THE LATE QUATERNARY VEGETATIONAL AND CLIMATIC HISTORY OF FAR NORTHERN NEW ZEALAND

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Frontispiece: The Kauri Sanctuary, Omahuta State Forest.

To Lucy M. Cranwell

pioneer in New Zealand palynology

Abstract

Sediments from 3 peat mires and two lakes from the Aupouri Peninsula, Karikari Peninsula and the Bay of Islands district of Northland, New Zealand, are analysed for their pollen and charcoal records to reconstruct a 100,000-year late Quaternary history of vegetational and climatic change. Northland has a complex geological history which includes Upper Pleistocene to Holocene volcanism. The region has a warm, moist climate, which promotes deep weathering of rocks, clay-rich soils and mass movement, particularly in the period following human settlement with clearance of most of the natural rainforest. Throughout the Pleistocene the climate of Northland remained relatively mild in comparison to the more southern regions of New Zealand. This thesis determines how the far northern vegetational cover and its composition have changed in response to late Quaternary climate changes through detailed pollen analysis of sediment cores. Studies of recent pollen deposits were undertaken to provide analogues for interpretation of the relationship between pollen rain and plant communities. Because New Zealand is one of the few land masses in the southern hemisphere south of 35° S, and lies just poleward of the subtropical convergence, it is uniquely placed to record climatic changes in the vast expanse of the Southern Ocean. These records of climatic fluctuations have global importance because of 1) New Zealand's small size and remoteness from other land masses, 2) the lack of large ice sheets at the Last Glacial Maximum which ensured rapid vegetational response to ameliorating climate, and 3) the potential for correlating high-resolution, well-dated terrestrial and marine records.

At the height of the Last Glacial (Otiran) most of New Zealand south of 37° S was unforested. Landscapes not directly affected by glaciation were largely dominated by grass and shrublands. Forest patches survived in microclimatically favoured locations where they were protected from heavy frosts, cold maritime polar airmasses and strong winds. During the *ca* 100,000 years investigated, the pollen profiles demonstrate that the Northland region retained permanent forest cover, although composition of far northern forests changed significantly in response to fluctuating weather patterns. These vegetational and climatic changes are summarised below:

1) Kaihinu Interglacial, ^{18}O Sub-stage 5c-a, *ca* 100-74 ka

The regional vegetation of far northern New Zealand was dominated by kauri-podocarp-hardwood forest. The most important tall trees were *Agathis australis*, *Dacrydium cupressinum* and *Phyllocladus*. *Ascarina lucida*, a small, frost- and drought-sensitive understorey tree, was common. Angiosperm trees dominated coastal forest. The commonest species were *Beilschmiedia*, *Quintinia*, *Metrosideros*, *Nestegis*, *Elaeocarpus* and *Ixerba brexioides*. The climate is interpreted as having been mild and moist. Temperatures may have been 1-2° C cooler than present.

2) Last Glacial (Otiran), ^{18}O Stages 4-2, *ca* 74-14 ka

Regional vegetation changed significantly during the Otiran Glaciation. Whilst the far northern forests remained predominantly diverse conifer-hardwood assemblages, warmth-loving species became increasingly restricted in their distribution, particularly *Ascarina lucida*. From *ca* 74 ka, *Agathis australis*

became scarce in the Kaitaia area, but remained a significant element of regional forest further east. *Dacrydium cupressinum* was a common emergent tree. Between 74-59 ka, climates were generally cool and moist with increased incidence of winter frost in exposed areas. Lowland forests moved seaward to occupy newly exposed continental margins as sea level retreated consequent upon expansion of global ice caps. The following period from 59-43 ka was characterised by increased abundance of *Dacrycarpus dacrydioides*, *Metrosideros* species, *Quintinia* and *Syzygium maire*. These species are associated with wetter conditions. *Ascarina lucida* was also more common at this time. Regional forests were predominantly podocarp-hardwood assemblages. *Agathis australis* was present in these forests, but not dominant. The climate between 59-43 ka (^{18}O Sub-stage 3b) is considered to have been relatively warmer and wetter than the preceding Stage 4. From 43-24 ka (^{18}O Sub-stage 3a) kauri-dominated mixed conifer-hardwood forest expanded. Significant increases of hardy podocarps *Podocarpus* and *Prumnopitys taxifolia* occurred. *Agathis australis* reached its greatest abundance since the Last Interglacial, and *Ascarina lucida* was scarce. Climate was characterised by drier summers and cooler winters. As glaciation in more southern latitudes intensified, northern climates became increasingly colder, drier and windier, particularly from *ca* 30 ka. Natural fires were more common. The replacement of kauri-podocarp-hardwood forest with beech-podocarp-hardwood forest followed rapidly, and by the Last Glacial Maximum (LGM) Northland forests as far north as Kaitaia were dominated by *Fuscospora*. From Kaitaia south all typically warm northern elements were restricted in their distribution. In the far northern region temperatures may have been depressed by as much as 3-3.5°C, and rainfall was probably reduced to about 2/3 it s present level.

3) The Lateglacial, 14-10 ka

Dacrydium cupressinum, *Dacrycarpus dacrydioides*, *Ascarina lucida* and *Dodonaea viscosa* became more abundant from *ca* 14 ka. *Fuscospora*, *Podocarpus* and *Prumnopitys taxifolia*, which had expanded during the harsher climates of the LGM, became more restricted in their distribution. Climate became increasingly more equable as conditions ameliorated.

4) The Holocene, 10 ka to present

Changes in composition of northern forests progressed even more rapidly from the onset of the Postglacial. Across the far northern region beech-dominated podocarp-hardwood forest was rapidly replaced by kauri-podocarp-hardwood forest. *Fuscospora* declined sharply and became very much restricted in its distribution. *Dacrydium cupressinum* dominated the regional forests. Hardy podocarps, *Manoao colensoi*, *Podocarpus*, *Prumnopitys ferruginea* and *P. taxifolia* became less common than previously. *Ascarina lucida* reached its greatest abundance between *ca* 10 - 7.6 ka. The early Postglacial climate was probably the warmest and most equable for the past 80 ka. Temperatures in the Kaitaia region may have been 1-2°C warmer than present.

The mid- to late Postglacial, from *ca* 7-3 ka, is characterised by the decline in *Ascarina lucida*. *Metrosideros* and *Libocedrus* also became less common, whilst hardy podocarps such as *Manoao colensoi*, *Podocarpus* and *Prumnopitys taxifolia* increased in abundance. Far northern climates were

probably slightly drier and cooler in this period as a more seasonal, dry summer/wet, cool winter regime became established. Increased cyclone activity is also suggested during this time. These weather patterns are in line with those suggested for other parts of New Zealand. Climatic variability continued into the late Holocene, and the pollen records indicate vegetation disturbance up to the time of first human settlement.

The appearance of high frequencies of *Pteridium esculentum* and microscopic charcoal in pollen records, coincident with forest decline, is recognised as evidence for Polynesian deforestation. The clearance of indigenous forests occurred as a nation-wide event from 800-600 yr B. P. In Northland, where climates and soils were probably more favourable, deforestation events may have occurred a little earlier. At Lake Tauanui first human impact may have occurred as early as *ca* 1000 yr B. P., and at Lake Taumatawhana by *ca* 900 yr B. P. Forest clearance at the Wharau Road Swamp locality was somewhat later at *ca* 600 yr B. P. Subsequently, European settlement, commencing in the early 1800s, is identified by the advent of exotic pollen types such as *Cupressus*, *Pinus*, *Ulex europaeus* and *Plantago lanceolata*.

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TAXONOMY

The taxonomic nomenclature used in this thesis follows that of Allan (1961), Moore and Edgar (1976), and subsequent revisions made by Brownsey *et al.* (1985), Connor and Edgar (1987) and Webb *et al.* (1988). The new monotypic genus *Manoao* erected by Molloy (1995) replaces that of *Lagarostrobos* for what was previously known as *Dacrydium colensoi* (Connor and Edgar, 1987). *Nothofagus* classifications follow Hill and Read (1991), and Hill and Jordan (1993). *N. fusca* type pollen species are designated *Fuscospora* after McGlone *et al.* (1996). It was not always possible to identify pollen and spores to the lowest taxonomic level as some types from the same family were too similar to differentiate between species. For this reason the following pollen types are recognised and are listed with their constituent taxa:

Leptospermum type	*L. scoparium, Kunzea ericoides*
Metrosideros undiff.	all New Zealand *Metrosideros* spp.
Neomyrtus type	*Neomyrtus* sp., *Lophomyrtus* spp.
Fuscospora	all *Nothofagus* spp. except *N. menziesii*
Podocarpus type	*P. hallii, P. totara*
Taraxacum type	all species in the tribe Lactuceae (Asteraceae)
Cyathea dealbata type	*C. dealbata, C. medullaris*
Cyathea smithii type	*C. smithii, C. colensoi*

Chapter 1

INTRODUCTION

The islands of New Zealand occupy a critical position in the vast expanse of the Southern Ocean. They comprise one of the few land masses in the Southern Hemisphere south of 35°S (Figure 1.1), and are situated just equatorward of the Sub-tropical Convergence. Thus New Zealand is well placed to record climatic changes over geological time. These records of climatic fluctuations have global importance because of their role in calibrating and corroborating deep-sea core records from adjacent oceans. New Zealand's small size and isolation from other land masses means that its climate records directly reflect global changes in the ocean-atmosphere system. The lack of large ice-sheets at the Last Glacial Maximum (LGM) enabled rapid vegetation response to ameliorating conditions which followed. There is enormous potential for correlating high resolution, well-dated terrestrial and marine records and therefore identifying the commencement of major global climatic changes.

Northland and the New Zealand Late Quaternary

The evidence for substantial changes to the climate and vegetative cover of New Zealand during the Late Pleistocene and Holocene epochs is now reasonably well documented for most of the country south of Auckland (latitude 37°S). Pollen analysis of peat deposits and lake sediments has been a major contributor to this evidence. Other lines of research have revealed complementary evidence from glacial activity (*e.g.* Burrows *et al.*, 1976), soil erosion and loess stratigraphy (*e.g.* Palmer and Vucetich, 1989), and ocean sediment studies (*e.g.* Stewart and Neall, 1984). Generally the Lateglacial/Holocene has ample suitable material to study, and more than 50 published pollen sites cover the country which span all or most of the last 14, 000 years. Longer records are less common. Well-dated tephras in many sediments, together with radiocarbon dates, provide a robust chronology; yet fewer than half of New Zealand sites are sufficiently well-dated to give comprehensive chronologies. This is particularly true for the northern third of the North Island where few pollen diagrams have yet been published and no LGM polliniferous deposits have been clearly identified. Few identifiable ash deposits are preserved in Northland, owing to the direction of ash "fallout" and remoteness from source. Those sites which have been studied in Northland seldom have the benefit of tephrochronological markers to support other means of dating. Consequently radiocarbon

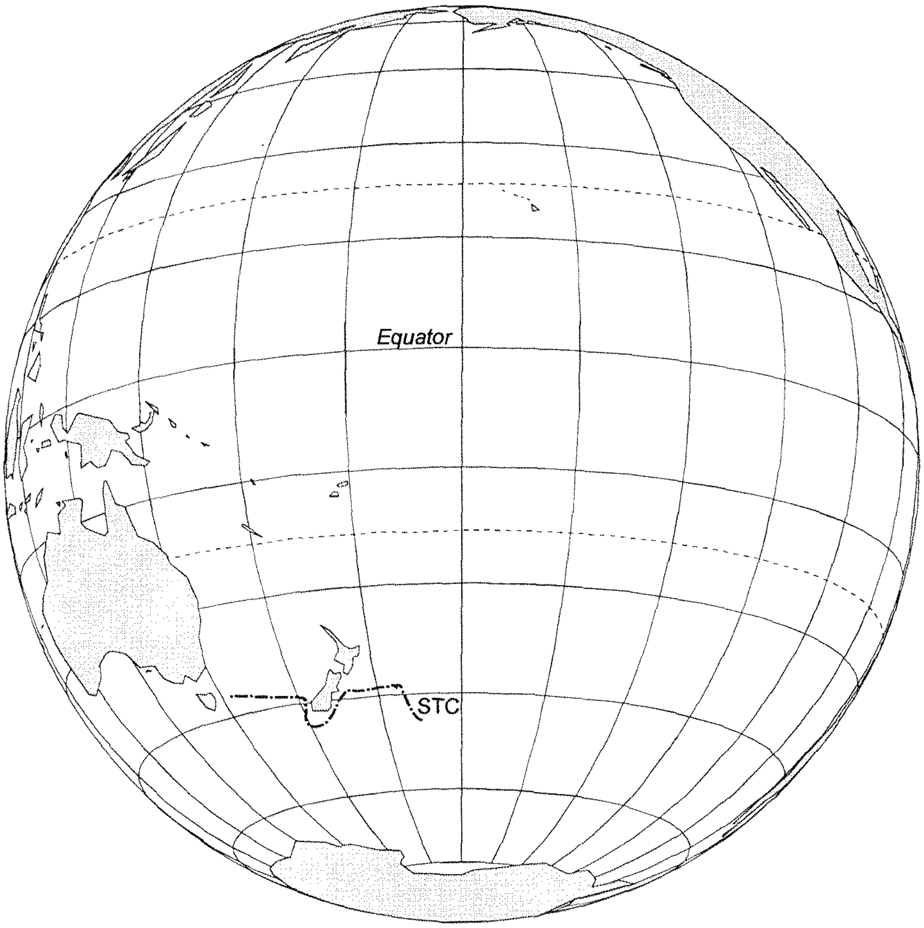


Figure 1.1 New Zealand and the Southern Ocean showing the Subtropical Convergence (STC).

dating has generally been the sole means of establishing a time frame in palynological studies. The method is limited by its reliability beyond 30,000 years (Hogg, 1982).

Radiocarbon dating in previous work in Northland has been subject to a number of problems (*e.g.* Newnham, 1992), not least of which has been the use of bulk samples to provide dates. This leads to dates which not only have a large inbuilt error, but also include material spanning inappropriately long periods of time. The consequence of using such dates is an ambiguous and imprecise interpretation of the climate record. A further problem is contamination of dates near the limit of the method (radiocarbon) and their confusion with younger dates (*e.g.* Newnham *et al.*, 1993). Accelerator Mass Spectrometry (AMS) dating can provide much more precise results using significantly smaller samples; sometimes a small twig or large seed is sufficient for this technique. With the difficulty in identifying tephras in Northland polliniferous deposits, the use of precision radiocarbon dating is essential if meaningful interpretations of climate change through time are to be achieved.

