of mangrove sediments have highlighted variations in post-depositional processes and taphonomic constraints.

In tropical/sub-tropical areas, palynological multiple profile studies of coastal deposits are restricted to mangrove sediment studies (e.g. Grindrod, 1985; 1988; Woodroffe et al 1987; Ellison, 1989). These studies have been effective for examining intertidal vegetation change from sub-fossil records based on the interpretation of the modern palynological responses of individual species to sea level fluctuations. Multiple profiles of mangrove sediment has allowed for palynological and sedimentary units to be correlated and tied to regional stratigraphic processes inferred from regional sea-level curves and from local stratigraphic events and processes including storms, coastal progradation and human activity. This approach is applied here to the Tukou marsh site on Rapa focusing on the palynological response of Pandanus and other associated pollen to mid-late Holocene sea level fluctuations.

Field methodology

In addition to the retrieval of Core 1 at Tukou, five cores were taken at 20 m intervals along a transect running through the centre of the marsh from the Core 1 site at the shoreline to the embankment behind the marsh. The five cores were all taken with a D-Section corer. An attempt was made with each coring point to reach bedrock or to a depth where compacted basal clays prevented further penetration. The relative position to high tide sea level was determined from laser transit measurements. The main parameters of each core are outlined in Table 6.5.
The same laboratory and numerical methods were applied to each of these cores as for Core 1. A total of 19 samples were submitted for AMS radiocarbon dating at different intervals throughout each core and these are listed in Table 6.2. The calibrations provided were calculated using the OxCal program version 3.10 with the IntCal04 calibration data set (Bronk Ramsey, 2001; 2005). Of these radiocarbon samples, two macro-charcoal and two plant macro-remain samples (Celtis cf. pacifica seeds, Pandanus cf. tectorius key) were submitted. The remaining 15 samples were submitted as pre-treated pollen concentrates processed using standard pollen protocols without the addition of carbon based acids.

A series of composite stratigraphic diagrams (Figures 6.10a and 6.10b) were constructed using the program C2 Data Analysis version 1.4 (Juggins, 2005). In each diagram, each core profile is vertically aligned according to relative sea level (at high tide) and their relative position from the original core site (Tukou Core 1). Calibrated radiocarbon age ranges and linear age models are presented for each core in these diagrams. Magnetic susceptibility data and total pollen and spore concentration (per cm$^3$) data are each presented in a composite diagram to illustrate the preservation conditions operating across the site (Figure 6.10a). Pandanus cf. tectorius pollen and Trilete Psilate fern spore concentrations (per cm$^3$), with foraminifera and dinoflagellate count data, are shown in a (Figure 6.10b) separate composite diagrams in order to outline regional versus local pollen representation across the site.

### Table 6.5 Main core parameters and central point estimates (cal. yr B.P.) for the oldest radiocarbon determinations for each core from Tukou.

<table>
<thead>
<tr>
<th>Core features</th>
<th>Core 3</th>
<th>Core 6</th>
<th>Core 2</th>
<th>Core 5</th>
<th>Core 4</th>
<th>Core 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of core (cm)</td>
<td>318</td>
<td>250</td>
<td>400</td>
<td>250</td>
<td>250</td>
<td>652</td>
</tr>
<tr>
<td>Basal clay reached</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Depth above high tide (cm)</td>
<td>300</td>
<td>243</td>
<td>196</td>
<td>161</td>
<td>111</td>
<td>20</td>
</tr>
<tr>
<td>Distance from shoreline (m)</td>
<td>105</td>
<td>85</td>
<td>65</td>
<td>45</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>Number of AMS radiocarbon determinations</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Oldest determination (depth in cm)</td>
<td>3,055 (240-242)</td>
<td>2,540 (210-212)</td>
<td>4,000 (256-258)</td>
<td>2,300 (244-246)</td>
<td>2,150 (194-196)</td>
<td>7,875 (624-626)</td>
</tr>
</tbody>
</table>

**Laboratory methods and data presentation**

Core lithology and radiocarbon ages with the associated linear age models are presented, along with magnetic susceptibility data (k) and total pollen and spore concentration data in Figure...
6.10a. These data are presented in order to define sedimentary units and to illustrate changing palynomorph preservation down each profile and across the Tukou Marsh site.

The stratigraphic relationships of Cores 2-6, divided into four sedimentary units, are described here in the context of Core 1. Direct indications of estuarine or littoral conditions are available from the shell macro-remains of bivalves and gastropods from the basal sediment unit (Unit I) of each core. Similar taxa to those found in the early-mid Holocene Zones (I-II) of Core 1 were represented in each core. Sediments from Unit I produced similar magnetic susceptibility readings to that derived from the basal Zones of Core 1. The deepest section of estuarine or littoral sandy sediment was obtained from Core 2 (184 cm section; -16 to -200 cm below modern sea level) in the central part of the marsh.

As in Core 1, above the basal sandy sediments of Cores 2-6, lies a predominantly silty organic unit (Unit II) varying in depth from 68 cm in Core 4 (+11 to −57 cm below modern sea level) to 6 cm in Core 6 (27 to 21 cm above modern sea level) and made up of differing degrees of silt and clay, but lacking any calcareous material. For Cores 2-6, this silty organic unit is overlain by a peaty unit (Unit III) topped by interbedded silty organics with some fine clay or silt lenses that are absent in Core 1. The peaty sections of Unit III are generally very fibrous consisting of root material, occasional seeds (Celtis cf. pacifica endocarps and Pandanus cf. tectorius fruits remains, termed keys or phalanges). Above Unit III lies an organic unit (Unit IV) consistent with the sedimentary features of the modern marsh. With the exception of Core 3, the most inland core site at Tukou, the upper part of this unit consists of either silty or clayey sediment with sedge (Cyperaceae) and grass (Paspalum conjugatum) roots. Sediments from the upper 75 cm of Core 3 appear to be derived from inwashed material from the surrounding embankment backing the marsh and produced magnetic susceptibility values up to 200 K units.

Two samples submitted for dating failed the AMS process due to a lack of concentrated carbon (these are shown in brown in Table 6.2). The oldest and most basal ages for each core, aside from Core 1 are highlighted as central point estimates in Table 6.5. The oldest age for these cores, 4,850-3,150 cal. yr B.P., was obtained from Core 2 and taken from a Pandanus cf. tectorius key (256 cm below the swamp surface or −56 cm below modern sea level) located from Unit I sediments. Apart from the large error on this determination, this Pandanus key may have been redeposited from beach drift and may represent a substantially older date than for sediment deposition. No dates for Unit I sediments were obtained from Cores 3 and 6. The age ranges for Unit I from Cores 2-6 vary between −4,000-2,500 cal. yr B.P. and are comparable to ages from the upper most sediments of Zone II Core 1. Dates obtained from both Unit II and III sediments vary from −2,500 to 1,000 cal yr B.P. Unit IV sediments are all younger than −1,000 cal. yr B.P. and these are discussed more in Chapter 7.
Figure 6.10a Composite stratigraphic diagram for Tukou Marsh showing the calibrated age ranges (lines and ticks; red ticks = the inferred post-European contact record; see Chapter 7), lithology (the scale grades from 1 = fine to 4 = coarse; the positions of plant macrofossils are also indicated) and bar histograms of magnetic susceptibility data (k) and pollen concentrations (per cm³). Pollen concentrations are presented proportionally with each tick mark representing 100,000 grains per cm³. The transparent vertical red bar within the radiocarbon age range histogram represents the earliest archaeological radiocarbon determination obtained for Rapa (770–540 cal. yr B.P.). Each core is spaced 20 m apart with Core 1 situated 5 m from the marsh shoreline. Each profile is vertically aligned with relative sea level with the modern high tide level marked by the black dashed line. The calibrated relative sea level curve chronology from Tahiti is presented with the Core 1 chronology in the same histogram. Four sedimentary units are delineated on the basis of major shifts in sediment deposition and are marked by coloured lines (black = Unit I; brown = Unit II; green = Unit III; red = Unit IV). The horizontal transparent red bars indicate the section of each core where the sedimentary units associated with palynological signatures of pre-European human impact are poorly constrained by radiocarbon ages as shown in Figure 6.10b and discussed in Chapter 7.
Figure 6.10b Composite stratigraphic diagram for Tukou Marsh showing the calibrated age ranges (lines and ticks; red ticks = the inferred post-European contact record; see Chapter 7), bar histograms of Trilete Psilate fern spore and Pandanus cf. tectorius pollen concentrations (per cm$^2$). Spore and pollen concentration data are presented proportionally with each single tick mark representing 50,000 grains per cm$^2$. Foraminifera and dinoflagellate counts are also presented as bar histograms. The stratigraphic alignment of each core is displayed as for Figure 6.10a with the modern high tide level marked by the black dashed line. Four Zones are distinguished on the basis of transitions in the palynological record and are located above the coloured lines (Zone I (Core I only); black=Zone II; green=Zone III; red=Zone IV). The horizontal transparent red bars indicate the section of each core where the sedimentary units associated with palynological signatures of pre-European human impact are poorly constrained by radiocarbon ages as shown in Figure 6.10a and discussed in Chapter 7.
The palynological data are divided into three palynological zones (II, III and IV) that correspond to the zones described for Core 1 with the exception of Zone I (Figures 6.9a and 6.9b; see above). Concentrations vary considerably across the site and chronologically throughout the four sedimentary units. The lowest concentrations (<50,000 per cm^3) are found in Zone II, and encompass Unit I and Unit II sediments and included the lower section of Unit III sediments for the four most inland cores (Core 3, 6, 2). No palynological analyses were attempted for Zone II sediments of Core 5. From the profile of Core 1, Zone II begins at around 4,000 cal. yr B.P. and terminates at around 1,500 cal. yr B.P. The development of Zone II may have been progressively delayed in the cores inland of Core 1 with the most secure age for basal Unit I (in Zone II) sediments established between 2,750-1,850 cal. yr B.P. from Core 5 (244-246 cm below swamp surface; see Table 6.2). I suggest that the organic sediments at the base of Tukou Marsh did not begin to accumulate across the site until ~3,000 cal. yr B.P. when sea level stabilised around modern levels (see calibrated RSL curve for Tahiti in Figure 6.10a after Bard et al 1996). The upper age limit of Zone II is progressively delayed by around 1,000 years from the most inland core (Core 3), culminating ~2,500 cal. yr B.P. to the most shoreward cores (Cores 1 and 4) ending at ~1,500 cal. yr B.P.

Apart from Cores 1 and 4, the greatest pollen and spore concentrations, indicative of Zone III, are found in the upper interbedded silty organic section of Unit III sediments (Zone III). Zone III is represented in the two core profiles nearest the shoreline (Cores 1 and 4) by peaks in concentrations above 100,000 (per cm^3) in Unit II sediments. Within Zone III the concentration peaks are greatest in the two most inland cores (> 500,000 per cm^3 for Core 3 and >300,000 per cm^3 for Core 6). The two cores taken from centre of Tukou Marsh produced slightly lower concentrations in this Zone (> 150,000 per cm^3 for Core 2 and >200,000 per cm^3 for Core 5). Zone III (initiated between ~2500 - 1500; ending between ~1000 - 500 cal. yr B.P.). As outlined for end of Zone II above, the initiation of Zone III is progressively delayed by around 1,000 years from the most shoreward cores (Cores 1 and 4) to the most inland core (Core 3). The chronological framework for the upper end of this Zone is more complex as the upper two sedimentary units are poorly constrained for some cores, particularly for the most inland (Core 3) and shoreward (Core 1) cores. From the remaining cores with good chronological controls, Zone III consistently ends and Zone IV begins between 1000 and 500 cal. yr B.P.

For all of the cores except Core 1, Zone IV is represented across the cores by a marked decline in pollen and spore concentrations in the upper most organic sediments of Unit III and includes Unit IV sediments. Pollen and spore concentrations in the four inland cores generally drop to <150,000 per cm^3 in this Zone. One exception to this trend is a single peak in concentration of >300,000 (per cm^3) is found in the upper section of this Zone for Core 6. As
mentions in the description of Core 1 the highest peak in concentrations found in this profile (~100,000 per cm³) is found in Zone IV or Unit IV sediments. This palynological Zone is discussed in more detail in Chapter 7.

**Palynomorph representation: the trilete psilate spore and Pandanus pollen record**

The radiocarbon ages and the associated linear age models for each core are presented with *Pandanus cf. tectorius* pollen and trilete psilate fern spore concentrations and foraminifera and dinoflagellate count data in a composite diagram in Figure 6.10b. The concentration data in this diagram are presented proportionally in order to emphasise the relative importance each palynomorph within each profile and across the coring transect. These data are presented to illustrate the incorporation of regional and local palynomorphs into the record and to assess the influence of marine conditions operating across the site. Trilete psilate fern spores are derived from numerous fern taxa and tend to be ubiquitous in Pacific island palynological records and are often regarded as regional signatures. As discussed earlier in this chapter, from modern pollen rain studies of *Pandanus*, deposition tends to be local, within short distances of the parent tree. *Pandanus* pollen concentration data are also used to assess the timing and development of coastal swamp forest and subsequent deforestation following human impact (see Chapter 7).

**Zone I** (as for the profile of Core 1)

Trilete Psilate spores make up between 15-80% of the total palynomorphs counted in Zone I (see Figure 6.10b). Spore concentrations in this Zone remain low until ~6,500 cal. yr B.P. and peak at ~5,000 cal. yr B.P. Both foraminifera and dinoflagellates are found in trace counts at the base of this Zone but were not located after around 5,000 cal. yr B.P. *Pandanus* pollen is only found in very low concentrations throughout Zone I.

**Zone II** (begins before 3,000; ending ~2,500 - 1,500 cal. yr B.P.)

Trilete psilate fern spores continue to dominate the early part of this Zone, as indicated from Core 1, but begin to decline to low concentrations (<10,000 spores per cm³) after 3,000 cal. yr B.P. If the basal radiocarbon ages are correct, this same trend is visible in the profile of Core 2. Like Zone I, *Pandanus* pollen is only found in very low concentrations throughout Zone II (<5000 grains per cm³). Both foraminifera and dinoflagellates are located in the early part of this Zone from 4,000 to 3,000 cal. yr B.P. and drop out of the record above the sandy sediment unit in the upper part of the Zone. In Core 2, foraminifera appear to decline before dinoflagellates. No foraminifera were identified in sediments from Core 4, whereas no dinoflagellates were found in Core 3. As mentioned, no palynological analyses were attempted for Zone II sediments of Core 5.
Zone III (begins ~2,500 – 1,500 cal. yr B.P.; ending ~1,000 - 500 cal. yr B.P.)

With the exception of a single peak in trilete psilate spores in Core 4 (186,000 spores per cm$^3$ at ~46 cm below sea level) at the base of Zone III, spore concentrations remain very low (<15,000 per cm$^3$) throughout this Zone across all of the profiles. The depth of Zone III (120 cm section lying at 100 cm above sea level) and the concentration of Pandanus cf. tectorius pollen (up to 600,000 grains per cm$^3$) are greatest in the most inland core (Core 3). Across the site from Core 3 there is a progressive decrease in Pandanus concentrations found for Zone III samples in core profiles taken closer to the shoreline, with Core 1 showing the lowest concentrations (<50,000 grains per cm$^3$). From the base of Zone III Pandanus pollen concentrations steadily increase, abruptly in some core profiles (Cores 2, 3 and 4), from their Zone II minimum, peaking towards the top of the Zone. Core 2 presents an exception to the above two trends having lower Pandanus concentrations (<140,000 grains per cm$^3$) than the other inland cores.

Zone IV (begins ~1,000 - 500 cal. yr B.P.; ending at the present)

Pandanus cf. tectorius pollen concentrations generally peak to their highest or near highest recorded levels at the base of this Zone within every core profile along the Tukou transect. These peaks are followed by a marked decline in locally deposited Pandanus pollen concentrations for most cores. This decline is associated with an increase in more regionally represented trilete psilate fern sporangium concentrations to levels near or greater to those found in Zones I and II.

Vegetation history

Early Holocene marine transgression Zone I (~6500 - 4000 cal. yr B.P.)

As for Zone I, Core 1 (see above)

Mid-Holocene highstand Zone II (initiated before >3000; ending ~2500 - 1500 cal. yr B.P.)

As for Core 1, fluctuations in the estuarine hydrology of a waterlogged fern swamp from 4,000 - 3,000 cal. yr B.P. is indicated by traces of both foraminifera and dinoflagellates as well as littoral/intertidal shell remains in sandy sediments found at irregular depths. For Cores 2, 3 and 6 these estuarine/intertidal sediments are located above the modern mid-tide line by 20, 22, 60 cm respectively (see Table 6.5 for a comparison of mid-Holocene sea level highstand estimates for
the Austral Islands). These measurements may represent material washed up during a storm surge, but they are regarded here as baseline observations of the probable mid-Holocene sea level highstand represented across the Austral Islands between 4,000 – 3,000 cal. yr B.P.

The preservation of regionally or extralocal palynomorphs, in this case Trilete Psilate spores, in low concentrations in the silty sediments deposited above these baseline measurements are thought to indicate a phase of sea level regression. This drop in sea level may have resulted in a shift in sedimentation from estuarine sands to near sterile alluvial silts (Unit II, see above) unconducive for palynomorph preservation. Total palynomorph concentrations recorded in Core 1 during this sedimentary section are the lowest found for the entire Holocene and are generally lower for all the core profiles. The lack of preservation of ubiquitous palynomorphs in these Unit II sediments may indicate a phase of rapid sedimentation, limited sediment accretion and possibly increased erosion characteristic of regressing sea level conditions, as discussed earlier in this chapter.

*Late Holocene Pandanus swamp forest Zone III* (initiated ~2500 - 1500 cal. yr B.P.; ending ~1000 - 700 cal. yr B.P.)

After around 2,500 cal. yr B.P. the coastal *Pandanus* forest rapidly expanded behind a prograding tidal-river levee formed during a period of stable sea level. This levee restricted any tidal influence on the site and allowed the predominantly freshwater swamp forest to develop. Swamp forest and its associated organic matter built up particularly towards the inland side of the swamp forming a thick peat deposit.

*Human impact Zone IV* (initiated ~1,000 – 700 cal. yr B.P. to present; see Chapter 7 for discussion)

As for Core 1, this Zone, divided into two parts, is characterised by swamp forest decline and the expansion of a more open marshland environment characteristic of the present day Tukou. This has already been discussed in the interpretation of Core 1 and will be addressed in more detail in Chapter 7.

**Palaeoenvironmental examination of Rimatara**

*Makatea Islands*

Rimatara is a low elevation (~83m above relative sea level) island with an area of 8.6 km² (913 ha) and is the western most Austral Island (see Figure 6.11 and 6.12). Along with Rurutu it is one
of six makatea islands of the South Pacific Superswell that consist, in geological terms, of an uplifted carbonate platform that either forms the greater part of the island (Wood and Hay, 1970), or where an annular limestone plateau surrounds a weathered volcanic bedrock core (Dickinson, 2001). Islands that strictly fall under this definition are concentrated within the southern Cooks Islands (Atiu, Mitiaro, Mauke, and Mangaia) and the Austral Islands in French Polynesia (Rimatara and Rurutu). Some other islands, including Niue and Makatea (French Polynesia) are often regarded as makatea islands, but lack the central volcanic bedrock core. One characteristic common to all of these islands is the extensive sediment infilled depressions situated along the inner rim of the annular limestone periphery at the base of the inland volcanic core. On most of makatea islands these are represented by modern surface swamp or moat, but two small brackish lakes are also known from Mangaia and Atiu. Because of the potential age these sedimentary features they have been subject to palaeoenvironmental research focusing on Holocene vegetation change.

It has been found that such moat swamp deposits may reach depths of more than 16 m below the sedimentary surface and potentially provide contiguous Holocene vegetation records rare for the Pacific Islands. Mid-Holocene aged deposits from these moat swamp and lake features have been examined on Mangaia (Ellison, 1994; Lamont, 1990) and Atiu (Parkes, 1997), situated between 550 km and 620 km west of Rimatara respectively, and their records are discussed below. One feature of these deposits is the high proportion of organic matter with a low magnetic mineral component indicative of minimal organic sedimentation. Increased sedimentation has been found in the upper horizons of these deposits suggestive of human activity. Such sedimentation, if related to human activity, is most likely a response to the introduction of agricultural practices including wet-field Colocasia esculenta (taro) cultivation (Prebble and Haberle in prep; see Chapter 7).

Mangaia

The most substantial examination of moat swamp/lake deposits comes from Mangaia in the Cook Islands (Ellison, 1994; Kirch, 1996; Kirch and Ellison, 1994; Kirch et al 1991; Kirch et al 1992; Lamont, 1990). Mangaia is the second largest island in the Cook Islands with an area of 51.8 km$^2$ and a maximum elevation of 169 m above sea level. Lamont (Lamont, 1990) and Kirch et al (1992) obtained a 15 m core (TIR-1)$^4$ representing 6,810 - 6,400 cal. yr B.P. of pollen deposition from Lake Tiriara in Veitaitai. Represented among the Holocene flora of this record are Urticaceae/Moraceae, Pandanus and Weinmannia. Arecaceae pollen is present throughout the record including Cocos nucifera. A number of ferns are represented including Acrostichum

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$^4$Kirch et al (1992) indicate that basal sediments were never reached in the coring procedure. Two other cores were obtained from the swamp in the northeast periphery of Lake Tiriara, but no results have been published.
Poaceae pollen was found throughout the core. *Acrostichum*, a salinity tolerant species, dominates the mid-Holocene pollen assemblages with increasing representation of tree and shrub species. Kirch *et al* (1992) suggest that by 1410 cal. yr B.P. tree and shrub pollen rapidly declined in response to increased anthropogenic burning represented by increased charcoal particle and fern spore (*Acrostichum* and *Dicranopteris*) counts. Erosion events are represented by thin clay bands found throughout the core with mostly inorganic sediments found in upper sections thought to be associated with human activity (see Chapter 7).

Ellison (1994) collected 21 sediment cores from the island, all taken from the moat swamp deposits bordering the *makatea* including an additional 11.5 m core from the centre of Lake Tiriara. Two moat swamp cores (VT6 and TM7) were examined for pollen with radiocarbon dates provided from 10 cm thick bulk sediment samples. Sedimentary and palynological data suggest that a number of lake environments existed during the mid-Holocene where there are now
clay-infilled swamps, presumably fed from the denuded surrounding hill-slopes as a result of human activity. With a subterranean hydrological connection (conduit) with the sea, Tiriara is the only lake, albeit brackish, remaining on Mangaia. Its surface level is regulated by small tidal fluctuations and to some degree rainfall (annual rainfall = 1967 mm). A series of solutional notches are situated on the perimeter of the lake and approximately 1.1 m above the modern lake surface. Ellison (1994) suggested that this may be a signature of a regional mid-Holocene sea-level rise (~6000 yr BP) determined from other geological records from the island (Yonekura et al 1988). In both analysed cores, Ellison (Ellison, 1994) found that Ficus, Arecaceae (Palmae), Guettarda speciosa, Weinmannia, Sophora, and Erythrina were formerly abundant during the early to mid-Holocene until the period of human settlement of the island (see Chapter 7 for discussion), confirming the earlier findings of Lamont (1990) and Kirch et al (1992).

Atiu

The only other makatea island examined for palynological records is Atiu. Atiu is the third largest island in the Cook Islands with an area of 26.9 km² and a maximum elevation of 72 m above sea level. In 1986, Parkes (1997) obtained a sediment core with a maximum depth of 8.4 m from Te Roto, the only moat lake present on Atiu. This sedimentary sequence represents a maximum of 9000 cal. yr B.P. of pollen deposition. The lake is about 3 to 4 m above sea level but like Tiriara exchanges water from the sea through a sub-makatea conduit system. The lake level may fluctuate with the tide and may become slightly brackish after heavy storms (Kauta'i, 1984), suggesting such water exchange maybe pressure related.

No complete pollen diagrams have been published for this record. Parkes does include an informative summary diagram within her 1997 paper. The flora represented within this Holocene record include Pandanus, Calophyllum and Trema along with Elaeocarpus, Allophyllus and Rapanea. Arecaceae pollen including a Pritchardia (P. vuylstekeana) type pollen are represented with Cocos nucifera dominating much of the mid-late Holocene record. Like in the Mangaia records, Acrostichum aureum dominates the early to mid-Holocene pollen assemblages with increasing representation of tree and shrub species. Parkes (1997) suggests that Acrostichum aureum and Cocos nucifera are capable of out-competing other plants that may be under stress from some extreme environmental factor. Evidence for human impact on the island in the form of increases in grasses, ferns, sedges with declines in the primary arboreal taxa begins in the upper 3m of the record (see Chapter 7 for discussion).
Rimatara

The moat lakes of the type found on Mangaia (Tiriara) and Atiu (Te Roto or Tiriroto) may have been present on Rimatara but have subsequently been infilled to form swamps. The moat swamps on Rimatara are likely to be hydrologically connected with the sea through a sub-makatea conduit system. Evidence for this comes from the location (by Ron Englund and the author) of a population of diadromous eels (Anguilla sp.) within a ponded area immediately below the makatea at Maunutu. A 1/10,000 scale map of Rimatara edited by the Service de l’Urbanisme, (1988; see Figure 6.12) indicates that the surface of all four of the moat swamp systems are no more than 1m above sea level. A series of solutional notches are situated on the perimeter of the swamp along the mato edge and are between 0 and 20 cm above the modern swamp surface. These observations and measurements were undertaken during the dry season (October-November) and it is probable that the water table of these moat swamps may rise with seasonal precipitation.

It has been concluded from such notch features on Mangaia (Cook Islands) that are raised above the moat swamp or lake surface by up to 1.1 m that this may reflect regional mid-Holocene (~6000 yr BP) sea level conditions (Ellison, 1994; Kirch and Ellison, 1994). From a brief survey of the coastline of Rimatara (by the author) palaeo-notch features of around 1-2 m above the modern notch are absent from the surface of the calcareous base. This lack of palaeo-notches may reflect a hydro-isostatic balance (island subsidence occurring at an equal rate to sea-level fall) or more likely reflects the degraded nature of the coast-facing sections of the mato. This is not unlikely given that on Rurutu there is only one mid-Holocene notch preserved at 1.7 m above a modern notch (Pirazzoli and Salvat, 1992; Dickinson, 1998; see above for further discussion of this subject).

Palaeoenvironmental examination of Maunutu Moat-Swamp, Rimatara

The modern moat-swamp: geography, climate and vegetation

A palaeoenvironmental survey of the moat swamp deposits of Rimatara, was conducted between October and November of 2004. Four large (>5 ha) swamp deposits can be distinguished on island (Mururau, Maunutu, Hareti’i, Tupapa), the largest being Mururau (~40ha) located to the north west of Amaru village (Figure 6.12). Mururau, has been drained on the northwest side with extensive artificial channels cut to feed some of the eastern conduits (natural channels that drain the moat swamps and extend below the makatea - known as mato on Rimatara). Much of the southeast side of Mururau swamp has been in-filled to form a sports field and community centre. Such infilling and drainage appears to have had an effect on the surrounding vegetation with extensive stands of Hibiscus tiliaeus and Pandanus encroaching on much of the northern/mato side of the swamp. Little of Mururau swamp is currently cultivated with thick vegetation made up
of weedy taxa making access to many parts of the swamp difficult. The land reclamation and other developments on Mururau Moat-Swamp meant that this site was deemed unsuitable for palaeoenvironmental investigation.

Figure 6.12 Map of Rimatara and insert of Maunutu Swamp based on the Rimatara 1/10 000 scale (Service de l'Urbanisme, 1988) showing the five core sites (black dots) and multiple profile transect lines discussed in the text.

Hareti'i and Maunutu moat-swamps (see Plate 6 and 7) were comparatively unmodified, although extensive cultivations of *Morinda citrifolia* now encroach on some parts of Maunutu. *Colocasia esculenta* (taro) and *Musa* spp. (including fei) cultivations are situated on most of the inland embankments of the swamp and extend into the swamp by no more than 100 metres. Many areas of formerly cultivated land was either in fallow or abandoned. This to some degree could be assessed by the extent of some of the main agricultural weeds including *Ludwigia octovalvis* and *Commelina diffusa* (see Plate 7). The central parts, according to one local informant were never cultivated with post-production gardens remaining in fallow for two years.
The *Colocasia esculenta* cultivation systems are mostly situated at the confluence of stream channels draining the elevated inland parts of the island. In the southern part of the island where the *mato* is absent or degraded, these systems have probably encroached upon a number of former moat swamps. At Maunutu most of the inland periphery is currently cultivated for *C. esculenta*. The drier embankments to the south above the swamp surface are planted with *Morinda citrifolia* (*noni*) orchards and to the north with *Cocos nucifera* groves. Tethered goats (*Capra hircus*) and pigs (*Sus scrofa*) are often found on the periphery these orchards and garden sites.

The climate on Rimatara is tropical/subtropical. Rimatara and in 2004, based on measurements from Tubuai (~350 km east of Rimatara) probably received less than 2000 mm of annual rainfall (Tubuai Meteo, unpublished data). Most of the rainfall occurs during the summer months with winter being the driest season. Temperatures fluctuate between 20°C in winter months to 25°C in summer. Maunutu is fed by one permanent stream draining the north-west catchment of the Oromana Plateau the highest elevated area of the island lying ~ 80 m above sea level. Hydrological data are unavailable for the Maunutu catchment. Thunder and lightning occur infrequently at any time of the year.

The modern vegetation of the surface of Maunutu swamp consists primarily of *Cyclosorus interruptus* fern interspersed with the exotic taxa *Kyllinga brevifolia*, *Emilia sonchifolia* var. *javanica*, *Ludwigia octovalvis*, *Paspalum* spp. and *Commelina diffusa*. Some rare indigenous taxa situated in small pockets throughout the swamp include the sedge *Cladium mariscus* subsp. *jamaicense* and the fern *Acrostichum aureum*. The inland periphery of the swamp consists of *Colocasia esculenta* cultivations, *Cocos nucifera* and *Morinda citrifolia* plantations, as described above, with a range of exotic taxa located along the swamp embankments and the adjacent swamp itself. The inner rim of the *mato* is vegetated with a range of arboreal taxa including *Hibiscus tiliaeus*, *Pandanus tectorius*, *Premna serratifolia*, *Barringtonia asiatica* and *Calophyllum inophyllum*.

**Field, laboratory and numerical methods**

With an area of ~20 ha and comparatively unmodified by recent human activity, Maunutu Moat-Swamp was chosen as the focus point for a multiple core profile examination of swamp stratigraphy and palynology on Rimatara. A total of five sedimentary cores were obtained from the swamp using a Russian D-section corer. These cores were taken along two transects that cross the broadest latitudinal and longitudinal stretches of the swamp surface (Figure 6.12). A depth of 7.5 m was reached at two of the coring sites, though it is probable that more sediment (perhaps up to 7 - 8 m) may be located beneath this depth (see Table 6.6).

The same laboratory and numerical methods were applied to each of Maunutu cores as for the Tukou cores. Radiocarbon samples and mineral magnetic susceptibility analysis was only conducted on one core from Maunutu (Core 1 Transect 2) and this is the only core presented in...
this chapter. The palynological results of the remaining cores are presented in Chapter 7. Two samples were submitted for AMS radiocarbon dating at different intervals throughout each core and these are listed in Table 6.7. The calibrations provided were calculated using the OxCal program version 3.10 with the IntCal04 calibration data set (Bronk Ramsey, 2001; 2005). Both these samples were submitted as a pre-treated pollen concentrate, processed using standard pollen protocols without the addition of carbon-based acids.

Pollen and spore identification was assisted by reference material collected on Rimatara by Jacques Florence, Jean-Yves Meyer and Jean-François Butaud and regional reference collections held at the Australian National University. As for Tukou analyses, all pollen taxa names refer to the family or genera of extant plant taxa with the exception of the fossil classification Arecaceae: Iguanurinae type which is derived from an extinct palm of that sub-tribe.

The concentration (per cm³) data for pollen, spores and microcharcoal particles, magnetic susceptibility data as well as percentage pollen and spore data were placed into stratigraphic diagrams (Figures 6.13a and 6.13b using the program C2 Data Analysis version 1.4 (Juggins, 2005). This program was also used to numerically examine the relationship between samples using correspondence analysis (CA).

<table>
<thead>
<tr>
<th>Core features</th>
<th>Core 1 transect 1</th>
<th>Core 2 at intersection of transects 1 &amp; 2</th>
<th>Core 3 transect 1</th>
<th>Core 1 transect 2</th>
<th>Core 3 transect 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of core (cm)</td>
<td>650</td>
<td>750</td>
<td>550</td>
<td>750</td>
<td>455</td>
</tr>
<tr>
<td>Basal sediments reached</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Elevation above sea level (m)</td>
<td>~4</td>
<td>~1</td>
<td>?</td>
<td>~3</td>
<td>?</td>
</tr>
<tr>
<td>Distance from closest embankment (m)</td>
<td>~100</td>
<td>~300</td>
<td>~20</td>
<td>~50</td>
<td>~50</td>
</tr>
<tr>
<td>Number of AMS radiocarbon determinations</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Oldest determination (depth in cm)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>835</td>
<td>(105-107)</td>
</tr>
</tbody>
</table>

Table 6.6 Main core parameters and central point estimates (cal. yr B.P.) for the oldest radiocarbon determinations for Maunutu core 1 transect 2.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Material dated</th>
<th>Pollen conc/ce</th>
<th>Lab Code</th>
<th>C14 Age (uncal.)</th>
<th>Error</th>
<th>2σ</th>
<th>2σ central point estimates</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maunutu Core 1 Transect 2</td>
<td>Post-contact interpolation</td>
<td>125</td>
<td>25</td>
<td>180 ± 70</td>
<td>125</td>
<td>55</td>
<td>25-27 cm</td>
<td>Post-contact interpolation</td>
</tr>
<tr>
<td>25-27 cm</td>
<td>Pollen</td>
<td>6658123</td>
<td>WK-17089</td>
<td>500</td>
<td>35</td>
<td>545-465</td>
<td>505</td>
<td>60</td>
</tr>
<tr>
<td>90-92 cm (Wk)</td>
<td>Pollen</td>
<td>363120</td>
<td>WK-19099</td>
<td>918</td>
<td>32</td>
<td>910-720</td>
<td>815</td>
<td>95</td>
</tr>
</tbody>
</table>

Table 6.7 List of AMS radiocarbon dates obtained from the Maunutu Swamp sediment profiles. Presented are the sample depths, radiocarbon laboratory (Wk= University of Waikato Radiocarbon Laboratory), material dated, pollen concentrations/ce, laboratory sample codes, uncalibrated determinations and calibrated ages to 2σ and 2σ central point estimates. Dates were calibrated using the OxCal program version 3.10. Post-European contact interpolated date estimates (in red) are referred to in Chapter 7.
Late Holocene vegetation change: Maunutu Core 1 Transect 2

Core stratigraphy and chronology

Only the top 200 cm of this core is presented. The basal sedimentary unit (200-80 cm) of this core consist primarily of uncompact food brown gyttja. This unit grades into lighter brown more compacted fine clay above 80 cm to the swamp surface. Increasing magnetic susceptibility measurements (K units) appear to correspond to these increasing proportions of clay minerals but these levels remain very low throughout the core. Sediments lying in the upper 5-15 cm of the core are interspersed with *Ludwigia octovalvis* and *Commelina diffusa* roots.

Only two AMS dates were obtained for Maunutu Core 1 Transect 2 at different intervals from the upper part of the core (Table 6.6) and these are presented as linear-age models in stratigraphic diagrams.

Palynological analysis

The different palynomorphs identified from Maunutu Core 1 Transect 2 that are probably derived from indigenous taxa are listed in Table 6.8 along with their presence/absence in either Zone I or II listed and their biogeographic affinity. Proportional palynological data from Maunutu Core 1 Transect 2 are presented according to the occurrence of taxa throughout the core in proportions of either >5 (Figure 6.13a) or <5% (Figure 6.13b). Taxa are grouped from left to right according trees and shrub, herb, fern and fern ally groups. Taxa are sorted within these groups in stratigraphic succession using the sort function in C2 Data Analysis program (Juggins, 2005). The core is divided into two palynological zones on the basis of the major vegetation changes.

Zone I (200-105 cm; > 800 cal. yr B.P.)