The integration of palaeoclimatic data from sites throughout New Zealand indicates that during the LGM most of the country south of Auckland was deforested. Grass and shrub-dominant communities were widespread; forest species south of 38°S only survived in small micoclimatically favoured areas where there was protection from heavy frosts and strong, cold desiccating winds (Figure 1.2). The paucity of information available for Northland does not allow a reconstruction of LGM vegetation cover with any certainty. Only four published terrestrial pollen diagrams cover this period (Dodson *et al.*, 1988; Newnham, 1992; Newnham *et al.*, 1993). One pollen record from Paranoa Swamp near Cape Reinga together with a younger, Holocene record, indicates persistent podocarp-hardwood forest for the past 17,000 years (Dodson *et al.*, 1988). There is no evidence for the period of time immediately prior to this. Two pollen profiles from Aupouri Peninsula near Houhora have radiocarbon dates in the range 30,000 to 4000 years (Newnham *et al.*, 1993). These provide only a tentative reconstruction of far northern vegetation during the Last Glaciation and Holocene because there is considerable uncertainty over the radiocarbon ages. There is evidence that mixed podocarp-hardwood forest was present prior to the LGM, but the LGM itself may be missing from these sequences owing to possible hiatuses in sedimentation (Newnham *et al.*, 1993). At Otakairangi, near Whangarei, a 30,000 year long pollen site provides a rather better record indicating persistence of

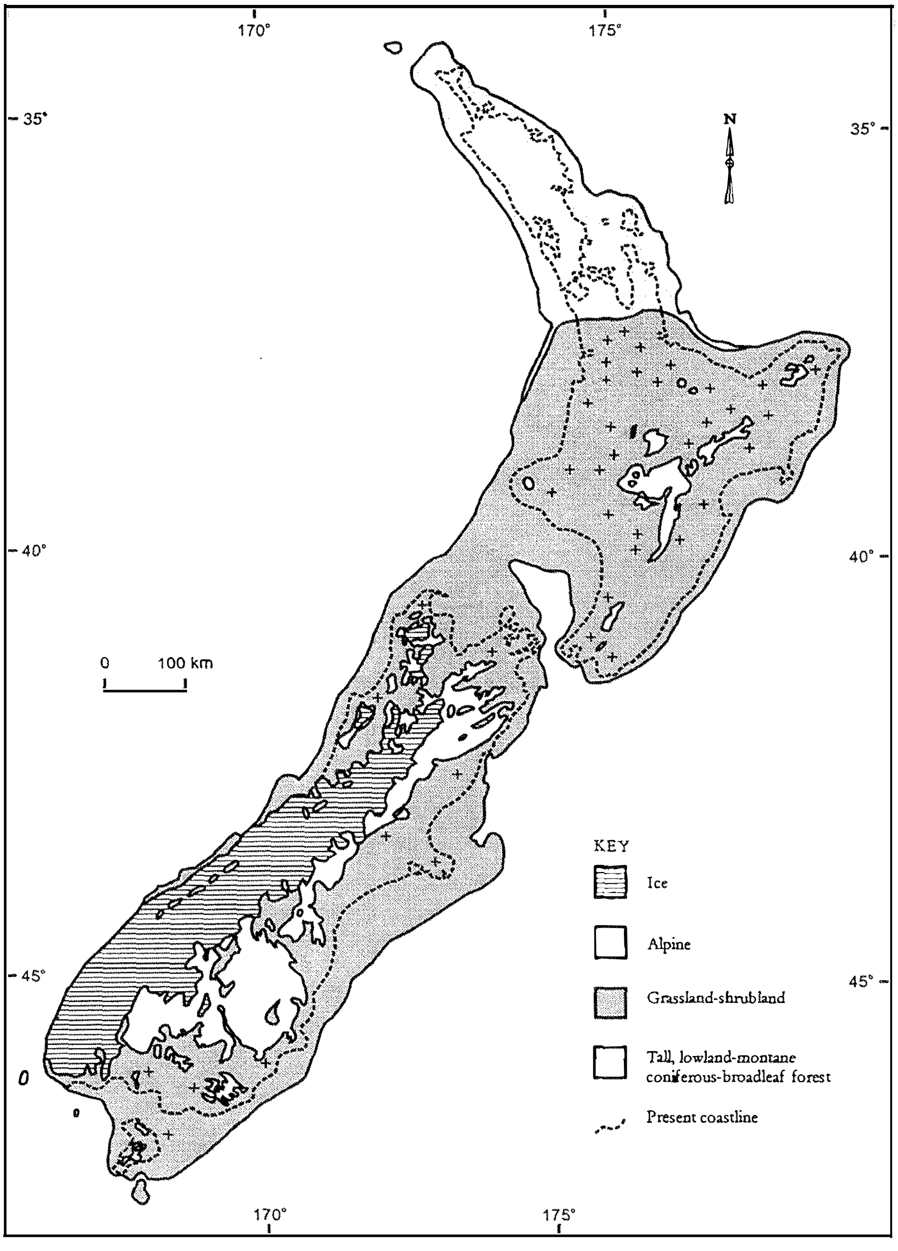


Figure 1.2 New Zealand vegetation at the Last Glacial Maximum (after McGlone *et al.* 1993)

diverse podocarp-hardwood forest throughout the sequence, at times dominated by *Fuscospora* (Newnham, 1992). However, like the Aupouri Peninsula sites, this record also suffers from uncertainties surrounding the radiocarbon ages. Consequently the vegetation and climates of the Last Glacial (LG) are currently best described by marine deep sea cores from the Bay of Plenty (Wright *et al.*, 1995).

Last Glacial to Present Vegetation and Climate of Northland

The marine deep sea core record of Wright *et al.* (1995) establishes a well dated sequence of northern vegetational history and climate change during the last 59,000 years (isotopic stage 4/3 boundary to present). Onshore vegetation changes record full conifer-hardwood forest between 59-43 ka followed by a change to vegetation which reflects cooler/drier conditions followed by a return to full forest during the Holocene. More specifically the vegetation of Stage 3b consisted of conifer hardwood forest dominated by *Agathis australis* with relatively high levels of *Libocedrus* and *Cyathea smithii*-type tree ferns. It is suggested Northland experienced a cooler (2-3°C decrease in mean annual temperatures), moister climatic regime than present (Newnham, 1992; Newnham *et al.*, 1993; Ogden *et al.*, 1993). During Stage 3a-2, *Fuscospora* forest spread into Northland, and tree fern-rich, conifer-hardwood forest became much more restricted. Some open scrub and grassland was present indicated by abundances of *Halocarpus*, *Phyllocladus*, Asteraceae and grasses (Wright *et al.*, 1995). Dodson *et al.* (1988) do not record any similar flora at their Cape Reinga site (northern tip of Northland Peninsula), nor does Newnham (1992) from his Otakairangi sequence. Wright *et al.* suggest a fall in temperature of 3-4°C during the LGM in Northland with drier, frostier conditions, consistent with climates recorded in the central North Island and Bay of Plenty at this time (McGlone and Topping, 1983; McGlone *et al.*, 1984; Pillans *et al.*, 1993). In the later stages of the LGM *Agathis australis*, *Dacrydium cupressinum* and *Cyathea smithii* type increase sharply; *Fuscospora* and *Halocarpus* vanish between 16.5-14.6 ka (inferred) followed by a resurgence between 14.6-10 ka. This implies an early warming/moistening of climate followed by reestablishment of cooler/drier glacial conditions. A similar *Fuscospora/Halocarpus* interval is recorded at 13 ka from Otakairangi (Newnham, 1992). Increased levels of mire taxa (restiads and sedges) during the LGM suggest extension of mires on coastal plains exposed by lower sea level. The subsequent decline in mire taxa is consistent with rising sea level in the Holocene.

An abrupt resurgence of conifer-hardwood taxa and tree ferns is observed at the beginning of stage 1 (10 ka). *Dacrydium cupressinum*-dominant, *Ascarina lucida* and tree fern-rich forest was established throughout northern New Zealand from 10 ka (McGlone, 1988; Newnham, 1992; Newnham *et al.*, 1989; Wright *et al.*, 1995) as increasingly warm and moist climates predominated. The spread of *Agathis australis* and *Phyllocladus*, and decline of *Ascarina lucida* characterise the late Holocene as slightly cooler, more variable climates prevailed.

A few terrestrial Northland pollen sites record mainly Holocene environments. One from McEwan's Bog south of Whangarei has a 6,500 year long record which indicates podocarp-forest was dominant until European clearance (Kershaw and Strickland, 1988). A feature of this record is the abundance of *Fuscospora*, particularly after 4 ka. The sequence is either too condensed or incomplete to identify the onset of Polynesian deforestation. A pollen site near Dargaville has a record almost 9000 years long indicating regional beech-podocarp-hardwood forest from *ca* 9-7.5 ka which was replaced by podocarp-hardwood forest as *Fuscospora* declined rather abruptly (MacDonald, 1984). This record lacks good chronology, and there is no clear evidence for the onset of Polynesian deforestation. Chester (1986) reports several late Holocene records from the Bay of Islands, none older than *ca* 3000 yr B. P., in a study of Polynesian deforestation. The onset of clearance from Chester's study remains poorly defined.

Whilst the terrestrial records have suggested that temperatures at the LGM may have decreased by as much as 3-4°C, records for the oceanic climate give a rather different picture. Wright *et al.* (1995) postulate only small temperature changes (<2°C) for subtropical sea surface waters cf. CLIMAP (1981) which shows as much as 4°C cooling off western New Zealand during the LG. The data for eastern New Zealand also show relatively little cooling (<2°C) during the LG, although near shore cooling may have been much greater owing to wind-induced upwelling (Hendy, 1995 in Wright *et al.*, 1995). Although an extremely steep thermal gradient was present off the South Island during the LG which led to an extremely cold, dry, windy climate, it is suggested a relatively small temperature change in the north of the North Island produced climate similar to present or only slightly cooler and probably drier (McGlone *et al.*, 1993; Nelson *et al.*, 1993; Wright *et al.*, 1995). If this were the case in Northland, then one might expect the northernmost forests to have remained little changed in their composition during the LG. Forests with northern elements, including *Agathis australis*, exist today at high altitude in the Coromandel Peninsula (Cranwell and Moore, 1936). However, the fossil record indicates that forests in far northern New Zealand did undergo significant change during the LG. If temperatures *per se* were not greatly reduced, then other factors must be invoked which worked together with temperature depression to influence vegetation change. A decrease in effective precipitation is a likely causative agent. Wright *et al.* (1995) report that the Antarctic

Convergence underwent a substantial northward shift (at least 5° latitude) during the LG. However, the Subtropical Convergence (STC) probably remained stable in its current position, at least to the east of New Zealand because of the influence of the Chatham Rise (Fenner *et al.*, 1992). No such barrier exists to the west of New Zealand, and cold water probably extended far northward which would have facilitated intrusion of frigid maritime polar airmasses. Cooler water in the Tasman Sea may have had a controlling influence on the lower rainfall experienced over New Zealand during the LGM. In Northland it seems likely that isolation of tropical sources of monsoon from Australia, New Guinea and New Caledonia was more important in controlling precipitation. Many of the dominant tree taxa in Northland forests are drought sensitive, and any significant reduction in precipitation would likely have markedly restricted their abundance. *Agathis australis*, *Ascarina lucida* and *Dacrydium cupressinum* would have been particularly susceptible to moisture deficit (Franklin, 1968; Ecroyd, 1982; McGlone and Moar, 1977). Other species more tolerant of drought and cold, such as *Fuscospora*, *Manoao colensoi*, *Podocarpus* and *Prumnopitys taxifolia*, could then have increased their distribution. Following the LGM, a rapid return southward of the STC into the Tasman Sea could have been the means for abrupt climatic and vegetational changes on land by raising precipitation over the entire New Zealand region (McGlone *et al.*, 1993). This would encourage a return of forests similar to those extant prior to the LG.

Prehistory of New Zealand

In spite of more than 200 years of debate, the manner in which the Pacific was settled remains contentious. Whilst the large islands between mainland Southeast Asia, New Guinea, Australia and its near neighbours of western Melanesia are known to have been reached by at least 30-40,000 years ago (Irwin, 1992) and possibly earlier (Hiscock and Kershaw, 1992), exploration of the vast expanse of the remote Pacific to the east is not thought to have begun until after 3,500 years ago (Irwin, 1992). The latter episode is described by Irwin as a "burst of sophisticated maritime and Neolithic settlement" (*op. cit.*, p. 3). The islands of the Pacific possess diverse habitats for humans. Those to the east generally occur as volcanic mountains emergent at the surface as volcanic islands, or are sub-surface and appear as low islands crowned by coral reefs. The larger, high islands to the west are geologically diverse and rich in resources for human settlement, whilst those to the east offer a rather more restricted range of resources, particularly many of the low islands which have limited soils and water. Recent research indicates that remote parts of eastern Polynesia were settled by *ca* 2000 yr B. P. (Irwin, 1992). However, cool and more difficult sailing conditions delayed settlement south of the tropics, and the earliest colonists reached New Zealand only about 1000 years ago (Figure 1.3; Davidson, 1984; Irwin, 1992; Anderson and McGlone, 1992).

A shift in the thinking of Polynesian prehistory began a decade ago with the publication of Kirch's *Rethinking Polynesian Prehistory* (1986) which seriously challenged the orthodox model of the sequence and chronology of first and subsequent colonisations of Polynesia. The timing of first settlement of New Zealand has been the subject of considerable scientific interest and earnest debate, and remains poorly defined. Counterpoised against the "orthodox position" (identified with Davidson, 1981, 1984) which would date human arrival to 1000-1100 years ago are the "short prehistory" of *ca* 800-600 years (Anderson, 1991; McGlone *et al.*, 1994; McFadgen *et al.*, 1994), and the "early hypothesis" of 2000-1500 years (Sutton, 1987, 1988). However, Sutton's assertions have been vigorously contested by Enright and Osborne (1988) who suggest that much of the evidence used by Sutton (1987) has been misinterpreted.

Some of the debate has focused on archaeological visibility. Anderson (1991) argues that the first people in New Zealand are readily seen in the archaeology of moa-hunter sites. Sutton (1988, 1994) suggests that archaeological visibility may not be that simple and is dependent upon the size of founding populations, the susceptibility of the landscape to discernible effects of human impact, the effects of that impact and the rate of increase of human population. Brewis *et al.* (1990) have argued that population growth rates for pre-European Maori were extremely low, probably less than one percent. If a founding population was small, *e.g.* less than 100, then it might take at least 350 years to reach 1000. The question is would these people be archaeologically visible?

Anderson (1991) has argued for a short prehistory on the basis of analysis of approximately 300 archaeological radiocarbon dates. These dates are concentrated in the central and southern regions of New Zealand. Anderson culled many of them on the basis of uncertainties including inbuilt ages for wood dates, calcium carbonate contamination, and non-collagen residual carbon contamination or mineralisation of moa bone material. Only a very limited amount of archaeological research has been done on the early period in Northland and the number of radiocarbon dates is few. The oldest are charcoal dates of 775 ± 61 yr B. P. (NZ-916) from Houhora, Aupouri Peninsula and 525 ± 89 yr B. P. (NZ-647) from Moturua in the Bay of Islands, and a marine shell date of 1010 ± 35 yr B. P. from Twilight Beach near Cape Reinga.

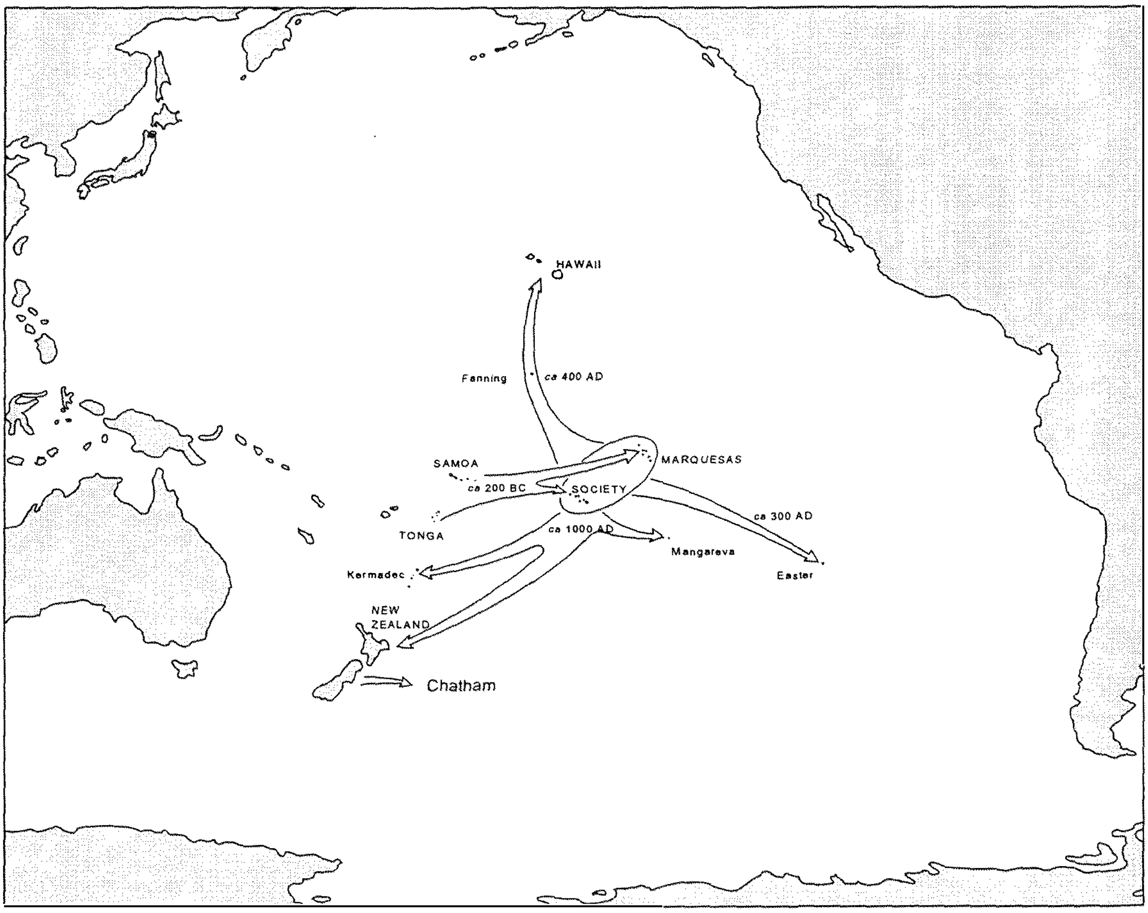


Figure 1.3 The Pacific and Polynesian dispersal patterns (redrawn after Kirch, 1986).

These dates are uncalibrated conventional determinations (Anderson, 1991). More recent dating of Houhora material has yielded additional charcoal dates of 774 ± 87 yr B. P. (NZA-2437) and 727 ± 86 yr B. P. (NZA-2438), and a date on marine shell of 812 ± 37 yr B. P. (NZ-7920) (Anderson and Wallace, 1993). The distribution of moa-hunting sites is discontinuous and relatively few occur in Northland. The stratigraphic complexity of moa-hunter sites and the small number of radiocarbon determinations from most sites indicate that more detailed work is required to establish reliable chronologies.

Evidence for colonisation may derive not only from habitation sites, but also from anthropogenic environmental changes, particularly forest disturbance/clearance and burning. For example recent palaeoenvironmental evidence demonstrates considerable earlier human disturbance on Mangaia Island, Central Polynesia (Kirch *et al.*, 1991, 1992; Kirch and Ellison, 1994). Prior to human settlement of New Zealand the forest cover was virtually complete (Figure 1.4). Palaeoenvironmental evidence in New Zealand indicates sustained deforestation after 1000 yr B. P. (McGlone, 1983, 1989), and probably after 800 yr B. P. (Anderson and McGlone, 1992). There is a strong peak in the published deforestation dates at *ca* 600 yr. B. P. (McGlone, 1989). The evidence for deforestation during the Polynesian era is derived from charcoal and wood in soils, soil instability leading to soil erosion and sedimentation, and pollen records within affected areas which show a decline of forest pollen and increase in non-forest pollen, especially bracken, grasses, shrubs and microscopic charcoal. Whilst evidence of soil erosion and increased sedimentation is not a reliable indication on its own, where it is linked with evidence of repeated burning and deforestation the inference of human impact is justifiable.

All North Island sites show prominent, persistent bracken in the post-forest clearance phase. The mild, moist climates of the North Island ensure rapid regrowth after fire (McKelvey, 1973). Bracken is easily suppressed by regenerating forest (Dring, 1965) and its continued presence relies on constant burnoff of the vegetation. Deforestation was concentrated in areas where rainfall was less than 1000 mm/a, although widespread clearance was possible in the range 1000-1600 mm/a. However, if rainfall was over 1600 mm/a only limited clearance was possible (McGlone, 1983). This may account for the reason why much of Northland was still forested when early European clearance began (see Figure 9.4). Whilst the drier regions of the South Island were extremely prone to natural fire and accidental burning, it seems likely that forest destruction by fire in the north was deliberate and sustained (McGlone, 1983).

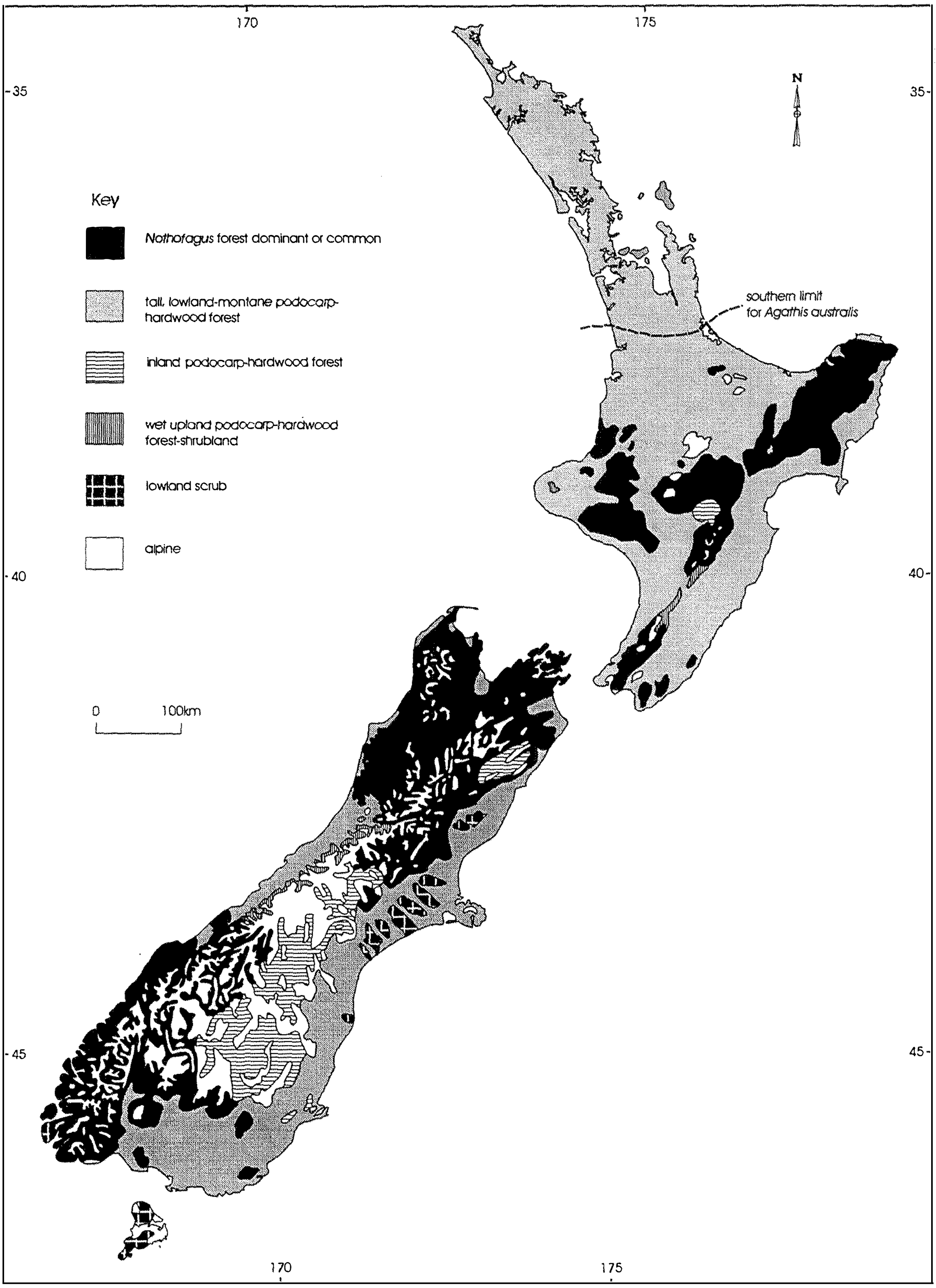


Figure 1.4 The vegetative cover of New Zealand prior to human settlement *ca* 1000 yr B. P. (after McGlone *et al.*, 1993).

There are a number of important reasons why Polynesians destroyed forests in spite of the rich resources they contained such as edible fruits, large populations of ground and tree-dwelling birds and construction materials. These are:

1) Clearance for bracken. The rhizome of bracken (*Pteridium esculentum*) has been identified as an important food throughout all of pre-European New Zealand (Colenso, 1880; Best, 1942). The maintenance of bracken fernland would have inevitably led to fire spreading into adjacent forest.

2) Clearance for cultivation of crops. This was probably more common in the North Island where kumara growing was an important activity and the climatic conditions were more suitable.

3) Clearance for travel. The difficulty of travelling through dense forest led to the practice of burning to keep tracks open, especially on ridges.

4) Clearance for habitation. Although the total area occupied by dwellings and fortification was probably not great the need for protection from potential enemies was. Clearance around settlements provided security from surprise attack.

5) Clearance for hunting. Fire as an aid to hunting was not essential as moa appear to have declined as rapidly from intact forest as those that were cleared (Anderson, 1982). It may have become more common to burn off vegetation to flush out game as bird numbers declined. However, fire in tall forests is not readily controlled, and New Zealand forests are extremely sensitive to fire, especially in areas where summer drought is common.

McGlone sums up the use of fire neatly, saying "Fire was the primary instrument of land management and it was used liberally" (1983: 23). The extent of forest clearance was principally determined by rainfall. Areas with a high rainfall, such as the west coast of the South Island and Taranaki (and possibly much of Northland), retained forest except for small coastal patches or areas of high fertility. Elsewhere in the drier areas deforestation was more or less complete.

Avian extinction, particularly that of moas, has been clearly associated with people (Anderson, 1989a; Anderson and McGlone, 1992). Of the approximate 300 moa sites recorded, 76% are in the South Island. The chronology for moa sites peaks between 1300-1250 A.D. It seems likely that other avian extinctions and depletions were also a consequence of human settlement

(Anderson and McGlone, 1992), either directly by hunting as in the case of avian megafauna (moas, geese, adzebill, pelican, eagle), forest destruction or predation by rats. Anderson and McGlone argued for a pattern of regional attractiveness of New Zealand to the Maori. During the colonisation period the South Island held sway because of having the largest and most accessible reserves of high-protein food (of animal origin), and because horticulture appears to have been little practised at this time (Anderson, 1989b), although this is far from clear. When the high-protein foods became scarce, it is argued that the north became more favourable, firstly because of the greater availability of wild foods, as well as shell fish and fish species. Colenso (1880) identified a considerable number of pre-European plant foods which were of importance in the Maori diet, including bracken rhizome and forest fruits. In the absence of animal proteins, these were important subsistence foods throughout the year. Thus it might have been possible for small numbers of people to exist in Northland for some time without causing significant burnoff. Secondly, the warmer climate and more fertile soils favoured gardening. The model for a shorter prehistory assumes that the early settlers were dependent on high-protein food sources, either by necessity, or preference. However, this need not be the case.

To the early settlers coming from the tropical Pacific, climate and soils would have been major constraints to agricultural settlement. Bulmer (1988) identifies three important environmental factors crucial to successful colonisation: 1) favourable climate, 2) fertile soils, and 3) accessible seafood. The optimal zone in terms of climate for initial settlement of New Zealand is Northland where average annual temperatures range around 15°C (see section on climate), and rainfall is plentiful. Whilst there are relatively few large areas with good soils, those on recent volcanics and in lowland valleys are of high fertility (Bulmer, 1989). Access to seafood in the north was never a problem as there is no shortage of large, sheltered harbours.

It has been suggested that anthropogenic deforestation cannot be reliably distinguished from natural deforestation, even when linked with the characteristic peak of bracken spores following fires (Anderson and McGlone, 1992). This may be true over short time intervals in areas subject to active volcanism where widespread fires follow eruptions, either by direct ignition or from increased lightning activity. However, Wilmshurst and McGlone (1996) have shown that, in the case of the Taupo eruption of 1850 yr B. P., forest regeneration was rapid. Tall forest redeveloped within 120-225 years. Where pollen records indicate high levels of bracken spores and charcoal fragments, coincident with a significant decline of forest taxa, the inference of anthropogenic deforestation is entirely justified.

Summary

The vegetational and climatic record for Northland over the late Quaternary is sketchy and poorly dated. No sites provide unambiguous data for the LGM or the period immediately preceding it. Sequences for the Lateglacial and Postglacial are also poorly represented, so that no clear picture is evident for the Glacial-Postglacial transition. When much of the rest of New Zealand was dominated by grass and shrubland during the LGM, Northland's vegetation remained inadequately described. The on-going debate over first colonisation of New Zealand may be clarified by palynological research which can distinguish between natural effects and cultural impact. Recent reports (Holdaway, 1996) of radiocarbon ages of up to 2000 yr B. P. on bone gelatin from Pacific rats (*Rattus exulans*) suggest that human contact with New Zealand may have occurred long before the traditional time of human arrival *ca* 1000 years ago (Davidson, 1984). These dates on rat bone have only served to heighten speculation about colonisation. Their validity has been challenged on the basis of potential inbuilt age from reservoir effects via dietary influence (Anderson, 1996). Far northern New Zealand offers a number of environmental inducements for early settlement (Bulmer, 1988). If the first humans to settle in New Zealand did arrive earlier than is generally accepted, then Northland is likely to hold the evidence of their occupancy. Northern New Zealand is one of the most exciting regions of the country in which to study vegetation and climate change. The area is of crucial importance to both palaeoclimatic studies and archaeology. One of the long-standing problems in the research of the far north of New Zealand has been the difficulty in accurately dating bog and lake deposits. Many of the dates from the Northland Peninsula yield ambiguous chronologies which are not readily matched to the stratigraphy or their pollen records (*e.g.* Newnham, 1992; Newnham *et al.*, 1993). Large numbers of AMS dates and good pollen stratigraphy are needed to resolve these anomalies.

By the use of palynology this thesis aims to define more clearly the vegetational history, and hence the inferred climate, of northern New Zealand over the Last Glacial and Postglacial periods. A total of seven cores from sites in the northern half of Northland were analysed (Figure 1.5). Particular emphasis was placed on that period encompassing the LGM, between *ca* 22 ka and 14 ka, through to the mid-Postglacial (*ca* 5 ka). In this thesis the reconstruction of Late Quaternary vegetative cover and climatic conditions allows an assessment of how severely Northland was affected during the LGM, and how rapidly vegetation responded to rising temperatures and changes in precipitation regimes and windflow patterns. This builds on previous work by Newnham (1992), Newnham *et al.* (1993) and Ogden *et al.* (1993) to provide a clearer picture of the history of northern forests. Much debate has occurred in the literature with regard to the refuge hypothesis (see *e.g.* Wardle, 1963, 1988; Clayton-Greene, 1978; McGlone, 1985) and this research provides new insights on this issue in the New Zealand context. The analysis of sites which have a late Postglacial record up to the present day provide some much needed data for the debate over first colonisation of New Zealand.

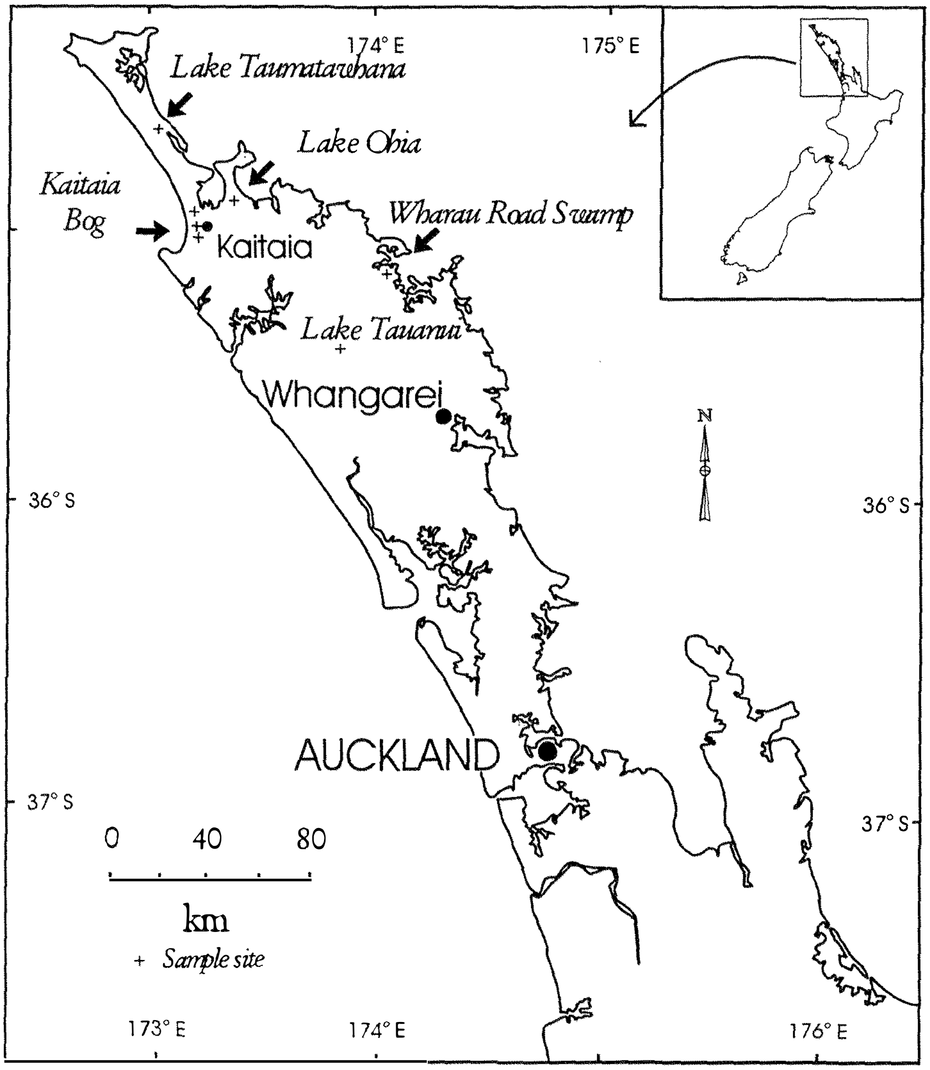


Figure 1.5 Location of coring sites in this study, far northern New Zealand.