High proportions of *Pandanus cf. tectorius* and *Acrostichum aureum* are found with a range of tree, shrub and fern taxa represented in low proportions. *Pandanus* declines towards the top of this Zone. No charcoal counts observed in this Zone. Palynomorph concentrations are highest in the lower section of this Zone (>100,000 per cm³)
<table>
<thead>
<tr>
<th>Pollen taxa</th>
<th>Family</th>
<th>Present in Zone I</th>
<th>Present in Zone II</th>
<th>Indigenous representatives in modern flora</th>
<th>Biogeographic affinity</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acrostichum aureum</em></td>
<td>Pteridaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>Acrostichum aureum</em></td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Amaranthaceae</td>
<td>Amaranthaceae</td>
<td>Y</td>
<td>Y</td>
<td>Extinct?</td>
<td>Introduced?</td>
</tr>
<tr>
<td><em>Angiopteris</em></td>
<td>Pteridaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>Angiopteris rapensis, A. longifolia</em></td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>cf. Apocynaceae</td>
<td>Apocynaceae</td>
<td>N</td>
<td>Y</td>
<td>Extinct?</td>
<td>Introduced?</td>
</tr>
<tr>
<td><em>Arecaceae</em>: Iguaninaceae</td>
<td>Arecaceae, Subfamily</td>
<td>Y</td>
<td>Y</td>
<td>Extinct?</td>
<td>?</td>
</tr>
<tr>
<td><em>Arecaceae</em>: Liliaceae</td>
<td>Arecaceae, Tribe</td>
<td>Y</td>
<td>Y</td>
<td>Extinct?</td>
<td>?</td>
</tr>
<tr>
<td><em>Asteraceae</em>: Tubuliflorae</td>
<td>Asteraceae</td>
<td>Y</td>
<td>Y</td>
<td><em>numerous species</em></td>
<td>?</td>
</tr>
<tr>
<td><em>Asteraceae</em>: Liliaceae</td>
<td>Asteraceae</td>
<td>Y</td>
<td>Y</td>
<td><em>numerous species</em></td>
<td>?</td>
</tr>
<tr>
<td><em>Barringtonia</em></td>
<td>Combretaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>Barringtonia asiatica</em></td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Casuarina</em></td>
<td>Casuarinaceae</td>
<td>N</td>
<td>Y</td>
<td><em>Casuarina equisetifolia</em></td>
<td>Indo-Pacific, probably exotic/contamination</td>
</tr>
<tr>
<td>cf. <em>Calyxophyllum</em></td>
<td>Clasidaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>Calyxophyllum</em></td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Cyclosorus interruptus</em></td>
<td>Thelypteridaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>Cyclosorus interruptus</em></td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Cyperaceae</em>: Dilleniaceae</td>
<td>Cyperaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>numerous species</em></td>
<td>Pan-tropical, cosmopolitan</td>
</tr>
<tr>
<td>cf. <em>Dichrocardia</em></td>
<td>Calycanthaceae</td>
<td>N</td>
<td>Y</td>
<td><em>Dichrocardia linearis</em></td>
<td>Pan-tropical</td>
</tr>
<tr>
<td><em>Dryopteris</em></td>
<td>Dryopteridaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>numerous species</em></td>
<td>Pan-tropical</td>
</tr>
<tr>
<td><em>Euphorbiaceae</em></td>
<td>Euphorbiaceae</td>
<td>Y</td>
<td>N</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td><em>Fabaceae</em></td>
<td>Fabaceae</td>
<td>Y</td>
<td>Y</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td><em>Glochidion</em></td>
<td>Euphorbiaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>Glochidion societatis</em></td>
<td>FP</td>
</tr>
<tr>
<td><em>Hibiscus tiliae</em></td>
<td>Malvaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>Hibiscus tiliae</em></td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Hypolepis</em></td>
<td>Dendronariaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>Hypolepis punctata, H. sensuflora</em></td>
<td>Indo-Pacific/Pan-tropical</td>
</tr>
<tr>
<td>cf. <em>Jasminium</em></td>
<td>Oleaceae</td>
<td>Y</td>
<td>Y</td>
<td>Extinct?</td>
<td>Introducted?</td>
</tr>
<tr>
<td><em>Lycopodium sp.</em></td>
<td>Lycopodiaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>numerous species</em></td>
<td>?</td>
</tr>
<tr>
<td><em>Macaranga</em></td>
<td>Euphorbiaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>Macaranga rathwaeensis</em></td>
<td>Indo-Pacific/FP</td>
</tr>
<tr>
<td>Malvaceae</td>
<td>Malvaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>numerous species</em></td>
<td>?</td>
</tr>
<tr>
<td><em>Monolete Psilata</em></td>
<td>?</td>
<td>Y</td>
<td>Y</td>
<td><em>numerous species</em></td>
<td>?</td>
</tr>
<tr>
<td><em>Myrtaceae</em></td>
<td>Myrtaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>numerous species</em></td>
<td>?</td>
</tr>
<tr>
<td><em>Pandanus cf. tectorius</em></td>
<td>Pandanus</td>
<td>Y</td>
<td>Y</td>
<td><em>Pandanus tectorius</em>; <em>Pandanus tequestri</em>;</td>
<td>Indo-Pacific/Endemic?</td>
</tr>
<tr>
<td>Poaceae</td>
<td>Poaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>numerous species</em></td>
<td>?</td>
</tr>
<tr>
<td><em>Pteris</em></td>
<td>Pteridaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>numerous species</em></td>
<td>?</td>
</tr>
<tr>
<td><em>Polygalaceae</em></td>
<td>Polygalaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>numerous species</em></td>
<td>?</td>
</tr>
<tr>
<td>Prema</td>
<td>Labiatae</td>
<td>N</td>
<td>Y</td>
<td><em>Prema serratifolia</em></td>
<td>Indo-Pacific/FP</td>
</tr>
<tr>
<td>Rubieae</td>
<td>Rubieae</td>
<td>Y</td>
<td>Y</td>
<td><em>numerous species</em></td>
<td>?</td>
</tr>
<tr>
<td>cf. Scirocopia</td>
<td>Goodeniaceae</td>
<td>N</td>
<td>Y</td>
<td><em>Scirocopia toetula</em></td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Solanaeae</em></td>
<td>Solanaceae</td>
<td>N</td>
<td>Y</td>
<td>Extinct?</td>
<td>Introduced?</td>
</tr>
<tr>
<td><em>Sophora tenebrosa</em></td>
<td>Fabaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>Sophora tenebrosa</em></td>
<td>Pacific</td>
</tr>
<tr>
<td><em>Sphaeroestephanos</em></td>
<td>Thelypteridaceae</td>
<td>Y</td>
<td>Y</td>
<td><em>Sphaeroestephanos</em></td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Timodrus</em></td>
<td>Rubieae</td>
<td>Y</td>
<td>Y</td>
<td><em>Timodrus polygamous</em></td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Tournefortia argentea</em></td>
<td>Botaniginea</td>
<td>Y</td>
<td>Y</td>
<td><em>Tournefortia argentea</em></td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Tremata</em></td>
<td>Ulmaceae</td>
<td>Y</td>
<td>N</td>
<td>Extinct?</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Tribe Psilata</em></td>
<td>?</td>
<td>Y</td>
<td>Y</td>
<td><em>numerous species</em></td>
<td>?</td>
</tr>
<tr>
<td><em>Triumfetta</em></td>
<td>Malvaceae</td>
<td>Y</td>
<td>N</td>
<td><em>Triumfetta procumbens</em></td>
<td>Indo-Pacific</td>
</tr>
</tbody>
</table>

Table 6.8 Palynomorphs from Maunutu Core 1 Transect 1. Listed are the presence/absence of palynomorphs in Zones I and II. Also listed are the possible representatives of the palynomorphs found in the modern flora and the biogeographic affinity of these taxa. "Pollen or spore type wind blown." pollen or spore type capable of long distance dispersal (after Close et al 1978). FP=French Polynesia
Figure 6.13a Percentage diagram for Maunutu Core 1 Transect 2 (200 cm shown of a total of 7.5 m). The following are presented in the diagram from left to right: Core lithology (>0= increasingly coarse), magnetic susceptibility values (k), calibrated radiocarbon ages (line and ticks), taxa (pollen and spores: taxa with ≥5% of total palynomorph sum are presented as colour coded bars; samples with proportions <5% are presented as triangle symbols) and total palynomorph concentrations (per cm³), microcharcoal particle concentrations (per cm³), palynomorph richness (number of taxa), Correspondence Analysis Scores (CA score 1) and palynological zones. Two palynological zones (Late Holocene swamp forest Zone I; Human impact Zone II) are presented. The horizontal transparent red bar indicates the section of the core where the sediments associated with palynological signatures of pre-European human impact are poorly constrained by radiocarbon ages as shown in Figure 6.13b and discussed in Chapter 7.
Figure 6.13b Percentage diagram for Maunutu Core 1 Transect 2 (200 cm shown of a total of 7.5 m). The following are presented in the diagram from left to right: Core lithology (>0 = increasingly coarse), magnetic susceptibility values (k), calibrated radiocarbon ages (line and ticks), taxa (pollen and spores: taxa with <5% are presented as coloured triangle symbols) and total palynomorph concentrations (per cm³), microcharcoal particle concentrations (per cm³), palynomorph richness (number of taxa), Correspondence Analysis Scores (CA score 1) and palynological zones. Three palynological zones (Late Holocene swamp forest Zone I; Human impact Zone II) are presented. The horizontal transparent red bar indicates the section of the core where the sediments associated with palynological signatures of pre-European human impact are poorly constrained by radiocarbon ages as shown in Figure 6.13a and discussed in Chapter 7.
Zone IIa and IIb: (105 to 0 cm; ~800 cal. yr B.P. to the present)

Zone IIa is represented by a marked decline in Pandanus pollen and Acrostichum aureum spores in association with an increase in Cyperaceae, Poaceae and fern taxa. Most of the tree and shrub taxa recorded in Zone I are not represented in this Zone. The highest charcoal counts are observed in the lower samples of Zone IIa. A peak in the extinct Arecaeeae: Iguanurinae type palm pollen (25 %) is recorded between 85-87 cm (Zone IIa). Colocasia pollen from the introduced cultigen is recorded in Zone IIa in conjunction with a range of other possible introductions (Casuarina equisetifolia, Erythrina variegata, Aleurites moluccana, cf. Sapindus, Hibiscus tiliaceus; see Chapter 7 for further discussion).

With the exception of Pandanus, Arecaeeae and Tournefortia argentea all of the indigenous taxa recorded in Zone I are not represented Zone IIb. Colocasia esculenta pollen is not represented within Zone IIb. A number of probably recent (since European contact) introductions enter the record in this Zone (Commelina diffusa, Ludwigia octovalvis, Labiatae (mint) and Pinus; see Chapter 7 for further discussion).

Correspondence analysis (CA)

Correspondence analysis was performed on the percentage data all pollen and spore taxa identified in Tukou Core 1. Eigenvalues (Axis 1) generated for each sample are presented as proportions of the total variation in the dataset in each of the two stratigraphic diagrams (Figures 6.13a and 6.13b). These values account for 75 % of the variation in the entire dataset. These values are primarily controlled by the proportions of Pandanus cf. tectorius type pollen within each sample. The greatest variation that exhibited in this core occurs at the interface between Zones I and II from ~800 to 550 cal. yr B.P.

Vegetation history

Late Holocene swamp forest Zone I (> 800 cal. yr B.P.)

Before ~800 cal. yr B.P. a well established Pandanus swamp forest with an understorey of Acrostichum ferns dominated the edge of Maunutu which was then a lake. Other established taxa found in or around this forest included many coastal tree species currently found on the mato (e.g. Triumfetta procumbens, Tournefortia argentea, and Barringtonia asiatica)
Human impact Zone II (~800 cal. yr B.P. to present; see Chapter 7 for discussion)

This Zone, divided into two parts (Zone IIa and IIb), is characterised by palaeoenvironmental human impact signatures including swamp forest decline in response to unprecedented burning indicated by peaks in microcharcoal particles. Zone IIa is defined by the presence of introduced cultigen pollen, namely *Colocasia esculenta*. The later Zone (IIb) is defined by the presence of post-European contact pollen indicators (e.g. *Ludwigia octovalvis* and *Commelina diffusa*). These divisions are outlined in more detail in Chapter 7.

**Palaeoenvironmental implications for pre-human disturbance, plant colonisations and extinctions in OIRO**

Exposure to tectonic activity, fluctuating sea levels, tsunamis, cyclones and volcanic ash fallout have produced an uneven array of geomorphic signatures across many islands in OIRO. Apart from the palaeobotanical proxies for fluctuating sea level focused on the Post-glacial marine transgression and mid-Holocene highstand (e.g. mangrove sediments; Ellison, 1989) most of the aforementioned disturbances are generally poorly exhibited in proxy records for floral or vegetation change (e.g. pollen, charcoal particles, phytoliths and plant macro-fossils). Equally, given the poor taxonomic resolution of the palaeobotanical record, few records of plant colonisations and extinctions are available for the Holocene, prior to human colonisation, or in any preceding epoch.

The limited time-depth of the palaeobotanical record from OIRO is largely a function of the relative brevity of island orogeny compared to continental regions and this is a key factor in limiting the detection of evolutionary (speciation) and colonisation events. Many of these events can now be inferred, particular for the mid-Miocene to Pliocene, from the molecular phylogenetic record for certain plant groups. These inferences are in turn, heavily dependent on geological age constraints on islands that remain uncertain for many archipelagos including the Austral Islands.

The late Holocene expansion of coastal swamp forests and marshes exhibited on many OIRO sites between 4,000 and 1,000 cal. yr B.P., including on Rapa, may represent a peak period of plant colonisation for the Holocene. The palaeobotanical record on Rapa has provided some unique insights into the initiation and development of coastal swamp forest and marsh vegetation. Similar records have been found in Micronesia (e.g. Athens and Ward, 1995; 2001; 2004) and Tonga (Fall, 2005), human impact expanding the time-depth of much of the late Holocene is likely to have distorted the initiation of development at these sites. The Tukou record suggests that this forest expansion took place very rapidly perhaps in response to rapidly changing sea level.

The poor preservation of palaeobotanical remains in the early Holocene marine transgression sediments at Tukou on Rapa, suggests that coastal swamp forest development was
restricted by high coastal sedimentation and rising sea levels. It could be inferred that entire coastal habitats suitable for particular vegetation types were removed or absent prior to the late Holocene vegetation development phase. These coastal environments on Rapa were colonised or re-colonised by a suite of coastal strand taxa (e.g. *Pandanus tectorius* and *Triumfetta procumbens*) either being formerly absent or extirpated during the glacial sea-level lowstand, or restricted in distribution to isolated coastal stands. These late Holocene coastal environments were also re-colonised by a diverse array of lowland forest taxa that inhabit the steep slopes immediately behind the coastline (e.g. *Celtis pacifica*) and some taxa restricted to higher elevation habitats (e.g. members of the Asteraceae e.g. *Fitchia rapensis*).

Enright and Gosden (1992) briefly summarised the evidence for extinctions from Remote Oceania citing Southern’s (1986) *Quintinia* extinction record from Taveuni and Colinvaux’s (1972) *Azolla* extinction from El Junco, Galápagos Islands during the Late Glacial/Holocene transition. No unequivocal extinction records are available from the Austral Islands for this period and the palaeobotanical record from Rapa has not yet revealed any early or mid-Holocene extinctions. Extinctions records are more prevalent for the human colonisation period (directly dated from archaeological rockshelter deposits on Rapa ~770-540 cal. yr. B.P. and inferred from sedimentary sequences from Rimatara at ~800 cal. yr B.P.). From the Tukou Core 1 and Maunutu Core 1 Transect 1 records an extinct palm or two different palm species have become extinct within this time-frame on Rapa. A number of species may have also become extinct within this timeframe from Rimatara including undetermined representatives from the Amaranthaceae, Apocynaceae and Solanaceae and the genera *Coprosma, Jasminum* and *Premna* (See Table 6.8). The palaeoenvironmental and archaeological context for these extinctions is discussed in the following chapter.
Chapter 7
‘the stone age stratum beneath’¹: a synthesis of the archaeobotanical record of the Austral Islands

In the previous chapter I addressed the palaeoenvironmental context for the plant colonisation, vegetation development, plant speciation and extinction for OIRO and the Austral Islands. In this chapter I discuss the archaeobotanical record as a means of defining the chronology of human arrival and subsequent environmental impacts. I then address the late Holocene palaeoenvironmental context for human colonisation of the Austral Islands. I emphasise the archaeobotanical evidence as a basis for interpreting palynological signatures and chronologies particularly for defining plant introduction and exploitation by the earliest colonists of the islands. I also attempt to provide a chronological framework for plant extinctions observed in the palaeoenvironmental record.

The archaeological chronology for OIRO and archaeobotanical remains

As discussed in Chapter 1, the timing of the earliest human colonisation of Remote Oceania is uncertain. The most recent radiocarbon estimates from archaeological material from OIRO point to an interval between 300-1200 cal. yr B.P. for Samoa, Tonga, the Marquesas Islands and the Hawaiian Islands (e.g. Anderson et al 1999, Anderson and White, 2001; Anderson and Sinoto, 2002; Anderson et al 2003; Rolett and Conte, 1995; Rolett 1998; Steadman et al 1994; Tuggle and Spriggs, 2000). The earliest dates for human colonisation of the islands in the immediate vicinity of the Austral Islands are slightly younger, lying between 1200-1000 for the Society Islands, ~1000 cal. yr B.P. for the Cook Islands (e.g. Kirch et al 1995; see Chapter 1), ~900 cal. yr B.P. for the Gambier Islands (Anderson et al 2003) and after 1000 cal. yr B.P. for Easter Island, best recorded by radiocarbon dates from Anakena associated with bones of extinct birds (Steadman et al 1994; Hunt and Lipo, 2006; see Chapters 3 and 4). Weisler (1996) dated the beginning of occupation in the Pitcairn Island group at about 1200 cal. yr B.P., but this has been criticised by Anderson (2000) who suggests the this date is not securely tied to cultural events. As already mentioned in Chapter 1, the earliest dates from Austral Island material range from 960-660 cal. yr B.P. established from basal archaeological material from the Tuituiaroa excavation on Rurutu (Verin, 1969: 307; no lab number available) and 1300-650 cal. yr B.P. (Lab no. ANU

¹ From Peter Buck – Te Rangi Hiroa, An Introduction to Polynesian anthropology ‘the true native picture had been obscured by the accretions of over a century of contact with a foreign culture. Here again the historical method [i.e. the study of myths, genealogies and legends] was useful in clearing off the layers which covered the stone age stratum beneath.’ (1945: 126)
(11599) from the wood of *Tournefortia argentea* excavated from the Atiahara site on Tubuai (Rod Wallace, unpublished data).

Aside from charcoal, the recovery of identified plant remains from archaeological sites in OIRO has been minimal. Abundant charcoal (unidentified to species) from stratified oven features and the cracked endocarps of *Aleurites moluccana* are the most common archaeobotanical remains found (discussed in Chapter 1). The most abundant and diverse assemblages of botanical material including a range of introduced plant cultigen material has been well preserved in dry archaeological deposits sequences from large rockshelters in OIRO including Tangatatau on Mangaia in the Cook Islands (see Chapter 1) and the Mauna Kea rockshelters on the island of Hawai‘i (Allen, 1981). One cave sinkhole deposit on Kaua‘i in the Hawaiian Islands at Māhā’ulepū Cave also provided well-preserved archaeobotanical remains overlying a pre-human aged deposit (Burney et al. 2001) (see Tables 7.1a and 7.1b for a list of archaeobotanical remains from these rockshelter and cave deposits). A large proportion of the archaeobotanical material identified is from introduced economic plant species (see Table 7.1b). Corm and tuberous material from crop cultigens (e.g. *Colocasia esculenta*, *Cyrtosperma merkusii* (syn. *C. chamissonis*) and *Ipomoea batatas*) are also well preserved in some sections of these sequences.

The specific identification and radiocarbon dating of archaeobotanical remains has been integral for fine-tuning the chronology for human colonisation in OIRO. In Chapter 1 I commented on the potential for inbuilt ages of archaeological wood charcoal to create a significant age bias of many hundreds of years. In the case of the Tangatatau (see Chapter 1) and Mauna Kea excavations the basal archaeological material yielding the oldest radiocarbon ages was obtained from unidentified wood charcoal, casting doubt on the security of the archaeological chronology proposed for these sites. The presence material from introduced plant cultigens in archaeological sites, particularly as remains of corms or tubers and the hard parts of fruits and nuts from arboricultural crops, provide a proxy for human presence at a site. If found throughout an archaeological sequence, they also potentially provide confirmation of sustained human activity given that corm, tuber, fruit or nut remains are unlikely to have significant in-built ages.

The oldest AMS radiocarbon ages obtained from *Aleurites moluccana* endocarps (470-280 cal. yr B.P. Lab no. Beta 110273) and *Lagenaria siceraria* exocarps (530-320 cal. yr B.P. Lab no. Beta 113789) from the archaeological deposits at Māhā’ulepū Cave (Burney et al. 2001) represents one of an increasing number of attempts in OIRO to date material with a known in-built age. Due to the inherently low in-built age from *A. moluccana* endocarp and *L. siceraria* rind (exocarp), these radiocarbon dates are thought to present a reliable chronology lying between 500 cal. yr B.P. to the present. To whether this represents the initial presence of humans at the Māhā’ulepū is uncertain given that the chronological timeframe established for the Hawaiian Islands from other archaeological sites exceeds 1000 cal. yr B.P.
The oldest radiocarbon date on *A. moluccana* endocarp found in OIRO and the Hawaiian Islands was obtained by Tuggle and Spriggs (2001) from the Bellows Dune, O’ahu (Hawaiian Islands) giving a conventional calibrated age of 1750-750 cal. yr B.P. (Lab. no. Beta-20842b). The wide radiocarbon error for this date suggests that the age of material may exceed the timeframe for human colonisation of the Hawaiian Islands, however, the integrity of this date was questioned by the authors. This may have been a result of the low amount of sample (1.7 grams) of endocarp submitted for conventional dating, well below the ideal weight for charcoal or wood samples (10-20 grams of wood or 8-10 grams of charcoal; Fiona Petchey pers. comm.). Another comparatively early *A. moluccana* endocarp date was obtained from the Kawainui Marsh excavation, O’ahu by Allen-Wheeler (1981) dated to 680-430 cal. yr B.P. (Lab no. Beta-3344).

As discussed in Chapter 3, the presence of material remains of translocated plants in archaeological contexts represents a greater order of human activity than is implied by their mere deposition. The presence of *A. moluccana* and *L. siceraria* at Māhāʻulepū represents an additional chronological signature for human activity manifest in the labour of their production. After introduction and a 3-4 month seed germination period, propagated *A. moluccana* plants may take 3-4 years before producing fruit (Clarke and Thaman, 1993; Elevitch and Manner, 2006 [http://www.agroforestry.net/tti/Aleurites-kukui.pdf](http://www.agroforestry.net/tti/Aleurites-kukui.pdf)). Besides the production of nuts essential for torch lights, these trees have been noted ethnographically as food, mulch, fodder and shade for root and tuber crops for many island groups in OIRO, particularly the Hawaiian Islands (e.g. Whistler, 1991; Abbott, 1992). By contrast, *L. siceraria* from seed can yield multiple fruit crops within a year and are thus chronologically mediated by seasonal harvests.

To whether both these plants were placed in broad-scale production upon introduction or became part of a later agricultural expansion can to some degree be inferred from contextual information. Within the same stratigraphic contexts at Māhāʻulepū, Burney *et al* (2001) identified remains of other introduced crops including *Colocasia esculenta* corms, *Dioscorea* sp. tuber and *Cordyline fruticosa* stem, suggesting that agricultural production was not restricted in extent or diversity. Burney *et al* (2001) also highlighted the presence of abundant extinct or extirpated terrestrial avifaunal remains in the deposits underlying the cultigen rich unit at Māhāʻulepū suggesting a later expansion of agricultural systems. Given the lack of archaeobotanical material preceding 500 cal. yr B.P., however, clearly the timing and extent of agricultural development on Kauai cannot be resolved with the Māhāʻulepū record alone.
<table>
<thead>
<tr>
<th>Indigenous taxa</th>
<th>Mauna Kea</th>
<th>Tangatahu</th>
<th>Māhā’ulepū</th>
<th>Tangarutu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia koa (Fabaceae) phyllode</td>
<td>+</td>
<td>n</td>
<td>?</td>
<td>n</td>
</tr>
<tr>
<td>Argemone glauca (Papaveraceae) seed</td>
<td>+</td>
<td>n</td>
<td>-</td>
<td>n</td>
</tr>
<tr>
<td>Argyroxiphium sp. (Asteraceae) leaf</td>
<td>+</td>
<td>n</td>
<td>-</td>
<td>n</td>
</tr>
<tr>
<td>Caesalpinia major (Fabaceae) seed</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Canthium sp. (Rubiaceae) pollen</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Chamaesyce sp. (Euphorbiaceae) pollen</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Cheirodendron sp. (Araliaceae) pollen</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Chenopodium sp. (Chenopodiaceae) seed, pollen</td>
<td>+ seed</td>
<td>n</td>
<td>+ pollen</td>
<td>n</td>
</tr>
<tr>
<td>Coprosma sp. (Rubiaceae) seed</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Deschampsia australis (Poaceae) seed</td>
<td>+</td>
<td>?</td>
<td>-</td>
<td>n</td>
</tr>
<tr>
<td>Dodonaea sp., Diospyros sp., Sapindus sp. (Sapindaceae) pollen</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Dubautia sp. (Asteraceae) leaf</td>
<td>+</td>
<td>n</td>
<td>-</td>
<td>n</td>
</tr>
<tr>
<td>Exocarpus sp. (Santalaceae)</td>
<td>-</td>
<td>?</td>
<td>+</td>
<td>n</td>
</tr>
<tr>
<td>Freycinetia sp. (Pandanaceae) leaf, pollen</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Hernandia sp. (Hernandiaceae) seed</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hibiscus tiliaceus (Malvaceae) fibre, bark</td>
<td>+ bark</td>
<td>-</td>
<td>-</td>
<td>+ fibre</td>
</tr>
<tr>
<td>Kanaloa sp. (Fabaceae) seed?, pollen</td>
<td>-</td>
<td>n</td>
<td>+</td>
<td>n</td>
</tr>
<tr>
<td>Metrosideros sp. (Myrtaceae) leaf, pollen</td>
<td>+ leaf</td>
<td>-</td>
<td>+ pollen</td>
<td>-</td>
</tr>
<tr>
<td>Myrsine sp. (Myrsinaceae) leaf, pollen</td>
<td>+ leaf</td>
<td>-</td>
<td>+ pollen</td>
<td>-</td>
</tr>
<tr>
<td>Nestegis sp. (Myrtaceae) pollen</td>
<td>-</td>
<td>?</td>
<td>+</td>
<td>n</td>
</tr>
<tr>
<td>Pandanus sp. (Pandanaceae) leaf, keys, pollen</td>
<td>+ leaf</td>
<td>+ keys, leaf</td>
<td>+ keys, pollen</td>
<td>+ keys, leaf</td>
</tr>
<tr>
<td>Pipturus sp. (Urticaceae) fibre</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pritchardia sp. (Arecaceae) pollen</td>
<td>-</td>
<td>?</td>
<td>+</td>
<td>n</td>
</tr>
<tr>
<td>Psychotria sp. (Rubiaceae) seed</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pieralysia sp. (Apocynaceae) seed</td>
<td>-</td>
<td>n</td>
<td>+</td>
<td>n</td>
</tr>
<tr>
<td>Rauvolfia sp. (Apocynaceae) seed</td>
<td>-</td>
<td>?</td>
<td>+</td>
<td>n</td>
</tr>
<tr>
<td>Rumex sp. (Polygonaceae) seed</td>
<td>+</td>
<td>?</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Santalum sp. (Santalaceae) seed</td>
<td>+</td>
<td>-</td>
<td>?</td>
<td>-</td>
</tr>
<tr>
<td>Silene sp. (Caryophyllaceae) seed</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Solanum sp. (Solanaceae) pollen</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Sophora sp. (Fabaceae) seed</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Strophelia sp. (Ericaceae) seed</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Trisetum sp. (Poaceae) stem</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Zanthoxylum sp. (Rutaceae) pollen</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 7.1a A comparative list of the indigenous plant taxa recorded in the Mauna Kea Quarry excavations on Hawai’i (Allen, 1981), Tangatahu (Mangaia, Cook Islands; Kirch et al. 1995 and Kirch, 1996), the archaeological deposit at Māhā’ulepū Cave (Kaua’i, Hawaiian Islands; Burney et al. 2001) and the Tangarutu (Rapa, Austral Islands) excavations. n = not known from island or site. ? = identification only to family, not genera or species.
<table>
<thead>
<tr>
<th>Introduced taxa</th>
<th>Mauna Kea</th>
<th>Tangatatau</th>
<th>Māhā’ulepō</th>
<th>Tangarutu</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Adenostemma lavenia</em> (Asteraceae) seed</td>
<td>+</td>
<td>?</td>
<td>-</td>
<td>n</td>
</tr>
<tr>
<td><em>Aleurites moluccana</em> (Euphorbiaceae) endocarp</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>Artocarpus altillis</em> (Moraceae) wood, fruit</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Cocos nucifera</em> (Arecales) endocarp, husk, leaf,</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>?</td>
</tr>
<tr>
<td>bracts, wood charcoal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Colocasia esculenta</em> (Araceae) corn</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>Cordia subcordata</em> (Boraginaceae) seed</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>Cordyline fruticosa</em> (Laxmanniaceae) stem, leaf</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>Cyrtosperma merkusii</em> (Araceae) corn</td>
<td>n</td>
<td>+</td>
<td>n</td>
<td>n</td>
</tr>
<tr>
<td><em>Daucus sp.</em> (Apiaceae) seed</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Dioscorea sp.</em> (Dioscoreaceae) tuber, leaf, stem</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>Ipomoea batatas</em> (Convovulaceae)</td>
<td>+</td>
<td>+</td>
<td>?</td>
<td>-</td>
</tr>
<tr>
<td><em>Inocarpus fagiifera</em> (Fabaceae) wood charcoal</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>n</td>
</tr>
<tr>
<td><em>Lagenaria siceraria</em> (Cucurbitaceae) exocarp</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>Leucaena leucocephala</em> (Fabaceae) seed</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>n</td>
</tr>
<tr>
<td><em>Musa sp.</em> (Musaceae) leaf</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Oxalis corniculata</em> (Oxalidaceae) seed</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>n</td>
</tr>
<tr>
<td><em>Piper methysticum</em> (Piperaceae) root, stem</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>n</td>
</tr>
<tr>
<td><em>Propsis pallida</em> (Fabaceae) seed</td>
<td>-</td>
<td>?</td>
<td>+</td>
<td>n</td>
</tr>
<tr>
<td><em>Saccharum officinarum</em> (Poaceae) stem</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Schizostachyum glaucophyllum</em> (Poaceae) stem</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Solanum nigrum</em> (Solanaceae) seed</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Syzygium sp.</em> (Myrtaceae) wood, charcoal, seed</td>
<td>+</td>
<td>-</td>
<td>+pollen, seed</td>
<td>-</td>
</tr>
<tr>
<td><em>Touc hardia latifolia</em> (Urticaceae) fibre</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>?</td>
</tr>
</tbody>
</table>

Table 7.1b A comparative list of the introduced plant taxa recorded in the Mauna Kea Quarry excavations, Hawai‘i (Allen, 1981), Tangatatau, Mangaia, Cook Islands (Kirch et al 1995 and Kirch, 1996), the archaeological deposit at Māhā’ulepō Cave (Burney et al 2001) and the Tangarutu (Rapa, Austral Islands) excavations. The indigenous status of *C. subcordata* was uncertain in OIRO (Wagner et al 1990; Whistler, 1991) until Burney et al (2001) identified seed material dating well prior to human colonisation of the Hawaiian Islands. These taxa are post-European contact introductions. *S. cumnii* is a post-contact introduction whereas *S. malaccense* is thought to be a pre-contact introduction (Whistler, 1991). n=not known from island or site; ?=identification to be confirmed.

This same problem was discussed for the Tangatatau record on Mangaia in Chapter 1. Kirch et al (1995) found that the presence of the most diverse assemblage of introduced cultigens in the upper stratigraphic units of the record is associated with the reduced number of extirpated terrestrial avifaunal remains more commonly found in the lower units. Kirch et al (ibid) apply a model of delayed extinction where the association of plant cultigens and extinct avifauna fits the notion of progressive agricultural development, an idea advocated by Kirch in his other commentaries on island settlement strategies in pre-European contact Remote Oceania. This
hypothesis does not exclude the possibility that rapid extinction or extirpation of terrestrial avifaunal taxa on Mangaia may have coincided with the onset of agricultural activity. In the Tangatatau and Māhāʻulepū records, however, the presence of the hard endocarp of *Aleurites moluccana* throughout the sequence, even in the lowest stratigraphic horizons, suggests that the lack of other plant cultigen remains may be a function of either preservation conditions in the lower excavation units or differential site use and botanical remain deposition by the rockshelter inhabitants.

**The archaeological chronology for OIRO and palaeobotanical remains**

The chronological uncertainties for archaeological material from sites in OIRO are matched by the uncertainties surrounding the palaeoenvironmental context for initial human colonisation and plant introduction on the islands and this is especially apparent for the situation on Mangaia (see Chapter 1; addressed further in this chapter) and Easter Island (see Chapters 3 and 4). For many sites in OIRO, however, chronologies constructed from archaeological assemblages are generally consistent with evaluations of the initial timing of human impact determined from palaeoenvironmental records (e.g. Athens, 1993; 1997; Anderson, 1995; Athens and Ward, 2004).

As for the palynological signatures for human activity from Mangaia and Easter Island, they have generally been built on such indirect indices as charcoal particle concentrations or changes in seral plant pollen or fern spores. The key problem cited for the archaeological application of palaeoenvironmental records has been the lack of direct palynological indicators either as the recovery of artefacts stratified within sedimentary deposits or the recovery of cultigen pollen unequivocally introduced to the site. Even where cultigen pollen have been located (e.g. *Cyrtosperma merkusii* pollen from Ngerchau, Palau, Federated States of Micronesia; Athens and Ward, 2001) criticisms of the resulting interpretations continue to revolve around the reliability of the generated chronologies, the equivocal representation of disturbance indicators, and the lack of taphonomic integrity of the cultural indicators and as well as a variety of other issues intrinsic to the methodology (e.g. Anderson, 2003b; see Chapter 1).

The most comparable palaeoenvironmental datasets for assessing both the chronology of initial human colonisation and initial plant introductions have been provided for the Hawaiian Islands. Four palynological records from Oʻahu have revealed pollen signatures of both *Colocasia esculenta* and *Aleurites moluccana* that provide indications of their early and potentially widespread presence (Ward, 1981; Ward in Beggerley, 1990; Ward in Hammatt, 1990; Athens and Ward 1996; 1997; see Table 7.2). The earliest palynological signature provided for these introduced cultigens, dated to ~670 cal. yr B.P. comes from an alluvial swamp deposit at Kahana (Ward in Beggerley, 1990) where pollen from *Cordyline fruticosa* and *Casuarina* were
identified in associated sediments. These pollen types occur in association with increases in disturbance indicators including charcoal particles, seral fern spores and grass pollen. Two species recorded late in the pollen record, possibly of post-European contact introduction, include the agricultural weeds *Commelina diffusa* and *Ludwigia octovalvis* (see below).

<table>
<thead>
<tr>
<th>Palaeo-environmental pollen record</th>
<th>Deposit setting</th>
<th>Earliest age (cal. yr B.P.) for human impact in palynological record</th>
<th>Earliest age (cal. yr B.P.) for <em>Colocasia</em> and/or <em>Aleurites</em> pollen</th>
<th>Possible domesticates or arboricultural species represented</th>
<th>Increase of human disturbance indicators represented</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Kawaiulua, O‘ahu, Hawaiian Islands Ward in Hammatt (1990)</td>
<td>Coastal marsh</td>
<td>800</td>
<td>520</td>
<td><em>Colocasia esculenta</em>, <em>Aleurites moluccana</em>, <em>Cordyline fruticosa</em>, <em>Pandanus</em></td>
<td>charcoal, grasses, ferns: <em>Pteridium esculentum</em>, <em>Cyclosorus interruptus</em> other taxa: <em>Dodonaea viscosa</em></td>
</tr>
</tbody>
</table>

Table 7.2 Three core sites from O‘ahu (Hawaiian Islands) with records of *Colocasia* and *Aleurites* pollen. The earliest inferred calibrated radiocarbon ages for cultigen pollen presence palynological indications of human impact are also presented. Other potential domesticated plants within the associated pollen assemblages with *Colocasia* and *Aleurites* pollen are listed as well as the presence of human disturbance indicators. 1. The description of *Colocasia* pollen has been given as tentative.