Aims and objectives

At the outset of this research project, the late Quaternary vegetational and climatic history of northern New Zealand was poorly explained, in part because of the ambiguous chronologies of the sites thus far investigated, and also because few records of continuous sedimentation during the Last Glacial (LG) to present day had been discovered. The pollen record of Dodson *et al.* (1988) from Cape Reinga does not have a sufficiently long history (only 17 ka) to make definitive statements about LG climates of Northland. The site is also quite distant from the rest of "mainland" Northland so that its history may not bear an intimate relationship to the environments further south. The records from Aupouri Peninsula of Newnham *et al.* (1993) and Ogden *et al.* (1993) give valuable information about parts of the LG but lack reliable chronologies, and the mid-Northland site of Newnham (1992) which may have a 30 ka record is also not well dated. In addition the commencement of human settlement which is of considerable interest to both the scientific community and the public remains poorly defined.

This thesis aims to address the inadequacies in the current state of this knowledge by exploring a number of avenues. In order to better define the commencement of human settlement, suitable sites are required which contain sequences of continuous sedimentation of polliniferous material spanning the late Holocene period. These sequences need to be old enough that the "natural", pre-human period can be clearly identified and differentiated from the post-human environmental impact. To this end three sites (Lakes Taumatawhana and Tauanui, and Wharau Road Swamp) with sedimentation histories dating back to the mid-Holocene were investigated for their pollen records, as part of a FRST-funded project to identify the location and date of first Maori colonisation of Northland. Investigation of the LG and early Holocene is a more difficult proposition, chiefly because of the paucity of suitable material which can be reliably dated from this time period. There are few readily accessible sites which have sufficiently old sequences of continuous sedimentation. In this study one major site adjacent to Kaitaia (Kaitaia Bog) has been identified, from which three cores have been investigated producing integrated environmental histories for the past *ca* 70 ka. One further site, Lake Ohia, east of Kaitaia, provides a record believed to derive from the Last Interglacial. Analysis of these sites was thought to be central to clarifying the composition of LG forests in far northern New Zealand and their response to climatic deterioration, especially during the LGM when regions south of Auckland were largely deforested. In particular, the question of whether forest cover did in fact persist throughout Northland during the LGM may be answered.

By the use of closer sampling intervals than many of the previous studies in Northland on sediment cores of continuous sedimentation, together with the use of AMS dating to provide less ambiguous chronologies, pollen records from a variety of sites and time intervals would be integrated to provide a detailed picture of the late Quaternary environmental history of far northern New Zealand.

Regional Setting

Geology

The Northland Peninsula strikes in a north-westlery trend away from the Auckland isthmus, at right angles to the north-easterly trend of the remainder of New Zealand (Figure 1.6). The peninsula is narrow, ranging from 10 km to 100 km wide and some 300 km long. It is the northernmost region of mainland New Zealand, lying mostly between latitudes 34 and 37°S. Generally the relief is low rolling country mostly below 300 m, although the highest altitudes exceed 600 m a. s. l.. Owing to a warm, wet climate and plentiful supply of rocks rich in minerals such as feldspars and augite, the region is characterised by deeply weathered rocks and clay subsoil profiles which are mostly more than one metre deep, and generally strongly leached (Ballance and Williams, 1982). However, localised high fertility soils do occur associated with volcanic, alluvial, and colluvial deposits (Taylor and Sutherland, 1953).

The underlying geological structure of Northland is related to major Tertiary tectonic events in the South-west Pacific region and is reflected in the gross shape of the peninsula seen today. The long straight western coast is characterised by the effects of extensive progradation along the outline of a drowned coast in strong contrast to the intricately embayed eastern shoreline (Cotton, 1974). The bulk of the sand available for progradation along the western coast has been ultimately derived from rhyolitic explosive eruptions in the central volcanic zone of the North Island. Long distance transport up the coast, mainly by way of sediment discharged from the Waikato River, has provided a steady supply of volcanic beach sand. In sharp contrast the east coast is mostly free of extensive progradation, due in part to the weaker wave attack from dominantly westerly wind-driven waves, and in part to less available material for dune building.

Five major types of geological events have determined many of the different rock types of the Northland region (Figure 1.6). The sequence began with the introduction of an extensive succession of soft sedimentary rocks in the upper Oligocene, consisting mainly of mudstones, sandstones and fine-grained limestones. Resting on top of old volcanic rocks, formerly part of the Pacific Ocean crust, these sedimentary rocks were displaced with their underlying crust by gravity to form what is known as the Northland Allochthon *ca* 25 million years ago (Ballance and Spörli, 1979), and rafted up onto Permian-Cretaceous greywacke basement rocks.

Between about 22 and 15 million years ago eruptions of two chains of andesitic island arc volcanoes occurred on both the eastern and western sides of Northland. Most of these Lower Miocene volcanic deposits have been eroded away by the sea. As the volcanic activity declined

Miocene volcanic deposits have been eroded away by the sea. As the volcanic activity declined in the Middle Miocene *ca* 15 ma, block faulting and westward tilting caused the western side of the peninsula to be depressed, and the eastern side to be elevated. This led to widespread erosion of the eastern rock units that form the previous sedimentary and volcanic basement (Ballance and Williams, 1982).

Later volcanic activity in the mid- to late Pleistocene recurred throughout Northland in various fields intermittently. Chiefly this was associated within the Kaikohe, Bay of Islands, and Whangarei districts. Activity continued almost to the time of human settlement. The volcanism of this period produced the numerous basaltic scoria cones so characteristic of the Northland landscape.

The final and most recent major geological event in this sequence has been the Quaternary period resulting in major climatic and sea level changes. Shoreline changes of the late Pleistocene were controlled by eustatic sea level changes; the different heights of the same shorelines now observed in different parts of New Zealand have resulted from later tectonic movements (Fleming, 1979). Evidence derived from radiocarbon dates for shallow-water shells indicates sea levels of approximately -90 metres by the onset of the Holocene (Norris, 1972; Pautin, 1957; in Fleming, 1979).

Substantial parts of the Northland coastline consist of sand deposits accumulated in the Pleistocene which have linked together the Northland Archipelago (Figure 1.7). The two most extensive areas where this has occurred are the enclosed west coast Kaipara Harbour, and the Aupouri Peninsula (Aupouri Tombolo) which joins Mount Camel, Cape Reinga and North Cape to the mainland (Ballance and Williams, 1982).

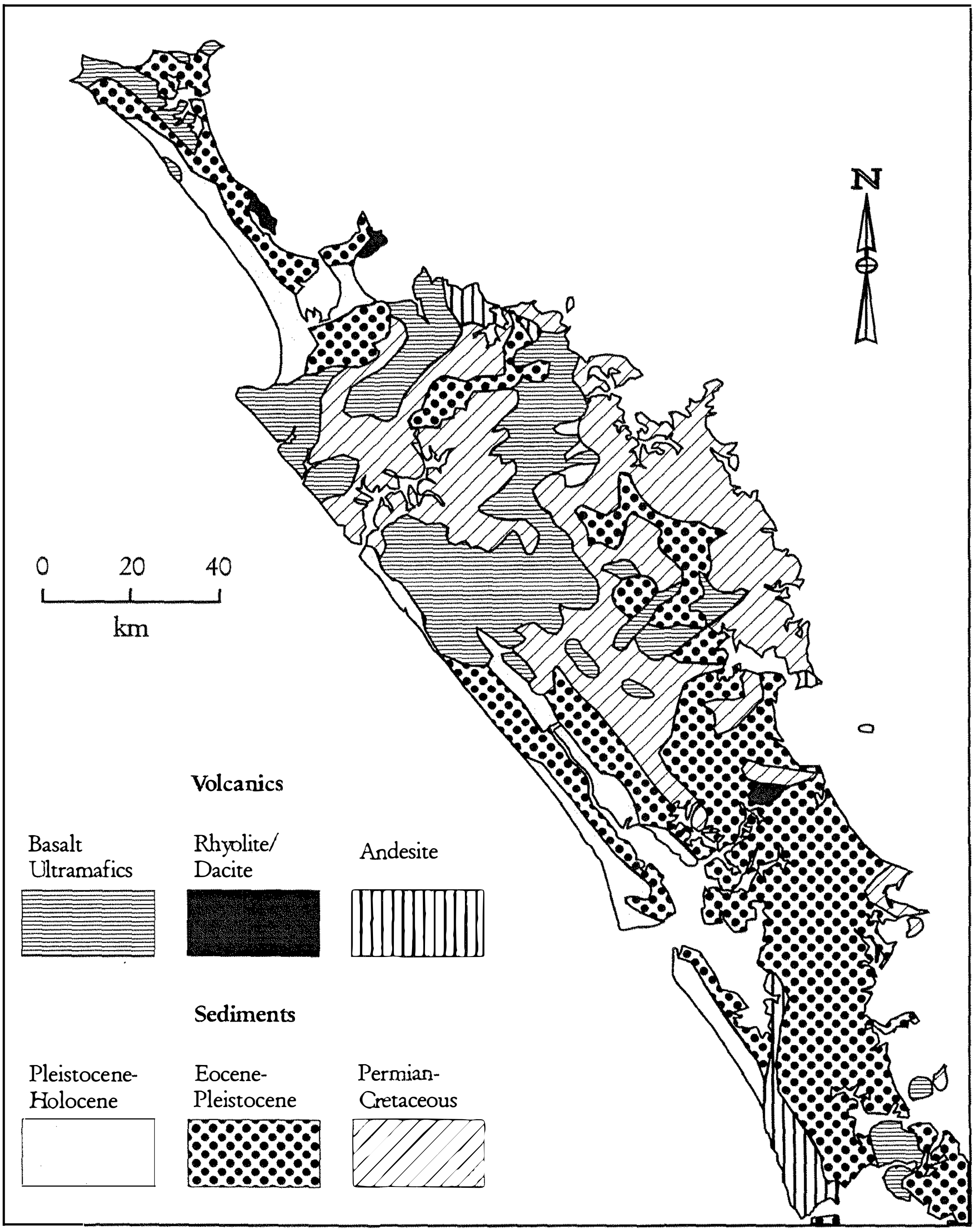


Figure 1.6 Generalised geological map of Northland (after Brothers, 1965).

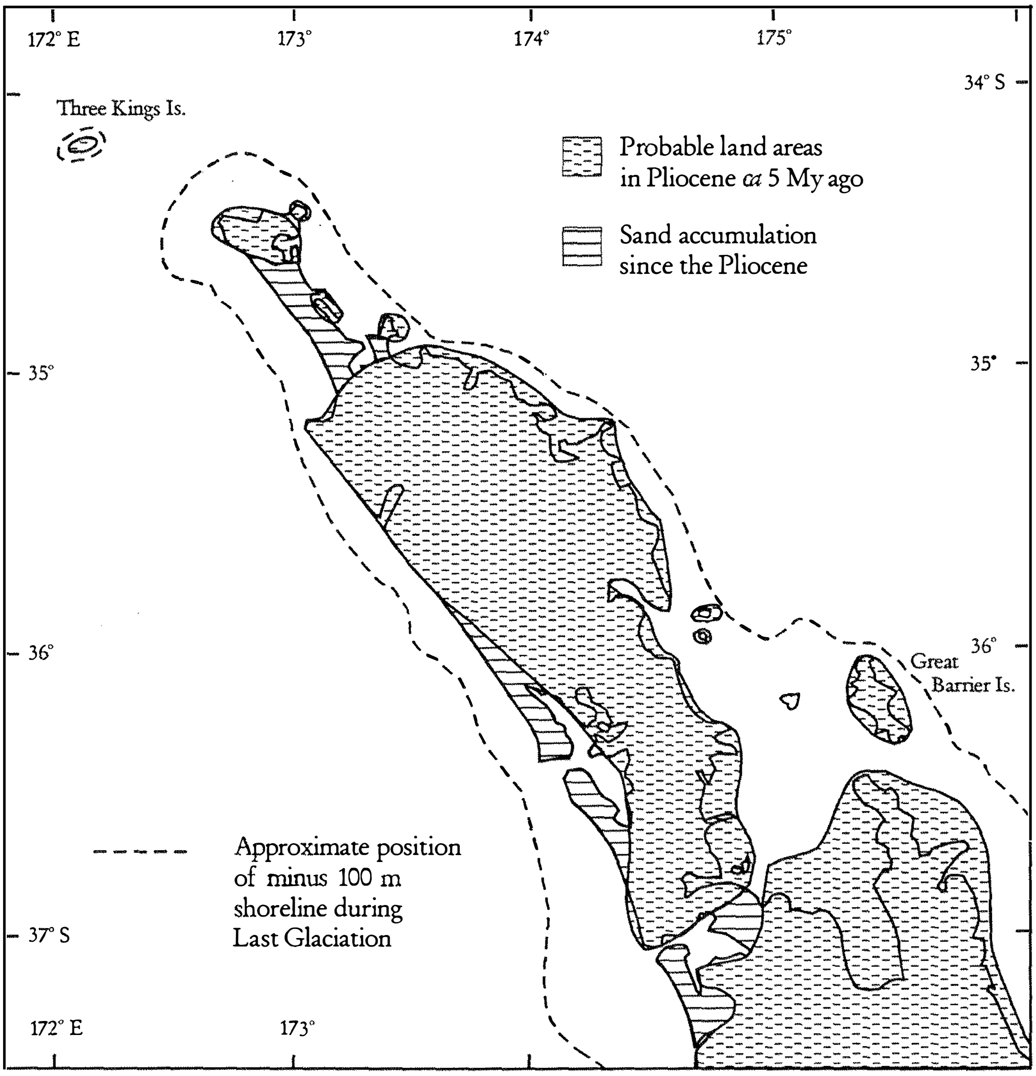


Figure 1.7 The linking of the "Northland Archipelago". After Fleming (1979), and Ballance and Williams (1982).

Present day vegetation

Prior to European clearance the vegetative cover of Northland was dominated by vast unbroken tracts of forest, although it is known that parts of Northland were deforested following Polynesian settlement (Dieffenbach, 1843; Matthews and Matthews 1940; Chester 1986). The largest remaining tracts of forest occur north of Whangarei. These include the Raetea, Herekino, Warawara, Omahuta-Puketi, Waipoua and Russell State Forests (Figure 1.8). Smaller but significant forest remnants occur throughout the peninsula, but are smaller and more scattered in the south. Northland forests are characterised by *Agathis australis* (kauri), a massive columnar tree with a huge spreading crown, belonging to the Araucariaceae, which attains heights of 30-60 m. Most forests are podocarp-broadleaved hardwood associations. They occupy a range of soils from leached clays and podzolised sands to more fertile soils developed over basalt, in alluvium or on colluvial slopes. Kauri occurs on infertile soils, mostly confined to spurs, ridges and high plateaux. The kauri association commonly includes the gymnosperms *Dacrydium cupressinum*, *Phyllocladus trichomanoides*, *Podocarpus hallii* and *P. totara*. *Halocarpus kirkii* and *Phyllocladus glaucus* may be locally common. Typical associated angiosperm hardwoods include *Beilschmiedia tarairi*, *B. tawa*, *Dysoxylum spectabile*, *Ixerba brexioides*, *Quintinia serrata* and *Weinmannia silvicola* (McKelvey and Nicholls, 1959). Kauri forests merge into valley-floor stands characterised by *Podocarpus totara*, *Prumnopitys ferruginea* and *P. taxifolia*, *Alectryon excelsus*, *Vitex lucens*, and on wet alluvial soils *Dacrycarpus dacrydioides* and *Laurelia novae-zelandiae*. Extensive forests without kauri occur on rolling clay uplands (Wardle, 1991).

A striking feature of New Zealand phytogeography is the occurrence of centres of endemism and disjunction. The northern half of the North Island (north of *ca* 39°S), the Nelson-Marlborough, and Otago-Southland regions form floristic centres with high proportions of endemic and disjunct species (Figure 1.9; McGlone, 1985; Wardle 1988). The areas between are characterised by relative floristic poverty. Approximately 95 species are endemic north of 38°S (Wardle, 1991). The majority of these are woody (*ca* 55%) and some 18% are tall trees (McGlone, 1985). They include *Agathis australis*, *Halocarpus kirkii*, *Beilschmiedia tarairi*, *Caldcluvia rosifolia*, *Ixerba brexioides*, *Planchonella costata*, *Toronia toru*, *Dracophyllum latifolium* and *Phebalium nudum*. The high proportion of endemic woody species in the northern centre contrasts markedly with the type of endemics in the more southerly regions and reflects the greater degree of woodiness of the northern flora as a whole (McGlone, 1985). In addition a number of taxa which are confined to the warmer parts of New Zealand have disjunct distributions and occur in the northern part of the South Island and north of 39°S, including

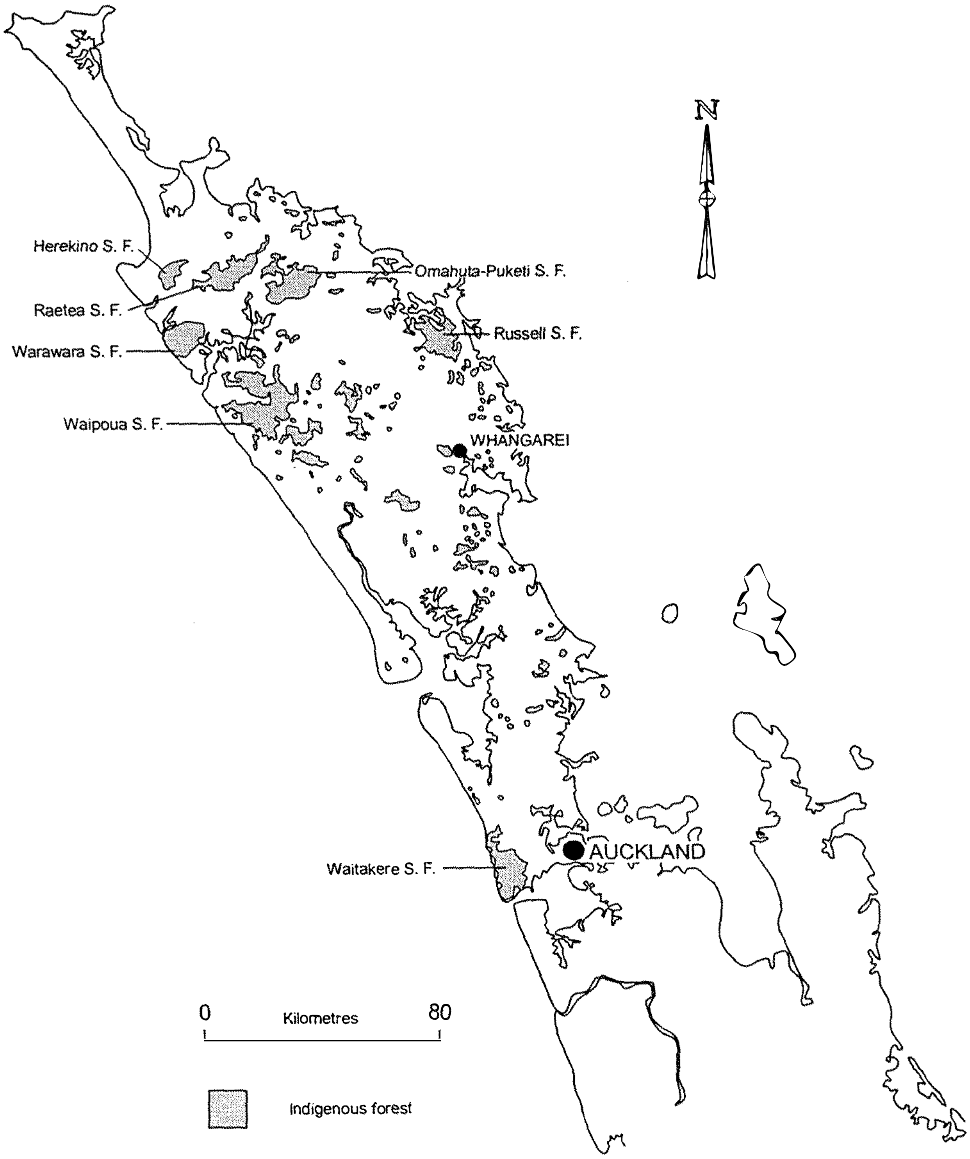


Figure 1.8 Indigenous forests in Northland today.

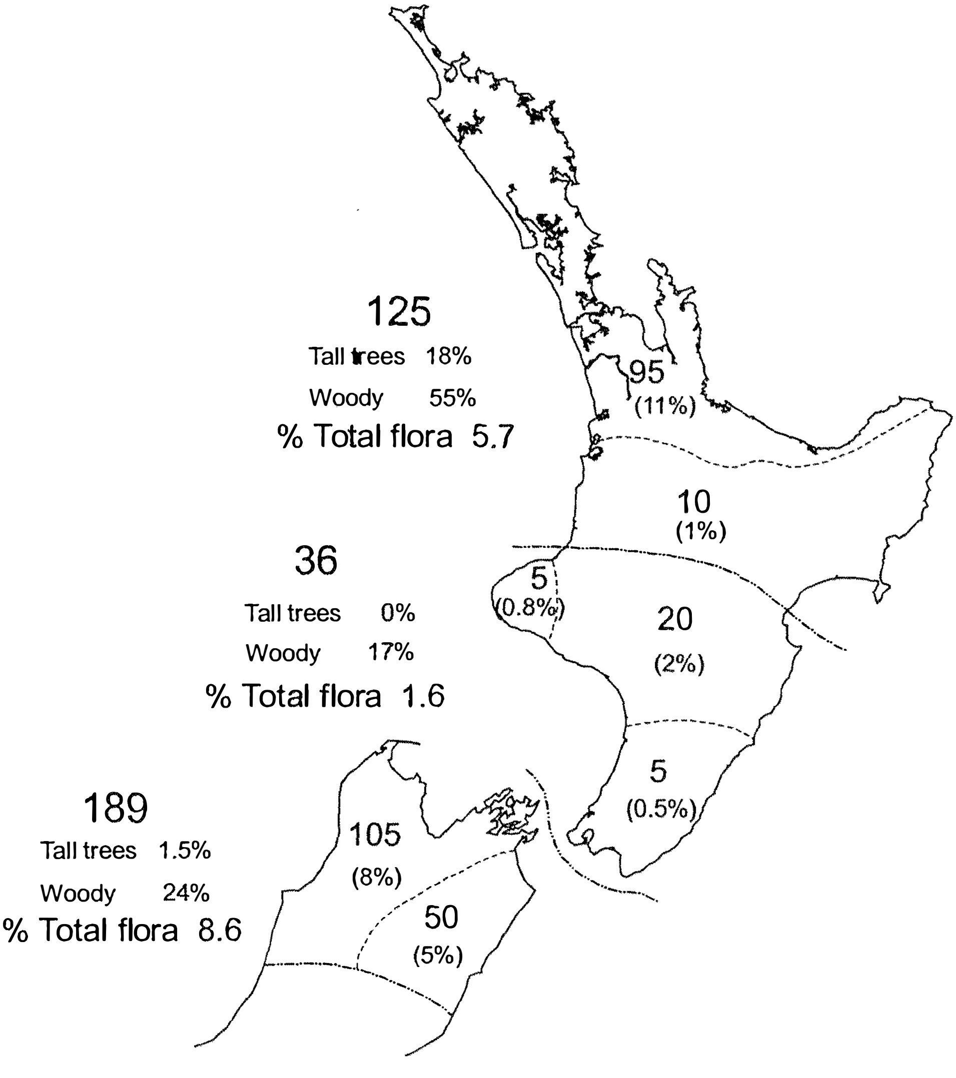


Figure 1.9 Floristic centres with high proportions of endemism in higher plants. The total number of endemics in each zone, and their percentage of the total flora of that zone are given. The zones are subdivided by dashed lines to give the numbers of endemics and their percentage of the total flora of the subzones. The figure is redrawn after McGlone (1985).

Libocedrus plumosa, *Phyllocladus trichomanoides*, *Lycopodium cernuum* and *Blechnum fraseri*.

One of the curious features of New Zealand forests is the distribution of *Nothofagus* species. *Nothofagus* distributions are characterised by extensive forest tracts where the species is dominant, often to the near exclusion of other trees (McGlone *et al.*, 1996). Generally the distribution patterns can be explained by their climatic and edaphic characteristics. However, there are a number of apparently suitable areas where *Nothofagus* is absent, or nearly so (Wardle, 1964, 1988; McGlone, 1985). These are the so-called "*Nothofagus* gaps", the most important of which are Stewart Island, the central Westland gap, the central Canterbury gap, the Manawatu gap, and Taranaki (Figure 1.10; McGlone *et al.*, 1996). There are scattered occurrences of *Nothofagus truncata* in Northland forests (Figure 1.11). Small stands of at most 2-3 acres exist in the Omahuta State Forest (Sexton, 1941), the Pekerau Valley to the south of Karikari Peninsula, and near the Ruakaka State Forest (MacDonald, 1984). Elsewhere in Northland scattered trees occur in the Waipoua State Forest and scenic reserves south of Whangarei (MacDonald, 1984; Wardle, 1984). Offshore, *Nothofagus truncata* and *N. solandri var. solandri* are recorded on Little Barrier Island (Mason and Preest, 1954; Wardle, 1984). The fossil record (Newnham, 1992; Kershaw and Strickland, 1988) suggests that *Nothofagus* in Northland may have been much more widespread in the past, but its occurrence and distribution are poorly defined.

The biogeography of New Zealand plants has attracted considerable scientific interest since the first detailed studies of the flora last century, and continues to the present. Explanations for the patterns of distribution of the higher plants have focused on the effects of climate change during the Last Glaciation (Wardle, 1963, 1988; Burrows, 1965), and long-term consequences of tectonism extending back into the Tertiary (McGlone, 1985). The fossil record indicates that forest cover was drastically reduced during the Last (Otiran) Glaciation (McGlone, 1988). The glacial refuge hypothesis states that prior to the LGM endemic and disjunct species had a wider, or more continuous distribution. When the expansion of ice during the LGM physically excluded plants from many regions it is theorised that plants tended to become concentrated in refugia. These refugia are thought to have occurred in scattered coastal locations of northern and southern South Island, with major refugia north of latitude 38-39° S (Wardle, 1963). Wardle (1963, 1988) argued that the effects of glaciation on the present distribution of the higher plants were profound. Following deglaciation plants moved southwards, upwards and outwards from

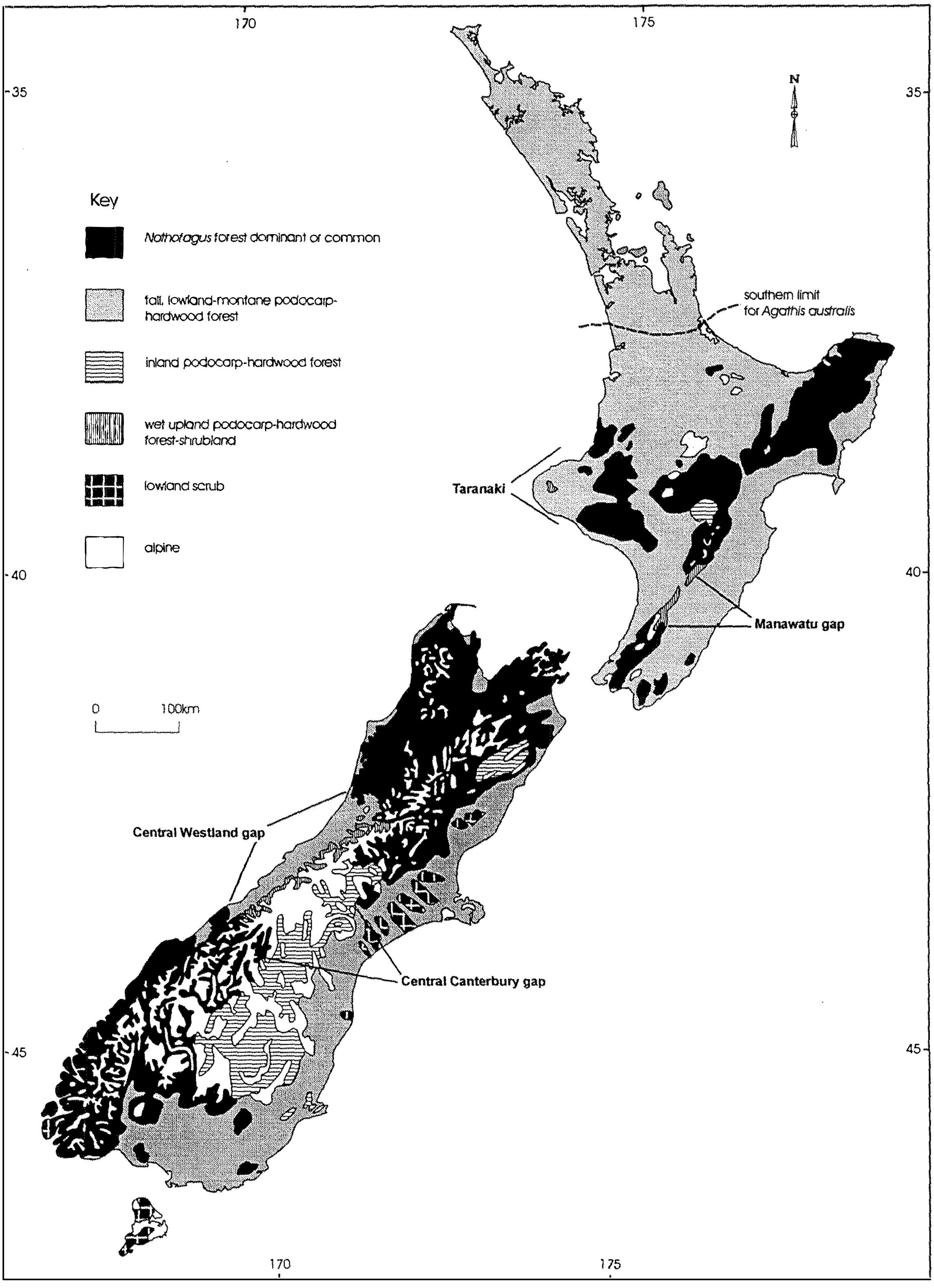


Figure 1.10 *Nothofagus* gaps (after McGlone *et al.*, 1996).

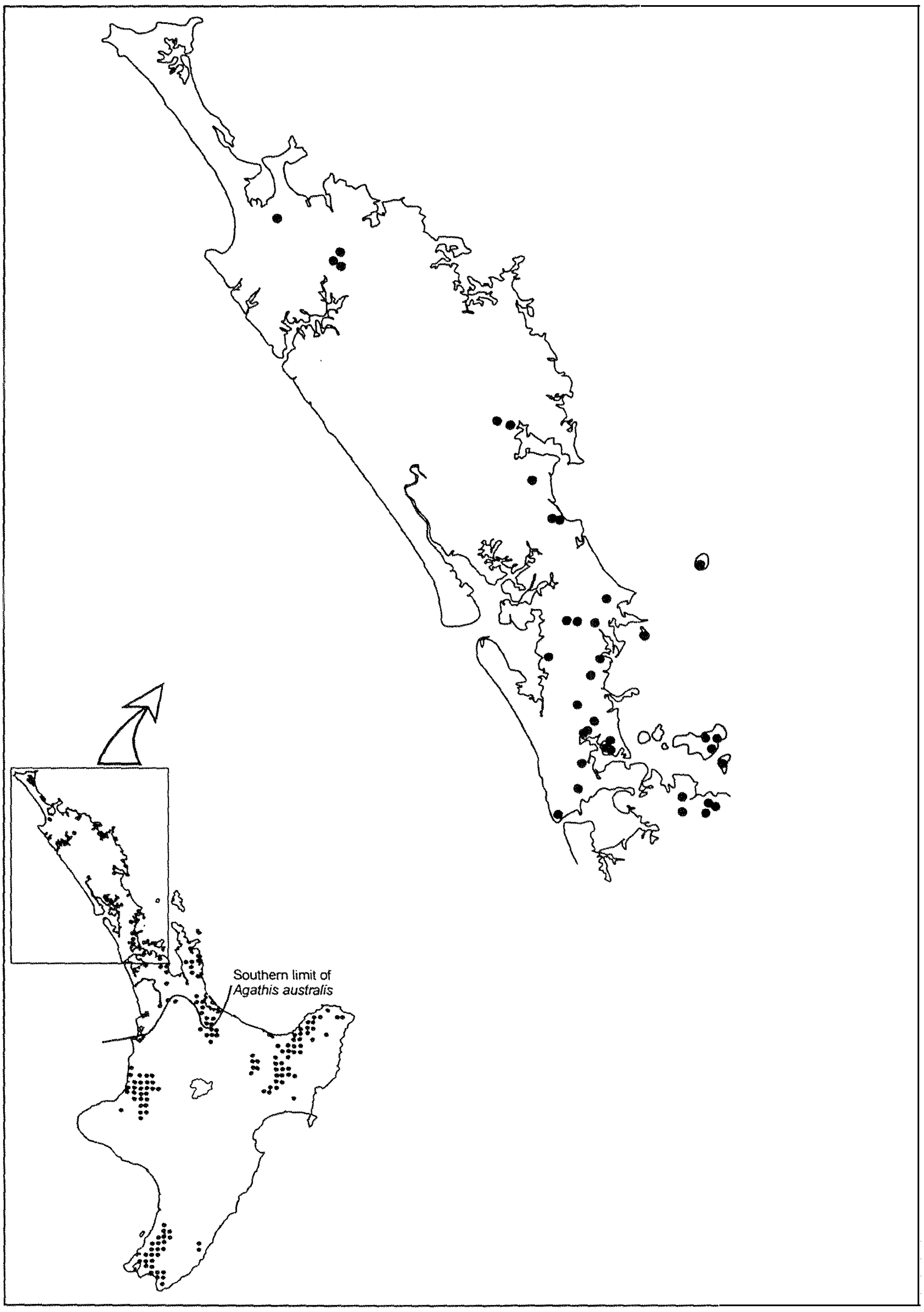


Figure 1.11 The distribution of *Nothofagus truncata* in North Island and Northland, New Zealand. Data sources from MacDonald (1984) and Wardle (1984).