One other alluvial swamp deposit at Maunawili and two coastal marsh deposits at Kapunahala and Kawaiulua yielded very similar sequences with comparable ages for human impact signatures (between ~1000-730 cal. yr B.P.) and plant cultigen pollen (~650-500 cal. yr B.P.). Two other possible cultigens, *Pandanus* and *Cocos nucifera* were recorded within these deposits in association with *Colocasia esculenta* and *Aleurites moluccana* pollen. Athens and Ward (1997) also located *A. moluccana* endocarp and wood from Maunawili (Core 1) at 86-94 cm below the swamp surface and provided an interpolated age from a charcoal date of 688-655 cal. yr B.P. (Lab no. Beta-5490)
In coastal marsh deposits at Kapunahala (Athens and Ward, 1996) and Kawainui (Ward in Hammatt, 1990), the consistent presence of cultigen pollen and increases in human impact signatures (charcoal particles and seral taxa) appear to be directly associated with the decline in coastal swamp forest taxa including *Acacia koa* and an undetermined species of *Pritchardia* palm. These taxa are now absent from the modern vegetation in the vicinity of these marshes. The range of *Pritchardia* pollen morphologies is too poor to distinguish between species (Ward in Hammatt 1990), but given the diversity of *Pritchardia*, with a number of species represented across the Hawaiian Islands, these pollen records are likely to represent a species extinction or at least extirpation occurring sometime after 500-300 cal. yr B.P. The precise timing of *Pritchardia* palm extirpation is unclear and may be, as discussed for the Easter Island palm (see Chapter 4), insoluble given the available evidence.

The presence of introduced (exotic) plant material in archaeological rockshelter deposits and palaeobotanical deposits presents two questions for both archaeological and palaeoenvironmental research. At what time were the plants identified in archaeological settings first introduced and what was the environmental impact of their production as measured from palynological evidence? In this chapter I aim to address these two questions for the Austral Islands focusing on archaeological material and the palaeoenvironmental deposits (already outlined in Chapter 6) obtained from Rapa. Lying southwest of Easter Island, Rapa is the southernmost island of OIRO to be colonised prior to European contact. Anderson (1991; 2000) originally suggested that it was colonised later again, at about 800 cal. yr B.P. An archaeological expedition was conducted in 2002 in order to ascertain the chronology of colonisation of the island and to obtain evidence of human exploitation of the island’s resources.

**Archaeological excavations on Rapa**

Excavations on Rapa were concentrated on coastal rockshelters deposits as they were expected to yield better evidence of initial habitation on the island because they were readily accessible for habitation to the earliest colonists. Megalithic fortification structures found along the ridgelines of the island caldera were also excavated and are discussed in Kennett *et al* (in press). Of the few rockshelters located on the island most are less than 10 m in maximum dimension. Excavations at Akatanui, Angairao, and the upland shelters at Taga (Plate 3) showed shallow stratigraphy with a low abundance and diversity of cultural material and are only briefly discussed here. The base of the Angairao rockshelter stratigraphy dates to ~550 cal. yr B.P. (Lab no. ANU 11851; 650-460 cal. yr B.P.) which is essentially the same as the oldest age at Akatanui, while the upland rockshelter at Taga is younger still. The Akatanui sequence is more indicative of continuous occupation from ~580 cal. yr B.P. (Lab no. UCI 14767; 650-545 cal. yr B.P.) up to the period
European colonisation due to the presence of a number of historic artefacts (e.g. glass). Of the aforementioned rockshelters, archaeobotanical remains were richest at Akatanui with abundant wood charcoal fragments and *Aleurites moluccana* endocarps throughout a number of excavated sequences in what appear to be cooking oven deposits.

### The Tangarutu sequence

The Tangarutu rockshelter in Anarua Bay (Plate 8), on the more sheltered western coast, is of such a notable size (80 x 40 m) that it is likely to have been used from the earliest period of settlement. The rockshelter is probably of last interglacial age or earlier with its base lying >2 m above sea level. The shelter is filled up to ~4 m above sea level with calcareous dune sand, generated during a previous sea-level highstand or the early Holocene marine transgression. The back of the rockshelter is positioned ~55 m from the high tide line of a boulder beach (see Figure 7.1 insert) located north of the rockshelter. The base of the shelter below the overhang and drip line, between 20 to 30 m from the high tide line, is littered with large boulder debris. These boulders overlie dune sand that form the eastern and western buttresses of the shelter. The western section of the shelter shows signs of recent alluvial and colluvial sedimentation with an incised channel evident stretching along the front of the inner face of the shelter. Reddish brown basaltic sediments associated with this channelling appear to be derived from the talus hillslope above the western buttress of the shelter.

Small test excavations on the rockshelter dune sand at the southern end of the shelter by Walczak (2001; 2003) produced calibrated radiocarbon dates between 550-200 cal yr B.P. (Lab. no. Ly-8577 and Ly-8578). Since Walczak’s excavations, the local islanders have removed archaeological material from the rockshelter for building sand. This may have resulted in the removal of the majority of the archaeological deposit. During the 2002 expedition, the remaining undisturbed dune sands towards the back of the shelter were augured, sampled at all exposed sections then 4 m² of the deepest and richest deposit was excavated. The eastern section of the shelter disclosed approximately 150 cm of continuous cultural stratigraphy, which included shellfish, fish and bird bone, leaf and nut fragments, abundant wood and charcoal remains of ovens and other cultural material. This deposit was excavated in two 50 x 100 cm sections (East Section 1 and East Section 2) at 5 cm spit intervals for the first 40 cm and at 10 cm spit intervals for the remainder of the deposit. Other than the plant remains listed in Tables 7.1a and 7.1b, the faunal remains and artefacts excavated at the site are not discussed here.

Radiocarbon dates on charcoal samples, unidentified to taxa, indicate that the base of Tangarutu site dates to between 800-600 cal. yr B.P. (Lab no. UCI 14767, 920-740 cal. yr B.P.; Lab no. ANU 11848, 770-540 cal. yr B.P.; see Table 7.3) with the upper deposits dating to ~400
The basal ages extend the chronology of occupation obtained by Walczak (2001; 2003) an additional 200 to 300 years. This Tangarutu sequence is suggestive of initial habitation and represents the prime coastal rockshelter of the island. The other coastal shelters were utilised later and later again in upland areas (e.g. Taga) as the overall pattern of settlement gravitated towards the use of fortified villages along the island’s ridgeline (see Kennett et al, in press). These ages are consistent with the recent archaeological assessments from elsewhere in southeast OIRO.

Archaeobotanical remains from Tangarutu

The Tangarutu Rockshelter has yielded a diverse range of plant materials comparable in part to other sites in the remote Pacific. Plant remains were recovered by hand picking during dry sieving (3 mm mesh) or as individual finds located from different layers, particularly of leafy material. The stratigraphic profile of the East Section 1 excavation is presented in Figure 7.2 along with weights for each type of excavated plant material. Three radiocarbon ages were taken from fruit and nut remains from East Section 1 (see Table 7.3), one each from Aleurites moluccana endocarp, Lagenaria siceraria pericarp and one from a Pandanus cf. tectorius key. As opposed to unidentified charcoal, the inbuilt age potential of the fruit and nut remains are expected to be minimal and thus allow for a reduced age bias of potentially many hundreds of years for charcoal. Unfortunately, the basal Pandanus key produced a large uncalibrated error due to inadequate carbon concentration.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Material dated</th>
<th>Weight of material</th>
<th>Lab Code</th>
<th>C14 Age (uncal.)</th>
<th>Error</th>
<th>2 σ</th>
<th>2 σ central point estimates</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1 Spit 4 20-25 cm</td>
<td>Lagenaria siceraria pericarp</td>
<td>2g/100 g</td>
<td>UCI 14763</td>
<td>320 (AMS)</td>
<td>15</td>
<td>460-300</td>
<td>380</td>
<td>80</td>
</tr>
<tr>
<td>E1 Spit 4 20-25 cm</td>
<td>Aleurites moluccana endocarp</td>
<td>12g/100 g</td>
<td>ANU 12101</td>
<td>410 (Conventional)</td>
<td>60</td>
<td>540-310</td>
<td>425</td>
<td>115</td>
</tr>
<tr>
<td>E1 Spit 19 110-120 cm</td>
<td>Pandanus cf. tectorius key</td>
<td>2.55g/2.55g</td>
<td>ANU 12102</td>
<td>660 (Conventional)</td>
<td>150</td>
<td>950-300</td>
<td>625</td>
<td>325</td>
</tr>
<tr>
<td>E2 Spit 23-25 130-150 cm</td>
<td>Unidentified charcoal</td>
<td>10g/10 g</td>
<td>ANU 11848</td>
<td>710 (Conventional)</td>
<td>70</td>
<td>770-540</td>
<td>645</td>
<td>145</td>
</tr>
<tr>
<td>East Section T1 150 cm</td>
<td>Unidentified charcoal</td>
<td>?</td>
<td>UCI 14769</td>
<td>905 (AMS)</td>
<td>20</td>
<td>920-740</td>
<td>830</td>
<td>90</td>
</tr>
</tbody>
</table>

Table 7.3 List of radiocarbon dates obtained from the Tangarutu Rockshelter East section square E1. Presented are the sample depths, radiocarbon laboratory (UCI = University of California Irvine; ANU=Australian National University), material dated, weight of material dated/the amount of material found in spit, laboratory sample codes, uncalibrated determinations and calibrated ages to 2σ and 2σ central point estimates. Dates were calibrated using the OxCal program version 3.10.
Figure 7.1 Plan view of Tangarutu Rockshelter with an insert of cross section view along the North-South Transect. The East section excavation is marked. Only the first 50 x 50 cm square (E1) is presented in this thesis. Figures drawn by Atholl Anderson and digitized by Lynn Schmidt.
The East Section deposit can be divided into three units, a basal and upper cultural unit overlying a basal sterile sand unit. In the basal cultural unit of the deposit from 140 to 35 cm in depth, fragments of charcoal associated with rounded basaltic stones indicative of a cooking oven. Small amounts of *A. moluccana* (10-35 g/spit) were located in the upper part of this unit from 100 to 40 cm. Above 35 cm a 5-10 cm thick layer of leafy remains distinguishes the upper unit that upon sieving produced pieces of *Hibiscus tiliaceus* cordage and fragments of plaited *Pandanus* and *Freycinetia* baskets (Judith Cameron pers. comm.). The amount of *A. moluccana* in each spit increased to weights between 70-140 g/spit. Also in this unit the amount of unburnt wood remains increased whereas the amount of charcoal and oven stones present decreased. Fragments of bottle gourd (*Lagenaria siceraria*) and *Pandanus* keys (individual drupes of syncarpous fruits) were also identified within this unit, with one sample of *L. siceraria* dated. Other plant remains, including the abundant wood and charcoal material, have yet to be identified.

Two small-consolidated organic parcels located from the upper unit of East Section 1, initially thought to be coprolite samples, were processed for pollen as a further means of identifying the presence of plant species within the Tangarutu deposit. Percentage pollen diagrams of these samples are presented in Figure 7.3. The uppermost sample found in Spit 1 (5 cm in depth) produced a range of pollen and spores, most known as wind dispersed palynomorphs. The presence of *Freycinetia* and Euphorbiaceae pollen in these samples suggests that material from these plants may have been brought into the site. In the lower sample found in Spit 2 (10 cm in depth), 75% of the palynomorphs identified are from Freycinetia (cf. *F. arborea* or *F. rapensis*). Other pollen types probably introduced rather than wind blown into the site include a Rubiaceae, cf. Liliaceae type and a high percentage of Cyperaceae pollen (~18%). The high percentage of *Freycinetia* pollen is indicative of the probable introduction of these large flowers into the site (see Plate 9 and 10), either brought in with leaves for weaving basketry or as an item for consumption (hence the coprolite determination).

In summary, the Tangarutu sequence represents around 300 to 400 years of occupation. As shown in Tables 7.1a and 7.1b, the plant remains found in the Tangarutu deposit are less species diverse overall than the other sites listed within OIRO. However, the plant remains found appear to be in considerably higher in concentration than the other sites. With the exception of wood charcoal, probably made up of mostly indigenous taxa, remains of introduced taxa make up the greatest proportion of plant remains identified. The basal cultural unit outlined is indicative of an oven and an associated midden initially used by around 700 cal. yr B.P. There appears to be a transition to either a living space or midden by around 400 cal. yr B.P.
Palaeoenvironmental examination of the anthropogenic sediments from Rapa

As mentioned in Chapter 6, small sedimentary catchments are located at the base of windward boulder and leeward sandy beach embayments of the island (see Figure 6.5). The more deeply incised windward embayments are characterised by higher energy fluvial/alluvial systems, forming in places extensive swamp deposits adjacent to abandoned *Colocasia esculenta* terraced pondfields. These swamps possess highly organic clay and silt deposits preserving botanical remains. The sedge *Schoenoplectus subulatus* var. *subulatus* dominates the vegetation of most of these swamp sites. The swamp deposits were cored with the intent on reaching basal clays or bedrock from Akatanui (2 m deep Core 1; see Figures 7.4 and 7.5), Hiri (3 m deep Core 1; Figure 7.6) and Anarua (1.8 m deep Core 1; Figure 7.7). Magnetic susceptibility (K) measurements from these cores provide some indication of the extent of organic accumulation at each site. Radiocarbon ages were obtained from charcoal particles found in the basal sediments of these cores revealing 2σ ages of 543-510 (Lab. no. UCIAMS 2194), 1400-650 (Lab. no. ANU 12154), and 950-100 (Lab. no. ANU 12155) cal. yr B.P., respectively. The radiocarbon date from Akatanui Core 1 corresponds to the archaeological chronology established from the Tangarutu rockshelter and suggests that these sediments were deposited during the early colonisation phase of the island. The age ranges of the two dates from Hiri and Anarua are insufficient to indicate the precise timing of sediment deposition.

An additional 2.5 m core was obtained and radiocarbon dated from an upland swamp deposit located above Anatakuri Bay, at Otaikui (see Figure 7.8). The swamp appears to be formed behind a landslip and little evidence remains of any agricultural features. The vegetation of the swamp consists mostly of the sedge *Schoenoplectus subulatus* var. *subulatus*. A fragment of charcoal from the core gave a modern determination (Lab. no. ANU 12157) suggesting these sediments were recently deposited.
Figure 7.2 Cross section view of the 180 cm deep East Section 1 excavation from Tangarutu Rockshelter. Presented are the section lithology, calibrated radiocarbon ages (line and ticks) (see Table 7.3) and material weights per excavated spit (the top 10 spits were excavated to a depth of 5 cm with the lower 7 spits to a depth of 10 cm. The deposit is divided into three units, a sterile basal sand layer underlying a charcoal rich oven feature with oven stones within a sandy matrix (basal cultural unit). From 35 cm to the surface *Aleurites moluccana* and pieces uncharred wood dominate a sandy matrix overlying a leafy layer at between 35-30 cm in depth (upper cultural unit).
Figure 7.3 Percentage diagram of pollen and spore assemblages from two consolidated organic samples from the East Section 1 excavation (Spits 1 and 2), Tangarutu Rockshelter. Taxa with ≥5% of total palynomorph sum are presented as colour coded bars; samples with proportions <5% are presented as triangle symbols) and total palynomorph counts.
Figure 7.4 Photograph (c/o D. Kennett) of Akatanui showing the position of two rockshelters, the extent of abandoned agricultural terraces and the location of three coring locations (only one mentioned in the text). The position of Akatanui is marked on a thumbnail satellite image of Rapa in the top left corner of the figure.
Figure 7.5 To the left of the figure, the sediment lithology and magnetic susceptibility measurements (K) and the basal radiocarbon age of the Akatanui Core 1 are shown. To the right are satellite images of Akatanui. A. shows the location of the Pare Taga fortification structure located along a ridgeline above the bay. B. shows the location of some of the remnant agricultural terraces and the position of the Akatanui core. The position of Akatanui is marked on a thumbnail satellite image of Rapa in the top left corner of the figure.
Figure 7.6 To the left of the figure, the sediment lithology and magnetic susceptibility measurements (K) and the basal radiocarbon age of the Hiri Core 1 are shown. To the right are photographs (c/o D. Kennett and A. Anderson) of Hiri. A. shows the extent of Hiri wetland and the position of Hiri Core 1. B. shows the author at the core site amongst a dense stand of *Schoenoplectus subulatus* var. *subulatus*. The position of Hiri is marked on a thumbnail satellite image of Rapa in the top left corner of the figure.
Figure 7.7 To the left of the figure, the sediment lithology and magnetic susceptibility measurements (K) and the basal radiocarbon age of the Anarua Core 1 are shown. To the right are photographs (c/o D. Kennett) of Anarua. A. shows the extent of Anarua wetland and embayment and the position of Anarua Core 1. B. shows the boulder beach at the head of Anarua backed by Pandanus tectorius trees. The position of Anarua is marked on a thumbnail satellite image of Rapa in the top left corner of the figure.
Figure 7.8 To the left of the figure, the sediment lithology and magnetic susceptibility measurements (K) and the basal radiocarbon age of the Otaikui Core 1 are shown. To the right is a photograph (c/o D. Kennett) of Otaikui that shows the extent of the wetland and the position of Otaikui Core 1. The position of Otaikui is marked on a thumbnail satellite image of Rapa in the top left corner of the figure.
Palaeoenvironmental examination of the anthropogenic sediments from Tukou Marsh

On Rapa, as outlined in Chapter 6, the palynological record of Tukou indicates that coastal Pandanus swamp forests expanded after around 2500 cal. yr B.P. in response to changing sedimentary conditions following a mid-Holocene sea level high-stand. Within or around the period represented from the basal ages of the Tangarutu archaeological sequence, certainly after around 1000 cal. yr B.P., between 50 and 120 cm of colluvial sediments accumulated at different rates across Tukou marsh (see below). This period is represented by a rapid increase in sedimentation across Tukou, comparable to the accumulation rates found from deposits in the other embayments (e.g. Akatanui, Anarua and Hiri). The Pandanus pollen and trilete fern spore records (see Figure 6.10b, Chapter 6) indicate that swamp forest declined consistently across the site in what appears compatible with human impact. In Chapter 6 the stratigraphy and chronology of Cores 1 to 6 from Tukou were described in the context of coastal swamp forest development. In this section, I will outline some of the key palynological indicators for human impact and attempt to further define the stratigraphy and chronology for each core. Following from this I explore each of the cores individually in order define some of the key ecological responses to human impacts at Tukou.

Palynological analysis of early human environmental impact from the Tukou records

The palynological data of all of the Tukou Cores are presented in a composite stratigraphic diagram (see Figure 7.9). This examination of the Tukou core transect focuses on radiocarbon ages, charcoal particle concentrations, Pandanus cf. tectorius, Arecoideae (Iguanurinae type) and Colocasia esculenta pollen as key markers of human activity and agricultural practices at the site. As in the composite diagrams presented in Chapter 6, the cores are divided into four palynological zones on the basis of the major vegetation changes and comparable to those zones described for Tukou Core 1. Within the pre-European contact Zone IVa, transparent red horizontal bars indicated in Figure 7.9 mark the sections where a range of palynological signatures of pre-European human impact overlap and to where a sedimentary hiatus may have occurred. These possible hiatuses and the overlapping human indicators of Zone IV are discussed in detail here.

In the composite stratigraphic diagram, the upper Zone (IV) is divided into two subzones (IVa and IVb) on the basis of palynological marker taxa that represent the pre-contact (IVa) and
European periods (IVb). These subzones are discussed in more detail later in this chapter in reference to the chronology of pre-European and European period human impacts.

Charcoal signatures

From the Tukou Core 1 record, charcoal particles first appear in high concentrations at the base of Zone IV. From the presence of charcoal particles radiocarbon dated from Zone I of this core I have suggested, contrary to Kirch and Ellison (1994), for example, that burning was part of the pre-human island ecosystem and that charcoal is a disturbance signal that may remain equivocal in the absence of other human impact indicators. Nevertheless, the presence of high concentrations of charcoal particles in Zone IV of Core 1 appears to be unprecedented and not directly tied to sedimentation or preservation and as a working hypothesis reflects human-induced burning at the site. In Zone IV of Core 1, counter to what may be expected, increasing charcoal concentrations overlap with increasing Pandanus pollen concentrations (this trend is highlighted by the transparent red bar in Figure 7.9). I suggested in Chapter 6 that peaks in Pandanus pollen found in Zone IV of Core 1 may be representative of one of the following: sediment compaction in the early part of the Zone allowing for pollen to accumulate and become more concentrated with depth; the opening of forest conditions allowing for more pollen deposition; or the possibility that Pandanus responds to burning by increased flowering and pollen production. The decline in charcoal signals in the later part of this Zone also corresponds with a decrease in Pandanus pollen concentrations. I also suggested that this may represent a decrease in the amount of available fuel available for burning at Tukou after an initial peak in human-induced fires.

The key problem identified from the analysis of the Core 1 dataset in Chapter 6 is establishing the chronology for deforestation represented by Pandanus pollen decline and presumably increases in charcoal particles. No radiocarbon dates were taken from Zone IV sediments of Core 1, but a linear interpolation model of the radiocarbon ages obtained suggests that the base of Zone IV encompasses the radiocarbon chronology established from the archaeological record (indicated by the vertical red transparent bar within the radiocarbon age histogram in Figure 7.9).

More radiocarbon ages obtained from the five additional Tukou cores (Cores 2-6) better establish the chronology of charcoal particle increases. The chronology for the onset of microcharcoal particle concentrations in identified from pollen concentrates has been inferred from linear radiocarbon interpolations based on central point estimates (see Table 7.4). The earliest age obtained for microcharcoal particles comes from Core 2 in the centre of the marsh established from a direct AMS date at 2454 cal. yr B.P. with the youngest age determined from Core 1 with an interpolated age of 770 cal. yr B.P. The concentration of charcoal particles also
varies considerably across the site. The highest concentrations occur in Core 6 and concentrations overall are higher in Cores 2-6 than in Core 1. Differential fuel loads across the site may explain this variation in charcoal concentrations. The intensity of human activity at the site, historically higher towards the inland part of the marsh where evidence for past agricultural activity is most apparent, may also explain the spatial variation in charcoal concentrations.

All of the interpolated ages for the onset of microcharcoal concentrations from all of the Tukou cores are consistently older than the earliest age determination obtained from the archaeological record of Tangarutu (see Table 7.4 and Figure 7.9). The average central point estimate age interpolation lies at 1305 cal. yr B.P. and provides a firm indication that microcharcoal particles do not provide robust evidence for early human activity on Rapa. All of the interpolated ages for the highest peaks in microcharcoal concentrations, however, are recorded within the archaeological chronology established for Rapa. With the exception of Core 1, having an interpolated age of 770 cal. yr B.P., all of the concentration peaks lie in the upper part of Zone IV. For Core 2, the highest microcharcoal concentrations are located in the most modern sediment samples near the marsh surface.

Plant introduction: the Colocasia esculenta pollen record

Apart from charcoal particle increases, no plant cultigen pollen or any unequivocal palynological signatures of human presence were identified from Tukou Core 1. Pollen from the cultigen Colocasia esculenta was identified from each of the remaining five cores from Tukou, all within Zone IV sediments (see Plate 11 for pollen micrographs). The presence of Colocasia pollen provides a more secure indication of human presence as it could only have been derived from introduced and domesticated populations (Prebble and Haberle in prep). The distribution of C. esculenta in Remote Oceania is restricted by oceanic barriers (Matthews, 1995; 2004) and may also be limited by the lack of suitable hydrological environments for it to establish without human intervention. C. esculenta pollen has now been identified in thirteen pollen records across the Indo-Pacific suggesting that the records from Rapa (and Rimatara; see below) are not anomalous (Prebble and Haberle in prep).

From the composite stratigraphic diagram (Figure 7.9), like Pandanus pollen and microcharcoal particles C. esculenta pollen concentrations are also differentially represented across the site. The highest concentrations are found in Cores 2 and 4 in the central part of the marsh, with the lowest concentrations found in the most inland core (Core 3). This trend could be explained by Colocasia cultivation activity whereby plants are actively prevented from flowering during cultivation mainly by corm harvesting prior to flowering C. esculenta is known to be a poor pollen producer, and relatively rare in the pollen record (e.g. Haberle, 1994; Prebble and
Haberle in prep). The high concentrations of *C. esculenta* pollen represented in some cores may reflect a response to the increased seasonality of the more subtropical climate of Rapa. Alternatively, high *C. esculenta* pollen concentrations in sediments may reflect the high local presence of feral plant populations outside of immediate cultivation that may have been allowed to set flowers. One hypothesis is that this may have been an integral strategy in the early establishment of *Colocasia* crops allowing for genetic exchange and the extension of cultivar diversity in an environment different from the island homeland of the early settlers.

The interpolated ages for the onset of *C. esculenta* pollen from Cores 2-6 fall in an age bracket that overlaps the earliest age determination obtained from the archaeological record of Tangarutu (see Table 7.4 and Figure 7.10). The average central point estimate age interpolation for *C. esculenta* pollen lies at 757 cal. yr B.P. and provides the most robust evidence for early human activity on Rapa. This average estimated age is older than expected and reflects the poor chronological control for the first appearance of *C. esculenta* pollen in three of the five cores (Cores 3, 4 and 5). The onset of *C. esculenta* in Core 2 is constrained by four AMS ages and provides the most reliable earliest age for the onset of cultivation on Rapa at 615 cal. yr B.P.

With the exception of Core 4, all of the peaks in *C. esculenta* pollen occur in the latter part of Zone IVa. With a central point estimate age of 769 cal. yr B.P., the sample showing first appearance of *C. esculenta* pollen in Core 4 also has the highest concentrations. If this age is accepted, the early presence of high pollen concentrations of *C. esculenta* in the most shoreward core site may reflect the above hypothesis of high local presence of feral plant populations outside of areas of immediate cultivation.

Later in the sequence, certainly by Zone IVb, *Colocasia* pollen drops out of the record possibly representing a change in landuse practices at the site. It is possible that harvesting of *Colocasia* intensified to the point where both cultivated and feral plants were prevented from flowering. Another alternative is that with the introduction of feral grazing animals, including goats, cattle and horses, feral populations *Colocasia* may have been browsed to the point where flowering was prevented. Few feral specimens survive on the island today and no flowers have been recorded or collected on the island by any visiting botanist (Jean-Yves Meyer, pers. comm.).
Figure 7.9 Composite stratigraphic diagram for Tukou Marsh showing the calibrated age ranges (lines and ticks; red ticks = the inferred post-European contact record), bar histograms of charcoal particles, *Pandanus cf. tectorius*, Arecoideae (Iguanurinae type), and *Colocasia esculenta* pollen concentrations (per cm$^3$). An attempt was made to present the concentration data proportionally with each single tick mark representing 200,000 charcoal particles (per cm$^3$), 100,000 *Pandanus*, 1000 Arecoideae (Iguanurinae type) and 1000 *Colocasia* pollen grains (per cm$^3$). The stratigraphic alignment of each core is displayed as for Figure 6.10a and 6.10b with the modern high tide level marked by the black dashed line. Four Zones are distinguished on the basis of transitions in the palynological record and are located above the coloured lines (Zone I (Core 1 only) at base; black=Zone II; green=Zone III; yellow=Zone IVa; red=Zone IVb). The transparent red horizontal bars indicates the section of each core where a sedimentary hiatus influences each record and where palynological signatures of pre-European human impact overlap as discussed in the text).
<table>
<thead>
<tr>
<th>Sample depth (cm) below marsh surface</th>
<th>Palynological event</th>
<th>2σ linear interpolated ages (cal yr B.P.)</th>
<th>Error</th>
<th>Average linear interpolated ages for event (range) across the site</th>
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<tr>
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<tr>
<td>80-82cm</td>
<td>Micro charcoal peak</td>
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<td>-</td>
<td>367(4-489)</td>
</tr>
<tr>
<td>80-82cm</td>
<td>Micro charcoal onset</td>
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<td>-</td>
<td>1305 (770-2545)</td>
</tr>
<tr>
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<tr>
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<td>-</td>
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<td>-</td>
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<tr>
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<td>-</td>
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<td>-</td>
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<td>-</td>
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<td>Micro charcoal onset</td>
<td>1365</td>
<td>-</td>
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</table>

Table 7.4 List of 2σ linear interpolated central point estimates for key palynological-based events determined from the Tukou marsh sediment profiles. Presented are the sample depths of the key events, central point estimates and where available (marked by *) the central point estimate error of direct AMS determinations.
Palm extinction: the Arecoideae (Iguanurinae type) record

In the description of Core 1 provided in Chapter 6, I outlined the presence of an Areaceae: Iguanurinae type palm pollen type which is derived from an extinct palm of that sub-tribe (see Plate 12 for pollen micrographs). This determination is based on the broad morphological comparison under light microscopy of reference Areaceae palm pollen collected by the author and present in the Australian National University pollen reference collection. The classification scheme developed by Harley and Baker (2001) was also useful in making the sub-tribe determination. Scanning electron microscopy (SEM) of pollen was attempted but has not yet provided images of sufficient quality to make any higher order determination. Further support for this palm determination came from the identification of palm type phytoliths from the highly organic Zone III sections of Cores 2 and 3 (see Plate 13 for phytolith micrographs). The morphology of these phytoliths remains to be examined in more detail under light microscopy and SEM are not discussed further in this thesis.

The near absence of the Areaceae: Iguanurinae type pollen from the Zone IV of Core 1 pointed to the possibility that, like on Easter Island, human-induced deforestation may have contributed to palm tree extinction. As shown in the composite stratigraphic diagram (Figure 7.9), Iguanurinae type palm pollen was identified from each of the Tukou Cores. As for Colocasia pollen, palm pollen concentrations varied considerable across the site, but were most concentrated (close to 7000 grains/cc) in Zone III sediments of the most inland core (Core 3). Palm pollen concentrations tended to be highest in Zone III sediments across the site, but were also high in Zone II of Core 2, the central most part of Tukou Marsh and in Zone I of Core 1. This pollen concentration shift from the lower shoreward zones to the higher inland zones may signify a successional inland expansion from the mid to the late Holocene.

The interpolated ages for the decline and dropout of Iguanurinae type palm pollen from all core records fall in an age bracket that overlaps the earliest age determination obtained from the archaeological record of Tangarutu (see Table 7.4 and Figure 7.10). The average central point estimate age interpolation for Iguanurinae type palm pollen lies at 725 cal. yr B.P., close to the age estimate provided for the onset of Colocasia pollen. I suggest that this record provides further robust evidence for early human activity on Rapa. Again the average estimated age is older than expected and reflects the poor chronological control for the dropout of Iguanurinae pollen, this time in two of the five cores (Cores 3, and 6). The estimated timing of dropout of Iguanurinae type palm pollen in Core 2, the most well constrained core from Tukou, is 585 cal. yr B.P., only 35 years after the recorded onset of Colocasia pollen in the same record.
Additional palynological signatures of human impact from Tukou (Cores 2-6)

In this section I will broadly outline the main features of the series of stratigraphic diagrams of percentage palynological data constructed using the C2 Data Analysis program (Juggins, 2005). Palynological data from Tukou Cores 2-6 are presented according to the occurrence of taxa throughout the cores in proportions of either >5% (Figure 7.10a, 7.11a, 7.12a, 7.13a and 7.14a) or <5% (Figure 7.10b, 7.11b, 7.12b, 7.13b and 7.14b). Taxa are grouped from left to right according to trees and shrubs, herb, fern and fern ally groups. Taxa are sorted within these groups in stratigraphic succession using the sort function in C2 Data Analysis program. The cores are divided into four palynological zones on the basis of the major vegetation changes. The key palynological events of human impact namely, microcharcoal onset, Colocasia pollen onset and Arecoideae: Iguanurinae decline, are marked with dashed lines for each stratigraphic diagram.

In describing these diagrams, I will focus on describing the main changes in vegetation and the palynological taxa not described for Core 1 or in my interpretation of the palynological concentrations presented in the composite stratigraphic diagrams. A more detailed discussion of these diagrams will be provided in forthcoming publications.

**Zone I (~6,500 - ~4,000 cal. Yr. B.P.) Early Holocene marine transgression**

None of Cores 2-6 revealed Zone I aged sediments.

**Zone II (~4,000 - ~2,500 cal. yr B.P.) Mid-Holocene highstand**

The palynological signatures of Cores 2, 3, 4 and 6 from Zone II (Zone I absent in all these cores) generally correspond closely with those of Core 1. Sediments representative of Zone II in Core 5 were not examined. Fern spores dominate the early part of this Zone in all cores but decrease by ~3,000 cal. yr B.P. in response to increasing Pandanus cf. tectorius and Cyperaceae pollen. Palynomorph concentrations are generally very low throughout this Zone. Both foraminifera (Cores 2, 3, and 6) dinoflagellates (Cores 2, 4 and 6) have been located in the sediments throughout this Zone (see Chapter 6 for and interpretation of these data).

A number of additional indigenous taxa were recorded in Zone II sediments of Cores 2, 3, 4 and 6 (see Table 7.4 for list of taxa identified in the palynological record from Tukou). These include Myoporum rapensis (Myoporaceae; having tree and prostrate shrub growth forms), Geniostoma (Loganiaceae; tree), Omalanthus (Euphorbiaceae shrub; only recorded from Zone I sediments in Core 1; not listed in Table 7.4) pollen and Dicranopteris (Gleicheniaceae fern) spores. Amaranthaceae (herbs) and Santalaceae (tree; probably Santalum insulare now
endangered on the island) pollen were also identified but only recorded from Zone II sediments in Core 2 and Core 6 respectively.

**Zone III (~2,500 - 1,000 cal. yr B.P.) Late Holocene Pandanus swamp forest**

The palynological signatures of Cores 2-6 from Zone III generally correspond closely with those of Core 1. *Pandanus cf. tectorius* pollen along with palynomorph concentrations generally increase in this Zone. Trilete fern spores including *Cyathea* tree fern and *Angiopteris* types decline in this Zone. In contrast to Core 1, the higher representation of some taxa in this zone are notable, including *Sophora tomentosa, Glochidion* and *Meryta* in Core 2, Arecales: Iguanurinae type in Core 3 (as discussed above) and *Triumfetta* in Core 6. Only two additional species in Zone III sediments were identified from these records, including cf. *Psychotria* (Rubiaceae) from Core 2 and *Scaevola taccada* (Goodeniaceae) from Core 3 (see Table 7.4).

**Zone IVa (~1,000 - ~125 cal. yr B.P.) the pre-European human impact record**

As found in Core 1, tree and shrub taxa decline or are absent in this Zone. Cyperaceae and Poaceae (both <40 and >40µm size classes) increase to considerably higher levels than in the previous Zones. No introduced taxa were located in Zone IV of Core 1 and human impact signatures can only be attributed to peaks in microcharcoal concentrations regarded as an equivocal signature of human impact. Human impact signatures are more apparent in the palynological records from Cores 2-6 where a range of introduced palynomorphs were located (Table 7.5). Seven introduced taxa entered the record in this Zone, three of which are agricultural cultigens (*Aleurites moluccana, Colocasia esculenta* and *Cordyline fruticosae*), one is an inadvertent weed introduction (*Sonchus oleraceus*) often associated with *Colocasia* cultivation sites, with the status of the remaining three possible introductions (*Casuarina, Convolvulaceae, cf. Ipomoea* and *Erythrina variegata*) remaining uncertain (see Chapter 8 for a discussion on these taxa).