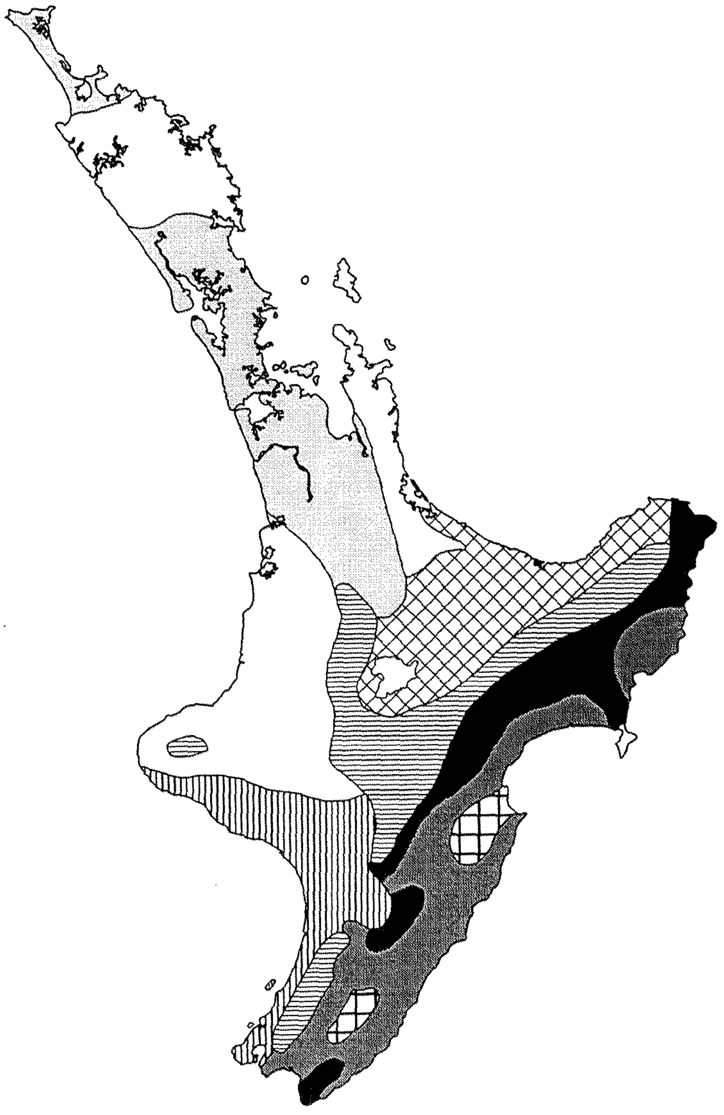
refugia. If this were so then Northland could have been a significant Holocene source of forest species. Wardle (1988) considers that physical constraints merely restrict the potential limits of plant distribution, and that actual distributions are influenced by biotic and stochastic factors. He further states that plant distributions which were consequent upon LGM climates persist at variance to the present environment. It is argued that the adjustment of vegetation to Postglacial environments is not yet complete because of discrepancies between Holocene environments and present plant distributions. Thus many plants are thought to still be in the process of spreading solely as an adjustment to Postglacial conditions.

The tectonic hypothesis (McGlone, 1985) proposes that floristic centres of endemism and disjunction originated in the latter part of the Tertiary as a consequence of tectonism which led to the isolation of the northern centre. Whilst anomalous and disjunct distributions reflect environmental constraints of the present day, McGlone (1985) argues that the explanation must be sought in the major geological events since the Miocene. In particular the movements of land following large scale tectonism, the fluctuations of sea level which resulted in the Plio-Pleistocene submergence of the lower half of the North Island, and the creation of new environments as a result of orogeny, both in the Southern Alps and the southern ranges of the North Island. In this way McGlone argues that the more stable areas, geologically, have retained more species than those areas subjected to inundation or habitat loss in more tectonically mobile regions.

The glacial hypothesis rests largely on the tenet that distribution patterns developed during the Otiran Glaciation are today expressed by patterns which are discordant with Postglacial environments (Wardle, 1988). Wardle argues that these patterns (Last Glacial and Postglacial) probably repeat similar plant distributions of earlier glaciations. Should the fossil record indicate that regional floras existed intact within their regions through the Otiran Glaciation, then the glacial refuge hypothesis will be brought into question.

Climate

Northland is characterised by a warm, humid and rather windy climate (Figure 1.12). Few extremes occur owing to the modifying effect of extensive adjacent oceans, the relatively low latitudes, and also the strong influence of the subtropical high pressure belt. The rainfall varies from *ca* 1100 mm yr^{-1} in coastal areas to 2500 mm yr^{-1} in upland areas (Figure 1.13). Most of this falls in the winter half year, while summers are usually dry, with soil moisture deficits between



A	░	Warm humid summers, mild winters. Annual rainfall 1000 mm to 1500 mm withmaximum in winter. Prevailing wind S. W., but occasional strong gales and heavy rains from E. or N. E. from Auckland northwards and about Coromandel.
A2	☐	Similar to A, but much wetter. Rainfall 1500 mm to 2400 mm.
B	▨	Sunny rather sheltered areas which receive rains of very high intensity at times from N. E. and N. Vedry warm summers and mild winters. Annual rainfall 1000 mm to 1800 mm withwinter maximum.
C	▒	Very warm summers, day temperatures occasionally rise above 32°C with dry foehn N. W. winds. Annual rainfall 1000 mm to 1500 mm; marked decrease in amount and reliability of rain in spring and summer. Moderate winter temperatures with maximum rainfall in this season.
CO	▦	Drier than type C; rainfall 600 mm to 1000 mm.
C2	■	Cooler and wetter hill climates. Very heavy rains at times from S. andS. E.; annual rainfall mainly 1500 mm to 2000 mm.
D	▥	W. to N. W. winds prevail with relatively frequent gales. Annual rainfall 900 mm to 1300 mm. Rainfall reliable and evenly distributed throughout the year. Warm summers, mild winters.
H	▤	High rainfall; mountain climates

Figure 1.12 Climatic zones of the North Island (after Tomlinson, 1976).

November and April for 55 days on average. Occasionally tropical cyclones reach Northland. Those that do and still retain very low pressures with hurricane force winds are rare. However, other storms of tropical origin affect Northland once or twice a year between December and April. They bring heavy rain and strong easterly winds (Moir *et al.*, 1986). Airflow is predominantly from the south-west, especially in winter and spring (Tomlinson, 1975). Summer and autumn winds from the easterly quarter are about equal in frequency to those of the south-west. This is due to the changing location of the high pressure belt which is further south during the summer and autumn months than at other times (Moir *et al.*, 1986). Most parts of Northland receive about 2000 hours of sunshine per year. This is fairly uniform throughout the region, and the mean monthly air temperatures range from 19.5°C to 10.5°C. Mean annual temperatures range from 14 - 15.5°C in the west and south to 15.5 - 16°C in the north and east (Figure 1.14). Winters are mild with many parts experiencing only a few shallow ground frosts each year, generally in sheltered inland areas (Moir *et al.* 1986).

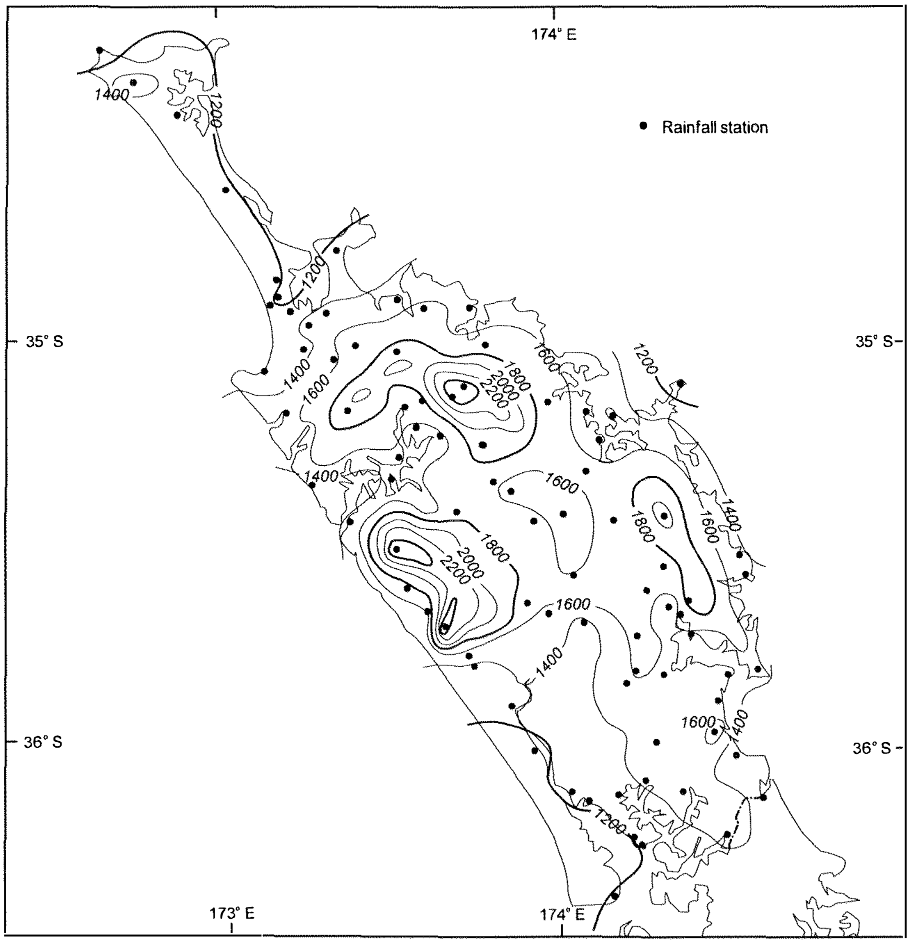


Figure 1.13 Mean annual rainfall, Northland, 1941-1970 (after Moir *et al.*, 1986)

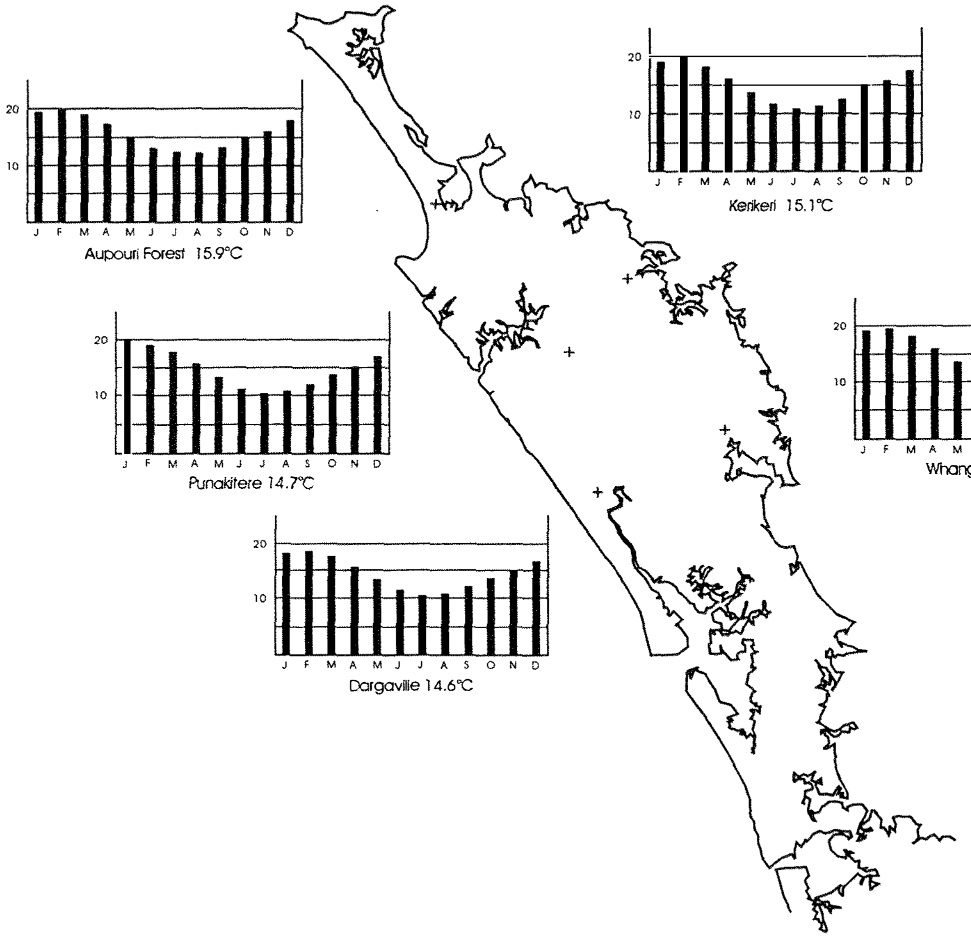


Figure 1.14 Northland mean monthly and mean annual temperatures at selected stations; data from temperature normals 1941-1970 (N. Z. Meteorological Service, 1978).

Approach to thesis

After this introductory chapter the thesis is organised in the following manner. Chapter 2 describes in detail the methodology employed in this study together with sampling strategies, taxonomic nomenclature and the approach used to estimate charcoal concentration and hence fire history. Justification of the pollen sums used is also given here.

In Chapter 3 surface samples of moss polsters and soils are analysed for their modern pollen rain. These data are compared to vegetation data in order to establish relationships between proportions of pollen taxa and their representation in various plant communities. These results may then be used to help interpret the fossil pollen records.

Chapters 4-6 are presented as papers which have either been published or accepted for publication in refereed journals. These papers derive from the FRST project "Identification of the location and date of first Maori colonisation of Northland and Auckland using palynological and sedimentological evidence for environmental change". Each of these papers presents the results of pollen analysis from a Holocene site in Northland together with sediment analyses for two of the sites (Lake Taumatawhana and Wharau Road Swamp). The contributions of my co-authors is clearly stated at the beginning of Chapter 4.

Chapter 7 is also presented as a published paper and describes a longer history from two cores from Kaitaia Bog. These records are truncated and have no late Holocene sediments which might preserve evidence of human impact. In Chapter 8 the two oldest records from this study are analysed. Although one of these cores (Lake Tangonge) is derived from Kaitaia Bog it is presented here with the Lake Ohia core for the following reasons. The Lake Ohia sequence lacks a well-defined chronology and is better discussed in conjunction with the Lake Tangonge record. The other Kaitaia Bog cores have shorter chronologies and are already published jointly (see Chapter 7). The long record for Lake Tangonge may be correlated by palynostratigraphy and interpretation of the pollen record to that of Lake Ohia, although it is likely that a hiatus exists between the two records. Correspondence analysis of the data and comparison of the Tangonge and Ohia pollen spectra with other Last Glacial records is made in order to assess the arguments for a Last Interglacial (Isotope Stage 5c-a) age for the Lake Ohia record and Last Glacial age for the Tangonge spectra.

A summary of conclusions from the preceding chapters of the late Quaternary vegetational and climatic history of far northern New Zealand is presented in Chapter 9.

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Chapter 2

METHODS

Core collection

Sediment cores at all swamp and bog sites were collected using a d-section Russian peat sampler (Jowsey, 1996). Where practical a transect was made across the site to ascertain the cross-sectional stratigraphy of the site. Those cores from lake deposits were recovered using a modified piston mud sampler (Walker, 1964) operated from a raft. In each instance the cores were examined and described in the field as they were collected, and then sealed in plastic electrical conduit trunking prior to return to cool storage at Massey University.