Apart from the decline in *Pandanus cf. tectorius* and Arecales: Iguanurinae type pollen, as already discussed, a number of tree and shrub taxa are either absent from Zone IV or decline after a peak during the previous Zones. Taxa that decline include *Sophora tomentosa, Glochidion, Myrtaceae undifferentiated* and *Triumfetta (T. procumbens)*. The absence of some taxa in Zone IV from all of the Tukou cores that were present in the previous zones in some cases may represent extinction or local extirpation events in the record. The key taxa in this regard are *Santalum, Meryta* and *Glochidion*. *Santalum* is currently restricted in distribution on the island to only two small remnant populations. Both *Meryta* and *Glochidion* have notable species radiations on other islands from French Polynesia and may have had a number of representatives in each genus prior to human impact (see Chapter 8 for a discussion on these taxa).
Figure 7.10a Percentage diagram for Tukou Core 2 (total of 4 m). The following are presented in the diagram from left to right: Core lithology, magnetic susceptibility values (K), calibrated radiocarbon ages (line and ticks; the transparent vertical grey bar within the radiocarbon age range histogram represents the earliest archaeological radiocarbon determination obtained for Rapa (770-540 cal. yr B.P.), taxa (pollen and spores: taxa with ≥5% of total palynomorph sum are presented as colour coded bars; samples with proportions <5% are presented as triangle symbols) and total palynomorph concentrations (per cm³), microcharcoal particle concentrations (per cm³), foraminifera and dinoflagellate counts, palynomorph richness (number of taxa), Correspondence Analysis scores (CA score 1) and palynological zones. Three palynological zones (Mid-Holocene highstand Zone II; Late Holocene swamp forest Zone III; Human impact Zone IV) are presented with Zone IV divided into a Polynesian phase (IVa) and a European phase (IVb). The dashed blue line indicates the relative position of high tide. The transparent horizontal red bar indicates a chronological lacunae bracketed by the onset of microcharcoal and the point of intercept between the archaeologically defined onset of human colonisation (770-540 cal. yr B.P.). The black horizontal dashed lines indicate the onset of microcharcoal and Colocasia pollen and the decline of an extinct palm (Areaceae: Iguanurinae type) as discussed in the text.
Figure 7.10b Percentage diagram for Tukou Core 2 (total of 4 m) as for Figure 7.10a showing taxa with <5% representation in every core sample (coloured triangle symbols)
Figure 7.11a Percentage diagram for Tukou Core 3 (total of 3.15 m). The following are presented in the diagram from left to right: Core lithology, magnetic susceptibility values (K), calibrated radiocarbon ages (line and ticks; the transparent vertical grey bar within the radiocarbon age range histogram represents the earliest archaeological radiocarbon determination obtained for Rapa (770-540 cal. yr B.P.), taxa (pollen and spores: taxa with ≥5% of total palynomorph sum are presented as colour coded bars; samples with proportions <5% are presented as triangle symbols) and total palynomorph concentrations (per cm³), microcharcoal particle concentrations (per cm³), foraminifera counts, palynomorph richness (number of taxa), Correspondence Analysis scores (CA score 1), fungal spores measures (1=frequent, 2=common, 3=abundant) and palynological zones. Three palynological zones (Mid-Holocene highstand Zone II; Late Holocene swamp forest Zone III; Human impact Zone IV) are presented with Zone IV divided into a Polynesian phase (IVa) and a European phase (IVb). The dashed blue line indicates the relative position of high tide. The transparent horizontal red bar indicates a chronological lacunae bracketed by the onset of microcharcoal and the point of intercept between the archaeologically defined onset of human colonisation (770-540 cal. yr B.P.). The black horizontal dashed lines indicate the onset of microcharcoal and Colocasia pollen and the decline of an extinct palm (Areceae: Iguanurinae type) as discussed in the text.
Figure 7.11b Percentage diagram for Tukou Core 3 (total of 3.15 m) as for Figure 7.11a showing taxa with <5% representation in every core sample (coloured triangle symbols)
Figure 7.12a Percentage diagram for Tukou Core 4 (total of 2.5 m). The following are presented in the diagram from left to right: Core lithology, magnetic susceptibility values (K), calibrated radiocarbon ages (line and ticks; the transparent vertical grey bar within the radiocarbon age range histogram represents the earliest archaeological radiocarbon determination obtained for Rapa (770-540 cal. yr B.P.), taxa (pollen and spores: taxa with ≥5% of total palynomorph sum are presented as colour coded bars; samples with proportions <5% are presented as triangle symbols) and total palynomorph concentrations (per cm³), microcharcoal particle concentrations (per cm³), dinoflagellate counts, palynomorph richness (number of taxa), Correspondence Analysis scores (CA score 1) and palynological zones. Three palynological zones (Mid-Holocene highstand Zone II; Late Holocene swamp forest Zone III; Human impact Zone IV) are presented with Zone IV divided into a Polynesian phase (IVa) and a European phase (IVb). The dashed blue line indicates the relative position of high tide. The transparent horizontal red bar indicates a chronological lacunae bracketed by the onset of microcharcoal and the point of intercept between the archaeologically defined onset of human colonisation (770-540 cal. yr B.P.). The black horizontal dashed lines indicate the onset of microcharcoal and Colocasia pollen and the decline of an extinct palm (Areaceae: Iguanurinae type) as discussed in the text.
Figure 7.12b Percentage diagram for Tukou Core 4 (total of 2.5 m) as for Figure 7.12a showing taxa with <5% representation in every core sample (coloured triangle symbols)
Figure 7.13a Percentage diagram for Tukou Core 5 (total of 2.5 m). The following are presented in the diagram from left to right: Core lithology, magnetic susceptibility values (K), calibrated radiocarbon ages (line and ticks; the transparent vertical grey bar within the radiocarbon age range histogram represents the earliest archaeological radiocarbon determination obtained for Rapa (770-540 cal. yr B.P.), taxa (pollen and spores: taxa with ≥5% of total palynomorph sum are presented as colour coded bars; samples with proportions <5% are presented as triangle symbols) and total palynomorph concentrations (per cm³), microcharcoal particle concentrations (per cm³), palynomorph richness (number of taxa), Correspondence Analysis scores (CA score I) and palynological zones. Two palynological zones (Late Holocene swamp forest Zone III; Human impact Zone IV) are presented with Zone IV divided into a Polynesian phase (IVa) and a European phase (IVb). The dashed blue line indicates the relative position of high tide. The transparent horizontal red bar indicates a chronological lacunae bracketed by the onset of microcharcoal and the point of intercept between the archaeologically defined onset of human colonisation (770-540 cal. yr B.P.). The black horizontal dashed lines indicate the onset of microcharcoal and Colocasia pollen and the decline of an extinct palm (Arecaceae: Iguanurinae type) as discussed in the text.
Figure 7.13b Percentage diagram for Tukou Core 5 (total of 2.5 m) as for Figure 7.13a showing taxa with <5% representation in every core sample (coloured triangle symbols)
Figure 7.14a Percentage diagram for Tukou Core 6 (total of 2.5 m). The following are presented in the diagram from left to right: Core lithology, magnetic susceptibility values (K), calibrated radiocarbon ages (line and ticks; the transparent vertical grey bar within the radiocarbon age range histogram represents the earliest archaeological radiocarbon determination obtained for Rapa (770-540 cal. yr B.P.), taxa (pollen and spores: taxa with ≥5% of total palynomorph sum are presented as colour coded bars; samples with proportions < 5% are presented as triangle symbols) and total palynomorph concentrations (per cm³), microcharcoal particle concentrations (per cm³), foraminifera and dinoflagellate counts, palynomorph richness (number of taxa), Correspondence Analysis scores (CA score 1) and palynological zones. Three palynological zones (Mid-Holocene highstand Zone II; Late Holocene swamp forest Zone III; Human impact Zone IV) are presented with Zone IV divided into a Polynesian phase (IVa) and a European phase (IVb). The dashed blue line indicates the relative position of high tide. The transparent horizontal red bar indicates a chronological lacuna bracketed by the onset of microcharcoal and the point of intercept between the archaeologically defined onset of human colonisation (770-540 cal. yr B.P.). The black horizontal dashed lines indicate the onset of microcharcoal and *Colocasia* pollen and the decline of an extinct palm (Arecaceae: Iguanurinae type) as discussed in the text.
Figure 7.14b Percentage diagram for Tukou Core 6 (total of 2.5 m) as for Figure 7.14a showing taxa with <5% representation in every core sample (coloured triangle symbols)
Table 7.5 Additional palynomorphs recorded from Tukou Cores 2-6 not recorded in Core 1. Listed are the presence or absence of palynomorphs in Tertiary sediment (after Cranwell, 1964b), early to mid-Holocene sediments (Zones II and III) and in Zone IV sediments aged <1,000 cal. yr B.P., the botanical status and biogeographic affinity of taxa.

<table>
<thead>
<tr>
<th>Pollen taxa</th>
<th>Family</th>
<th>Present in Tertiary</th>
<th>Present in Zone II</th>
<th>Present in Zone III</th>
<th>Present in Zone IV</th>
<th>Indigenous representatives in modern flora</th>
<th>Biogeographic affinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amaranthaceae</td>
<td>Amaranthaceae</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>?</td>
<td>Pan-tropical/Endemic</td>
</tr>
<tr>
<td>Arecales/</td>
<td>Arecales/</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Liliaceae</td>
<td>Liliaceae</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Canavalia sericea</td>
<td>Indo-Pacific/Endemic</td>
</tr>
<tr>
<td>Canavalia</td>
<td>Fabaceae - Sf</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Psychotria sericea</td>
<td>Indo-Pacific/Endemic</td>
</tr>
<tr>
<td>cf. Psychotria</td>
<td>Rubiaceae</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Psychotria rapensis, Dicranopteris</td>
<td>Indo-Pacific/Endemic</td>
</tr>
<tr>
<td>Dicranopteris</td>
<td>Gleicheniaceae</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Dicranopteris linearis</td>
<td>Indo-Pacific/Endemic</td>
</tr>
<tr>
<td>Dodonaea viscosa</td>
<td>Sapindaceae</td>
<td>Y?</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Dodonaea viscosa</td>
<td>Indo-Pacific/Endemic</td>
</tr>
<tr>
<td>Gentianum</td>
<td>Loganiaceae</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Gentianus quadrangulare, G. rapense, G. rupestris</td>
<td>Indo-Pacific/Endemic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>var. micranthum</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Myoporum</td>
<td>Indo-Pacific/Endemic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Myoporum</td>
<td>Indo-Pacific/Endemic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Myoporum var. micranthum</td>
<td>Indo-Pacific/Endemic</td>
</tr>
<tr>
<td>Santalaceae</td>
<td>Santalaceae</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Exocarpos paliformis, Santalum insulare</td>
<td>Indo-Pacific/Endemic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>var. margaretan</td>
<td></td>
</tr>
<tr>
<td>Scabiosa taccada</td>
<td>Goodeniaceae</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Scabiosa taccada</td>
<td>Indo-Pacific/Endemic</td>
</tr>
</tbody>
</table>

From calculations of linear interpolated age/depth estimates for each core (see Table 7.6) the rate of sediment accumulation generally increases in Zone IVa deposits above rates found for Zone III. These rates vary across the site with the most rapid sedimentation found in Core 4 towards the shoreline and the least in Core 3, the most inland core where the rate decreased slightly from Zone III. The trend in Core 3 may reflect the poor radiocarbon age control for this core with only two determinations obtained.

Zone IVb (~125 cal. yr B.P. - present) the post-European contact record

No firm palynological signatures are available from Tukou Core 1 indicating the onset of post-European contact. Living roots of the introduced grass species Paspalum conjugatum are present in the upper 22 cm of Core 1, but the penetration of grass roots are unlikely to represent the full extent of post-European contact influences on the Core 1 record, thus this Zone has not been defined for this core.

In Cores 2-6, this Zone IVb is defined by the presence of palynological markers of post-European contact period. The initial presence of these markers has been used as a chronological indicator with a central point estimate age of 125 cal. yr B.P. (taken from an age range of 100-150 cal. yr B.P.), an age that approximates AD 1830 in calibrated radiocarbon years. The two primary
post-European contact period pollen markers are from the inadvertent weed introductions *Commelina diffusa* (Commelinaceae) and *Ludwigia octovalvis* (Onagraceae). The exact status of these two herbaceous weed taxa in the Austral Islands is uncertain, but from the palynological record (including from Rimatara; see below), these taxa appear to enter the pollen record late in the human impact sequences.

These two species are commonly found encroaching active or fallow *Colocasia* agricultural fields or abandoned cultivation systems. In some swampy areas these species form dense monotypic stands. They tend to flower prolifically with their pollen locally dispersed and readily incorporated into the underlying soil matrix. I suggest that the presence of these *Commelina diffusa* and *L. octovalvis* pollen in sedimentary records associated with either active or formerly cultivated sites are potentially indicative of European contact.

<table>
<thead>
<tr>
<th>Pollen taxa</th>
<th>Family</th>
<th>Present in Zone IVa (pre-European colonisation)</th>
<th>Present in Zone IVb (post-European colonisation)</th>
<th>Biogeographic affinity</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Aleurites malaccaena</em></td>
<td>Euphorbiaceae</td>
<td>Y</td>
<td>Y</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Alyssum stellata</em></td>
<td>Apocynaceae</td>
<td>N</td>
<td>Y</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Casuarina</em></td>
<td>Casuarinaceae</td>
<td>Y</td>
<td>Y</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Colocasia esculenta</em></td>
<td>Araceae</td>
<td>Y</td>
<td>Y</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Convolvulaceae</em></td>
<td><em>cf. Ipomoea</em></td>
<td>Y</td>
<td>N</td>
<td>? Probably <em>Ipomoea pes-caprae</em> not <em>I. batatas</em></td>
</tr>
<tr>
<td><em>Commelina diffusa</em></td>
<td><em>Cornelinaeae</em></td>
<td>N</td>
<td>Y</td>
<td>Indo-Pacific/Cosmopolitan</td>
</tr>
<tr>
<td><em>Coreline fruticosa</em></td>
<td><em>Laxmanniaceae</em></td>
<td>Y</td>
<td>Y</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Erythrina variegata</em></td>
<td>Fabaceae</td>
<td>Y</td>
<td>Y</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td><em>Ludwigia octovalvis</em></td>
<td><em>Onagraceae</em></td>
<td>N</td>
<td>Y</td>
<td>Indo-Pacific/Pan Tropical</td>
</tr>
<tr>
<td><em>Plantaginaceae</em></td>
<td><em>Plantaginaceae</em></td>
<td>N</td>
<td>Y</td>
<td>?</td>
</tr>
<tr>
<td><em>Souchus atracaceus</em></td>
<td><em>Asteraceae</em></td>
<td>Y</td>
<td>Y</td>
<td>Cosmopolitan</td>
</tr>
</tbody>
</table>

Table 7.6 Palynemorphs from Rapa of introduced taxa. Listed are the presence or absence of palynomorphs in Zones IVa and IVb, biogeographic affinity of taxa. ¹Pollen or spore type wind blown. ²Pollen type capable of long distance dispersal (after Close et al 1978). ³Inadvertent introduction. ⁴Possible introduction.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Core 3</th>
<th>Core 6</th>
<th>Core 2</th>
<th>Core 5</th>
<th>Core 4</th>
<th>Core 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone IVb</td>
<td>0.04 cm/yr</td>
<td>0.56 cm/yr</td>
<td>0.48 cm/yr</td>
<td>0.4 cm/yr</td>
<td>0.4 cm/yr</td>
<td>0.104 cm/yr</td>
</tr>
<tr>
<td>Zone IVa</td>
<td>0.068 cm/yr</td>
<td>0.076 cm/yr</td>
<td>0.14 cm/yr</td>
<td>0.078 cm/yr</td>
<td>0.140 cm/yr</td>
<td></td>
</tr>
<tr>
<td>Zone III</td>
<td>0.109 cm/yr</td>
<td>0.059 cm/yr</td>
<td>0.02 cm/yr</td>
<td>0.095 cm/yr</td>
<td>0.073 cm/yr</td>
<td>0.101 cm/yr</td>
</tr>
</tbody>
</table>

Table 7.7 Sedimentation rates (cm/yr) based on linear age/depth interpolations (cal. yr B.P.) for each core from Tukou.

As a consequence of human population decline on the islands following early European impacts (e.g. black-birding and disease epidemics; see Chapter 5), agricultural activity probably decreased considerably leaving larger formerly cultivated areas abandoned or in fallow. Under such conditions, weeds such as *C. diffusa* and *L. octovalvis*, if already present on the island may
have increased in abundance in the absence of weeding and crop maintenance. Alternatively, these weeds may have been introduced in the early European colonisation period given the increased amount of visits by trading ships, increasing the opportunity for weed introduction. The seeds of *C. diffusa* and *L. octovalvis* could remain embedded in soil attached to corms or tuber crops frequently traded between the islands.

It is plausible that the presence of *C. diffusa* and *L. octovalvis* pollen may be indicative of some pre-European contact change in agricultural production. However, the presence of these two pollen types late in the human impact records from three palynological sequences from what are thought to be former *Colocasia* agricultural fields on O'ahu in the Hawaiian Islands (Kahana Valley, Maunawili and Kapunahala; see Table 7.2) and two cores from an active *Colocasia* cultivation at Maunutu Swamp on Rimatara (see below), points to the firm likelihood that these two pollen types provide reliable post-European contact signatures in pollen records from OIRO.

The use of pollen markers, in this case, provides a more reliable means of constructing a chronology than radiometric measurements (Radiocarbon and $^{210}$Pb dating) particularly for sediments that may be aged between AD 1800 and 1900. A radiocarbon plateau lying between 1700 and 1800 and then between 1820 and 1950 (see Figure 4.5, Chapter 4) restricts the reliable use of radiocarbon determinations for this period. Equally, the accuracy of $^{210}$Pb dating of sediments is dependent on a number of factors but generally can only provide reliable age determinations for the last 140 years. This reliability is also dependent on the age model used and the ability to calibrate dates using independent evidence such as palynological markers or documented landuse histories (see Gale et al 1995).

From the pollen-based chronology of post-European contact proposed for the Tukou Cores 2-6 allowing linear interpolated age/depth estimates to be calculated (see Table 7.6). With the exception of Core 3, in which the Zone IVb stratigraphy is very shallow (only 5cm) with poor radiocarbon age control, the resulting sediment accumulation rates for each core exceed that of Zone IVa. These rates vary across the site with the most rapid sedimentation found inland and progressively decreasing towards the shoreline (from Core 6 to Core 4).

**Correspondence analysis (CA)**

Correspondence analysis was performed on the percentage data of all pollen and spore taxa identified in Tukou Core 2-6. Eigenvalues (Axis 1; CA 1 scores) generated for each sample are presented as proportions of the total variation in the dataset in each of the two stratigraphic diagrams (Figures 6.9a and 6.9b). These values account for the variation in the entire dataset and are primarily controlled by the proportions of *Pandanus cf. tectorius* type pollen within each sample. With the exception of core 4, the most pronounced change in each dataset is exhibited in Zone IVb where *Pandanus cf. tectorius* is almost entirely absent. These data lend further support for the differentiation of Zone IVa from IVb, but also suggest that the most substantial vegetation
change occurs at the transition between these Zones. Correspondence analysis scores also suggest that vegetation did alter considerably in Zone IVa, but the level of variation between each sample points to a more gradual transition when compared to the variation evident in Zone IVb.

Non-pollen palynomorph signatures: the fungal spore record from Tukou Core 3

There use of non-pollen palynomorphs (e.g. fungal spores, bacterial cells etc.) in palaeoenvironmental research has become increasingly important, particularly for mapping vegetation and human-induced environmental change from sedimentary sequences (Van Geel, 2001). In addition to palynological analysis of Core 3, four slides were examined for microscopic fungal spores. Some fungal spores (e.g. Podospora and Sporormiella) have been noted as effective proxies for animal dung (coprophilous fungi) and have been used, for example as an indicator of the early expansion of cattle husbandry in Northern Europe (Van Geel, ibid). The intention was to examine representative samples from each Zone in order to identify particular spores than may form a useful indicator of human activity at Tukou.

Ten of the most commonly occurring fungal fossil spores were identified by Mike Macphail at the ANU on the basis of morphological grouping and the systematic form to genera. The relative abundance of each spore was estimated then placed into the pollen and spore diagrams shown in Figures 7.11a and 7.11b the results of which are briefly discussed here. Monoporisporonites was the only spore found in Zone II and were also located in Zone IVa sediments. Dictyosporites, Dicellaesporites, Perisporonites were the only taxa identified in Zone III sediments. Seven taxa were found in Zone IVa sediments including Monoporisporonite, as mentioned, Basidiosporites, Exesisporites, Granasporonites, Triangulasporites, Diporisorites and Multicellites/Pluricellaesporites.

The conclusions drawn from the fungal spore data are that morphologically simple types are more common in the sediments from Tukou than multicellular types (Dictyosporites and Multicellites/Pluricellaesporites); and individual samples tend to be dominated by few rather than several taxa. No coprophilous fungi were identified in Zone IVa which is encouraging given that there are no archaeological or ethnographic indications that animals, apart from Rattus exulans, being introduced pre-European contact. The author examined the uppermost Zone IVb sample of Core 3 for coprophilous fungi but none were identified. Further samples are set for examination in the future with the intention of identifying these spores as a proxy for the introduction of for cattle, goats, horses and pigs and thus providing an additional marker post-European contact.

A summary of human impact on vegetation at Tukou
In Figures 7.10a-d, broad graphical environmental reconstructions are provided for time slices at −1400, −700, −400 cal. yr B.P. and the present day. These show colour coded squares positioned at each core site relating the proportion of each vegetation type. At −1400 cal. yr B.P., coastal tree and shrub swamp forest dominated by *Pandanus* expanded along a prograding shoreline. Around the time of initial human colonisation of the island at −700 cal. yr B.P., the earliest evidence of human modification of Tukou is found from the most inland core (Core 3) where the reduction of coastal swamp forest appears to take place more rapidly. By −400 cal. yr B.P. non-forest vegetation expands across the entire swamp with coastal forest vegetation almost absent from the inland parts of Tukou. From these broad environmental reconstructions and the *Colocasia* pollen concentration record I suggest that early *Colocasia*-based agricultural activity was concentrated on the most inland part of the coastal swamp forest and progressively expanded shoreward during the initial 2-300 years of human occupation.

The transition from the −400 cal. yr B.P. to the present day represents the most marked vegetation change found in any of the Tukou records. The vegetation of the marsh surface is dominated by introduced agricultural grasses (e.g. *Paspalum subjugatum*), adventive herbs (e.g. *Commelina diffusa* and *Ludwigia octovalvis*) and the rush *Schoenoplectus subulatus* subsp. *subulatus*. Some indigenous sedges and rushes (e.g. *Carex* spp) remain at the site but are now rare. No indigenous tree or shrub taxa remain on the marsh, but some species are found in pockets on the embankment at the back of the marsh (e.g. *Hibiscus tiliaceus* and *Metrosideros collina*).

**Palaeoenvironmental examination of anthropogenic sediments from makatea islands**

As discussed in Chapters 2 and 6, makatea islands include depositional environments that are filled with organic-rich sediments. In Chapter 6, I outlined the palaeoenvironmental records from Mangaia and Atiu in the Cook Islands in reference to mid-late Holocene vegetation change. Here I will briefly summarise the human impact signatures evident from these islands and provide a re-interpretation of the anthropogenic sediment stratigraphy in light of my own research from Rimatara. These sequences, particularly those from Mangaia, have been subject to much scrutiny by archaeologists primarily interested in the chronology of human colonisation of Remote Oceania. In Chapter 6, I described one representative core (Core 1 Transect 2) from Maunutu moat-swamp, Rimatara. In this chapter I will examine the anthropogenic sediments from this core in detail and then describe two additional cores from Maunutu, focusing on the sequence of human impact events inferred in the absence of supporting archaeological excavation data.
Figure 7.15a Vegetation reconstruction of Tukou at ~1400 cal. yr B.P. prior to human arrival on the island. The satellite image of Tukou shows the position of each core in the multiple profile transects as well as other surrounding features. The vegetation of each core inferred for ~1400 cal. yr B.P. is indicated by colour coded boxes representing the proportional representation of each vegetation type shown in the colour coded legend.

Figure 7.15b Vegetation reconstruction of Tukou at ~700 cal. yr B.P. at the approximate time of initial human settlement based on the archaeological chronology established from the Tangarutu excavation. The satellite image of Tukou shows the position of each core in the multiple profile transects and other surrounding features. The vegetation of each core inferred for ~700 cal. yr B.P. is indicated by colour coded boxes representing the proportional representation of each vegetation type shown in the colour coded legend.
Figure 7.15c Vegetation reconstruction of Tukou at ~400 cal. yr B.P. The satellite image of Tukou shows the position of each core in the multiple profile transect and other surrounding features. The vegetation of each core inferred for ~400 cal. yr B.P. is indicated by colour coded boxes representing the proportional representation of each vegetation type shown in the colour coded legend.

Figure 7.15d Vegetation of Tukou at present. The satellite image of Tukou shows the position of each core of the multiple profile transect and other surrounding features. The present vegetation of each core is indicated by colour coded boxes representing the proportional representation of each vegetation type shown in the colour coded legend.
Mangaia

From the Lake Tiriara palynological study (Lamont, 1990), discussed in Chapter 6, Kirch et al. (1992) suggest that by 1410 cal. yr B.P. tree and shrub pollen rapidly declined in response to increased anthropogenic burning represented by increased charcoal particle and fern spore (Dicranopteris) counts. Erosion events are represented by thin clay bands found throughout the core with mostly inorganic sediments found in upper sections thought to be associated with human activity. As on Rapa, lowland swamp areas on Mangaia are utilised for wet-field Colocasia agriculture. In 1967, only 125ha of the moat swamp areas lying adjacent to the makatea had been terraced Colocasia cultivation (Allen, 1971) whereas early European accounts of the island, including by James Cook on board the HMS Resolution in April 1777 (Beaglehole, 1955-57), indicate that these cultivation systems were formerly more extensive. The areas of swamp and lake separating the makatea from the wet-field systems are not cultivated often as a consequence of impinging estuarine conditions or poor soil fertility. This also appears to be the case on other makatea islands including Atiu and Rimatara (see below).

As yet, no precise indications for the timing of human colonisation or the onset of Colocasia agriculture on Mangaia have been forthcoming, the former being a subject of ongoing debate (Anderson, 1994; Anderson, 1995; Ellison, 1994; Kirch and Ellison, 1994). The palaeoenvironmental records analysed by Ellison (1994) indicate a different timing of major human induced environmental change to that indicated from the archaeological record (2500 cal. yr B.P. to ~1000 cal. yr B.P., respectively). Ellison (1994) identified an initial increase in charcoal particle concentrations (~500,000 particles per cm³) in a sample from the VT6 core (at ~8.5 m) bracketed by relative ages inferred from dates obtained from a duplicate core (VT2) at 2850-2350 cal. yr B.P. (Lab no. Beta 52830). A similar charcoal particle peak was noted in a sample at ~2.2 m in depth bracketed by a 10 cm bulk sediment age at ~2000 cal. yr B.P. Anderson (1994) suggests that old carbon eroded off the makatea limestone may have influenced the radiocarbon age chronology obtained and hence the 2,500 cal. yr B.P. interpretation of human-induced environmental change.

Aside from the decline in swamp forest taxa and the increase in charcoal particles, other indicators of human activity from these palynological records include the increased concentrations of the ferns Cyclosorus interruptus and Dicranopteris, regarded by Ellison (1994) as disturbance taxa. The direction of vegetation decline in both the VT6 and TM 7 records are not, however, entirely comparable, as Pandanus tectorius, for example appears to decline in the VT6 record but increases in the TM7 record. As discussed in Chapter 6 in reference to Maunutu Core 1 Transect 2, this may reflect the increased flowering and pollen production of Pandanus in response to burning.
Atiu

Parkes (1997) examined one 8.4 m deep sediment core taken from the central part of Te Roto moat-lake on Atiu. As outlined in Chapter 6, the flora represented within the Holocene record include *Pandanus*, *Calophyllum* and *Trema* along with *Elaeocarpus*, *Allophyllus* and *Rapanea*. Two palms are represented in the record including a *Pritchardia* species (*P. vaylstekeana* type) and *Cocos nucifera*, the latter common in much of the mid-late Holocene record. Like in the Mangaia records and the Maunutu Core 1 Transect 2 record from Rimatara, *Acrostichum aureum* dominates the early to mid-Holocene pollen assemblages with increasing representation of tree and shrub species.

The upper 3.5 m of this sedimentary record is bracketed by ages at 1410–1260 cal. yr B.P. (Lab no. unpublished at 3.52 m) and 680–310 cal. yr B.P. (Lab no. SRR-3282 at 2.85–2.90 m). Palynological evidence for human impact from this record comes in the form of increases in grasses, ferns, sedges in conjunction with a decline in the primary arboreal taxa beginning in the upper 3 to 2.85 m of the record. Parkes (ibid) sees the appearance of *Casuarina* and *Ipomoea batatas* pollen, in this upper part of the record and an increase in *Dicranopteris linearis* fern spore representation as firm indicators of human activity. The above stratigraphic changes are supported by magnetic susceptibility data that indicates an initial peak of mineral sediment accumulation occurring at around 3.5 m. From diatom assemblage data, at 2.5 m down the core, taxa characteristic of benthic and brackish water conditions (e.g. *Amphora coffeaeformis*) and the marine-resting spore, *Chaetoceros*, decline in response to increasing abundance of epiphytic diatoms (e.g. *Pinnularia subcapitata* and *Thalossiosira weissflogii*).

Palaeoenvironmental examination of anthropogenic sediments from Maunutu Moat-Swamp, Rimatara

On Rimatara, as outlined in Chapter 6, the palynological record of Maunutu Core 1 Transect 2 (see Figures 6.13a and 6.13b, Chapter 6) indicates that a *Pandanus* swamp forest interspersed with an *Acrostichum aureum* fern understorey dominated the moat lake/swamp settings prior to ~800 cal. yr B.P (Zone 1). Other established taxa found in or around this forest included many coastal tree species (e.g. *Triumfetta procumbens*, *Tournefortia argentea*, and *Barringtonia asiatica*). Increased mineral sediment deposition evident in the upper horizons of these deposits is indicative of human activity. This sedimentation is most likely a response to the introduction of agricultural practices including wet-field *Colocasia esculenta* cultivation, a claim supported by the presence of *C. esculenta* pollen in sediments with an interpolated radiocarbon age of ~750 cal. yr B.P.
In this section, I will examine in more detail the palynological signatures of human impact from Maunutu Core 1 Transect 2, and present two additional records from different sites at Maunutu as part of the same multiple profiling approach employed at Tukou. Following the same interpretative framework as for Tukou examining the onset of charcoal particles and *Colocasia* pollen in the record as well as the decline of an Arecaceae: Iguanurinae type pollen, I will then briefly summarise the human impact signatures then provide a re-interpretation of the anthropogenic sediment stratigraphy in the context of the debate on the Mangaian records.

**Palynological signatures of human impact from Maunutu Core 1 Transect 2**

As outlined in Chapter 6, this Zone can be divided into two subzones (Zone IIA and IIb) on the basis of the presence of pre- and post-European contact pollen indicators. For Core 1 Transect 1, the onset of *Colocasia esculenta* pollen in the record established the base of Zone IIA and as proposed for the pollen record of Tukou, the presence of pollen from the introduced weeds, *Ludwigia octovalvis* and *Commelina diffusa*, provide a good indication of post-European contact sedimentation. As for the Tukou cores, the initial presence of these markers has been used as a chronological indicator with a central point estimate age of 125 cal. yr B.P. (taken from an age range of 100-150 cal. yr B.P.), an age that approximates AD 1830 in calibrated radiocarbon years (these ages are presented in Figures 6.13a and 6.13b).

**Pre-European contact Zone IIA (~800 cal. yr B.P. to ~125 cal. yr B.P.)**

As already discussed in Chapter 6, a number of tree and shrub taxa are either absent from Zone IIA or decline after a peak during in the previous zone. Some of the taxa that decline or are absent in Zone IIA include *Pandanus* cf. *tectorius*, *Macaranga*, *Glochidion societales* and *Triumfetta procumbens*. The absence of some taxa in Zone IIA that were present in the previous zone in some cases may represent extinction or local extirpation events in the record. The key taxa in this regard are cf. *Coprosma* and *Trema*, both absent from the modern flora of the island.

From calculations of linear interpolated age/depth estimates for this core the rate of sediment accumulation for Zone IIA lies at ~0.11 cm/yr. This rate of accumulation is lower than for all of the anthropogenic sediments identified from Rapa, but is considerably lower than the rates calculated for Atiu by Parkes (1997) averaging at 0.27 cm/yr, although her calculations incorporated the entire human impact sequence. Sedimentation rates were not calculated by Ellison (1994) in her Mangaia study, but appear to vary considerable from site to site, with the VT6 core recorded close to 1 cm/yr for the upper 6 m deep grey clay unit.

One of the key features of the Maunutu Core 1 Transect 2 record is a peak in the extinct Arecaceae: Iguanurinae type pollen recorded at the base of Zone IIA. This may be representative
one of two possible scenarios; firstly, that the removal of *Pandanus* swamp forest allowed for increased pollen deposition from taxa surrounding the immediate periphery of the swamp. This is not supported by palynological data given that no other pollen types appear to enter the record in greater proportions, however, it is possible that palms are one of the few taxa adapted to swampy soil substrates and able to cohabit areas dominated by *Pandanus* groves. Another alternative is that the removal of *Pandanus* trees from the swamp allowed palm groves to establish in the absence of *Pandanus* as a competitor.

The concentration peaks of microcharcoal particles at the base of Zone IIa are very high at 10 million particles per cm$^3$ and exceed the highest concentrations recorded from the VT6 core, the highest recorded from Mangaia (Ellison, *ibid*) by tenfold. No microcharcoal particles were identified from the few Zone I samples analysed, suggesting that such peaks are likely to reflect human-induced burning.

The onset of the first microcharcoal concentration peak at the base of Zone IIa coincides with the onset of *Colocasia* pollen. From a linear interpolated age model for this core, onset of *Colocasia* pollen in the record gives an estimate central point estimate of 743 cal. yr B.P. As the primary signature for agricultural activity at the site, it appears that agricultural activity was initiated very early on the island. *Casuarina equisetifolia* enters the record at this same time, although this may represent exotic, long distance dispersed pollen from outside the island. Other probably introduced taxa enter the record later in the zone including *Erythrina variegata, Aleurites moluccana* and cf. *Sapindus*.

By around 300 cal yr B.P. *Colocasia* pollen drops out of the record possibly representing a change in land use practices at the site. As I have suggested for the Tukou record, it is possible that harvesting of *Colocasia* intensified to the point where both cultivated and feral plants were prevented from flowering. As flowering specimens are unknown on the island today, either prevention from flowering from harvesting or by browsing by feral animals may provide an explanation for poor pollen representation within the record. As *Colocasia* is a poor pollen producer such a hypothesis is difficult to test.

**Post-European contact Zone IIb (~125 cal. yr B.P. to the present)**

There is a number of tree and shrub taxa are either absent or become absent in Zone IIb that were represented in Zone IIa, including *Macaranga, Glochidion societales*, *Homalium* and *Premna*. Both the Arecaceae: Iguanurinae type and Solanaceae pollen drops out of the record in this zone suggesting these taxa may have become extinct during the post-European contact period as no indigenous representatives exist in the modern flora of the island (see Table 6.8, Chapter 6).

Linear interpolated age/depth estimates for sediment accumulation in Zone IIb nearly double the estimates calculated for Zone IIa, lying at a rate of ~0.2 cm/yr. Charcoal concentrations tend to be higher in zone IIb sediments than in the later part of the previous zone.
and may represent a slight increase in burning activity post-European contact. Overall, there is a decrease in the amount of fuel available for burning at Maunutu after an initial peak in human-induced fires in Zone IIa.

As at Tukou, the two primary post-European contact period pollen markers are from the inadvertent weed introductions *Commelina diffusa* and *Ludwigia octovalvis*. Both species are extremely abundant at Maunutu in some areas forming 100% monotypic cover and are found encroaching active or fallow *Colocasia* agricultural fields or abandoned cultivation systems (refer above for further discussion of these taxa). Other taxa that enter the record as potential post-European contact markers included pollen of the Labiatae mint family, currently found around cultivated areas. The appearance of small counts of *Cocos nucifera* in the record at this time is surprising given the uncertainty of its indigenous status on the island. The presence of *Pinus* pollen, presumably from plantations established in the early-mid 20th century is also difficult to interpret as these pollen types can disperse long-distances and can easily contaminate pollen preparations.

**Additional palynological signatures of human impact from Maunutu (Core 3 Transect 1 and Core 3 Transect 2)**

*Stratigraphy and palynological analysis*

A brief description of the main core parameters of these cores and other cores taken in the multiple profile transect undertaken at Maunutu is provided in Table 6.6, Chapter 6 and the core site locations are shown in Figure 6.12. Only the top 120 cm of Maunutu Core 3 Transect 1 is presented. The basal sedimentary unit (120-80 cm) of this core consist primarily of uncompacted dark brown gyttja. This unit grades into lighter brown more compacted fine clay above 80 cm to the swamp surface. As for Maunutu Core 1 Transect 2, sediments lying in the upper 5-15 cm of the core are interspersed with *Ludwigia octovalvis* and *Commelina diffusa* roots. Maunutu Core 3 Transect 2 was taken from a site near the base of the *mato* raised limestone shelf under a *Hibiscus tiliaceus* canopy. Only the top 100 cm of Maunutu Core 3 Transect 2 is presented with almost the entire core consisting of uncompacted dark brown gyttja apart from the upper 5-10 cm that consist of loose organic matter.

The proportional data for pollen and spores, total palynomorph and microcharcoal particles concentrations and palynomorph richness (number of taxa) were placed into stratigraphic diagrams (*Figures 7.16a, 7.16b and 7.17*) using the program C2 Data Analysis version 1.4 (Juggins, 2005). This program was also used to numerically examine the relationship between samples using correspondence analysis (CA) and used here to define the major points of variability in the record. The proportional data from Maunutu Core 3 Transect 1 and Core 3
Transect 2 are presented according to the occurrence of taxa throughout the core in proportions of either >5 or <5%. Taxa are grouped from left to right in tree and shrub as well as herb and fern groups. Taxa are sorted within these groups in stratigraphic succession using the sort function in C2 Data Analysis program (Juggins, 2005). The cores are divided into two palynological zones on the basis of the major vegetation changes, with only Maunutu Core 3 Transect 1 yielding signatures enabling the division of Zone Ila from IIb.

**Pollen-based chronology**

No AMS radiocarbon dates are available for either of these cores. Instead, the presence of *Colocasia* pollen was used as a palynological marker in order to provide relative interpolated ages based on the radiocarbon ages obtained for these signatures from Maunutu Core 1 Transect 2. The sample depth for the onset of *Colocasia* in the record is given a central point estimate age of 743 cal. yr B.P. The initial presence of pollen from the introduced weeds, (in the case of Core 3 Transect 1, *Sonchus oleraceus* and *Ludwigia octovalvis* were selected; see below), are again used as chronological indicators with a central point estimate age of 125 cal. yr B.P. (taken from an age range of 100-150 cal. yr B.P.). The above ages are presented as linear age depth models in the stratigraphic diagrams in Figures 7.16a and 7.16b. As no cultural pollen markers were available for Maunutu Core 3 Transect 2, no age interpolations were calculated and the two stratigraphic zones presented are based on the presence of microcharcoal particle concentrations and the major vegetation changes represented.

**Zone I Pandanus/Acrostichum swamp forest (>~800 cal. yr B.P.)**

**Maunutu Core 3 Transect 1**

Only one sample has been examined from this Zone. A high proportion of *Pandanus* and *Acrostichum aureum* is recorded with a range of tree, shrub and fern taxa mostly represented in low proportions. Pollen concentrations are low and no charcoal concentrations were observed in this Zone. Araliaceae (cf. Meryta) pollen is recorded in this zone but is not known from the modern flora and has not been recorded in any other core from Maunutu.

**Maunutu Core 3 Transect 2**

A high proportion of *Acrostichum aureum* fern with a range of tree, shrub and other fern taxa are represented. *Pandanus* cf. *tectorius* appears to increase towards the top of this Zone. No microcharcoal concentrations were observed in this Zone. *Trema* and cf. *Myoporum* pollen is
recorded in this zone but like the Araliaceae pollen is now absent in the modern flora (see Table 7.6 for a list of taxa recorded in these two cores, but absent in Maunutu Core 1 Transect 1). *Trema cannabina*, now rare on the Cook Islands, is probably the closest relative to what may have existed on the Austral Islands. *Myoporum rimatarense* was recorded on the island in 1934, probably by Harold St. John and Raymond Fosberg during the Mangareva expedition funded by the Bishop Museum (Anonymous in Cooke, 1934: 56-58).

*Human impact Zone II* (~800 cal. yr B.P. to the present)

**Maunutu Core 3 Transect 1: Zone IIa (~800 cal. yr B.P. to ~125 cal. yr B.P.)**

As found in Maunutu Core 1 Transect 2, tree and shrub taxa decline or are absent in this Zone. *Pandanus* and *Acrostichum aureum* decline as Cyperaceae, Poaceae and fern taxa increase in abundance. Charcoal particles are observed in high concentrations throughout much of this Zone. *Colocasia esculenta* pollen is recorded only in this Zone in conjunction with the possible introduced taxa *Casuarina*, *Erythrina variegata* and cf. *Canna indica* (see Table 7.7 for a complete list of introduced taxa located in the Maunutu pollen record).

**Zone IIb (~125 cal. yr B.P. to the present)**

Many of the indigenous taxa recorded in the lower Zones are not represented in this Zone. As in Core 1 Transect 2, *Colocasia esculenta* pollen drops out of this Zone as does *Aleurites moluccana*. Pollen from a number of recent post European contact introductions enter the record in this Zone including *Sonchus oleraceus*, *Commelina diffusa* and *Ludwigia octovalvis*. The initial appearance of *Cocos nucifera* pollen in this zone suggests that it may also have been introduced at this time. All four of the above introduced taxa are used as a pollen-based marker for establishing the base chronology for Zone IIb.

**Maunutu Core 3 Transect 2**

Charcoal concentrations mark the beginning of this zone as no firm palynological signatures are available from this core indicating the onset of human colonisation or post-European contact. *Acrostichum aureum* declines in response to an increase in Cyperaceae, Poaceae and fern taxa. Eight of the ten tree and shrub taxa recorded in Zone I are not represented in this zone. *Arecaceae: Iguanurincae* type pollen indicate that this palm may have continued to survive well into the human impact period, possibly within the post-European contact.
### Table 7.8 Additional palynomorphs recorded from Maunutu not recorded in Core 1 Transect 1. Listed are the presence or absence of palynomorphs in Zones I sediments >1000 cal. yr B.P., Zone IIa sediments aged <1,000 cal. yr B.P. and in Post-European contact aged sediments on Zone IIb. The indigenous representatives of the palynomorph and the biogeographic affinity of these taxa are also listed.

<table>
<thead>
<tr>
<th>Pollen taxa</th>
<th>Family</th>
<th>Present in Zone Ia (pre-European colonisation)</th>
<th>Present in Zone IIa</th>
<th>Present in Zone IIb (post-European colonisation)</th>
<th>Indigenous representatives in modern flora</th>
<th>Biogeographic affinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allophyllus rhomboides</td>
<td>Sapindaceae</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Allophyllus rhomboides</td>
<td>Indo-Pacific/French Polynesia</td>
</tr>
<tr>
<td>cf. Meryta</td>
<td>Araliaceae</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Extinct?</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>cf. Mypoporum</td>
<td>Myoporaceae</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Myporum rimatense (Extinct within last 70 years)</td>
<td>Indo-Pacific/Endemic</td>
</tr>
<tr>
<td>cf. Tetragonia tetragonioides</td>
<td>Aizoaceae</td>
<td>Y</td>
<td>N</td>
<td>?</td>
<td>Tetragonia tetragonioides</td>
<td>Indo-Pacific</td>
</tr>
</tbody>
</table>

### Table 7.9 Palynomorphs of introduced taxa from Ririnata. Listed are the presence or absence of palynomorphs in Zones IIa and IIb and the biogeographic affinity of taxa. 1Pollen or spore type wind blown. 2Pollen type capable of long distance dispersal (after Close et al 1978). 3Inadvertent introduction. 4Possible introduction.

<table>
<thead>
<tr>
<th>Pollen taxa</th>
<th>Family</th>
<th>Present in Zone Ia (pre-European colonisation)</th>
<th>Present in Zone IIa</th>
<th>Present in Zone IIb (post-European colonisation)</th>
<th>Biogeographic affinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aleurites melanocoma</td>
<td>Euphorbiaceae</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>cf. Canna indica</td>
<td>Cannaceae</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Pan-tropical</td>
</tr>
<tr>
<td>Casuarina2</td>
<td>Casuarinaceae</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Cocos nucifera</td>
<td>Areaceae</td>
<td>N</td>
<td>Y</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Colocasia esculenta</td>
<td>Areaceae</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Commelina diffusa2</td>
<td>Commelinaceae</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Indo-Pacific/Cosmopolitan</td>
</tr>
<tr>
<td>Erythrina variegata2</td>
<td>Fabaceae</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Labiatae</td>
<td>Lamiales</td>
<td>N</td>
<td>Y</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Ludwigia octovalvis2</td>
<td>Omoraceae</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Indo-Pacific/Pan Tropical</td>
</tr>
<tr>
<td>cf. Morinda carolfia</td>
<td>Rubiaceae</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Indo-Pacific</td>
</tr>
<tr>
<td>Pinus sp.1,2</td>
<td>Pinaceae</td>
<td>N</td>
<td>Y</td>
<td>?</td>
<td>North America</td>
</tr>
<tr>
<td>cf. Sapindus</td>
<td>Plantaginaceae</td>
<td>Y</td>
<td>N</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Sonchus aegyptius2</td>
<td>Asteraceae</td>
<td>N</td>
<td>Y</td>
<td>?</td>
<td>Cosmopolitan</td>
</tr>
</tbody>
</table>

### A summary of human impact on vegetation at Maunutu

Before around 800 cal. yr B.P. a well-established *Pandanus* swamp forest with an understorey of *Acrostichum* ferns covering a swamp along the periphery of a moat-lake system. Palm trees lined the inland forest fringe of the swamp. Other established taxa found in or around this forest included many coastal tree species currently found on the *mato* (e.g. *Triumfetta procumbens*, *Tournefortia argentea* and *Barringtonia asiatica*).

As at Tukou, upon human arrival at around 800 cal. yr B.P. this *Pandanus* forest was rapidly burnt off in the processes of converting the most inland areas of the swamp to establish *Colocasia* crops. Sedimentation increased considerably at the site and up to around 50 cm of sediment was deposited across the site in the proceeding 3-400 years during high rainfall events, a process enhanced by continual forest depletion. It is possible that a lake, if it had existed, was in-
filled during this time. Other introduced crops were established on the inland periphery of the
swamp (e.g. *Aleurites moluccana*) as forest was progressively removed.

A species of palm tree, recognised in the pollen record from Maunutu from a pollen type
with the same morphological characteristics as the taxa identified from the pollen record of
Tukou (*Arecaceae: Iguanurinae* type), appears to have formed a large component of the island’s
vegetation prior to human arrival. Upon human arrival this palm was steadily declined, but
continued to survive in small pockets in areas removed from agricultural production and forest
clearance activity. The timing of palm extinction appears to have taken place sometime after
European contact by association of the pollen type with introduced weed indicators (e.g.
*Ludwigia octovalvis* and *Commelina diffusa* pollen).

After first European contact in 1812, contact with trade ships and other vessels increased
and as a result stock animals were introduced during the trade exchanges and with the
establishment of mission stations on the island (see Chapter 5). A number of species appear to
have declined or become extinct since this time, probably as a result of direct browsing, including
the extinct palm tree and a species of *Myoporum*. Increased contact allowed for the establishment
of a number of weed species including *Ludwigia octovalvis* and *Commelina diffusa*.

Sites within the swamp, away from the main area of agricultural activity, particularly in
close proximity to the *mato*, largely escaped the direct effect of human activity. Evidence for
sediment influxes is considerably less than sites adjacent to agricultural fields. It is possible that
some species may have survived well into the post-European period. No evidence of any
introduced cultigens or weeds are recognised in the most isolated of the Maunutu cores (Core 3
Transect 2).

Re-interpretation of the human impact record from Mangaia

After coming to the conclusions regarding the nature of anthropogenic impacts on Rimatara a
number of points raised in the context and comparison of the palaeoenvironmental evidence for
human colonisation of Mangaia (*sensu* Kirch and Ellison, 1994; Anderson, 1994) can be
addressed. Firstly, the depth and radiocarbon age of the grey clay deposits that overly lake peats
on Mangaia, ~8.5 m in depth in the VT6 core from Lake Tiriara, that accumulated during the
human impact sequences on these islands are unusually large. Large sediment deposits, thought to
be a result of human-induced erosion and agricultural activity of such a magnitude have been
recorded from some alluvial high island sites in the Fijian Archipelago and the Hawaiian Islands.
On the relatively low elevation *makatea* islands, the availability of mobile sediment is much less.
From the Maunutu moat-swamp deposits the accumulation of anthropogenic sediments of a
period of ~800 cal. yr B.P. did not exceed 1 m. I would suggest that even on Atiu the estimates of
~3 m of anthropogenic sediment accumulation are high.
There are two possibilities for why the sediment accommodation space and the rate of deposition in moat-lake settings are so high. Firstly the underlying parent limestone substrate is likely to be highly topogenous as a result of Quaternary uplift of the limestone shelf (mato) with variable accommodation space available in different parts of these sedimentary catchments. Such spatial variability may allow for considerably different rates of sedimentation across the site and also the potential re-mobilisation of sediments within the system following compaction from the addition of sediments overlying the deposit. Secondly, this spatial differential in sedimentation would also be enhanced by the position and energy of inflowing streams. Wilmshurst and McGlone (2005) have shown that reworking of sediment in lakes fed by streams, including pollen sized sediment fractions, is common in contrast to lakes with no inflowing streams where reworking is not a major factor. Such processes are also likely to contribute to the range of radiocarbon dates that may be obtained. As mentioned in Chapter 1, McGlone and Wilmshurst (1999) have shown that there appears to be a differential between the radiocarbon age ranges obtained by dating human disturbance signatures in New Zealand lake sequences as opposed to swamps or mires despite having comparable sedimentary horizons.

Anderson (1994) pointed out a number of other potential problems with the dating of these sediments. Contrary to his suggestion that the radiocarbon ages may be contaminated by mobilized limestone from the surrounding mato, a more likely explanation is that 10 cm of stratigraphy utilized for each bulk conventional radiocarbon sample submitted by Ellison (1994) could represent sediment deposited over a period of up to 1,000 years. As a key example, close to 1,000 years of sediment deposition was recorded between 3-3.5 m on the Lake Te Roto sediments by Parkes (1997) from the base of the anthropogenic horizon. Such variability maybe a contributing factor in the ages obtained from bulk sediment samples from Mangaia.

The palynological signatures of human impact from Mangaia recorded by Ellison (1994) and Atiu by Parkes (1997) appear consistent with those obtained from Rimatara. The appearance of high concentrations of charcoal particles and the high proportion of the ferns Dicranopteris linearis and Cyclosorus interruptus from the Ellison’s Mangaia records in what have been defined as human impact sedimentary horizons are comparable to the unequivocal human impact zones identified at Maunutu. The decline of palm pollen and a range of other forest taxa support Ellison’s claims.

As discussed in Chapter 1, the sedimentary and palynological signatures obtained from Mangaia, were gathered within the methodological framework of providing background palaeoclimatic information where lake sediments are regarded as the most ideal depositional settings for such records. From the Maunutu and Tukou studies, I suggest that less conventional pollen depositional sites, namely the swamps within or directly adjacent to historically abandoned or active agricultural areas, should be examined if anthropogenic impacts are the main focus for study. At Maunutu, the contrast between the core records taken from sites adjacent to agricultural areas (e.g. Core 1 Transect 2 and Core 3 Transect 1) and the records points lying distant from
these areas are considerable. The primary advantage is the increased likelihood of identifying pollen from introduced and agricultural species in the former rather than the latter. Palynological records from sites taken at points distant from these agricultural horizons (e.g. Maunutu Core 3 Transect 2) are limited to charcoal concentrations and decreasing forest taxa representation as the primary human impact indicators.

Although only two AMS radiocarbon ages have been obtained for a single core from Maunutu, the associated palynological signatures with unequivocal cultural indicators from dated horizons appear consistent. The comparability of ages, palynological signatures and sedimentation pattern from Maunutu with Tukou is striking and reflects a consistent pattern of vegetation change described for other islands in the OIRO.
Figure 7.16a Percentage diagram for Maunutu Core 3 Transect 1 (total of 1.2 m of 5.5 m taken ~20 m from the southeast embankment; see Figure 6.12 Chapter 6). The following are presented in the diagram from left to right: core lithology, pollen-based chronology (line and ticks; the criteria for the selection of these dates are discussed in the text), taxa (pollen and spores: taxa with ≥5% of total palynomorph sum are presented as colour coded bars; samples with proportions <5% are presented as triangle symbols) and total palynomorph concentrations (per cm³), microcharcoal particle concentrations (per cm³), palynomorph richness (number of taxa) and palynological zones. Two palynological zones (a pre-human impact late Holocene swamp forest Zone I and a human impact Zone II) are presented with Zone IV divided into a Polynesian phase (IIa) and a European phase (IIb). The transparent horizontal red bar indicates a possible sedimentary lacunae that overlaps the earliest probable pollen signature and the onset of microcharcoal. The black horizontal dashed lines indicate the onset of microcharcoal and Colocasia pollen and the decline of an extinct palm (Arecaceae: Iguanurinae type) as discussed in the text.
Figure 7.16b Percentage diagram for Maunutu Core 3 Transect 1 (total of 1.2 m of 5.5 m) as for Figure 7.16a showing taxa with <5% representation in every core sample (coloured triangle symbols).
Figure 7.17 Percentage diagram for Maunutu Core 3 Transect 2 (total of 1 m of 4.55 m taken ~50 m from the side of the mato; see Figure 6.12 Chapter 6). The following are presented in the diagram from left to right: core lithology, taxa (pollen and spores: taxa with ≥5% of total palynomorph sum are presented as colour coded bars; samples with proportions <5% are presented as triangle symbols; taxa with <5% are presented as triangle symbols) and total palynomorph concentrations (per cm$^3$), palynological richness (number of taxa), microcharcoal particle concentrations (per cm$^3$) and palynological zones. Two palynological zones Pre-human impact Zone I and a human impact Zone II are presented. The transparent horizontal red bar indicates a possible sedimentary lacunae that overlaps the earliest probable pollen signature and the onset of microcharcoal. The black horizontal dashed lines indicate the onset of microcharcoal and Colocasia pollen and the decline of an extinct palm (Arecaceae: Iguanurinae type) as discussed in the text.
Conclusions: A diachronic synthesis of botanical sources

Defining the botanical status of introduced plants

The introduction of plants to Oceanic Island Remote Oceania (OIRO) has been a subject alluded to throughout the development of Pacific botany (e.g. Seemann, 1865-73; Guppy, 1906; Ridley, 1930; Brown, 1935; Merrill, 1946) and is important given the potential overlapping roles of long distance and human dispersal mechanisms in shaping island floras. In recent ethnobotanical treatments of (e.g. Kirch and Yen, 1982; Whistler, 1991) and in a number of floral compendiums of island archipelagos (e.g. Wagner et al 1990; Florence, 1997; 2004) there has been a tendency for the introduced botanical status of plant species to be given on the basis of their human introduction potential. This potential may include, for any plant, its ethnographic, historical or current status of human utility as wild (natural), domesticated or feral. For many botanical compendiums, for example, those compiled for French Polynesia over more than 100 years (Drake de Castillo, 1893; Brown, 1935; Florence, 1997; 2004), it is more often the conspicuous characteristics of a plant within a regional flora that defines human introduction potential. Disjunct or vicariant geographic distributions may enhance the conspicuous features of a species set against a flora where continuous or sympatric species distributions prevail. Some introduced species determinations established in the earlier compendiums have been based on a range of subjective criteria that cannot be supported by the available evidence.

In a recent review of the history of plant introductions since the global expansion of European, Beinart and Middleton (2004) suggest that much of how plant introductions are perceived is dependent on the way plants fit into culturally constructed categories. These categories (e.g. indigenous and introduced) are tied to the developing scientific perception of plant origins within the complex framework of past ecological conditions and dispersal processes.

As shown in previous chapters, the endemic and/or indigenous character of island floras must be seen in the context of disturbance histories. The extent of floral distribution is not only influenced by the distribution of ancestral species in relation to geological changes, but also ecological disturbances and human impact. Since people first settled OIRO, the decimation of indigenous flora and fauna has been unequivocal, but the precise timing and ecological influence of human-induced disturbance processes are more difficult to determine. Human-induced disturbance may provide indigenous plant species with a sufficient biological advantage as to permit them with invasive or exotic characteristics. Coastal strand taxa (e.g. Scaevola taccada, Guettarda speciosa etc.), for example, with long distance dispersal mechanisms (e.g. buoyant
seeds) that allow for multiple and frequent establishment may present an ecological advantage in more open ecosystems resulting from human impact. Indigenous plants adapted to fire (e.g. *Dicranopteris* fern) or drought (e.g. ferns such as *Histiopteris*) may also find advantage in human impacted environments.

To aid in this discussion, I use a modified version of Matthews’ (1996: 118-119) table of ‘theoretical plant categories’, which he considered when interpreting extant or past plant distributions that have or may have been manipulated by humans (Table 8.1). Matthews uses a set of four variables to define the culturally constructed terms ‘natural’, ‘wild’, ‘feral’, ‘naturalised’, ‘domesticated’, ‘cultivated’, ‘indigenous’ and ‘introduced’. In Matthews’ version, these are defined according to cultivation, genotype and dispersal histories of each species. In my own restructuring of Matthews’ definitions in Table 8.1, the wild and cultivated habitat categories have been removed and replaced by a disturbance history category in order to incorporate the influence of natural and human-induced disturbance rather than cultivation activity per se.

In restructuring this table, I stress that dispersal is heavily influenced by disturbance and that this relationship may explain much of the variation that exists in phytogeographic patterning in the region. As discussed in Chapter 2, this may apply more to the floras of island groups, including OIRO, than to continents. The key point I address in presenting this table is that unless the modification of a plant can be unequivocally attributed to a specific disturbance, any botanical categorisation scheme will lack robustness. Not only is plant dispersal potentially influenced by disturbance, but the genetic makeup of a plant may also be transformed along a continuum of potential modification. I suggest that by making an assessment of disturbance and dispersal histories developed from the palaeoenvironmental, archaeological and historical contexts of plant origins and introduction, as defined in the previous chapters, the botanical status of plants from the Austral Islands may be more adequately defined.

A synthesis of plant introduction on the Austral Islands

In this chapter, I discuss the characteristics of plants introduced to OIRO by human, focusing on those plants discussed by a number of authors, including Guppy (1906), Ridley (1930), Merrill (1946), Barrau (1965), Yen (1973; 1974a) and Whistler (1991). Some of these taxa have an uncertain introduction status and the reasons for this uncertainty are explored. I focus on taxa represented in the Austral Island’s flora and described in the three main floral compendiums for French Polynesia (Drake de Castillo, 1893; Brown, 1931a; 1931b; 1935 and Florence, 1997; 2004). Taxa are grouped in separate tables for trees and shrubs (Table 8.2a and 8.2b), herbs (Table 8.3) and inadvertent introductions (Table 8.4). Each table is divided into the
following categories of presence/absence data: pre-human palaeobotanical records; archaeobotanical records; anthropogenic palaeobotanical records and botanical survey records.

<table>
<thead>
<tr>
<th>No.</th>
<th>Cultivation history</th>
<th>Genotype</th>
<th>Dispersal history</th>
<th>Disturbance history</th>
<th>Botanical status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>progenitors never cultivated</td>
<td>wild type</td>
<td>natural dispersal</td>
<td>pre-human disturbance</td>
<td>indigenous</td>
</tr>
<tr>
<td>2</td>
<td>=</td>
<td>=</td>
<td>natural dispersal</td>
<td>human colonisation, other disturbance</td>
<td>indigenous</td>
</tr>
<tr>
<td>3</td>
<td>=</td>
<td>=</td>
<td>dispersed by humans within indigenous range</td>
<td>human colonisation, other disturbance</td>
<td>indigenous</td>
</tr>
<tr>
<td>4</td>
<td>=</td>
<td>=</td>
<td>dispersed by humans beyond indigenous range</td>
<td>human colonisation, other disturbance</td>
<td>introduced</td>
</tr>
<tr>
<td>5</td>
<td>= modified by humans</td>
<td>natural dispersal</td>
<td>other disturbance</td>
<td>indigenous</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>=</td>
<td>=</td>
<td>natural dispersal</td>
<td>human colonisation, other disturbance</td>
<td>indigenous</td>
</tr>
<tr>
<td>7</td>
<td>=</td>
<td>=</td>
<td>dispersed by humans within indigenous range</td>
<td>human colonisation, other disturbance</td>
<td>indigenous, cultivated</td>
</tr>
<tr>
<td>8</td>
<td>=</td>
<td>=</td>
<td>dispersed by humans beyond indigenous range</td>
<td>human colonisation, other disturbance</td>
<td>introduced, cultivated</td>
</tr>
<tr>
<td>9</td>
<td>progenitors cultivated</td>
<td>wild type</td>
<td>natural dispersal</td>
<td>other disturbance</td>
<td>indigenous</td>
</tr>
<tr>
<td>10</td>
<td>=</td>
<td>=</td>
<td>natural dispersal</td>
<td>human colonisation, other disturbance</td>
<td>indigenous</td>
</tr>
<tr>
<td>11</td>
<td>=</td>
<td>=</td>
<td>dispersed by humans within indigenous range</td>
<td>human colonisation, other disturbance</td>
<td>indigenous</td>
</tr>
<tr>
<td>12</td>
<td>=</td>
<td>=</td>
<td>dispersed by humans beyond indigenous range</td>
<td>human colonisation, other disturbance</td>
<td>introduced</td>
</tr>
<tr>
<td>13</td>
<td>= modified by humans</td>
<td>natural dispersal</td>
<td>other disturbance</td>
<td>Indigenous, naturalised, cultivated</td>
<td></td>
</tr>
<tr>
<td>14</td>
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<td>=</td>
<td>dispersed by humans within indigenous range</td>
<td>human colonisation, other disturbance</td>
<td>indigenous, cultivated</td>
</tr>
<tr>
<td>15</td>
<td>=</td>
<td>=</td>
<td>dispersed by humans beyond indigenous range</td>
<td>human colonisation, other disturbance</td>
<td>introduced, cultivated</td>
</tr>
</tbody>
</table>

Table 8.1 Theoretical plant categories (1-15; adapted from Matthews, 1996: 118) defined according to cultivation history (two alternatives, genotype (two alternatives), dispersal history (three alternatives) and disturbance history (three alternatives). In this table, the wild and cultivated habitats categories (second column in Matthews, *ibid*: 118) have been removed and replaced by an additional category that has been added to the dispersal history category to incorporate the influence of human disturbance rather than cultivation activity *per se*. Matthews (*ibid*: 120) commented on the possibility that some categories may be difficult to recognise in the field. For example, category 5, although rare could apply to some plant species if some natural disturbance process occurred outside of human activity.
As the availability of botanical information for each taxon varies considerable, with no one taxon having a complete record (i.e. some taxa have no palaeobotanical record and have only been recorded in modern botanical surveys), I focus on taxa that reflect the variation of available palaeobotanical, archaeobotanical and botanical survey data. Each taxon is also assigned a theoretical plant category described in Table 8.1 as a means of defining the relationship between plant distribution and dispersal and disturbance history. Taxa with no modern botanical survey record are presumed to be extinct and are discussed separately later in the chapter.

Tree and shrub taxa of the Austral Islands

On the Austral Islands a number of tree and shrub taxa regarded as indigenous to OIRO appear to survive only in cultivation (e.g. *Cocos nucifera* and *Thespesia populnea* on Rapa). Others appear to have become naturalized from cultivated populations (e.g. *Cordyline fruticosa*). For some taxa the introduced and cultivation status is clear given the lack of sexual reproductive traits whereby plants are reliant on human propagation of vegetative clones. For example, in *Broussonetia papyrifera* (see below) the cumulative effects of increasing mutations evident in wild and cultivated populations eventually led to vegetative propagation dependence (Matthews, 1996). For other taxa, the status of indigenous plants given the pre-human extent of their sub-fossil records is difficult to define given the possibility that people may have introduced additional populations or varieties (e.g. *Pandanus tectorius*; see below). For many taxa the botanical status cannot be securely given because of the lack of botanical source evidence.

Taxa recorded in all botanical sources:

*Pandanus tectorius* Parkinson (*Pandanaceae*) (Brown, 1931; St. John, 1979a)

Whistler (1991) earlier questioned the status of *Pandanus tectorius* as an introduced species to OIRO. He suggested that *P. tectorius* of both Tonga and Samoa is represented by both indigenous and introduced populations, but queried the indigenous status of *Pandanus* on the Cook, Society, Marquesas, and Hawaiian Islands. High concentrations of *Pandanus* pollen from Holocene aged sediments on both Rapa (macrofossils also present) and Rimatara establishes the indigenous status of this taxon on these islands and presumably the other Austral Islands. Athens (1997) cited an unpublished report of a geological macrofossil of *Pandanus* located on the Hawaiian Islands with a minimum age of 500,000 years.
<table>
<thead>
<tr>
<th>Botanical species</th>
<th>Pre-human palaeobotanical records</th>
<th>Archaeo botanica l records</th>
<th>Anthropogeni c palaeobotanlc al records</th>
<th>First contact accounts 1769-1834</th>
<th>Botanical survey data 1921-1934</th>
<th>2002-04</th>
<th>Plant categor y (Table 8.1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spondias dulcis (Anacardiaceae)³</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Rapa, Tubuai¹</td>
<td>Rima tara¹</td>
<td>1-4</td>
</tr>
<tr>
<td>Alpcia stellata (J.R. Forst. and G. Forst.) Roem. &amp; Schult. (Apocynaceae)²</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>All populated islands</td>
<td>All populated islands</td>
<td>1-4</td>
</tr>
<tr>
<td>Cocos nucifera L. (Arecaceae: Coccoe)¹</td>
<td>-</td>
<td>-</td>
<td>Rima tara (pollen)</td>
<td>Rapa (introduced)</td>
<td>Rapa, Tubuai, Rurutu</td>
<td>Rima tara</td>
<td>1-15, except Rapa: 12, 15</td>
</tr>
<tr>
<td>Cordia subcordata Lam. (Boraginaceae)⁵</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Rima tara¹</td>
<td>1-4</td>
</tr>
<tr>
<td>Casuarina equisetifolia L. (Casuarinaceae)⁴</td>
<td>Rapa (pollen)</td>
<td>Rapa (pollen), Rima tara (pollen)</td>
<td>Rapa, Tubuai, Rima tara</td>
<td>Rapa, Tubuai</td>
<td>Rapa, Rima tara</td>
<td>Rima tara¹</td>
<td>1-15</td>
</tr>
<tr>
<td>Calophyllum inophyllum L. (Chilaciac)⁴</td>
<td>Rima tara (pollen)</td>
<td>Rima tara (pollen)</td>
<td>Rapa, Rima tara</td>
<td>Rapa, Rima tara</td>
<td>Rima tara, Rima tara</td>
<td>Rima tara¹</td>
<td>1-4</td>
</tr>
<tr>
<td>Terminalia catappa L. (Combretaceae)³</td>
<td>-</td>
<td>-</td>
<td>Rima tara (pollen)</td>
<td>Rima tara</td>
<td>Rima tara</td>
<td>Rima tara¹</td>
<td>1-4</td>
</tr>
<tr>
<td>Acnahites molluccana (L.) Willd. (Euphorbiaceae)⁴</td>
<td>Rapa (endocarp), Rima tara</td>
<td>Rapa (pollen, Rima tara (pollen))</td>
<td>Tubuai</td>
<td>Rapa, Rima tara</td>
<td>All, 4, 12, 15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erythrina variegata L. (Fabaceae)⁵</td>
<td>Rapa (pollen), Rima tara</td>
<td>Rima tara (pollen)</td>
<td>Rima tara, Rima tara</td>
<td>All, Rima tara, Rima tara</td>
<td>Rima tara</td>
<td>1-4</td>
<td></td>
</tr>
<tr>
<td>Inocarpus fagiifera (Parkinson) Fosberg (Fagaceae)⁷</td>
<td>-</td>
<td>-</td>
<td>Rima tara (pollen)</td>
<td>Rima tara</td>
<td>Rima tara, Rima tara</td>
<td>Rima tara¹</td>
<td>1-15</td>
</tr>
<tr>
<td>Cordyline fruticosa (L.) Chev. (Laxmanniace)¹</td>
<td>Rapa? (charred tuber)</td>
<td>Rapa, Rima tara (pollen)</td>
<td>Rapa, Rima tara</td>
<td>All islands</td>
<td>All islands, 4, 8, 12, 15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hibiscus tiliaceus L. (Malvaceae)⁴</td>
<td>Rapa (pollen)</td>
<td>Rapa (pollen, Rima tara (pollen))</td>
<td>Rapa</td>
<td>Rapa, Rima tara</td>
<td>All islands</td>
<td>All islands</td>
<td>1-15</td>
</tr>
<tr>
<td>Thepesia populnea L. Sol. Ex Correa (Malvaceae)⁴</td>
<td>-</td>
<td>-</td>
<td>Rapa</td>
<td>Rapa, Tubuai</td>
<td>All islands</td>
<td>All islands</td>
<td>1-15, except Rapa: 4, 8, 12, 15</td>
</tr>
</tbody>
</table>

¹Brown (1931a); ²Brown (1935); ³Florence (1997); ⁴Florence (2004); ⁵Not all information available

Table 8.2a (Anacardiaceae to Malvaceae) Botanical source list of pre-contact introduced or indigenous trees and shrubs (including known arboricultural species) for the Austral Islands (arranged by family) recognized in the above references and by Whistler (1991).
<table>
<thead>
<tr>
<th>Botanical species</th>
<th>Pre-human palaeobotanical records</th>
<th>Archaeobotanical records</th>
<th>Anthropogenic palaeobotanical records</th>
<th>First contact accounts 1769-1834</th>
<th>Botanical survey data 1921-1934</th>
<th>Plant category (Table 8.1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Areocarpus altius (Park.) Fosberg (Monocot)</td>
<td>-</td>
<td>-</td>
<td>Rapa (pollen?); Rimatara (pollen)?</td>
<td>Ra’iivavae, Tubuai, Runutu</td>
<td>All populated islands</td>
<td>15</td>
</tr>
<tr>
<td>Browsonia papyrifera (L.) Vent. (Moraceae)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Ra’iivavae, Tubuai, Runutu</td>
<td>All populated islands</td>
<td>15</td>
</tr>
<tr>
<td>Ficus tinctoria Forst. subsp. tinctoria (Moraceae)</td>
<td>-</td>
<td>-</td>
<td>Rapa (introduced?); Ra’iivavae, Tubuai, Runutu</td>
<td>Rapa, Ra’iivavae, Rimatara</td>
<td>All inhabited islands</td>
<td>15</td>
</tr>
<tr>
<td>Musa spp. (AAB group) [syn. M. x paradisiaca, M. sapientum] (Musaceae: section Euomusa)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Rapa, Ra’iivavae</td>
<td>Rapa, Rimatara</td>
<td>15</td>
</tr>
<tr>
<td>Musa spp. [syn. M. feh, M. troweldry turned, M. bahistiana] (Musaceae: section Australimusa and Callimusa)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Rapa, Ra’iivavae</td>
<td>Rapa, Rimatara</td>
<td>15</td>
</tr>
<tr>
<td>Musa spp. (AAA group) [M. acuminate, M. nana, M. sinensis] (Musaceae: section Euomusa)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Rapa, Ra’iivavae</td>
<td>Rapa, Rimatara</td>
<td>15</td>
</tr>
<tr>
<td>Syzygium malaccense (L.) Merrill &amp; Perry (Myrtaceae)</td>
<td>-</td>
<td>-</td>
<td>Rapa (pollen?); Rimatara (pollen)?</td>
<td>Rapa, Ra’iivavae, Tubuai</td>
<td>All inhabited islands</td>
<td>1-15</td>
</tr>
<tr>
<td>Pandanus tectorius (pollen)</td>
<td>Rapa (pollen)</td>
<td>Rapa (pollen)</td>
<td>Tubuai</td>
<td>All inhabited islands</td>
<td>1-15</td>
<td></td>
</tr>
<tr>
<td>Parkinsonia (Pandanaeae)</td>
<td>Rimatara</td>
<td>Rimatara</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Piper methysticum Forst. f. (Piperaceae)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Gardenia saliensis D.C. (Rubiacaeae)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Tubuai</td>
<td>Rimatara</td>
<td>4, 8, 12, 15</td>
</tr>
<tr>
<td>Morinda citrifolia L. (Rubiacaeae)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Solanum repandum Forst. f. (Solanaceae)</td>
<td>-</td>
<td>-</td>
<td>Rimatara (pollen)?</td>
<td>-</td>
<td>All inhabited islands</td>
<td>1-4</td>
</tr>
<tr>
<td>Solanum viride Forst. f. ex Spring (Solanaceae)</td>
<td>-</td>
<td>-</td>
<td>Rimatara (pollen)?</td>
<td>-</td>
<td>All inhabited islands</td>
<td>1-4</td>
</tr>
<tr>
<td>Pipturus argenteus (Forst. f.) Wedd. (Orchidaceae)</td>
<td>-</td>
<td>-</td>
<td>Rimatara (pollen)?</td>
<td>Runutu, Rimatara</td>
<td>Rimatara</td>
<td>1-4</td>
</tr>
</tbody>
</table>

*Brown (1931a); Brown (1935); Florence (1997); Florence (2004); *Not all information available.*

**Table 8.2b (Moraceae to Urticaceae) Botanical source list of pre-contact introduced or indigenous trees and shrubs (including known arboricultural species) for the Austral Islands (arranged by family) recognized in the above references and by Whistler (1991).**

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With the unequivocal subfossil evidence, it is interesting that no reference was made of the palm like *Pandanus tectorius* trees in any first contact account for Ra'iivavae, Rurutu and Rimatara. *Pandanus* was often noted as 'screw palm' or 'palm apple' as done by Morrison (1935: 61) on Tubuai in the botanical vernacular of early European explorers. Menzies (Shineberg, 1986: 67) at Rapa in 1791 mentioned *Dracena* leaves, which probably refers to *Pandanus*, in reference to a girdle suspended around one of the islander's waist. Indications from the pollen records from Rimatara, suggest that these trees were probably common at first contact and remain abundant along the island's coastline.