Dating

As there were no tephras observed in any of the cores used for pollen analysis, core chronologies were provided by radiocarbon dating, except where the age of material exceeded the limitations of that method. In these instances ages have been interpreted by correlation with dated sequences from other sources (*e.g.* Wright *et al.*, 1995). Samples of 0.05-0.06 m length were submitted to the Rafter Radiocarbon Laboratory, Institute of Geological and Nuclear Sciences, Lower Hutt for Accelerator Mass Spectrometry dating (AMS). These dates are presented in this thesis as conventional radiocarbon years uncorrected for secular variation.

Pollen analysis

The reconstruction of vegetation histories was derived using pollen analysis of lake and swamp/bog sediment sub-samples. These sub-samples were taken at intervals of 10 cm throughout the length of the core except where closer sampling was necessary and a 5 cm interval was used. Pollen samples were treated following the standard chemical preparation techniques of Moore *et al.* (1991), and Fægri and Iversen (1989):

1) Digestion in hot potassium hydroxide to remove humic materials and disperse the matrix, followed by sieving to remove coarse particulate matter.
2) Deflocculation of clay rich samples using sodium pyrophosphate.
3) Hydrochloric acid treatment to remove any traces of carbonate matter prior to hydrofluoric acid treatment.
4) Hydrofluoric acid treatment to remove siliceous matter.

5) Oxidation using chloric oxides as oxidising agents to remove lignin. The oxidation stage may cause swelling of palynomorphs, and therefore precedes acetolysis which partially reverses the swelling (J. Wilmshurst pers. comm. 1995), rather than the sequence suggested by Moore *et al.* (1991).
6) Acetolysis to remove cellulose.
7) Residues containing concentrated pollen are stained with basic fuchsin and mounted in glycerine jelly on glass microscope slides. Alternatively some samples were dehydrated using an alcohol series and mounted in silicone oil.

All fossil samples were spiked with exotic *Lycopodium* spore tablets for calculation of pollen concentration (Stockmarr, 1971).

Pollen and spores were identified and counted using a Zeiss Axiophot photomicroscope, and a Leitz light microscope, at 400 x and 450 x magnification respectively. Counting was made along traverses spaced so as to minimise the effects of differential settling of palynomorphs on the slide during mounting. A pollen sum of 200-300 dryland pollen and spores were counted at each depth.

The reference collection of New Zealand pollen and spores held in the Department of Geography, and a smaller collection held in the Herbarium in the Department of Plant Biology and Biotechnology at Massey University, were used to check and assist with identifications. In addition the following texts, *Pollen Grains of New Zealand Dicotyledonous Plants* (Moar, 1993), *New Zealand Pollen Studies: The Monocotyledons* (Cranwell, 1953), *Spore Atlas of New Zealand Ferns and Fern Allies* (Large and Braggins, 1991), and *A Manual of the Spores of New Zealand Pteridophyta* (Harris, 1955), were used extensively. Taxonomic nomenclature follows that of Allan (1961), Moore and Edgar (1976), and subsequent revisions made by Brownsey *et al.* (1985), Connor and Edgar (1987), Webb *et al.* (1988), and Molloy (1995). *Nothofagus* classifications follow Hill and Read (1991), and Hill and Jordan (1993). *N. fusca* type pollen species are designated *Fuscospora* after McGlone *et al.* (1996). It was not always possible to identify pollen and spores to the lowest taxonomic level as some types from the same family were too similar to differentiate between species. For this reason the following pollen types are recognised and are listed with their constituent taxa:

Leptospermum type	*L. scoparium, Kunzea ericoides*
Metrosideros undiff.	all New Zealand *Metrosideros* spp.
Neomyrtus type	*Neomyrtus* sp., *Lophomyrtus* spp.
Fuscospora	all *Nothofagus* spp. except *N. menziesii*
Podocarpus type	*P. hallii, P. totara*
Taraxacum type	all species in the tribe Lactuceae (Asteraceae)
Cyathea dealbata type	*C. dealbata, C. medullaris*
Cyathea smithii type	*C. smithii, C. colensoi*

Pollen counts are expressed as percentages of the pollen sum and as absolute concentrations. The dryland pollen sum includes all terrestrial pollen grains as well as terrestrial fern spores. This sum was chosen to provide a more complete picture of the surrounding vegetation. However, for the "Lake Tangonge" site the pollen sum excludes pteridophytes except for *Pteridium esculentum.* At this site the high raw counts for many of the ground ferns suggested inwash of spores was significant. This contention is supported by the corroded nature of many of the spores in the Tangonge profile. Pocknall (1980) showed fern spores to be erratically represented in his South Island studies because of a tendency to be abundantly produced, but poorly dispersed. The analysis of surface sample studies in Northland yielded similar results. In some instances ground ferns such as *Paesia scaberula* were extremely over-represented. Where fern spores were clearly extremely over-represented they were excluded from the pollen sum. In the three Holocene records from Taumatawhana, Wharau Road and Tauanui, ferns were included in the pollen sum because the prime objective of those studies was to identify human disturbance. Ferns are often implicated in regrowth following burning. The sites in the dune country of Aupouri Peninsula have consistent low frequencies for ferns suggesting they are not common in the local flora. Wetland pollen types such as Cyperaceae, Restionaceae, and *Typha* are poorly dispersed and tend to over-represent local taxa. They were excluded from the pollen sum because interest in the pollen record lies chiefly in the dryland taxa and the abundance of these wetland types tends to obscure dryland spectra.

Sample collection for modern pollen studies

A total of 15 surface samples was collected from different sites throughout Northland, chosen to reflect a variety of plant communities and associations. These included 11 moss polster samples, 2 surface soil samples, and 2 surface swamp samples. At the moss polster sites at least 6 sub-samples were collected from within 20 m^2 forest plots and combined to form a single sample. Only moss growing on level or near-level surfaces was collected, and always the thickest portions were taken as these could be expected to be most effective as pollen traps. No particular bryophytic species were sought as it has been demonstrated by Bradshaw (1981) that neither species or growth form of mosses has any significant influence on type or degree of deterioration of palynomorphs. Generally the mats were only *ca* 1 cm thick, so the entire depth of mat was collected. Although the time span over which these moss polsters have collected pollen cannot be determined, it can be assumed that their pollen assemblages represent several seasons/years of deposition. Thus their respective pollen spectra provide an average which reduces the effects of any annual or seasonal fluctuations in pollen production. The surface soil samples were collected from "unimproved" pasture sites from the top 1-2 cm of soil at a central position in a 5 m radius circular plot. The surface swamp sediment samples were collected from the top 1-2 cm of sediment adjacent to pollen cores studied from the Taumatawhana and Wharau Road Swamps.

In the laboratory, field samples were homogenised and a sub-sample taken which was broken down in a "Waring" commercial blender so as to provide a larger surface area for chemical attack during chemical preparation. Pollen analysis followed the same basic preparation techniques as for fossil pollen analysis (Moore *et al.*, 1991).

Charcoal analysis

Estimates of charcoal concentration are used to reconstruct fire histories and so complement pollen analytical studies on vegetation history (*e.g.* Singh *et al.*, 1981; Patterson *et al.*, 1987; Elliot *et al.*, 1995). A number of methods can be used to measure charcoal content in pollen samples (*e.g.* the point count method of Clark, 1982, and the nitric acid digestion method of Winkler, 1985). In this study the system used follows that of Bush *et al.* (1992). Microscopic charcoal fragments were counted across a centre traverse(s) of the pollen slide until at least 10 exotic *Lycopodium* spores had been counted. From these counts estimates of charcoal concentration could be calculated which are independent of the pollen data. By calculating these estimates as absolute data, misleading peaks of charcoal in samples which have low pollen concentrations can be avoided. A further source of confusion in charcoal records may occur where high concentrations of charcoal fragments coincide with periods of slow sediment accumulation. This could result in misleading peaks where sedimentation concentrates charcoal fragments resulting in ambiguous fire histories. This study takes a conservative approach to charcoal analysis. Regional and local fire histories are deduced on the basis of discernible effects on vegetation, and particle size distribution of charcoal fragments. Pollen-slide charcoal tends to be biased toward non-local charcoal. More than 90% of most pollen-slide charcoal is 5-20 μm in length and considered to be non-local (Patterson *et al.*, 1987). Patterson *et al.* have argued that "large" charcoal fragments remain closer to source than "small" fragments which are spread over a wider area. The theoretical work of Clark (1988) indicates that processes involved in charcoal transport serve to export pollen-slide charcoal away from the source area landscape. Fine pollen-slide charcoal (5-50 μm) may be derived from sources up to 100 km or more from the site of deposition (Clark, 1988).

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Chapter 3

RECENT POLLEN STUDIES

Introduction

Information gained from modern pollen rain studies has become routinely used in the interpretation of Quaternary fossil pollen records, and indeed is the first step towards reconstructing a vegetational history. Data from modern pollen studies is used to clarify relationships between relative frequency of pollen/spores and species abundance in the local vegetation allowing a more informed and accurate interpretation of the fossil pollen record. Proportions of taxa in pollen records are not assumed to correspond with vegetation percentages. This is because pollen spectra are known to be biased according to pollen production and dispersal (Prentice, 1985; Prentice and Webb, 1986). A number of models have been proposed to explain the pollen-vegetation abundance relationship and pollen source area (*e.g.* Davis, 1963; Tauber 1965, 1967; Jacobson and Bradshaw 1981; Prentice, 1985; Sugita, 1993, 1994). Whilst traditional interpretation of pollen frequencies which assumes a linear relationship between pollen and tree abundance is still the first choice approach in Quaternary pollen analysis (Prentice and Webb, 1986), most New Zealand contemporary pollen rain studies have shown that given proportions of pollen taxa do not bear a linear relationship to their representation in the vegetation (McGlone and Wilson, 1996). This chapter seeks to establish the relationships between various plant communities in Northland and their respective contemporary pollen rain. Pollen rain has been variously described but for most purposes can be defined as pollen sedimentation from the air, either as true "rainout" where pollen grains are already contained in cloud droplets, as "washout" due to scavenging of the air as rain falls, or as airfall deposition by gravitational settling (Tauber, 1965). The importance of pollen transport by wind above the canopy is emphasised by Prentice (1985, 1988).

Little information on the relationship between recent or modern pollen deposition and the contemporary vegetation of New Zealand existed prior to the work of Moar (1970, 1971), Dodson (1976), Pocknall (1978, 1980, 1982), Macphail (1980) and McGlone (1982). Few modern pollen studies have been published since, other than Bussell (1988), Randall's (1990, 1991) studies in the Southern Alps of the South Island, Horrocks and Ogden's (1992) study of Mount Hauhungatahi, Central North Island, and most recently the Stewart Island study of McGlone and Wilson (1996). None of these papers examines the modern pollen rain of Northland, and only Newnham's unpublished work (1990) from Waipoua State Forest and Chester's (1986) Bay of Islands study examine northern forest sites in any detail. Generally these studies have involved the analysis of surface samples and this study continues that tradition. Carroll (1943) demonstrated the value of bryophytic polsters and mats for analysing recent pollen deposition, concluding that the relative proportions of pollen types trapped were similar regardless of moss species. Boyd (1986) showed that, providing the establishment of absolute quantities of pollen is not the primary interest, mosses are useful indicators of pollen rain. Others have also successfully used surface soils and litter (*e.g.* Crowley *et al.*, 1994; Kershaw and Bulman, 1994).

The study sites

The sites chosen for this study (Figure 3.1, Table 3.1) are intended to reflect a wide variety of plant communities, particularly forest types, to provide modern analogues for vegetation reconstruction work.

1. Rangitoto Island

Rangitoto Island is characterised by its rocky, poorly developed soils which have limited water-holding capacity. Kirk (1879) described conditions for plant life on Rangitoto as antagonistic. The pohutukawa (*Metrosideros excelsa*) forest site is characteristic of most of the vegetated parts of Rangitoto Island, and is a unique community in the present day flora of New Zealand. Dominated by *Metrosideros excelsa*, other important elements include *Griselinia lucida*, *Myrsine australis* and *Melicytus ramiflorus*. Less common, woody species include *Dodonaea viscosa*, *Knightia excelsa*, *Leucopogon fasciculatus*, *Leptospermum scoparium*, *Kunzea ericoides*, *Olearia furfuracea*, and *Pomaderris phylicifolia* (Kirk, 1879; Lidgard, 1960). Podocarps are absent. The sample site lies in the vicinity of McKenzie Bay, and the vegetation there broadly reflects that found throughout the island which supports more than 200 indigenous species (Kirk, 1879).

2. Omaha Kahikatea Forest

Kahikatea (*Dacrycarpus dacrydioides*) forest is much less common than it was formerly (Wardle, 1974; Beever, 1981), when it was abundant in many coastal areas and inland river valleys. The only large stands remaining in New Zealand are found in South Westland (Wardle, 1974). At Omaha, kahikatea forest forms a band some 1.5 km long and up to 200 m wide, and is recognised as the only remaining unmodified site of its type in Northland (K. Parnell, pers comm. 1992). It can be compared to the dense podocarp type L3 of McKelvey and Nicholls

(1959), and is dominated by *Dacrycarpus dacrydioides*, along with lesser amounts of *Dacrydium cupressinum*, *Vitex lucens*, *Beilschmiedia tarairi* and *Corynocarpus laevigatus*, as well as sub-canopy taxa such as *Rhopalostylis sapida* and *Cordyline australis.*

3. Orere Reserve

The Orere Reserve site near Kamo, Whangarei, is a podocarp-hardwood mosaic dominated by *Podocarpus totara*, most closely related to type E1 of McKelvey and Nicholls (1959). Other common canopy trees include *Beilschmiedia tarairi*, *Dysoxylum spectabile*, and *Vitex lucens*, with lesser amounts of *Metrosideros robusta*, *Dacrycarpus dacrydioides*, *Corynocarpus laevigatus* and *Knightia excelsa.* The sub-canopy includes numerous tree ferns, mainly *Cyathea medullaris* and *C. dealbata*, and small trees or shrubs such as *Melicytus ramiflorus*, *Macropiper excelsum*, *Coprosma arborea*, *Rhopalostylis sapida*, *Cordyline australis*, and *Myrsine australis.*

4. Lake Tauanui

The site at Lake Tauanui lies on a small island in the lake. Forest at this site is comparable to the podocarp-hardwood type E1 of McKelvey and Nicholls (1959). *Vitex lucens* and *Knightia excelsa* dominate, with significant amounts of *Beilschmiedia tarairi*, and *Metrosideros robusta* as small lianes. The sub-canopy is mostly made up of *Rhopalostylis sapida*, *Myrsine australis*, *Melicytus ramiflorus*, occasional *Dysoxylum spectabile*, and many young poles of *Podocarpus totara.* The understorey also includes *Macropiper excelsum*, and many young seedlings of the above species. Tree ferns include *Dicksonia squarrosa* and *Cyathea medullaris.*

5 & 6. Puketi State Forest

The two sites within the Puketi State Forest are representative of type B1 of McKelvey and Nicholls (1959), *i.e.* kauri-podocarp-hardwood forest. *Agathis australis* (kauri) is common throughout in small clumps or as widely spaced single trees. Associated with it are an assortment of locally frequent taxa including *Weinmannia silvicola*, *Beilschmiedia tarairi*, *Podocarpus hallii*, *P. totara*, *Prumnopitys ferruginea*, *P. taxifolia*, *Phyllocladus trichomanoides*, *Dacrydium cupressinum*, *Hedycarya arborea*, and tree ferns *Dicksonia squarrosa*, *Cyathea dealbata* and *C. medullaris.*

McKelvey and Nicholls (1959) describe unexploited, dense kauri forests still extant in Northland as being present in the Omahuta-Puketi, Herekino, and Warawara State Forests as well as the Waipoua Forest sanctuary. These they define as type A1 forests, nearly all of which occur above 300 m.

7. Warawara State Forest

The remote uplands of Warawara State Forest are typified by dense stands of mature kauri, many of which are stunted or stag-headed. In places these trees reach heights of 35-45 metres, forming an almost complete canopy. Below is usually a tier of smaller diameter podocarps, mainly *Prumnopitys ferruginea*, *Dacrydium cupressinum*, and *Phyllocladus trichomanoides*. The sub-canopy consists of a varied assemblage of poles up to 10 m. The commonest species are *Weinmannia silvicola*, *Beilschmiedia tarairi*, *B. tawa*, *Knightia excelsa*, *Elaeocarpus dentatus*, *Quintinia serrata*, and *Coprosma* sp. Although this forest mosaic is defined as a type A1 by McKelvey and Nicholls (1959), the forest plot site at Warawara more closely resembles type B1 with kauri locally absent.