Both leaf material and fruit keys from *Pandanus* have been identified from the Tangarutu rockshelter sequence, with an earliest inferred radiocarbon age of around 500 cal yr B.P. (see Chapter 7). Both the archaeobotanical and palaeobotanical evidence, however, does not preclude, as Whistler (1991) suggests, that additional varieties of *Pandanus tectorius* were not introduced pre-contact. *Pandanus* is a dioecious genus with extreme morphological diversity that can be considerably influenced by cultivation practices. This has resulted in a number of inconsistent taxonomic determinations of members of this genus (see Stone, 1976; 1988; and St. John, 1976; 1979c). St. John (in Fosberg and St. John, 1934) identified thirteen endemic species of *Pandanus* on Rapa alone. Most of these species have subsequently been grouped into *Pandanus tectorius* and one other species has yet to be described (Tim Motley and Jaques Florence pers. comm. 2004).

As yet no phylogenetic studies have been undertaken for *Pandanus tectorius* that may yet distinguish different intraspecific populations. The morphological diversity in *Pandanus* that St. John identified on Rapa may be a result of genetic or environmental processes, but may also reflect the introduction of cultivated varieties by islanders both pre- and post contact. The ethnobotanical importance of *Pandanus* in the Austral Islands (e.g. Stokes, m.s.a; m.s.b; Aitken, 1930), attested by the archaeobotanical record, but also from first contact and ethnographic sources provides some support for additional introductions.

The evidence for the indigenous status of *Pandanus* from the Austral Islands is overwhelming; however, the human introduction of particular cultivars cannot be discounted as a factor in the current population distribution of this tree. Although no genetic data are available to form any robust explanation, I would suggest that all of the modern populations may be derived from ancestral populations that have never been cultivated and/or populations that have been cultivated and thus fall into Categories 1-15 of Table 8.1.
Florence (2004) determined *C. equisetifolia* subsp. *equisetifolia* from modern Austral Island populations. He suggests its distribution is problematic because of its wind dispersed seeds and possible extension by human introduction to many islands of the Pacific. It was likely to have been introduced to Rapa either in the historic period or earlier but is probably indigenous to the other Austral islands. Whistler (1991) suggests that the distribution of *C. equisetifolia* in the east Polynesian Pacific is a result of human introduction. This tree is represented in large stands across the Austral Islands including on the atoll of Maria. On Rapa its distribution is limited to small littoral stands on many of the least exposed bays or still persists in remnant cultivations (e.g. Anarua Bay). Edwards (2003: 5) claims that *Casuarina* was more common on Ra‘ivavae prior to missionary arrival, where in 1819 they encouraged the felling of large stands for the construction of churches and other structures.

The palynological record is important when discussing the status of this tree on the Austral Islands. *Casuarina* pollen is represented throughout a Holocene swamp record on Rapa (Tukou) where it is only ever represented in trace counts. This is more likely to either represent contamination from modern airborne *Casuarina* pollen, or represents long distant wind transport from the Western Pacific (see Close et al 1978). At Maunutu on Rimatara, palynological records of *Casuarina* show a marked increase in representation within the last 1000 cal. yr B.P. This rise in pollen abundance is indicative of local pollen production and dispersal and is unequivocally associated with increases in a range of human impact indicators (e.g. *Colocasia esculenta* pollen and charcoal particle concentrations).

It is difficult to determine the indigenous status of *Casuarina* for the Austral Islands, as Florence (2004) has indicated, given its vagility and affinity within secondary habitats. From the palynological records from Rapa and Rimatara it is possible that *Casuarina* was originally present on most if not all of the Austral Islands, and then subsequently proliferated with the advent of human settlement and environmental disturbance. Florence (ibid) has tentatively given *C. equisetifolia* subsp. *equisetifolia* the status of naturalized or indigenous for all of the Austral Islands except Rapa. *Casuarina* was not recorded by Fosberg and St. John (1934) and since their 1934 survey, this tree has become naturalised after human introduction or from beach drift. The overall status for *Casuarina* in the Austral Islands determined by Florence comes in contrast to Ellison’s (1994: 13) interpretation of palynological records from Mangaia in the Cook Islands. She suggested *Casuarina* was introduced there given the absence of fossil pollen in pre-human aged sediments. But given that *Casuarina* is more often known as a coastal strand tree, I suggest
that the absence of pollen from the moat-lake and swamp cores of Mangaia may not be surprising and not necessarily indicative of its absence prior to human colonisation.

If both wind dispersal and human introduction play a role in the distribution of this tree, I would suggest that, like Pandanus tectorius, all of the modern populations may be derived from ancestral populations that have never been cultivated and/or populations that have been cultivated (Categories 1-15; Table 8.1).

**Taxa recorded in all botanical sources except the pre-human palaeobotanical records:**

*Aleurites moluccana* (L.) Willdenow (Euphorbiaceae) (Florence, 1997: 37-40; see Chapter 1 and 7)

Despite the abundance of preserved *Aleurites moluccana* endocarps in the archaeological record from Rapa (see Chapter 7), this tree was not listed in any first contact accounts of the island until the pearl trader and amateur naturalist Jacques Moerenhout (1837: 64) visited there in 1834. Stokes (m.s.a) noted the use of *A. moluccana* wood for the construction of canoes and the nuts for lighting. From visits to the island between the 1920s and 1930s both Stokes (ibid) and Fosberg (in Mueller-Dombois and Fosberg, 1998: 403), respectively, considered *A. moluccana* to be a major component of moist forests on Rapa. Robinson (1957) noted the use of *A. moluccana* candlenuts as the major source of night lighting on his visit to the island in 1952. Despite its importance only fifty years ago, few trees currently exist on the island. Some trees are located precariously on the margins of coastal plains or in a few localities around the major settlements of Ha‘urei and Area where the nuts provide fodder for pigs.

It is likely that until recently *A. moluccana* formed a major component of lowland forests on all of the Austral Islands. Tomás Gayangos (in Corney, 1913-1919: 126) recorded the presence of *A. moluccana* on Ra‘ivavae in 1775 year, describing it as ‘Tutuy’. With the exception of the larger high Islands of the Fijian Archipelago and the Hawaiian Islands, where *A. moluccana*, forms a conspicuous component of mesic vegetation from low to mid elevations (Smith, 1981; Wagner *et al*, 1999), the tree may require human maintenance and protection from browsing animals. On some islands, such as Henderson Island, the tree has been recorded in the past but is more recently noted as absent (Paulay and Spencer 1989).

Fosberg (1991: 18) has questioned whether or not the tree has been introduced to OIRO as the nuts of this tree are commonly found as beach-drift throughout the Pacific:

'The theory that it is an introduction is favoured and, indeed, suggested by the unlikelihood of its having climbed the steep mountain slopes [of the Hawaiian Islands] up to its present habitat without human assistance. If it was brought by humans and carried up the hills by them, it spread to
dominate a whole zone on many islands, forming pure stands and shading out almost all other plants, and made an important change. On some islands kukui forest occupies roughly the rainfall belt (between 1500 and 2250 mm of rainfall a year), with tongues of this forest running some distance down moist ravines to lower elevations. The landscape was modified conspicuously by the introduction of A. moluccana, whether by the hand of humans or dispersed naturally.

As well as from Tukou (Rapa) and Maunutu (Rimatara), Aleurites pollen has been located in stratified sedimentary deposits from O‘ahu in the Hawaiian Islands and Lahakai on Manus Island in Papua New Guinea (Southern, 1988) in which Colocasia pollen and other agricultural indicators are associated (see Table 7.2, Chapter 7 for the Hawaiian Island references; in addition to this list are records from Hawai‘i in Athens et al (1997) and Moloka‘i in Denham et al (1999) in which A. moluccana is one of the primary agricultural indicators; Clark and Cole (1997) also identified A. moluccana pollen in sediments from Totoya Island in Fiji, but not in contexts associated with other potential cultigens). Athens and Ward (1997) also located A. moluccana endocarp and wood from a sediment core (Maunawili, O‘ahu) with Colocasia pollen and agricultural indicators embedded in associated sediments. Such records suggest that A. moluccana is in some way associated with cultivation activity. I would suggest that on the basis of this cultivation site association that A. moluccana has been dispersed beyond its indigenous range and either maintained in cultivation or has become naturalised on the island (Categories 12 and 15; Table 8.1).

**Taxa without pre-human palaeobotanical and archaeobotanical records:**

*Cocos nucifera* L. (Arecaceae: subfamily Coccoeae) (Brown, 1931)

The question of the origin of the coconut was discussed in Chapter 3. *Cocos nucifera* has been found throughout the humid tropical Pacific in both wild and cultivated populations on atolls, high islands and the coastlines of the peripheral continents, from sea-level to elevations of ~1000 m (Harries et al 2004). The extent of natural dispersal of *C. nucifera* over long distances by floating coconuts has been widely debated and largely unresolved (Ward and Brookfield, 1992). Harries et al (2004) suggest the wild type *C. nucifera* evolved by floating between areas that fringe larger landmasses and islands.

The introduced or status of *C. nucifera* has been debated for OIRO at least since the Enlightenment voyages. Merrill (1946: 34) suggested that coconut ‘normally occurs only where it has been planted by man’ and that it is likely to have an Indo-Pacific origin. Fosberg (1960) regarded *C. nucifera* as a cultivated species, domesticated in some tropical region where its wild relatives are presumably extinct. Sauer (1971) favoured the view that coconut populations may be wild and a product of natural dispersal. Harries (1978; 1990) distinguished the morphological
differences (fruit component analysis) between wild and domesticated *C. nucifera* and proposed the Indo-Malayan region as the centre of domestication. The use of molecular markers such as RFLP (e.g. Lebrun *et al* 1999) and AFLP (e.g. Teulat *et al* 2000) generally support the conclusions of Harries' morphological analysis.

Arguments for the natural dispersal of *C. nucifera* in Remote Oceania (e.g. Ward and Brookfield, 1992) were to some degree confirmed by excavation of *C. nucifera* endocarp from Anawau Swamp on Aneityum in Vanuatu (Hope and Spriggs, 1983), dated to 6410-5950 cal. yr B.P. (no lab number available). This provided the first radiocarbon age outside of the expected age range for human occupation of a site in Remote Oceania. Palynological records from Atiu (Parkes 1997) and Mangaia (e.g. Ellison, 1994; Kirch *et al* 1992) in the Cook Islands indicate a prehuman presence of *C. nucifera* in this part of Remote Oceania. A number of palynological records from the Hawaiian Islands (e.g. Athens and Ward, 1997; Denham *et al* 1999) suggest that *C. nucifera* may have been introduced given the presence of pollen only in anthropogenic sediment horizons.

The presence of *C. nucifera* in the Austral Islands presents an interesting case in the debate on the natural vagility and human translocation. No palaeobotanical evidence for indigenous *C. nucifera* in the Austral Islands has been forthcoming. The *C. nucifera* pollen record from Rimatara (see Chapter 7) indicates that this tree may have been recently introduced to the island given its representation in sediments dating to the post-European contact period. *C. nucifera* was noted in the early European contact accounts for Ra‘ivavae, Tubuai and Rurutu but not for Rapa and Rimatara (see Chapter 5). On the HMS Discovery sighting of Rapa in 1791, both George Vancouver and his ship’s botanist, Archibald Menzies ‘observed no Cocoa Nut Trees anywhere on the Island’ (Shineberg, 1986: 67-68). Vancouver chose not to circumnavigate the island or venture much closer than a league (~ 4.5 km). No landfall was made and the ship was only anchored for one day along the west coast of the island. Out of all the European contact accounts recorded to 1834 on Ra‘ivavae, *C. nucifera* was only recorded by Tomás Gayangos (in Corney 1916-1919: 126) in 1775. Like the HMS Discovery visit to Rapa, no landfall was made with the Aguila and the Jupiter only moored for one night. No coconut husks were observed without which botanical determinations of early explorers tended to be misinformed. There is a possibility that the trees Gayangos observed were in fact another species of palm.

In 1829 the LMS Missionaries, Reverends Pritchard and Simpson (1830 in Stokes, m.s.a, Group 2 Box 7.1) visited Rapa noting that ‘One coconut palm was reported as present from a drift and was not recognized by the local natives’. After his visit to Rapa in 1865, John Vine Hall ascertained from one informant that ‘there were cocoa-nuts formerly on the Island, but blight destroyed them all some years ago’ (Hall, 1869a: 135). In his unpublished ethnography of Rapa, compiled between 1921-22, J.F.G. Stokes (m.s.a. Group 2. Box 7.1) notes that:
'Many coconut palms are now scattered through the island. Though vigorous and growing to a fair height, according to report – they drop their fruit before it matures. Other introductions at Tupuaki, on the northern coast, are said to have borne fruit that was “killed by thunder”.'

He also noted that a ‘white man who tried to grow coconuts for commerce at the northern end of the harbor apparently abandoned the venture as a failure’ (Stokes, ibid)

*C. nucifera* has been introduced within the last sixty years to Rapa where it is located around Ha’urei village and as isolated trees found in some sheltered embayments on the island. On Rapa, these palms currently produce small fruits that do not develop to full maturity, probably as a result of the more sub-tropical climate of the island. On Rimatara, Rurutu and Tubuai, *C. nucifera* fruits do reach full maturity and the established plantations are used primarily for local consumption and as pig fodder.

For most if not all of the Austral Islands I would suggest that *C. nucifera* has probably been introduced from cultivated progenitors prior to European contact, but naturally dispersed populations may have existed prior to human colonisation on the northern most Austral Islands in small coastal stands. Perhaps with the exception of populations from Rapa, that are likely to be derived from cultivated populations and reliant on cultivation for survival (categories 12 and 15; Table 8.1), *C. nucifera* from the Austral Islands, in this regard, could be placed into all of the theoretical plant categories listed in Table 8.1.

**Taxa without palaeobotanical or archaeobotanical records:**

*Artocarpus altillis* (Parkinson) Fosberg (Moraceae) (Florence, 1997: 142-145)

In 1961, Barrau identified the New Guinea region as a likely centre for the arboricultural species *Artocarpus altillis* (Barrau, 1963; 1976). Yen (1991b; 1995) went so far as to say that this sucker-propagated tree crop could have originated on the northern slopes of New Guinea where it was progressively adapted to coastal conditions along with a suite of other arboricultural species. He also proposed that New Guinea represents an independent centre of plant domestication where ‘the confluence of genetic materials and cultural ideas of environmental adaptation were given expression in Oceanic subsistence systems’ (Yen, 1993: 91). This hypothesis followed the findings of Golson and others (e.g. Golson, 1991) for an early Holocene or earlier antiquity of agricultural technology in the highlands of New Guinea, more recently synthesised by Denham et al (2003). As Kennedy and Clark (2004) have argued, the support for this regional unity of domestication practice, particularly of arboricultural species, remains a matter of debate in light of support for a geographic extension of Indo-Malaysian practices and cultigen use, including *A. altillis*, in lowland Near Oceania (e.g. Kirch, 1989).
Cultivated *A. altilis* in OIRO is characteristically seedless, whereas in the New Guinea region, cultivated forms are heavily seeded and are selected for seeds. There is considerable confusion in the literature about the wild or cultivated status of these seeded forms (Kennedy and Clark, 2004). Yen (1995) has suggested that *A. altilis* was increasingly selected for the seedless fleshy fruits along a geographic gradient from west (New Guinea) to east (Polynesia). Recent molecular work by Zerega (2003), using AFLPs, indicates that the cultivars of *A. altilis* have a polyphyletic lineage derived from a number of monophyletic wild species, namely *A. camansi* (New Guinea, but also possibly from the eastern Indo-Malaysian region) and *A. mariannensis* (Marianna Islands). The polyphyletic lineage of breadfruit populations from eastern Polynesia were more closely affiliated with *A. camansi* than with *A. mariannensis* to which modern Micronesian populations were closely related. An historical introduction of an *A. mariannensis* lineage of *A. altilis* cultivars from Micronesia to Tokelau, not recorded elsewhere in Polynesia, was detectable in the diversity amongst these populations as measured by the percentage of polymorphic loci. Zerega’s study demonstrates the efficacy of AFLP-based phylogeny to pinpoint original centres of diversity for *A. altilis* populations, but without knowledge of historical introduction of Micronesian cultivars to Tokelau and the eastern Polynesian population pool, the security of these claims would be weakened.

Kennedy and Clark (2004) suggest that the selection for seedlessness in *A. camansi* from New Guinea and the adjacent islands preceded hybridisation with *A. mariannensis*, but the timing and location of this event is unknown. In addition, the antiquity of *A. camansi* in New Guinea is unknown and it is unlikely to be understood for some time given that there is no comprehensive collection of breadfruit varieties or cultivars for the region. Following Yen (1991b; 1995), Kennedy and Clark (2004) suggest that the lower montane New Guinea centre of origin for *Artocarpus* is shared by a number of other arboricultural genera including *Canarium*, *Pometia* and *Burckella* (see Chapter 4), each having undergone a lowland and coastal expansion with progressive human selection. *A. altilis* is the only arboricultural species of this group distributed well into OIRO.

One seed fragment has been identified from a rockshelter excavation in the Yuat Gorge, Papua New Guinea, but may be from a recent mortuary setting (Gorecki, 1989 in Kennedy and Clark, 2004). Athens *et al* (1996) have identified what they believe to be charred *A. altilis* wood from an archaeological site from Katem Compound, Kosrae, Federated States of Micronesia, with an interpolated date of around 2,000 cal. yr B.P. The authors interpret this record as a strong indication for an introduced arboricultural component on the island that developed with first settlement. Kennedy and Clark, (2004) query their assumption that the charred wood represents the existence of the seedless *A. altilis* given that it could just as well represent wild or cultivated populations of *A. mariannensis*. Pollen was also identified from an adjacent sedimentary core,
although the accuracy of identifying this Moraceae type pollen grain is questionable, as has been highlighted for a putative record from the Philippines (Maloney, 1994).

A piece of wood that has been tentatively identified as *Artocarpus* wood from Taravai on Mangareva in the Gambier Archipelago has been dated to 760-650 cal. yr B.P. (Lab no. Beta-190119, Conte and Kirch, 2005). Some charred *A. altillis* wood remains from a sediment core obtained from Kapunahala on O‘ahu in the Hawaiian Islands revealed a date of 520-310 cal. yr B.P. (Lab no. Beta-82797, Athens and Ward, 1996). If the wood charcoal identification is correct, both of these ages provide firm evidence for Polynesian translocation of *A. altillis* to the eastern limits of OIRO. As yet no archaeobotanical material of breadfruit has been identified from the Austral Islands.

Stokes (m.s.a) noted in the 1920s that *A. altillis* (breadfruit) thrived on Ra‘ivavae and the islands further north, but not on Rapa. From accounts he collected of the early plant introductions to Rapa, he determined that this tree was introduced along with *Cocos nucifera* and the fe‘i *Musa sapientum* (Section: Eumusa) during the early missionary period (1826-1829 – see also Branagan, 1996: 71-72 for Stutchbury’s account). Visiting Rapa in 1829, Pritchard and Simpson (1830 in Stokes m.s.a Group 2 Box 7.1) reported that these plants were not thriving. Like many of these probable historic introductions, Stokes concluded that cooler climatic conditions on Rapa were not a primary factor in determining their limited production, but this was more due to a lack of maintenance. Browsing by feral and domesticated animals may have played a part in the status of this cultigen on Rapa.

The timing of introduction of breadfruit to the remaining Austral Islands, based on first contact accounts, is clearly pre-European. The Spanish voyage under Tomás Gayangos (1776: 126) was the first to record the tree crop (*Euru*) in the Austral islands on his visit to Ra‘ivavae in 1775. The arrival the HMS Bounty mutineers under James Morrison and Fletcher Christian to Tubuai in 1789, provides the most intriguing and prolific case of European introduction of flora and fauna to the Austral Islands. After arriving at Tubuai on May 25th, Morrison (1935: 48-73) describes the dumping of hundreds of breadfruit trees on the island to relieve the ship of its cargo before the return to Tahiti in order to gain supplies for the establishment of the mutineer’s settlement. Morrison also noted that breadfruit was cultivated on the island prior to this introduction. Today breadfruit is maintained in small groves or as isolated trees on all of the populated Austral Islands except Rapa.

*Broussonetia papyrifera* (L.) Ventenat (Moraceae) (Florence, 1997: 146-147)

Matthews (1996) has provided a summary of the biogeography and ethnobotany of *Broussonetia papyrifera* in Oceania. *B. papyrifera* is dioecious having a natural range with both male and
female populations extending from East Asia to mainland Southeast Asia. Limited information is available on its fertile status outside of this range with no flowering specimens known from herbarium records from OIRO and New Zealand (ibid: 125). The OIRO populations may also be derived entirely from clones from an entirely male population. Within OIRO, climate appears not to be a major limiting factor in its distribution, as it is known from early ethnographic and botanical surveys to have been grown in high latitude situations as far south as the North Island of New Zealand. As yet no molecular phylogenetic research has been undertaken on B. papyrifera populations in Oceania.

No archaeobotanical or palaeobotanical material has been identified from the Austral Islands. Orliac (2000) has identified B. papyrifera wood from archaeological charcoal assemblages from Easter Island (dating to 690-500 cal. yr B.P. see Chapter 4) suggesting the same may be possible from sources on the Austral Islands. These trees are small and are unlikely to constitute significant proportions of charcoal unless the oven feature was directly associated with a processing site where heartwood is directly discarded in large quantities. This is likely to be the case at the Akahanga rockshelter site (AK 551) on Easter Island where B. papyrifera made up 32% of the total identified oven charcoal (ibid: 139).

As B. papyrifera does not generally flower or set seed (Whistler, 1991: 55) within OIRO, it is unlikely that pollen or seed will be located in archaeological or sedimentary settings (Matthews, 1996). Identifying B. papyrifera pollen is problematic because of the morphological similarity with pollen from other members of the Moraceae and also the Urticaceae family. In the Austral Islands a number of species within the Moraceae are common including Ficus prolixa var. prolixa and the introduced arboricultural crop, Artocarpus altilis. On Rapa, this problem is conflated by the two species in the indigenous tree genus Strebulis (S. anthropophagorum and S. pendulimus). Horrocks et al (2004) identified B. papyrifera pollen and hair type phytoliths from a swamp core from Rangihoua Bay, Northland, New Zealand. Mid-Holocene dates for a section of peat with B. papyrifera type phytoliths coupled with the likelihood that these plants may not have flowered in Maori cultivations reduces the validity of this claim.

The pre-mission station introduction of B. papyrifera to Rapa, Ra’ivavae and Rurutu is uncertain given that the only accounts recording the plant on these islands were made by observers who never made landfall. The description of the clothing worn by islander’s who ventured on board the visitor’s ships provides some indication of it’s presence given the status of B. papyrifera as the predominant bark-cloth material in Remote Oceania. For example, the Discovery’s surgeon and botanist Archibald Menzies, on observing some of the Rapa islanders in 1791, records:

"The only clothing they wore were a narrow slip of cloth made from the bark of a tree which passed round their waist & between their legs, this cloth appear’d to be a very scarce article amongst them as..."
many of them had not sufficient of it to cover their nakedness, it was evident however that they
generally wore something for that purpose, as some of them had bunches of leaves of a species of
Dracaena [prob. *Pandanus tectorius* or *Cordyline fruticosa*] suspended to a girdle round their middle
for that intention.’ (Shineberg, 1986: 67)

It is possible, however, that the cloth was made from the bark of *Hibiscus tiliaceus* (*Purau*) found
on all of the Austral Islands.

Ethnographic descriptions of bark-cloth production on Rurutu and Tubuai have been
Stokes (m.s.a) documented bark-cloth production on Rapa where a ‘tapa’ beater was located as a
surface archaeological find (Buck, 1957: 171; Kooijman, 1972). No first contact records of bark-
cloth production have been noted for any of the Austral Islands, although all of the main
etnographic treatments of the islands suggest that it has an antiquity prior to contact.

Ethnographic accounts (e.g. Aitken, 1930) and botanical records (e.g. Fosberg and St. John,
1934) of the Austral Islands from as early as the 1920s all indicate that *B. papyrifera* was
cultivated within extensive groves, including on Rapa. Stokes (m.s.a Group 2 Box 7.2) observed
in 1921 that:

‘The growing of aute [*B. papyrifera*] has been given up, but apparently in former days it was
definitely cultivated. A dry-looking hill slope bordering the shore at Aupapa, Angaino Bay, is said
to have been an aute field; the patches are small, narrow, irregular terraces follow the contour of the
land. At the bottom of the slope the soil is retained by a rough stone wall.’

It is likely that on most of the islands, cultivation became increasingly limited after the
introduction of domestic animals including pigs, cattle and goats. William Colenso (1881: 18, in
Matthews, 1996) suggested that the plant became extinct in New Zealand soon after 1844, due
primarily to browsing by cattle. This may well have been the case on the Austral Islands. Bark-
cloth production is now minimal on the islands with plants generally cultivated within or adjacent
to household gardens. Some small groves are still maintained, but only in areas protected from
domestic and feral livestock.

Matthews (1996) suggests that populations of *B. papyrifera* in OIRO are derived from
cultivated progenitors and have been dependent on human dispersal and cultivation for survival.
Of the theoretical plant categories formulated by Matthews, *B. papyrifera* can be placed in
categories 14 and 15 of *Table 8.1*. 

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<table>
<thead>
<tr>
<th>Botanical species</th>
<th>Archaeobotanical records</th>
<th>Anthropogenic palaeobotanical records</th>
<th>First-contact accounts 1769-1834</th>
<th>Botanical survey data 1921-1934</th>
<th>2002-04</th>
<th>Plant category (Table 8.1)</th>
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<td>-</td>
<td>Rapa?</td>
<td>Rapa, Rimatara</td>
<td>All islands</td>
<td>All islands</td>
<td>12, 15</td>
</tr>
<tr>
<td><em>Colocasia esculenta</em> (L.) Schott. (Araceae)</td>
<td>Rapa? (tuber peelings)</td>
<td>-</td>
<td>All islands</td>
<td>All islands</td>
<td>All islands</td>
<td>12, 15</td>
</tr>
<tr>
<td><em>Cyrtosperma merkueli</em> (Haas) Schott. (syn. <em>C. camarostis</em>) (Araceae)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>12, 15</td>
</tr>
<tr>
<td><em>Ipomoea batatas</em> L. (Convolvulaceae)</td>
<td>-</td>
<td>Tubuai, Runuta, Rimatara</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>12, 15</td>
</tr>
<tr>
<td><em>Cucumis melo</em> L. (Cucurbitaceae)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>12, 15</td>
</tr>
<tr>
<td><em>Benincasa hispida</em> (Thunb.) Cogn. (Cucurbitaceae)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>12, 15</td>
</tr>
<tr>
<td><em>Lagenaria siccaria</em> (Molina) Stand. (Cucurbitaceae)</td>
<td>Rapa (shell)</td>
<td>Rapa, Rimatara</td>
<td>Rapa (D. alata, D. bulbifera, D. pentaphylla, D. sativa), Ra’ivavae, Tubuai (D. sativa), Rimatara (D. bulbifera, D. pentaphylla)</td>
<td>-</td>
<td>-</td>
<td>12, 15</td>
</tr>
<tr>
<td>* Dioscorea up. D. alata, D. bulbifera, D. pentaphylla, D. sativa* (Dioscoreaceae)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>12, 15</td>
</tr>
<tr>
<td><em>Manihot esculenta</em> Crantz (Euphorbiaceae)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>12, 15</td>
</tr>
<tr>
<td><em>Abrus precatorius</em> L. (Fabaceae)</td>
<td>-</td>
<td>Tubuai 2</td>
<td>Rapa, Ra’ivavae, Tubuai, Rimatara</td>
<td>-</td>
<td>-</td>
<td>12, 15</td>
</tr>
<tr>
<td><em>Tephrosia purpurea</em> (L.) Pers. (Fabaceae)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>12, 15</td>
</tr>
<tr>
<td><em>Erianthus maximus</em> Brongn. (Poaceae)</td>
<td>-</td>
<td>-</td>
<td>Rapa, Runuta</td>
<td>Rapa</td>
<td>-</td>
<td>12, 15</td>
</tr>
<tr>
<td><em>Saccharum officinarum</em> L. (Poaceae)</td>
<td>-</td>
<td>-</td>
<td>Rapa, Ra’ivavae, Tubuai, Rimatara</td>
<td>All islands</td>
<td>All islands</td>
<td>12, 15</td>
</tr>
<tr>
<td><em>Schizostachyum glaucifolium</em> (Rupr.) Muero (Poaceae)</td>
<td>-</td>
<td>-</td>
<td>Ra’ivavae, Runuta</td>
<td>Rimatara</td>
<td>-</td>
<td>12, 15</td>
</tr>
<tr>
<td><em>Taece</em> leontopetaloides (L.) Kunze (Taccaceae)</td>
<td>-</td>
<td>Tubuai 1</td>
<td>Rapa, Tubuai</td>
<td>Rapa, Rimatara</td>
<td>-</td>
<td>12, 15</td>
</tr>
<tr>
<td><em>Curculina longis L.</em> (Zingiberaceae)</td>
<td>-</td>
<td>-</td>
<td>Rapa, Ra’ivavae, Tubuai, Rimatara</td>
<td>-</td>
<td>-</td>
<td>12, 15</td>
</tr>
<tr>
<td><em>Zingiber zerumbet</em> (L.) Smith (Zingiberaceae)</td>
<td>-</td>
<td>-</td>
<td>Rapa, Ra’ivavae, Tubuai</td>
<td>All islands</td>
<td>All islands</td>
<td>12, 15</td>
</tr>
</tbody>
</table>

1 Brown (1931); 2 Brown (1935); 3 Florence (1997); 4 Wong et al. (2002); 5 Not all information available; 6 Aitken (1930)

Table 8.3 Botanical sources of probable herb introductions (including tuber, corm and rhizome cultigens) (arranged by family) to the Austral Islands recognized in the above references and by Whistler (1991). None of these species have been located in any pre-human palaeobotanical record.
Taxa only recorded in botanical surveys:

*Cordia subcordata* Lam. (Boraginaceae) (Brown, 1935)

Fruit remains of *Cordia subcordata* from Māhā‘ulepu cave excavations on Kaua‘i Island have been dated from between 5945–5300 cal. yr B.P. (Burney et al. 2001). Apparently Sinclair (1885 in Burney et al. *ibid*) earlier considered *C. subcordata* to be indigenous to the Hawaiian Islands, but this tree was formerly regarded as an introduction to these islands by many authors (e.g., Whistler, 1991). No macrofossil remains of *C. subcordata* have been located from the Austral Islands. *C. subcordata* was located only on Tubuai during the 1921-1934 surveys and on Rimatara in the most recent surveys (2004) where it is located in the vicinity of local villages. *C. subcordata* is probably aligned with the theoretical plant categories 1-6 listed in Table 8.1. It seems likely that its progenitors have never been cultivated and may have dispersed eastward to as far as the Austral Islands, with or without human assistance.

Herbaceous taxa of the Austral Islands

There are several herbaceous taxa that may have been intentionally or inadvertently introduced to the Pacific islands by people. Of the list of probable herb introductions into the OIRO region (Table 8.3), proposed in a number of botanical compendiums by several authors (e.g., Whistler, 1991), none have been recorded in the palaeobotanical record from Rapa or Rimatara in sediments that exceed the age for human colonisation established by the archaeological record.

Probable intentional herbaceous introductions

Taxa recorded in all botanical sources:

*Colocasia esculenta* (L.) Schott (Araceae) (Brown, 1931)

With the probable exception of the yam (*Dioscorea* spp.), the cultivated form of *Colocasia esculenta* has the greatest antiquity of domestication of any plant found with a modern distribution spanning the entire Indo-Pacific region. As for many domesticated plants from the region, the precise geographical area of origin of wild-type *C. esculenta* is uncertain. It seems likely that pre-human distribution of its wild type may have extended as far east as New Guinea and Northern Australia but was restricted by oceanic barriers further east (Matthews, 2004). For the genus as a whole, the most recent working hypothesis suggests that the main centre of *Colocasia* diversity lies in the southern slopes of the Himalayas, with a secondary centre expanding eastwards to the highlands of China (Yunnan) and Myanmar (Yoshino, 2002). The
number of *Colocasia* species present in this broad geographical region is still unclear with some species yet to be described (Hotta, 2002).

The fossil botanical evidence for identifying the pre-human distribution of wild-type *C. esculenta* throughout the Indo-Pacific is discussed by Prebble and Haberle (*in prep*). Recovery of macrobotanical evidence of cultivated *C. esculenta* has been restricted by the lack of adequate preservation sites for the soft, perishable corm tissue. Melinda Allen (1981) located corm material (possible shavings) from throughout the Ko'oko'olau Rockshelter excavation at Mauna Kea, O‘ahu, Hawai‘i, with an interpolated radiocarbon age range of 910-550 cal. yr B.P. (Lab. no. I-9744). She has also identified corm shavings from two other sites in the Hawaiian Islands (Allen, 1983; 1989). Kirch *et al* (1995) identified corm tissue from the Tangatatau Rockshelter on Mangaia with an interpolated radiocarbon age of around 1000-800 yrs B.P. (uncalibrated).

Starch grains and calcium oxalate raphides from *C. esculenta* corms (e.g. Therin *et al* 1999; Denham *et al* 2003) have been cited in support of the identification of this plant from a number of sites throughout the Indo-Pacific. If such analyses are accepted then the cultivation of *Colocasia* has an antiquity of at least 7,000 years at Kuk Swamp in the Wahgi Valley, Papua New Guinea. In this case, starch grain residues were isolated from stone tools associated with an artificial palaeosurface consisting of pits, runnels, stake and post-holes (Denham *et al* 2003). As yet, the current systematic separation of *Colocasia* type starch grains from other aroid species is insufficient. There are 127 species of aroids listed within the Pauasia floral region (Brunnitt, 2001) that includes Papua New Guinea and the Solomon Islands (http://www.kew.org/monocotChecklist/advsearch.do), many with economic potential that may contribute starch to the archaeological record.

The palynological evidence for *C. esculenta* cultivation is discussed in Chapter 1 and 7 (also in Prebble and Haberle, *in prep*). Evidence of this type appears to be restricted to sites in OIRO although four Holocene pollen records from outside of this region have been noted that probably represent wild-type *C. esculenta*. These include two sites from the highlands of Sumatra, Indonesia (Pea-sim-sim, Maloney, 1981; Tao Sipinggan, Maloney, 1982), one from the Morobe Province of Papua New Guinea (Lake Wanum, Garrett-Jones, 1979; Haberle, 1995) and one site from the Atherton Tablelands, Queensland, Australia (Lake Euramoo, Haberle, 2005). Justification for the distinction of cultivated *C. esculenta* inferred for pollen records from OIRO includes the likelihood of human dispersal by *Colocasia* cultivators, given the antiquity of aroid agriculture in the Western Pacific (Denham *et al* 2003). The stratigraphic position within these records is usually radiocarbon dated to within, or close to the archaeologically determined human settlement timeframe. The association of other agricultural and human impact signatures including pollen of other potential cultivars (e.g. *Aleurites moluccana*), high increases in fern spores, grass pollen and charcoal particle concentration provide an additional justification (Prebble and Haberle, *in prep*).
The phylogeographic evidence available for the examination of cultivated *C. esculenta* is equivocal. The interpretation of the available cytological and molecular data relies on the assumption that the sampled populations, from modern plants and/or herbarium specimens, can be distinguished on the basis of characteristics that distinguish among wild, domesticated and/or naturalised forms. In *C. esculenta* the cultivated forms are very diverse, with some populations exhibiting many phenotypic characters and genetic variations that are also present within wild-type plants whereas other populations may be distinct from the overall variation exhibited within the species (Yoshino, 2002; Matthews, 2004). The most intriguing molecular data lies in the disparate genetic diversity reflected in modern isozymes (Lebot and Aradhya, 1991) and random amplified polymorphism DNA (RAPD) analysis (Irwin, 1998) of geographically disjunct populations from Asia and the Pacific. A recent reassessment of these data by Yoshino (2002) suggests that such diversity may be a function of occasional hybridisation between cultivated Asian plants and other *Colocasia* species including *C. gigantea* found within part of the Asian distribution of *C. esculenta*. Such genetic disparity has been interpreted as evidence for independent domestication on the Sunda and Sahul continental shelves during the Pleistocene (Lebot, 1999). Yoshino (2002), however, has suggested that even long-term isolation of domesticated populations may not be sufficient to register such genetic change in plant populations that are cultivated by vegetative reproduction.

For the OIRO region, *C. esculenta* is clearly aligned with theoretical plant category 15 in Table 8.1, being dispersed by humans beyond the indigenous range and range of the original progenitor populations. The OIRO environments where both cultivated and naturalised populations of *C. esculenta* exist can be characterised by human disturbance.

From botanical sources of the Austral Islands, *C. esculenta* was identified in a number of early first contact accounts (e.g. Morrison, 1935; Bellingshausen in Barratt, 1988) and was identified on all of the Austral Islands by 1834. Most accounts of *C. esculenta* cultivation suggest that it was the primary staple upon European contact on all of the islands. First contact accounts also suggest that *C. esculenta* cultivation within irrigated pond field systems similar to that found elsewhere in OIRO.

The author has tentatively identified *C. esculenta* corn shavings from the Tangarutu rockshelter excavation dating between 400 and 200 cal. yr B.P., but further analysis is required to confirm this determination. *C. esculenta* pollen was identified from anthropogenic palaeobotanical records on both Rapa and Rimatara dating as early as 800-600 cal. yr B.P. (see Chapter 7).

Twenty-five morphologically distinct varieties of *C. esculenta* are currently recognised on Rapa with five of these believed to be recent introductions (e.g. from Samoa). This to some degree attests to the antiquity of *C. esculenta* cultivation on the island. While a number of varieties are known by some informants on the island, many of these can no longer be found (Tim
Motley pers. comm. 2003). Aitken (1930) recorded sixteen different varieties of *C. esculenta* during his ethnographic survey of Tubuai in the 1920s. Most of these varieties have been adapted to suit particular wet-field conditions, although in some cases cultivars are selected for dry-field systems.

On Rapa, *C. esculenta* is now absent from all of the northern bays of the island primarily due to the abandonment of irrigated pond field cultivation systems since European contact. Naturalised *C. esculenta* are present in small swamps inaccessible to browsing by cattle, goats and horses. The largest active cultivations remain in Ha’urei, Anatakuri and Hiri Bays to the south where attempts have been made to exclude feral animals. Areas formerly cultivated can to some degree be assessed by the extent of some of the main agricultural weeds including *Ludwiga octovalis* and *Commelina diffusa*.

On Rimatara, *C. esculenta* is still cultivated extensively along the inner periphery of the moat swamps features. These wet-field systems extend out into the swamp by no more than 100 m and are fed by small inland streams at the swamp margins. Many areas formerly cultivated are currently either in fallow or abandoned. The central parts of the moat swamps, according to one local informant were never cultivated with post-production gardens remaining in fallow for two years. Tethered goats (*Capra hircus*) and pigs (*Sus scrofa*) are often found in these fallow garden sites.

Like on Rapa and Rimatara, *C. esculenta* cultivation is in a similar decline on all of the remaining populated Austral Islands. The economic priority of the island communities is such that *C. esculenta* production is not in demand. Some recent historical factors may also have contributed to its recent decline. Taro blight and a range of viruses (e.g. Dasheen mosaic virus) have affected Pacific island *Colocasia* populations in the past, including the Australs and this coupled with an abandonment of cultivations is likely to have reduced the number of varieties.

Other taxa within the Araceae listed by Whistler (1991) as a possible introduction to OIRO include *Alocasia macrorrhiza* L., *Cyrtosperma merkusii* (Haask.) Schott. (syn. *C. chamissonis*) and *Amorphophallus paeoniifolius* (Dennst.) Nicolson (not listed in Table 8.3). *A. paeoniifolius* was not recorded in any of the available botanical sources for the Austral Islands, including modern floral survey data. In 1934, Fosberg and St. John (1934) identified only one cultivar of *Alocasia macrorrhiza* L. from Rapa within a name *raratao* suggesting it was introduced from Raratonga in the Cook Islands. Aitken (1930) also only identified one cultivar on Tubuai, suggesting that for both of these islands *A. macrorrhiza* was not a significant crop. This is likely to be the case for *Cyrtosperma merkusii* where two small cultivated populations were only recently identified from Rimatara in 2004 (Jean-François Butaud pers. comm. 2004)
Taxa with no anthropogenic palaeobotanical record:

*Lagenaria siceraria* (Mol.) Standl. (Cucurbitaceae) (Brown, 1935)

The most detailed summaries of the biogeography and ethnobotany of *L. siceraria* are provided by Heiser (1973, 1979) and Dodge (1943, 1978). Heiser (1973: 121) first proposed that *L. siceraria* maybe one of the first plants to have been domesticated by humans in the tropics. The evolutionary history of *L. siceraria* is uncertain given the lack of indigenous populations on any continent from which to establish a centre of origin. Based on the present number and distribution of wild *Lagenaria* species (five), Africa is assumed to be the geographic centre of origin for the genus (Decker-Walters *et al* 2001). Archaeological remains suggest that the domestication of *L. siceraria* may have independently developed in the Americas between 15,000 and 9000 yr B.P., and in East Asia between 10,000 and 6000 yr B.P. and in Africa between 5000 and 4000 yr B.P. (Heiser, 1979). Decker-Walters *et al* (2001) assessed the diversity of landraces of *L. siceraria* from each of the above areas including New Guinea, using random amplified polymorphic DNA. They found that the landraces of New Guinea could be distinguished from American specimens. This supports Heiser's (1973) earlier assertion that *L. siceraria* fruit shapes, to which he recognized two distinct subspecies, have multiple geographic origins.

Based on limited linguistic and archaebotanical evidence, Green (2000 following Ross, 1996) suggests that the *L. siceraria* was absent from Near Oceania at the time the closest islands in Remote Oceania were first settled around 3500 to 3000 yr B.P. Green (*ibid*) finds support for this claim in the absence of evidence from the rich archaebotanical assemblages from the waterlogged sites at Dongan in the lower Ramu, Papua New Guinea (Swadling, 1995; 1997; Swadling *et al* 1991). Green (2000) also sites the earliest known interpolated date for the Near Oceania for *L. siceraria* at 2720 - 2040 cal. yr B.P. (Lab. No. ANU-43) from the Manton site at Warrawau, upper Wahgi Valley, Central Highlands, Papua New Guinea (after Golson *et al* 1967; Powell, 1970). Golson (2002), however, has now revised the Manton gourd rind determination and has tentatively assigned it to the wax gourd *Benincasa hispida* (see below) on the basis of recent finds of this rind in an archaeological site at Kana (dated to 2995-1990 cal. yr B.P.; Lab. No. ANU-9487), at a slightly higher altitude to Manton, also in the Wahgi Valley. He also determines *B. hispida* on the basis of the lack of *L. siceraria* finds in New Guinea and Near Oceania and the general lack of certain determinations of gourd rind from archaeological sites throughout the Indo-Pacific.

Fragments of *L. siceraria* have also been identified from a number of sites in the Hawaiian Islands including the 'Ewa Plain (Gail Murakami, unpublished report, in Tuggle, 1997) and Kawaihui Valley (Allen-Wheeler, 1981) on O'ahu, as well as Maha'ulepu Caves, Kaua'i (Burney *et al* 2001). Horrocks *et al* (2000) identified *L. siceraria* pollen in an exposed section of two
archaeological stone garden mounds at Pouerua, Northland, New Zealand. They suggest that the presence of gourd pollen is important as it demonstrates the actual cultivation of this species at the site. These plants have an entomophilous flowering biology where pollen would only be deposited in the direct vicinity of the parent plant. This effect would be intensified given the low stature of *L. siceraria*. Horrocks *et al* (2002a) have identified *L. siceraria* pollen from dog or human coprolites of 630-310 cal. yr B.P. (Lab. No. NZA-12591) buried in a beach dune on Great Barrier Island in the Hauraki Gulf, New Zealand. These data suggest direct consumption of flowers, but it may also reflect consumption of residues on young *L. siceraria* or even inadvertent ingestion during hand pollination (Best, 1925 in Horrocks 2004: 323). Horrocks *et al* (2002b) has also identified *L. siceraria* pollen from a swamp core also on Great Barrier Island in a sedimentary sequence younger than 665 yr B.P., the age of the Kaharoa tephra.

The author has tentatively identified large rind fragments of *L. siceraria* material from the Tangarutu rockshelter excavation on Rapa dating between 400 and 200 cal. yr B.P., but further analysis is required to secure this determination (see Chapter 7). Some support for the antiquity of *L. siceraria* introduction to the Austral Islands comes from one first contact description of 'dried pumpkin' offered to Faddei Von Bellingshausen by an islander visiting from the Vostok whilst anchored offshore from the island, although this could equally describe *Ipomoea batatas* tubers. Ethnographic information collected by Stokes (m.s.a) and others on Rapa is also informative. *L. siceraria* was one of the few actively cultivated plants that Stokes remarked on whilst on Rapa between 1921-1922 other than *Colocasia esculenta, Dioscorea spp. and Ipomoea batatas*. Stokes found that 'Seeds of the gourd [called *koali*] are set in the ground with little preparation, and the plants are left to look after themselves' (Stokes m.s.a. Group. 2 Box 7.1).

Photographs of *L. siceraria* gourd from Rapa were taken by Rollo Beck during the Whitney Expedition of 1920. Later in 1934, Fosberg and St. John only identified *L. siceraria* cultivations at Akatanui Bay, a site now largely abandoned for cultivation.

Aitken (1930: 38) found that gourds had a number of uses on Tubuai:

'Coconut shells and gourds are used as cups, bowls, and bottles or storage jugs... gourds are more commonly preferred because of their greater capacity and because of the difficulty of working the hard wood of the coconut. The gourd is generally used in its entirety, only a small opening being cut in the top or end of the neck. This opening may be small, and fitted with a plug, or large, and provided with a cover, depending on the use for which the gourd is intended. The base of the gourd, cut so as to form a shallow, circular bowl, is sometimes used as a dish or basin. Gourds split lengthwise were not seen, but I was told that formerly they were used as platters. Most gourds used as containers were provided with sennit, netted tightly about them and provided with handles for carrying or hanging.'
He (ibid: 40) also found gourds ‘filled with raw fish in sauce’ called miti hue by the islanders. Based on the most recent botanical surveys of the Austral Islands, cultivation of L. siceraria is now rare if not absent from cultivation on all of the Austral.

In a critique of Green’s (2000) examination of the archaeological distribution of bottle gourd (L. siceraria), Golson (2002) has highlighted the phytogeographic implications of the wax gourd, Benincasa hispida, in OIRO in citing an analysis of its distribution and ethnobotany made by Whistler (1990; 1991). Whistler (1991) suggests that the wax gourd is indigenous to Southeast Asia but was introduced to OIRO as far east as Tahiti (noted by Parkinson (1973) in 1769) where it was often incorrectly determined as L. siceraria. Following Heiser (1979) and Purseglove (1968), Whistler (1990) suggests that the OIRO plants present a markedly different variety characterised by a different fruit shape used as containers for scented coconut oil throughout the region (termed huaroro in Davies, 1851 description of the Tahitian varieties). From Teuira Henry’s (1928 in Whistler, 1990) notes on Tahiti from between 1825 to 1847, he describes the plant as a small gourd ‘the size of a medium-size orange and has been used by Tahitians exclusively as containers of coconut hair oil’.

On the basis of Henry’s description of the wax gourd, the large rind collected from the Tangarutu rockshelter excavation on Rapa and dated to between 400 and 200 cal. yr B.P., are almost certainly L. siceraria (see Chapter 7). The size of some of the Tangarutu fragments indicates a gourd circumference much greater than a medium-size orange. The lack of evidence for coconut (C. nucifera) production on Rapa (see below), would make the cultivation of B. hispida redundant if they were exclusively used as containers of coconut oil. It maybe in part this reason that no B. hispida specimens were recorded on the Austral Islands in any first contact account or have been located since the first major botanical surveys of the 1920s.

The presence of L. siceraria on Rapa also provides contrary evidence to Green’s (2005) linguistic analysis of Yen’s Ellipse Model for Ipomoea batatas introduction to Polynesia from South America (see below). If indeed, as Green suggests, L. siceraria was brought with I. batatas, then the 400 cal. yr B.P. maximum age for bottle gourd on Rapa would suggest an early antiquity for both plants, certainly a pre-contact distribution.

Like Colocasia esculenta, it seems clear that L. siceraria has been dispersed by humans beyond its indigenous range and the range of the original progenitor populations into human disturbed island environments and thus fit into theoretical plant category 15 from Table 8.1.

Two other taxa within the Cucurbitaceae listed by Whistler (1991) as a possible introduction to most of OIRO include Cucumis melo L. and Luffa cylindrica (L.) M. Roem. (not listed in Table 8.3). C. melo was only recorded on Tubuai in the 1921-1934 botanical surveys. L. cylindrica was not recorded in any of the available botanical sources for the Austral Islands, including modern floral survey data.

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Taxa without anthropogenic palaeobotanical and archaeobotanical records:

*Ipomoea batatas* (L.) Lamarck (Convolvulaceae) (Brown, 1935)

From the growing body of botanical data, the closest related species to the *I. batatas* group are pan-tropical in distribution or are of an American centre of origin (Vavilov, *ibid*; Yen, 1963). This led some botanists such as Purseglove (1963; 1965) to suggest that the cultivated plant had multiple points of geographical origin from existing wild populations, focusing on the distribution of pan-tropical *Ipomoea* relatives. This debate climaxed with Heyerdahl's (1952; 1963) claim for an American Indian introduction to the Pacific, following his Kon Tiki drift voyage expedition. Merrill (1954a) vehemently opposed this hypothesis. He supported a more cultural diffusionist explanation based on the substantiated idea that cultivated plants clearly had their origins to the west (Southeast Asia), though he proposed an African origin for *I. batatas*.

Barrau (1957) proposed a tripartite hypothesis, taking into account the evidence for pre-Columbian transfers as well as Spanish transfers from Central America to Europe, Africa and later to Southeast Asia. Yen (1963; 1974) elaborated on these ideas, integrating an extensive systematic study of *I. batatas* variation, including cytological data, with archaeological, linguistic and historical information. With the advent of radioisotope dating after the 1950s, systematic archaeological excavation not only began to provide some security for establishing the time depth of island colonisation, but also enabled historical and long-term distributional patterns of some plants to be re-examined in the context of local sequences, rather than merely hypothesised by comparison between different regions.

Stratified archaeobotanical remains of *I. batatas* in Remote Oceania were first located from a circular stone dwelling at Anakena on Easter Island (Skjølsvold, 1961) providing an indirect date of AD 1526 +/- 100 (uncalibrated around 400 yr B.P.). Rosendahl and Yen (1971) located some charred tuberous remains of *I. batatas* at an excavation site at Lapakahi, in the Kohala district of Hawai’i and obtained a direct radiocarbon age of 550-0 cal. yr B.P. (Lab no. Westwood Laboratories 4400; 295 +/- 90 yr B.P.) where it is now thought to have been the dominant crop between 1450 and 1800 AD (Kirch, 1985). It was not until Hather and Kirch (1991) identified tuberous remains of *I. batatas* from the Tangataatu Rockshelter, Mangaia, Cook Islands, with an interpolated radiocarbon age of around 1000-800 yrs B.P. uncalibrated (Hather and Kirch, 1991; Kirch, 2000a), that Barrau’s tripartite hypothesis could be satisfactorily confirmed (Yen, 1998; Green, 2005) and much of the support for an early Spanish introduction extinguished (although see Langdon, 1996). More recently charred tuberous material has been identified from garden systems on Easter Island dating from contexts aged between 600-400 cal. yr B.P. (Wallin *et al* 2005; after Heyerdahl and Ferdon, 1961 see Table 4.5, Chapter 4). Recent attempts at directly dating sweet potato tubers have been undertaken by Coil and Kirch (2005) from material
excavated from the Kahikinui agricultural features on Maui (Hawaiian Islands), but only modern ages have been forthcoming (e.g. 270-0 cal yr B.P. Lab no. Beta-179678; 100 +/- 30 yr B.P.). *I. batatas* tubers have also been identified from a recent archaeological deposit on Nissan Island, Solomon Islands (Hather, 1994).

The pollen record of *I. batatas* within the Pacific region is restricted due to its entomophilous flowering biology where pollen would only be deposited in the direct vicinity of the parent plant *I. batatas* has large pollen grains of between 130-145 um which is large enough that it may not survive standard pollen processing procedures including acetolysis and filtering (Haberle, 1994; Haberle and Atkins, 2005), although Horrocks (2004) has identified pollen with no apparent damage from a Rarotongan variety. Despite these potential caveats, Athens et al (in Tuggle, 1997) and Fall (2005) have recorded *I. batatas* pollen from pre-European phase sediments from the ‘Ewa Plain, O’ahu in the Hawaiian Islands and Avai’o’vuna Swamp, Vava’u, Tonga, respectively.

Starch grains have shown the most potential for identifying tubers in the fossil record, including those from *I. batatas* (e.g. Therin et al 1999). However, the identification of tuber, corm, and rhizome species based on such structures has relied on site-context inferences and on a limited collection of reference material that cannot yet allow the systematic separation of the numerous extant starchy taxa present within the Indo-Pacific flora. Based on current reference material, a distinction may be made between starch grains from some of the more common starchy tubers (*e.g. I. batatas* and *Dioscorea* spp.) and aroids (*e.g. C. esculenta*). It is unclear whether starch grains could differentiate between other species of *Ipomoea*, prevalent throughout the tropics and temperate Pacific. Starch grains and xylem cells of *I. batatas* have been identified from a number of archaeological sites and one sedimentary core from New Zealand (see Horrocks, 2004; Horrocks and Lawlor, 2006; Horrocks et al 2004a; 2004b)

Increasingly, molecular markers of ancestry within a phylogenetic framework are being used to assess the population genetics of island organisms. Markers such as mitochondrial DNA (mtDNA) with amplified fragment length polymorphism (AFLP) analysis can provide historical data for movements and changes of different taxa, potentially to the species level. AFLPs have been extracted from seventy-six *I. batatas* specimens from the Pacific, the Philippines, Peru, Ecuador and Mexico (Rossel et al 1999-2000). The Philippines, New Guinea and most of the remaining Pacific specimens exhibited a Mexican origin, in line with the historical 17th century introduction from Mexico to Manila then to New Guinea. Only three of the Pacific specimens exhibited a Peru-Ecuador origin as anticipated by the tripartite hypothesis. Rossel et al (ibid) suggest that this provides evidence of some non-human, long distance dispersal (including seed dispersal by birds) from Meso-America to the Pacific. Green (2005) has concluded that these findings are problematic on the basis of a sample size of only nine Polynesian specimens that may not represent varieties with a pre-contact antiquity.
Green (2005) bases his claims for a refined version of Yen’s ellipse model and interpretation of the tripartite hypothesis largely on a working of the linguistic evidence. He suggests that the first introductions into Polynesia from South America took place within a geographical ellipse surrounding Mangaia, the Society Islands and the Marquesas group. Mangaia is favoured as a source location for the pre-contact New Zealand populations and the Marquesas firstly for the Hawaiian Islands and secondly for Easter Island via Mangareva. In the case of both the Hawaiian Islands and Easter Island he presents the case that introduction took place some centuries after initial settlement. He also suggests a number of other plant cultigens may have been brought with *I. batatas* including *Lagenaria siceraria* (bottle gourd – see below) and *Sapindus saponaria* (soapberry).

The botanical status of *I. batatas* in OIRO is now apparent from the research synopsis of Yen (1974) and more recently Green (2005). Like *Colocasia esculenta* and *Lagenaria siceraria*, *I. batatas* has been dispersed by humans beyond the indigenous range and the range of the original progenitor populations into human disturbed island environments in (theoretical plant category 15; Table 8.1). The antiquity of *I. batatas* on the Austral Islands is more difficult to define due to the lack of archaeobotanical and historical evidence for its presence.

Morrison (1935) did not identify *I. batatas* during his three month stay on Tubuai in 1789. It was not recorded on Rapa and Ra‘ivavae before 1834 and was not recorded on the remaining populated Austral Islands until either 1826 (Rurutu; Branagan, 1996) or 1834 (Tubuai, Rimatara; Moerenhout, 1837). Currently no archaeobotanical record of *I. batatas* is available from any of the Austral Island botanical sources. The author has tentatively identified charred tuberous material from the Tangarutu rockshelter excavation dating between 400 and 200 cal. yr B.P., but further analysis is required to secure this determination. From the Stokes (m.s.a) ethnographic survey of Rapa during the 1920s he suggests that the cultigen was present prior to European contact, but was of little agricultural importance. Aitken (1930) ascribes the same situation for Tubuai and with little information on *I. batatas* agriculture available for the remaining populated islands the situation is likely to have been the same.

There is currently no evidence to either support or deny Green’s (2005) linguistically-based refined ellipse model for *I. batatas* introduction from South America. Green, after Fischer (1996: 63) found that *I. batatas* was called *pata* on Rapa rather than the Tahitian *umara* as found in the vocabulary lists of the remaining Austral Islands. He suggests on this basis that *I. batatas* may have followed a different introduction group, and implies that this may have been through post-European contact introductions. If, by nature of the Austral Island environment, *I. batatas* did not form a major component of cultivation systems as recorded ethnographically, then claims of this nature remain very speculative. The archaeological presence of *I. batatas* on Easter Island may be due to the cultivation bias that existed there towards dryland cultivation systems in contrast to the wet-field bias evident on the Austral Islands, not the early or late timing of its introduction.
Some species of the genus *Dioscorea* spp. may have the greatest antiquity of domestication of any plant found with a modern distribution spanning the entire Indo-Pacific region (Coursey, 1979). Like *Colocasia esculenta*, the precise geographical area of origin of wild-type *Dioscorea* spp. are uncertain, although Africa, Southeast Asia (Burkhill, 1966) and the Pacific (Lebot, 1999) have been suggested. Hather (1996: 545–546) argues that some yams may have derived from 'closed' rather than 'open' seasonal forest, with the large storage tuber and climbing vine being an evolutionary response to prolonged conditions of low light. Of the four species listed in Table 8.3 *D. alata* L. and *D. bulbifera* L. are the most important in the OIRO with the antiquity of introduction or cultivation of the remaining species unknown.

The greater yam, *D. alata* is the most widespread of the cultivated species in OIRO (Lebot *et al* 1998) and may have been formerly domesticated in Southeast Asia then introduced to the Pacific (Barrau, 1965) but the modern centre of cultivar diversity is currently in New Guinea and the Solomon Islands (Alexander and Coursey, 1969; Martin and Rhodes, 1977; Coursey, 1979). However, there is some debate about the status of *D. alata* as a domesticate (Hahn 1995), hybrid (Coursey, 1979) or as a true species (Lebot *et al* 1998; Lebot 1999). According to Lebot (ibid) it has never been found 'wild', although Yen (1995) and Telford (1996) describe it as a recently naturalised species in Australia, and is not known to hybridise with other *Dioscorea* species. Lebot *et al* (1998) examined the isozyme variation of 22 cultivars of *D. alata* from across the tropics. No agreement could be found between morphological variation, geographic distribution and isozyme polymorphism.

The biomolecular relationships among fifteen aerial yam (*D. bulbifera*) cultivars from a number of sites across the tropics were examined using DNA restriction fragment length polymorphism (RFLP) analysis. From this analysis the chloroplast genomes were classified into nine distinct types with the Pacific types found to be significantly different from the Asian types. Accessions from OIRO sites were found to be closely related to those from New Guinea and Australia. Ramser *et al* (1996) examined 23 accessions from a similar tropical distribution using RAPDs and found that the cultivar genotypes could be aligned with three distinct geographical areas, with the Pacific accessions significantly different from Asian cultivars. Lebot (1999) suggests that this may represent independent domestication of *D. bulbifera* in Asia and the Pacific.

With the pollen of *Dioscorea* spp. species present in OIRO (see Table 8.3) being small and relatively indistinct, charred tuberous remains from archaeological sites have thus far been the most secure way of identifying subfossil *Dioscorea*. Hather (1994) identified charred tuberous
remains of *Dioscorea bulbifera* from material obtained during an archaeological excavation on Upolu Island, Samoa (no date published) summarized in Green and Davidson (1969; 1974). Burney *et al* (2001) have also identified charred tuberous remains of *cf. Dioscorea bulbifera* from the Māhā'ulepu caves excavation on Kaua'i, Hawaiian Islands dating to younger than 530-320 cal. yr B.P. (Lab no. Beta-115789).

Barton (2005) has identified Pleistocene-aged *Dioscorea* sp. Starch grains (*cf. D. alata*) from the Niah Cave Excavations, Sarawak, Malaysia, but was unable to determine whether these grains are from wild or domesticated specimens. Piperno *et al* (2000) found grains of *Dioscorea* spp. on milling stones from pre-ceramic horizons in Panama. Starch grains of *Disoscorea* spp. to date have not been reported in any sites from OIRO. *D. alata* has large, distinctively shaped and relatively easily identified starch grains (ovate, up to 55 µm). Its possible relative unimportance in agriculture systems in this region, suggested by its apparent rarity at first European contact, may in part account for this.

Of the four main cultivated species of yam recorded on the Austral Islands since first contact, the antiquity of *D. alata, D. bulbifera, D. pentaphylla* and *D. saliva* are all uncertain. No archaeobotanical or palaeobotanical evidence for any of these *Dioscorea* species is available for the Austral Islands. In 1820 Bellingshausen (Barratt, 1988: 199-221) described a ‘root like a radish’ from Rapa which may be a description for *Dioscorea*. In 1826 Stutchbury and Paulding found what they thought were yams on Rurutu and Rimatara, respectively (see relevant tables in Chapter 5). With the exception of Bellingshausen’s description, these accounts are not early enough to determine whether or not yams were grown prior to European contact in the Austral Islands. The lack of earlier accounts may be due to its limited use in cultivation as suggested by Stokes (m.s.a) for Rapa and Aitken (1930) for Tubuai.

Like the previous three cultivated taxa discussed, *Dioscorea* spp. have been dispersed by humans beyond the indigenous range and the range of the original progenitor populations into human disturbed island environments in (theoretical plant category 15; Table 8.1). But like *I. batatas* the antiquity of these species on the Austral Islands is more difficult to define due to the lack of archaeobotanical and historical evidence for their presence.

**Other probable intentional herbaceous introductions**

Little information is available for many of the remaining herb taxa listed in Table 8.3. *Manihot esculenta* Crantz, in the Euphorbiaceae, appears to have been a recent introduction to all of the Austral Islands where it is now one of the main staple foods. Of the legumes listed in Table 8.3, both *Abrus precatorius* L. and *Tephrosia pupurea* (L.) Pers. appear to be recent introductions to the Austral Islands, although the later is thought to be pre-contact introduced species to most of
OIRO including the Hawaiian Islands (Whistler, 1991). Both species pollen types are distinctive, but have not been found in any pollen records from Rapa or Rimatara.

Three cane grass species (Erianthus maximus Brongn., Saccharum officinarum L. and Schizostachyum glaucifolium (Rupr.) Munro) are listed by Whistler (ibid) as possible pre-contact introductions to most of OIRO. The status of *E. maximum* and *Schizostachyum* is unclear for the Austral Islands as they have only been recorded since 1934 and have been rarely noted in the most recent botanical surveys. Sugarcane (*Saccharum officinarum*) was noted by Stutchbury (Branagan, 1996) on Rurutu in 1826 and by Cumings (St. John, 1940) on Rapa in 1832, but these records are not early enough to determine its pre-contact introduction. *S. officinarum* is still cultivated on most of the Austral Islands, with some formerly large stands on either poorly maintained or in an abandoned state. Sugarcane phytoliths have been identified on some archaeological sites in the Pacific, but none have been located in the few samples examined for phytoliths from sites on Rapa.

An-owroot (*Tacca leontopetaloides* (L.) Kuntze) was identified by both Stutchbury (Branagan, 1996) and Paulding (1970) on Tubuai in 1826. These late first contact records are not early enough to determine whether or not it was grown prior to European contact. Lucy Cranwell (1964) identified Taccaceae type pollen from the Arahu lignite deposit on Rapa but this is unlikely to represent this species. The plant is now rarely grown on the Austral Islands.

Two ginger species, the tumeric *Curcuma longa* L. and *Zingiber zerumbet* (L.) Smith are listed in **Table 8.3**. *C. longa* was recorded as ‘tumeric’ by Morrison (1935) on his three month stay on Tubuai in 1789. *C. longa* was recorded on most of the Austral Islands during St. John and Fosberg’s 1934 botanical survey, but has not been recorded in any recent survey. The ginger *Z. zerumbet* was only recorded in the Austral Islands by 1934 and has become naturalised on most of the islands.

**Inadvertent herbaceous introductions (weeds)**

The problem of characterising the phytogeography of weeds in the Pacific was illustrated by H.B. Guppy (1906: 416) in his analysis of long distance dispersal mechanisms of Pacific plants:

‘Weeds follow the cultivators in all climates... [and the cultivator’s] share in weed dispersal is often as not merely restricted to producing the conditions favourable to the growth of weeds, and that the seeds are often brought by birds and other agencies.’

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1 See Daniels and Roach (1987); Daniels and Daniels (1993); Lu et al (1993) and Lebot (1999) for a description of *S. officinarum* origins, taxonomy and domestication
<table>
<thead>
<tr>
<th>Botanical species</th>
<th>Anthropogenic palaeobotanical records</th>
<th>Botanical survey data</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Ackyahaeus aspera</em> var. <em>aspera</em> L. (Amaranthaceae)⁵</td>
<td>?</td>
<td>All populated islands</td>
</tr>
<tr>
<td><em>Amaranthus viridis</em> L. (Amaranthaceae)⁴</td>
<td>?</td>
<td>Rapa, Ra’ivavae, Tubuai (historical introduction), Rurutu, Rimatara</td>
</tr>
<tr>
<td><em>Cyathula prostrata</em> (L.) Blume (Amaranthaceae)⁵</td>
<td>?</td>
<td>Ra’ivavae, Rurutu, Tubuai, Rimatara</td>
</tr>
<tr>
<td><em>Bidens pilosa</em> L. (Asteraceae)</td>
<td>-</td>
<td>Rapa, Ra’ivavae, Tubuai, Rimatara</td>
</tr>
<tr>
<td><em>Sida hericoccoides</em> L. (Asteraceae)</td>
<td>-</td>
<td>All populated islands</td>
</tr>
<tr>
<td><em>Sonchus oleraceus</em> L. (Asteraceae)</td>
<td>Rapa (pollen), Rimatara (pollen)</td>
<td>Marotiri and all populated islands</td>
</tr>
<tr>
<td><em>Canna indica</em> L. (Cannaceae)</td>
<td>Rimatana (pollen)?</td>
<td>Rapa, Ra’ivavae, Tubuai, Rimatara</td>
</tr>
<tr>
<td><em>Commelina diffusa</em> Burm. f. (Commelinaceae)</td>
<td>Rapa (pollen), Rimatara (pollen)</td>
<td>Late human impact Zones</td>
</tr>
<tr>
<td><em>Waltheria indica</em> L. (Malvaceae)⁴</td>
<td>-</td>
<td>Tubuai</td>
</tr>
<tr>
<td><em>Urena lobata</em> L. subsp. <em>lobata</em> (Malvaceae)⁴</td>
<td>Ra’ivavae, Tubuai, Rurutu, Rimatara</td>
<td>Rapa, Rimatara</td>
</tr>
<tr>
<td><em>Ludwigia octovalvis</em> (Jacq.) Raven (Onagraceae)⁴</td>
<td>Rapa (pollen), Rimatara (pollen)</td>
<td>Late human impact Zones</td>
</tr>
<tr>
<td><em>Oxalis corniculata</em> L. (Oxalidaceae)⁴</td>
<td>-</td>
<td>Rapa, Ra’ivavae, Tubuai, Rimatara</td>
</tr>
<tr>
<td><em>Persicaria glabra</em> (Will.) Gomez (Polygonaceae)⁴</td>
<td>?</td>
<td>Ra’ivavae, Tubuai</td>
</tr>
<tr>
<td><em>Eleusine indica</em> (Poaceae)</td>
<td>-</td>
<td>Rapa, Ra’ivavae, Tubuai, Rimatara</td>
</tr>
<tr>
<td><em>Digitaria setigera</em>, <em>Oplopus compositus</em>, <em>O. hirtellus</em>, <em>Paspalum conjugatum</em>, <em>P. orbiculare</em> (Poaceae)</td>
<td>-</td>
<td>All populated islands</td>
</tr>
<tr>
<td><em>Rumex crispus</em> L. (Polygonaceae)⁴</td>
<td>-</td>
<td>Rapa, Rimatara</td>
</tr>
<tr>
<td><em>Cardiospermum halicacabum</em> L. (Sapindaceae)</td>
<td>-</td>
<td>Rapa, Rimatara</td>
</tr>
<tr>
<td><em>Rorippa sarmotosa</em> (G.Forst. ex DC.) J.F. Macbr. (Solaneae)</td>
<td>-</td>
<td>Ra’ivavae, Tubuai, Rurutu, Rimatara</td>
</tr>
<tr>
<td><em>Solanum americanum</em> P. Mill (Solanaceae)⁴</td>
<td>-</td>
<td>Marotiri, Rapa, Ra’ivavae, Tubuai, Rimatara</td>
</tr>
<tr>
<td><em>Cyclosorus interruptus</em> (Willd.) H. H. (Thelypteridaceae)⁴</td>
<td>Rimatara (pollen)</td>
<td>-</td>
</tr>
</tbody>
</table>

¹Brown (1931a); ²Brown (1935); ³Florence (2004); ⁴Listed in St. John (from Daniel Nelson’s records of possible inadvertent pre-contact introductions to the Hawaiian Islands made in 1779); ⁵Listed in Whistler (1988) as a possible inadvertent pre-contact introductions to Western Samoa. ⁶Brown (1931b). ⁷Not all information available.

Table 8.4 Botanical sources of probable inadvertent plant introductions (weeds arranged by family) to the Austral Islands recognized in the above references and by Whistler (1991). None of these species have been located in any pre-human palaeobotanical or first contact record.
Guppy lists *Waltheria americana* (syn. *W. indica*), *Oxalis corniculata* (Oxalidaceae), *Urena lobata* (Malvaceae), *Sida spp.* (Malvaceae) and *Bidens pilosa* (Asteraceae) amongst a list of 37 possible 'aboriginal weeds' that may have reached the islands through a range of dispersal mechanisms including purposeful transport by people (*ibid*: 604-605). He defines aboriginal weeds on the basis of vagility as well as historically documented locations cited by James Cook's botanists during the 1769-1779 voyages to the Pacific. The involvement of humans in weed dispersal, as Guppy admits, is complicated not only by the range of other possible dispersal mechanisms, but also by their uncertain geographical origins given their capacity to naturalise in many different habitats. Contrary to Guppy, Ridley (1930: 634), to some extent down plays the role of alternative dispersal mechanisms, suggesting that some of these plants (e.g. *Oxalis corniculata*) were more likely to be inadvertent introductions brought directly by people. The status of weeds as aboriginal introductions to islands in Remote Oceania have been addressed specifically by Whistler (1988) and Leach (2005), or have been referred to in the most recent compendiums of island floras (e.g. Webb et al 1998; Wagner et al 1990; Florence, 1997; 2004).

Listed in Table 8.4 are a number of weed species that may have been inadvertently introduced to the Austral Islands by people prior to first contact. Determinations of pre-contact presence are based primarily on records of the botanists on Cook’s voyages to other islands in OIRO (e.g. Solander in Leach, 2005; Forster, 1786; Nelson in St. John, 1978; Drake de Castillo, 1893; Merrill 1954a, 1954b), but also on relevant palynological records from these same islands. For the Austral Islands, determinations of pre-contact presence of a number of weed species has been inferred by Florence (1997; 2004) in the latest compendium of the *Flore de la Polynésie française* following Drake de Castillo (1893) and Brown (1935). First contact accounts of the Austral Islands are concentrated on economic species (e.g. *Colocasia esculenta* etc.) where no records of weed species apart from cultivated vegetables were recorded between 1769 and 1834.

The palaeobotanical record for the Amaranthaceae, Malvaceae, Poaceae, Polygonaceae and Solanaceae in which several inadvertent weed species (see Table 8.4) are represented, is complicated by the presence of indigenous representatives of these families on the islands. The pollen morphology of these families are often indistinguishable to genus or species and thus the presence of pollen cannot be used to determine the presence of these weed species.

*Taxa recorded in anthropogenic palaeobotanical and botanical survey records:*


*Ludwigia octovalvis* appears to have originated as a pan-tropical species like most of its close relatives, but its current distribution extends also into sub-tropical and temperate area where it is
commonly found invading wetland environments. Daniel Nelson recorded *L. octovalvis* from the Hawaiian Islands in 1779 (St. John, 1978). *L. octovalvis* is noted as a persistent weed in irrigated *Colocasia esculenta* pondfields throughout the Pacific where in abandoned fields it can form dense monotypic stands. Kirch (1994) noted that *L. octovalvis* is common weed on field systems in the Western Pacific island of Futuna. L.A.M. Riley (1926) first collected this plant from Rapa in 1924, the earliest known record for the Austral Islands. Fosberg and St. John (1934) later recorded *L. octovalvis* from all of the Austral Islands with the exception of Rurutu.

Guppy (1906: 533) has indicated that the seeds of *Ludwigia (Jussiaea)* demonstrate a degree of buoyancy (‘a few days’) and may be capable of long distance dispersal, although this has not been successfully demonstrated. It seems more likely that this plant was transported as an inadvertent introduction embedded in soil attached to plants traded between or introduced to islands.

*L. octovalvis* pollen has been recorded in the upper human impact horizons of palynological records from the Hawaiian Islands (e.g. Athens and Ward, 1991; 1997) but also Yap in Micronesia (Dodson and Intoh, 1999) and in post-European contact period sediments on Moorea in French Polynesia (Parkes and Flenley, 1997; Parkes, 1997). Athens (1997: 269) maintains that *Ludwigia* pollen can be constrained to Polynesian phase levels to as early as around A.D. 1250. Athens and Ward (1997) located *Ludwigia* pollen from two samples associated with *Colocasia esculenta, Aleurites moluccana* and *Cordyline fruticosa* pollen from a sedimentary core from the Maunawili Valley (Maunawili Core 1, O‘ahu, Hawaiian Islands) of an age younger than 655 cal. yr B.P.

The Hawaiian records contrast with the Austral Island pollen record in which *L. octovalvis* appears late in the human impact horizons from both Tukou and Maunutu. *Ludwigia* pollen, as on the Hawaiian Islands, is likely to represent a population of weeds growing on or adjacent to active of fallow *Colocasia* pondfield cultivations, but the lack of pollen from these weeds in the early agricultural horizons defined by the presence of *Colocasia* pollen, attests to its late introduction.

The lateness of the *Ludwigia* record in the Austral Islands and Mo‘orea may be explained by two historical factors. The increased trade of produce between more distant archipelagos during the early European contact period (e.g. as recorded for *Alocasia* from the Cook Islands; see above), might explain the late arrival *L. octovalvis* and other agricultural weeds. Alternatively, if *L. octovalvis* was present on the island during the early Polynesian colonisation period, it is possible that agriculturalists prevented the weed from establishing. During the European colonisation period, the wide scale abandonment of agricultural systems that followed population decline (see Chapter 5) may have allowed already present *L. octovalvis* to encroach into fallow or abandoned fields.

Despite the historical and palaeobotanical indications, it is still plausible that *L. octovalvis*, may be indigenous to the Austral Islands and thus, I would place this inadvertent introduction
species in categories 1-4 of Table 8.1. I suggest that this range of theoretical plant categories would apply to most, if not all, of the inadvertent introductions listed in Table 8.4.

**Commelina diffusa** Burn. f. (Commelinaceae): syn. *C. nudiflora, C. pacifica* (Brown, 1935)

*C. diffusa* is regarded as a pan-tropical species, but its precise origin is unclear. On Cook’s second voyage to the Pacific in 1773, Georg Forster collected *C. pacifica* (syn. *C. diffusa*) from Tonga (Forster, 1786: 358) and New Caledonia. The plant was also known from the Hawaiian Islands at the time of Cook’s arrival (Hillebrand, 1888).

Like *L. octovalvis*, *C. diffusa* is noted as a persistent weed in irrigated *Colocasia esculenta* pondfields throughout the Pacific where in abandoned fields it can form dense monotypic stands. According to Meyer (2004) and Florence (1997) this plant is regarded as an invasive weed, where on Mangareva (Gambier Islands, French Polynesia) it threatens a small population of the rare endemic plant *Pilea sancti-johannis* (Urticaceae) along with a number of other indigenous species. Located on most of the Austral Islands in the earliest botanical surveys, it appears to be equally invasive, especially in lowland swamp and marsh environments and abandoned *Colocasia* agricultural fields.

*C. diffusa* pollen has also been recorded in the upper human impact horizons of palynological records from the Hawaiian Islands (e.g. Beggerley, 1990; Athens and Ward, 1997 see Table 7.2 in Chapter 7) and in probable post-European contact sediments on Mo’orea (Parkes and Flenley, 1990; Parkes, 1997), but less so from other sites in the Pacific. Like *L. octovalvis*, *C. diffusa* appears to be a pre-European contact introduction to the Hawaiian Islands. Again the Hawaiian records contrast with the Austral Island pollen record in which *C. diffusa* appears late in the human impact horizons from both Tukou and Maunutu and this can be explained by the same factors as discussed for *L. octovalvis*.

**Sonchus oleraceus** L. (Asteraceae) (Brown, 1935)

Leach (2005: 278) suggests that edible foliage of *Sonchus* (specifically referring to *S. aspera*) may have made it an intentional introduction into the Pacific, distributed as far south as New Zealand. She also suggests that its ecological preference for disturbed soils ‘would also have given its seeds a good chance of accidental inclusion with dirt-encrusted root crops’. Daniel Solander, on James Cook’s first voyage to New Zealand in 1769, identified *Sonchus oleraceus* (possibly *S. aspera*) from a range of cultivation sites (Solander in Leach, 2005). On Cook’s second voyage in 1773-4, Georg Forster collected *S. oleraceus* from Tonga (Forster, 1786) and
from Norfolk Island (Hoare, 1988; Hicks, 1988) although some of these determinations are debatable (Leach, 2005).

T.F. Cheeseman (1903), in compiling his early flora of Rarotonga, suggested the plant is indigenous to the Pacific region. Such an interpretation may have come in recognition of its very widespread representation across most islands in the Pacific. Fosberg and St. John (1934) recorded *S. oleraceus* from all of the populated Austral Islands in 1934.

Palynological records of *S. oleraceus* have not been forthcoming from the OIRO region. Trace counts of *S. oleraceus* pollen was identified in six records from both Rapa (4) and Rimatara (2). The majority of these records suggest that this plant was introduced post-European contact as it is most frequently associated in strata associated *Commelina diffusa* and *Ludwigia octovalvis* in the upper most human impact sequences.

*Canna indica* L. (Cannaceae) (Brown, 1935)

The origin of this pan-tropical plant is uncertain as it is naturalized throughout its range. Also uncertain is the timing of its introduction or naturalisation in OIRO. The earliest botanical record of the presence of *C. indica* in the Austral Island comes from Fosberg and St. John’s 1934 survey of Rapa and Ra’ivavae. The pollen record suggests that the arrival of *C. indica* into OIRO was late and perhaps arriving after European contact. Pollen indicative of *C. indica* was located from one sample located in the upper sediment horizons of Core 3 Transect 1 (see Figure 7.16b) from Maunutu Moat-Swamp on Rimatara. Situated immediately below the stratum defined as post-European in age by the presence of *Commelina diffusa* and *Ludwigia octovalvis*, it is plausible that *C. indica* was a plant introduced early in the European contact period. Ellison (1994) identified *C. indica* pollen from two modern surface samples from the edge of a *Colocasia* agricultural swamp on Mangaia and from an upland forest site from Rarotonga. From the examination of a series of sedimentary sequences from Mangaia, the lack of pollen at depth suggests that *C. indica* is likely to be a recent introduction.

*Taxa not recorded in the earliest botanical survey records:*

*Cyclosorus interruptus* (Willd.) H. Ito (Thelypteridaceae) (Brown, 1931b)

Along with *Ludwigia octovalvis*, Nelson also collected *Cyclosorus interruptus* from the Hawaiian Islands in 1779 (St. John, 1978). Leach (2005) suggests that despite not recorded by Daniel Solander in New Zealand, its presence in far northern New Zealand suggests an inadvertent relationship with *Colocasia* introduction and production given this was the most prime area for introduction of a tropical cultigen (Matthews, 1985). Leach, (ibid, after Sykes) suggests that for
most of the Cook Islands, this fern is dominant only in areas around *Colocasia* fields. For this reason Leach suggests that *Cyclosorus interruptus* may be one of many good candidates for Polynesian introduction. On Rimatara, however, *Cyclosorus interruptus* is common not only around *Colocasia* fields, but is also dominant in sections of moat-swamps that were unlikely to have ever been cultivated.

*Cyclosorus interruptus* was not identified in any of the palynological records obtained from Rapa, but on Rimatara two records from Maunutu Moat-Swamp suggest that this shield fern may have been introduced to the island prior to European contact. In both cores *Cyclosorus interruptus* was present in the earliest anthropogenic sediments, in some cases in high proportions (Core 3 Transect 1; see Figure 7.16a, Chapter 7).

**Taxa only recorded in the most recent botanical survey records:**

*Cardiospermum halicacabum* L. (Sapindaceae) (Brown, 1935)

Solander (in Leach, 2005) observed *Cardiospermum halicacabum* in the Society Islands in 1769. From a survey of botanical records from the Hawaiian Islands Wagner *et al* (1990) determined that *C. halicacabum* must have been introduced to the islands before 1819. Whistler (1988) suggests that *C. halicacabum* was introduced to Tonga by Polynesians. On the Austral Islands, however, this taxon was not recorded in any botanical survey until 2004 from Rimatara (see Table 8.4)

**Plant extinctions on the Austral Islands**

As discussed in Chapter 2, extinctions, as defined when a species is absent or reduced to non-reproductives (Simberloff, 1976), are most apparent on islands given that large areas hold more species than small areas and larger populations persist longer than small populations (Bond, 1994). In this sense, islands are predisposed to higher rates of extinction. The most common hypothesis for species extinction in OIRO has been developed from the abundant faunal record, which suggests that extinction came as a result of habitat loss following human colonization. As plants form a large proportion of island biotas it is surprising that compared to prehistoric faunal extinction records (e.g. terrestrial birds and snails; Steadman *et al* 1995; Solem, 1990), evidence for the plant extinction is rare. Despite this bias, Holocene pollen and macrobotanical records of more than fifteen plant species extinctions from Easter Island (e.g. Flenley *et al* 1991; see Chapter 4) and a several taxa from the Austral Islands have been identified.
Botanical survey records of plant extinction from OIRO

Historical botanical surveys of island floras have provided the greatest number of extinction records by virtue of the increasing resolution of field data. From recent IUCN Red Lists, the majority of the plant extinction records to 1998 are from OIRO, especially the Hawaiian Islands and French Polynesia where large historical datasets are available. Some of the plant extinctions include *Santalum fernandezianum* from the Juan Fernandez Islands; *Fitchia mangarevensis, Hernandia drakeana* and *Neisosperma brownii* from French Polynesia; *Kokia lanceolata, Melicope obovata, Melicope paniculata, Pelea obovata, Wikstroemia skottsbergiana* and *W. villosa* from the Hawaiian Islands and *Weinmannia spiraeoides* from Fiji.

For most of these records, human-induced habitat modification is assumed to be the primary cause of extinction. The historically documented ecological disruption caused by invasive alien species and the direct human modification of indigenous forest habitats leaves few other plausible mechanisms that could explain extinction events.

Plant extinctions recorded from botanical survey data from the Austral Islands

*Myoporum rimatarense* (Myoporaceae) (Fosberg and St. John, 1934)

*M. rimatarense*, presumably endemic to Rimatara was recorded on the island by Fosberg and St. John in 1934, but was not recovered during a survey conducted in 2004 (Meyer et al 2004). *Myoporum* pollen is also represented within both pre-human and anthropogenic sediments from the Maunutu palynological record.

*Metatrophis margaretae* F.B.H. Brown (Urticaceae) (Florence, 1997: 229-232)

By Simberloff's (1976) definition of extinction the shrub *Metatrophis margaretae*, the only representative of this endemic genus of Rapa, was apparently common enough to use as a source of firewood (Florence, *ibid*) but is now only known from one male individual (Meyer 2002a; 2002b).

*Charpentaria australis* S.H. Sohmer (Amaranthaceae) (Florence, 2004: 66-68)

*Charpentaria australis*, currently only found on Rurutu and Tubuai (Florence, 2004: 66-68), was recorded on Ra'ivave in 1934 by Fosberg and St. John and thus is now extinct on the island.
Arecaceae: Iguanurinae type

As discussed in Chapters 3 and 4, the extinct *Paschalococcus* palm determined from palynological and macrobotanical records from Easter Island (Selling, 1948; Dransfield et al. 1984; Flenley et al. 1991) perhaps represents the most renowned plant extinction, established from the palaeobotanical record. A number of authors have suggested that few if any modern parallels could be drawn for such a remote island environment. Lord Howe Island (Australia), however, may provide the closest environmental analogue for pre-human settlement of Easter Island as it is situated at an equivalent latitude, it has low rainfall and has within its flora four palm species (*Howea forsteriana*, *H. helmoreana*, *Hedyscepe canterbryanana* and *Lepidocarthus mooreana*) that cover most of the island terrain. The Juan Fernandez Islands (Chile) off the South American coast are another subtropical Pacific Island where a palm (*Juania australis*) has survived the impact of human colonisation.

If Lord Howe and the Juan Fernandez Islands provide an analogue for pre-human settlement Easter Island, then the Austral Islands, to some extent may provide a palaeoenvironmental context for comparison. It is clear from the palynological records of Rapa and Rimatara, that a palm or a number of palm species within the Iguanurinae tribe of the Arecaceae were decimated during the period of human colonisation of these islands.

A number of palynological records from other islands in OIRO indicate declines in Arecaceae pollen types that have been undifferentiated to species including from Mangaia (possibly including *Pritchardia* spp.; Ellison, 1994) and the Hawaiian Islands (*Pritchardia* spp. and possibly other palm species; e.g. Athens, 1997). It is unclear whether these records represent extinction events, but the declines appear to coincide with other evidence for human impacts on the islands.

*Meryta* spp. (Araliaceae) *M. chloristantha*, *M. brachypoda* (Brown, 1935)

Pollen of *Meryta* was only identified at Maunutu (Core 3, Transect 1) on Rimatara from underlying the anthropogenic sequence. As *Meryta* was not documented in any of the botanical surveys conducted in either 1934 or 2004, and is thus extinct on the island. This dioecious genus is comprised of around 30 species that are distributed across the Pacific, with each of its species is endemic to only one or a few islands (Tronchet et al. 2005). Two extant species are found on the Austral Islands, both *M. chloristantha* and *M. brachypoda* on Rapa (Meyer 2002a; 2002b) with
M. brachypoda on Ra’ivavae and Tubuai (Fosberg and St. John, 1934; Meyer 2002b; Meyer et al 2003). Tronchet et al (2005; also Tim Motley, unpublished data) used two nuclear-encoder spacer regions from the ribosomal RNA to resolve the genetic relationships between the Pacific populations of the Araliaceae genus Meryta. The spacer region data showed that the Austral Island populations are monophyletic, derived from a range of New Caledonian lineages (see Chapter 6 for further discussion).

From such data it seems plausible that Meryta pollen from Rimatara represents either M. brachypoda or an endemic species. It is also likely that Meryta was also formerly represented on Rurutu.

Coprosma spp. (Rubiaceae) C. rapensis, C. cookei, C. velutina, (Brown, 1935)

Like Meryta, pollen of Coprosma was only identified at Maunutu (Core 3, Transect 1) on Rimatara from underlying the anthropogenic sequence and was not documented in any of the botanical surveys conducted in either 1934 or 2004, and is thus to be extinct on the island. Coprosma is a diverse genus consisting of numerous species across most archipelagos in the Pacific. It is notable in that it has a wide Pacific distribution as far as the Juan Fernandez Islands but has never been recorded on mainland South America (Balgooy et al 1996). Three extant taxa have been recorded from the Austral Islands, C. rapensis, C. cookei, both endemic to Rapa and C. velutina found on Ra’ivavae and Rurutu. Like Meryta it is unclear as to whether the Coprosma extinction recorded at Maunutu represents a local extinction of a widespread species and/or the extinction of an endemic species.

Other extinct taxa recorded from the palynological record

Of the extinctions identified from the palynological record from the Austral Islands, the Maunutu record revealed the most extinctions. Only Arecaceae: Iguanurinae was identified as an extinct taxon from Rapa. Representatives of the Amaranthaceae, Apocynaceae, Oleaceae (Jasminum), Solanaceae and Ulmaceae (cf. Trema) were identified from the Maunutu pollen record on Rimatara, but are no longer present on the island.

Possible plant extinctions from the Austral Islands

Aside from the extinctions determined from historical and palynological records, a number of extinctions on the Austral Islands can be inferred on the basis of historical declines documented for other island groups, or by discrepancies in biogeographic patterns of certain taxa. Extinctions
have also been operating prior to human colonization as a function of other ecological and evolutionary processes. A number of plausible ecological mechanisms for species extinctions on islands include competing species interactions, climatic change and increased island insularity with geological movements and fluctuating sea levels. The relationship between these processes and extinction cannot be identified with any certainty from the botanical record from the Austral Islands. Again these inferred extinctions probably relate primarily to habitat modification by humans.

*Santalum* spp. (*Santalaceae, section Polynesica*) (Brown, 1935)

On Rapa, one specimen of *Santalum insularum* var. *margaretae* was identified by Fosberg and St. John in 1934 on the locality of Mt Taga. In 2002 the only remaining population on the island was found on Karapo Rahi Islet on the southern coast of the island (Meyer 2002a; 2002b). Small populations of *S. insularum* var. *raivavense* are located on Ra’ivavae, but not on any of the other populated Austral Islands. In French Polynesia, *S. insularum* is located across three archipelagos including the Austral, Society and Marquesas Islands, but is absent from the Tuamotu and Gambier Islands (Butaud et al 2005). The historical exploitation of sandalwood from the region, coupled with the impact of invasive and alien species (e.g. rats and goats) has meant that existing populations represent only relicts of their former distribution (Butaud et al ibid). It is likely that varieties of *S. insularum* are now extinct on many islands in French Polynesia.

*Elaeocarpus floridanus* Hemsley (*Elaeocarpaceae*) (Florence, 2004: 125-127)

This species is distributed across Ra’ivavae, Tubuai and Rurutu but is currently under threat from deforestation. It is usually found within patches of *Hibiscus tiliaceus* and *Aleurites moluccana* or *A. moluccana* and *Metrosideros* forest (Florence, 2004). It is present at a minimum elevation of between 15 and 330 m within mesic forest that may be degraded on parent substrates ranging from volcanic (Ra’ivavae) to calcareous soils (Rurutu). Extinctions of *Elaeocarpus* species have been demonstrated on Easter Island from the identification of cf. *E. rarotongensis* wood charcoal from archaeological sites on Akahanga and Orongo (Orliac, 2000, see Chapter 4, Table 4.5).

Gnawed endocarps of *Elaeocarpus* spp. have been located from Pacific rat (*Rattus exulans*) seed caches in Tonga (e.g. McKonkey and Drake, 2002; McKonkey et al 2003) and buried plant macro remain deposits in New Zealand (Wilmshurst et al 2004), suggesting these fruits are favoured as a food source for rodents. It is possible that populations of *Elaeocarpus* may have been decimated by such rodent predation on the Austral Islands soon after their introduction by people. The local vernacular names for *Elaeocarpus* from Rurutu (tutai iore, tutaiioire) that refer
to rat excrement (Florence, 2004: 127) may reflect local observations of rat-seed predation on the Austral Islands.

The small size of *Elaeocarpus* pollen and the tendency for these trees to be low pollen producers limits the potential for pollen identification from sedimentary records. As yet no pollen has been identified from the palaeobotanical record of Rapa or Rimatara, the only two Austral Islands where *Elaeocarpus* is absent from the modern flora. It is possible that these absences represent localised extinctions, but without further fossil data this will be difficult to substantiate.

**Trends in plant extinction**

At low taxonomic levels, recent faunal extinctions are concentrated in certain genera and families. Historic and fossil plant extinction records appear to show a similar trend. A bias appears to exist towards extinction of entire families (e.g. Arecaceae, Amaranthaceae, Oleaceae etc.) or select representatives of lowland forest genera (*Coprosma* and *Meryta* etc.). The relationship between fossil plant taxa described from Easter Island (see Chapter 4) and the Austral Islands and extant relatives from other islands suggests that most extinct taxa were large in size (trees), long-lived and low in fecundity. Preferential exploitation of certain taxa, for example of *Santalum* spp. for sandalwood and *Metaphomis* for firewood, is likely to have affected species decline and extinction on the Austral Islands and elsewhere in OIRO.

**Implications for future research**

In this thesis I have attempted to address a number of theoretical and methodological issues surrounding the human-led introduction and extinction of plants in the Austral Islands. There are clearly geographical and chronological biases that for many plant taxa render the relationship between human colonisation and the phytogeographic distribution and/or extinction of plants untenable particularly in relation to the downstream effects of human-generated disturbances. There are two problems in assessing the botanical status of plants that have a distribution or historical presence that may have been influenced by people. Firstly, assessing the status of introduced taxa that may have become naturalized on islands once released is complex, and may be represented in the different lines of botanical evidence in different ways. Secondly, the status of some indigenous taxa that may have declined or faced extinction on their own accord, particularly in response to other environmental factors independently of human activity is equally difficult to assess.

The difficulty in defining plant introductions or extinctions is matched by the complex task of defining disturbances, whether generated by humans or not. Much of what we describe as an
introduction, extinction or disturbance event are hypothetical and dependent on the generation of contextual botanical information that may rest on a limited theoretical foundation and limited material evidence. Plants thought to be robust indicators of human introduction to islands, for example, must at least have plant parts that preserve in the fossil record and are limited to human dispersal. However, the importance of such an introduction to the overall picture of environmental change may be negligible if no other environmental consequences are evident.

The primary methodological constraint on making more robust assessments of introduced or extinct plant taxa and of disturbance events or processes is the limited integration of botanical evidence in its multiple forms. Each form of evidence presents information with different chronological and taxonomic resolution and bias, but also presents different contextual information for environmental change. Braudel highlighted such biases that also apply more generally to historical phenomena *per se*, particularly in respect to the duration of historical events and processes. In establishing the duration of each line of evidence he suggests that by exploring the conjuncture between their chronological and geographical representations a more robust history is revealed, one that is less open to interpretive bias.

We do not yet have a robust model of environmental transformation in the Pacific Islands for the period following human colonization. Much of what we know of environmental change on islands has been biased by the dramatic avifaunal extinction record. But models of environmental change based on avifaunal evidence do not allow for the incorporation of material evidence that demonstrate downstream environmental consequences of such extinctions. As plants are the primary substrate for most other biological forms on islands, or indeed anywhere, historical sciences should concentrate on generating more robust theoretical models of environmental change using botanical evidence, but also for the development of methodologies that integrate the different forms of historical information.

In this thesis I have focused on the integration of palaeobotanical information with other forms of botanical data. Palaeobotanical analyses of Austral Island material contribute greatly to the definition of introduced or extinct plant taxa, particularly given the dearth of archaeobotanical and historical information. Part of this contribution is its efficacy in defining the environmental context for plant introductions and/or extinctions (i.e. disturbance processes), but also by generating contrasting forms of chronological information to that generated in other forms of stratified material remains, namely from archaeological sequences.

Palaeobotanical evidence from the Austral Islands suggests that the illustrated cases of Easter Island and Tikopia are not unique and that the chronological interpretation and taxonomic bias of plant extinction or introduction events on these islands are greatly distorted. For the OIRO region, there appears to be a number plant introductions and extinctions common to many of the islands. This is in part a result of the traits of Pacific Island cultures and how they influence island environments and the select suite of plants that they introduce, but is also a result of the traits of
certain representatives of island floras. Some taxa are predisposed to cultivation or a weed habit and some are predisposed toward extinction. Aside from these cultural or environmental concerns, the key problem that should be addressed is how well these plant taxa represent environmental changes caused by human activity or by other disturbance processes.

The main implications of this thesis are inherent to any; more spatially and temporally resolute records should be obtained, but greater attention should perhaps be given to the following theoretical and methodological concerns:

Theoretical directions:

- Develop sophisticated phytogeographic models of plant distribution in OIRO pinpointing the potential extent of key taxa. This is essential for identifying the potential introduction or extinction of many taxa.
- Develop stratigraphic and chronological models of fossil deposition across island groups and within a range of depositional settings. Depositional settings that preserve human impact sequences that are both temporally and taxonomically resolute have been poorly defined.
- Theoretical models of downstream response of fossil taxa to disturbance events should be developed. These models could be tested to some degree by sampling across a range of sites. Such models could also be generated for marker taxa of human activity.

Methodological directions:

- Greater attention should be placed on the taxonomic resolution of the palaeobotanical and archaeological record, focusing on key taxa with a phytogeographic distribution that can be adequately modelled as suggested above.
- Spatial sampling approaches to anthropogenic palaeoenvironmental sequences, like that employed in this thesis, should be employed at a greater number of sites and on more islands in OIRO with potentially resolute records.
- Methods for integrating multiple lines of botanical evidence should be developed whereby sampling focusing on resolving the three primary issues; human-caused introduction, extinction and disturbance.
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Plate 1 Tikopia after Cyclone Zoe, January 2003

Photo 1.

Jan. 03 (Australian Defence Department Media Centre)

Photo 2.

Grassland slopes of Rano Kao Jan. 03 (G. MacKay)

Photo 3.

Jan. 03 (Australian Defence Department Media Centre)

Photo 4.

Jan. 03 (Australian Defence Department Media Centre)

Photo 5.

Jan. 03 (G. MacKay)

Photo 6.

Canarium harveyi endocarp (PNG), ANU reference collection (D. O'Dea)
Plate 2. Easter Island vegetation

Photo 1.

View from south-side (inner-slope) of Rano Raraku crater with sculpted moai in the foreground. The swamp vegetation is dominated by *Schoenoplectus californicus* var. *tatora* Sept. 04 (M. Prebble)

Photo 2.

Grassland slopes of Rano Kao Sept. 04 (M. Prebble)

Photo 3.

Rano Kao caldera Sept. 04 (M. Prebble)

Photo 4.

Encroaching shrub vegetation on the inner slopes of Rano Kao. Not visible in this photo are a number of bananas (*Musa* sp.) growing along the lake periphery Sept. 04 (M. Prebble)

Photo 5.

View west over the grass slopes of Maunga Vai o Hao showing the inner *Melia azedarach* covered base of the caldera Sept. 04 (M. Prebble)

Photo 6.

*Colocasia esculenta* amongst *Melia azedarach* in a stoney swamp depression at the base of Maunga Vai o Hao caldera Sept. 04 (M. Prebble)

Photo 7.

*Jubaea Chilensis* endocarps near Vina del Mar, Chile; endocarps have been gnawed by rodents (A. Anderson, Sept. 04)
Plate 3. Arahu lignite and main marshlands of Haurei Harbour, Rapa

Photo 1.
Section of Arahu lignite 1980 (G. Paulay)

Photo 2.
Pare Taga on Taga ridgeline Aug. 02 (D. Kennett)

Photo 3.
Maatata Marsh Aug. 02 (D. Kennett)

Photo 4.
Maatata Marsh with cattle in foreground Aug. 02 (D. Kennett)

Photo 5.
View west over Haurei Harbour from Taga ridgeline with Aiko Marsh in the foreground Aug 02 (D. Kennett)

Photo 6.
View west over Tapuki Islet (Haurei Harbour showing Pare Morogo uta on top of ridgeline and Tukou Marsh below Aug 02 (M. Prebble)
Plate 4 Tukou Marsh, Rapa

Photo 1.

View of Tukou at low tide from west-side of Ha’urei Bay July 02 (M. Prebble)

Photo 2.

View of Tukou at low tide from west-side of Ha’urei Bay, showing water logged agricultural terraces July 02 (M. Prebble)

Photo 3.

View of Tukou delta at low tide from west-side of Ha’urei Bay; stands of *Casuarina equisetifolia* behind delta July 02 (M. Prebble)

Photo 4.

View of Tukou from east-side Ha’urei Bay; Tapui islet in the foreground July 02 (M. Prebble)

Photo 5.

View west of Tukou Core Site showing the adjacent eroded agricultural terraces; *Syzygium jambos* growing alongside terraces July 02 July 02 (M. Prebble)

Photo 6.

Waterfall and vegetation in upper catchment above Tukou July 02 (M. Prebble)
Plate 5. Tukou Marsh, Rapa cont.

Photo 1.
View of Tukou delta at low tide showing diversion drainage channels and eroded terrace boundaries near Tukou Core Site July 02 (M. Prebble)

Photo 2.
Eroded agricultural terrace behind Tukou Swamp Core Site; Syzygium jambos growing along erosion surface July 02 (M. Prebble)

Photo 3.
M. Prebble packing base of Tukou Core 1, at Tukou Marsh Aug 02 (D. Kennett)

Photo 4.
Schoenoplectus californicus var. californicus swamp land adjacent to the Tukou Core Site July 02 (M. Prebble)

Photo 5.
Upper catchment of Tukou delta with abundant stands of Schoenoplectus californicus var. californicus (M. Prebble)

Photo 6.
Embankment behind Core 3, Tukou Marsh Aug 02 (M. Prebble)
Plate 6. Rimatara moat swamps

Photo 1.

Coring at Hareti'i/Paparâmoa (B. Fontaine)

Photo 2.

Analysing cores at the Pension Taharia (B. Fontaine)

Photo 3.

Mato notch surface near Maunutu Core 3 Transect 2 (B. Fontaine)

Photo 4.

Mato notch surface near Hareti'i (HAR2) Core 2 (M. Prebble)
Plate 7. Rimatara moat swamps cont.

Photo 1.

*Achrostichum aureum* and *Barringtonia asiatica* at Hareti'i near the *mato* (M. Prebble)

Colocasia *esculenta* bed at Hareti'i with *Sonchus oleraceus* (M. Prebble)

Colocasia *esculenta* bed at Hareti'i with *Ludwigia octovalvis* (M. Prebble)

Photo 4.

Tethered pig at Tūpapa *Colocasia* cultivations (B. Fontaine)

Photo 5.

Coring at Paka Cave (B. Fontaine)
Plate 8. Tangarutu Rockshelter, Rapa

Photo 1.

View west of Tangarutu Rockshelter Anarua Bay Aug 02 (D. Kennett)

Photo 2.

View west of Tangarutu Rockshelter Anarua Bay, from off coast Aug 02 (D. Kennett)

Photo 3.

Interior dune of Tangarutu Rockshelter with East section towards the back of the shelter Aug. 02 (D. Kennett)

Photo 4.

East section excavation of Tangarutu Rockshelter Aug 02 (D. Kennett)
Plate 9 Plants from Rapa

Photo 1.

*Canna indica*, Haurei village Aug. 02 (M. Prebble)

Photo 2.

*Fagraea berteriana* in fruit, Anarua Bay Aug 02 (M. Prebble)

Photo 3.

*Myrsine rapensis*, Hiri Bay, Aug 02 (M. Prebble)

Photo 4.

*Freycinetia arborea* 1980 (G. Paulay)

Photo 5.

*Freycinetia arborea* 1980 (G. Paulay)

Photo 6.

*Piper excelsum* 1980 (G. Paulay)
Plate 10 Plants from Rapa cont.

Photo 1.

*Cyathea sp.*, Haurei 1980 (G. Paulay)

Photo 2.

*Cocos nucifera* and *Pandanus tectorius* Hiri Bay 1980 (G. Paulay), palm now absent

Photo 3.

*Myoporum rapensis* 1980 (G. Paulay)

Photo 4.

*Metrosideros collina* 1980 (G. Paulay)

Photo 5.

*Colocasia esculenta* with *Commelina diffusa* behind pondfield
Plate 11. Pollen micrographs of introduced taxa to the Austral Islands (reference pollen from field collection and ANH collection)

**Commelina diffusa** (Commelinaceae), Rimatara

![Pollen micrograph of Commelina diffusa](image1)

10 microns

**Achranthes Aspera** (Amaranthaceae), Rimatara

![Pollen micrograph of Achranthes Aspera](image2)

10 microns

**Sigesbeckia orientalis** (Asteraceae), Rimatara

![Pollen micrograph of Sigesbeckia orientalis](image3)

20 microns

**Solanum americanum** (Solanaceae), Rimatara

![Pollen micrograph of Solanum americanum](image4)

10 microns

**Urena lobata** (Malvaceae), Rimatara

![Pollen micrograph of Urena lobata](image5)

10 microns

**Alyxia stellata** (Apocynaceae), Henderson Island

![Pollen micrograph of Alyxia stellata](image6)

20 microns

**Colocasia esculenta** (Araceae) Tukou Core 3

![Pollen micrograph of Colocasia esculenta](image7)

20 microns
Plate 12. Pollen micrographs of indigenous taxa to the Austral Islands (reference pollen from field collection and ANH collection)

Hebe rapensis (Scrophulariaceae), Rapa

Acrostichum aureum (Pteridaceae), Rimatara

20 microns

Barringtonia asiatica (Barringtoniaceae), Rimatara

20 microns

Freylinia arbores (Pandanaceae), Rapa

Tournefortia argentea (Boraginaceae), Rimatara

20 microns

Triumfetta procumbens (Malvaceae) Rimatara

20 microns
Plate 13. Pollen micrographs of indigenous taxa to the Austral Islands cont. (reference pollen from field collection and ANH collection)

*Calophyllum inophyllum* (Clusiaceae), Rimatara

*Pandanus tectorius* (Pandanaceae), Rapa

*Macaranga raiavaensis* (Euphorbiaceae), Rimatara

*Pemphis acidula* (Lythraceae), Rimatara

*Scuelleqtqecclla* (Goodeniaceae), Rimatara

*Guettarda speciosa* (Rubiaceae) Rimatara
Plate 14. Monosulcate scabrate pollen and spherical verrucose phytolith micrographs of Arecales: Iguanurinae palm type from Rapa

Pollen micrograph, Tukou Core 3

Phytolith micrograph, Tukou Core 2

Pollen micrograph, Tukou Core 3

Phytolith micrograph, Tukou Core 2

20 microns

20 microns