8. Waipoua State Forest

The Waipoua site is dominated by large kauri and *Beilschmiedia tarairi*. *Weinmannia silvicola* and *Prumnopitys ferruginea* are locally common. Other sub-canopy species include *Dysoxylum spectabile*, *Caldcluvia rosifolia*, *Cordyline australis*, *Pseudopanax ferox*, *P. crassifolius*, and numerous tree ferns including *Dicksonia fibrosa*, *D. squarrosa* and *Cyathea dealbata.*

9, 10 & 11. Omahuta State Forest

The other three sites lie in the Omahuta State Forest which forms part of the Omahuta-Puketi conjoint forests. In the more inaccessible upland parts the forests are the type A1 associations of McKelvey and Nicholls (1959). In addition to the previously mentioned taxa, *Halocarpus kirkii* may sometimes be prominent in the upper tier and in the sub-canopy, *Ixerba brexioides* and *Toronia toru* are locally common. The more accessible areas which have been logged over have forest of type B1. The site at the Kauri Sanctuary is dominated by large mature kauri. Canopy species are comprised of *Podocarpus totara*, *Prumnopitys ferruginea*, *Beilschmiedia tawa* and *Elaeocarpus dentatus*. The sub-canopy includes *Caldcluvia rosifolia*, *Toronia toru*, *Coprosma lucida*, *Myrsine australis*, and *Leucopogon fasciculatus*. *Dicksonia squarrosa* is common, as is the climber, *Freycinetia baueriana*. *Metrosideros robusta* is present on some trees as a liane. The other sites, near the junction of the two main tributaries of the Pukekohe Stream, form part of an association which is now rare in Northland. This is the kauri-hard beech (*Nothofagus truncata*)

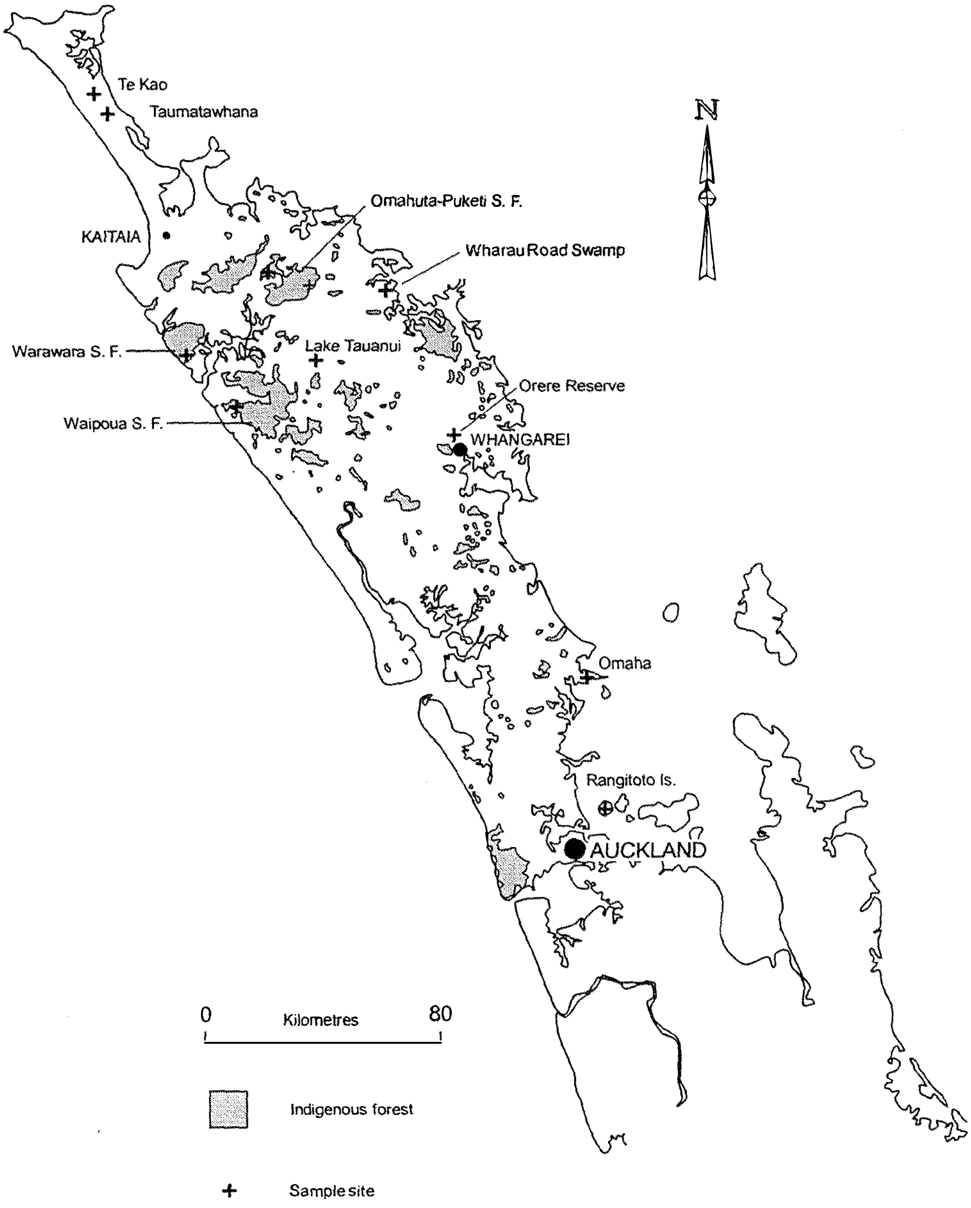

Figure 3.1 Modern pollen sample sites in northern New Zealand.

Table 3.1. Site Locations and their plant communities.

Site Location	Grid Reference[a]	Altitude[b]	Vegetation Type
Rangitoto Island	R11/739885	5	Pohutukawa forest
Omaha	R09/695387	5	Kahikatea forest
Orere Reserve	Q06/274127	160	Podocarp-hardwood forest
Lake Tauanui	P06/887332	230	Podocarp-hardwood forest
Puketi State Forest 1	P05/830653	300	Kauri-podocarp-hardwood forest
Puketi State Forest 2	P05/837664	300	Kauri-podocarp-hardwood forest
Warawara State Forest	O05/365423	240	Kauri-podocarp-hardwood forest
Waipoua State Forest	O06/616166	100	Kauri-podocarp-hardwood forest
Omahuta State Forest 1	O05/676623	320	Kauri-podocarp-hardwood forest
Omahuta State Forest 2	O05/665621	200	Kauri-beech -podocarp-hardwood forest
Omahuta State Forest 3	O05/666618	180	Kauri-podocarp-hardwood forest
Taumatawhana 1	N03/128204	60	*Typha-Eleocharis* swamp
Wharau Road	P05/052635	15	*Typha-Eleocharis* swamp
Te Kao	N03/098261	40	Grassland-shrubland
Taumatawhana 2	N03/128204	50	Grassland-shrubland

[a] NZMS 260 1:50,000 series; [b] metres above sea level

Plate 3.1 Rangitoto Island, McKenzie Bay

Plate 3.2 Omaha Kahikatea Forest

Plate 3.3 Orere Reserve, Whangarei

Plate 3.4 Lake Tauanui

Plate 3.5 Puketi State Forest Headquarters

Plate 3.6 Puketi State Forest, Manginangina Scenic Reserve

Plate 3.7 Warawara State Forest

Plate 3.8 Omahuta State Forest, Kauri Sanctuary

Plate 3.9 Omahuta State Forest, Pukekohe Stream, West Bank Site

Plate 3.10 Te Kao Grassland-shrubland Heath

Plate 3.11 Taumatawhana Swamp

Plate 3.12 Wharau Road Swamp

forest, type C1. Only a few stands of this type remain north of Auckland (Wardle, 1984), and the largest of these are in Omahuta and adjacent hinterland (Sexton, 1941). The first of these sites, on the west side of the Pukekohe Stream, contains no hard beech, but consists of an angiosperm canopy dominated by *Weinmannia silvicola*, *Knightia excelsa*, *Dysoxylum spectabile*, and *Caldcluvia rosifolia*. *Hedycarya arborea* is common, and numerous northern rata (*Metrosideros robusta*) vines are present, some up to 0.5 m in girth. Understorey species include *Rhopalostylis sapida*, and tree ferns, *Cyathea medullaris* and *Dicksonia squarrosa*. The east bank site is dominated by hard beech and *Weinmannia silvicola*. *Caldcluvia*, *Beilschmiedia tawa*, *Podocarpus hallii*, *Phyllocladus trichomanoides* and *Hedycarya arborea* are common. *Agathis australis* and *Elaeocarpus dentatus* are also present, and the understorey includes *Olearia rani* and *Cyathea dealbata*.

12 & 13. Taumatawhana and Te Kao Grassland-shrublands

The grassland sites at Taumatawhana Pa and Te Kao are typical of the Aupouri Peninsula where only isolated pockets of indigenous forest remain. They consist chiefly of a variety of introduced herbs such as *Anthoxanthum odoratum*, *Axonopus affinis*, *Agrostis capillaris* and *Pennisetum clandestinum*, and scattered shrubs such as *Leptospermum scoparium*, *Kunzea ericoides*, *Leucopogon fraseri*, *Coprosma* sp. and *Pomaderris phylicifolia*. The Taumatawhana site lies within an historic reserve, and the Te Kao site lies in an open field of unimproved pasture.

14 & 15. Taumatawhana and Wharau Road Swamps

Swamps are widespread throughout Northland. The Taumatawhana and Wharau Road swamps are typical, dominated by *Eleocharis acuta* and *Typha orientalis*. *Cordyline australis*, *Leptospermum scoparium*, and *Coprosma tenuicaulis* are common, but nowhere dominant, and *Phormium tenax*, though present is not abundant. At Taumatawhana, *Gleichenia dicarpa* and *Blechnum minus* are common.

Vegetation sampling

The complex nature of vegetation and its continuity across the landscape necessitates a degree of selectivity in the gathering of data. Complete enumeration and description of any plant community is quite impractical and consequently the sorts of data and where it is gathered from assume great importance. Merely listing species does not allow any exploration of the functioning of the vegetation, and therefore some measure of abundance of each species present is also required (Kellman, 1975). The choice of method rests, ultimately, on its applicability to the vegetation being studied, and there is no single appropriate method for each situation.

Forest sampling

There are a number of different methods which have been used for surveying forest vegetation, and each has its advantages and disadvantages. These include various plotless distance methods such as the nearest neighbour method of Cottam and Curtis (1949), and a modification of this, the point centred method (Cottam and Curtis, 1956); the Bitterlick variable-radius method (Bitterlick, 1948); and the random pairs method (Greig-Smith, 1964). A further plotless method for vegetation surveys, the point quadrat method, was introduced by Levy and Madden (1933), but as this is only really of use in grassland it was not further considered here.

In order to make comparisons between vegetation composition and pollen production of forest tree taxa, data on density and frequency are required, and the plotless method is not considered appropriate (Morley, 1976). Mark (1963) has shown that in analysis of New Zealand forest vegetation the plotless methods underestimate density values when compared with quadrat data. Consequently the method chosen is one involving plots and the tallying of data in an area of vegetation which is thought to be large enough to contain all the necessary elements of the vegetation under study.

The dominance of individual trees is related to bulk, which can be illustrated by a number of parameters *e.g.* tree height, basal area, total weight, foliage weight *etc.* Of these, height and basal area can be measured non-destructively. Basal area is thought to be more proportional to tree foliage which is thought to be most closely correlated with total pollen production of a tree (Ogawa *et al.*, 1965 in Morley 1976), and therefore dominance can be estimated from basal area measurements. The measure also takes account of the higher pollen production of bigger trees (Davis and Goodlett, 1960).

Considerable debate exists over the size and shape of plots that should be used, but frequently the choice has to be decided arbitrarily owing to site specific factors such as slope and non-uniformity of terrain. The forest sites sampled were surveyed using 20 x 20 m quadrats which were selected using random numbers in areas assessed as being representative of the forest association. The girth at breast height of all taxa exceeding 30 cm was recorded along with species' name.

Non-forest sampling

The survey of the swamp flora posed some difficulties as far as the choice of survey method was concerned. None of the plotless methods was considered appropriate, and the quadrat method used in the forest sites was also inappropriate. Other methods employed in non-forest vegetation also had many disadvantages in their implementation under swampy conditions. Eventually it was decided to use a system of estimating cover abundance based on field observations of the sample site. The method is simple and rapid in application. Although the method is one of subjective estimation and is necessarily general, its application has been successfully used by other palynologists (*e.g.* Maloney, 1979). A plot size of 10 x 10 m at each site was chosen by the random number method in the study area where core samples for fossil pollen analysis had been recovered (Figure 5.1 and 6.1).

The herb flora of the grassland-shrubland sites at Taumatawhana and Te Kao was surveyed in a different manner. Three chief methods have been used to sample herb flora: the use of quadrats, the line intercept method (Canfield, 1941), or the point intercept method (Levy and Madden, 1933). In this study it was felt important to have as complete a representation of the local species diversity as possible. Thus the line intercept method of Canfield (1941) is considered to be most appropriate for the purposes of this type of study (Bush, 1986). Tauber (1965) suggested that the majority of herb pollen will be deposited within 5 m of its source, so the sampling site was based on a radius of 5 m from a central randomly selected point. Eight radiating transect lines aligned to the major points of the compass of 5 m length were measured out, and all contacts of stem, leaf, pinnule, or flower along each line were recorded for each 0.5 m unit.

RESULTS

In the following section the values in parentheses represent percentages of total basal area of taxa > 30 cm in girth at breast height, and those in square brackets the percentage of the pollen sum for that taxon. Comparative sets of data relating pollen and spore frequency to basal area for tree types are summarised in Table 3.2 and Figure 3.2; those for swamp plants in Table 3.3 and 3.4; and those for grassland-scrub taxa in Table 3.5 and 3.6. The pollen diagrams are shown in Figure 3.3a, 3.3b and 3.3c as percentage data.

Forest Plots

Omahuta State Forest Site 1, Kauri Sanctuary

The Kauri Sanctuary site is on an elevated plateau, and is dominated by *Agathis australis* (83.7). These kauri are large, mature trees with girths of 7-7.5 m. Few other mature forest trees are present at this site, only *Podocarpus totara* (6.9), *Prumnopitys ferruginea* (4.8) and *Elaeocarpus dentatus* (1). Sub-canopy trees comprise *Caldcluvia rosifolia* (0.3), *Toronia toru* (0.1), and the tree fern *Dicksonia squarrosa* (0.6). At lower levels there are abundant *Coprosma lucida*, *Leucopogon* *fasciculatus*, *Freycinetia baueriana* and *Astelia trinervia*. *Myrsine australis*, *Olearia rani*, and seedlings of *Caldcluvia* and *Elaeocarpus* are common.

The most notable feature of the pollen spectrum is the poor representation of *Agathis* [27], even though it is anemophilous and by far the most dominant tree. Significant amounts of *Dacrydium cupressinum* [11.9] are recorded, in spite of its absence from the site. *Podocarpus* [7.8], and *Elaeocarpus* [0.6] are more or less proportionally represented, while *Prumnopitys* [3.2] is under-represented. Canopy species not recorded at the site, but present in the pollen spectrum, include *Halocarpus* [2.4], *Knightia excelsa* [1.1], *Metrosideros* [2.2] and *Phyllocladus* [2.8]. Tree ferns, *Cyathea* [5.7] and *Dicksonia squarrosa* [4.7], tend to be somewhat over-represented, but these species are common in the adjacent forest.

Omahuta State Forest Site 2, Pukekohe Stream

This site is a damp location adjacent to the stream. The canopy is dominated by angiosperm trees, particularly the Cunoniaceae species *Weinmannia silvicola* (29.3) and *Caldcluvia rosifolia* (19.4). Other common trees include *Dysoxylum spectabile* (9.8) and *Knightia excelsa* (12.3). Lesser amounts of *Beilschmiedia tarairi* (2.3), *Hedycarya arborea* (2.2), *Rhopalostylis sapida* (2.5) and *Metrosideros robusta* (2.8) as strangling lianes, were recorded. Tree ferns, *Cyathea medullaris* (16.4) and *Dicksonia squarrosa* (3.1), are abundant.

Of the angiosperm pollen types, only Weinmannia [29.7] is proportionately represented. Most are either very under-represented *e.g.* *Caldcluvia* [3.2] and *Dysoxylum* [0.3], or not recorded at all, *e.g.* *Beilschmiedia*, *Hedycarya* and *Rhopalostylis*. *Metrosideros* [3.5] is slightly over-represented. Numerous pollen types are recorded in significant amounts though not present at the site. The principal examples are *Nothofagus* [7.8], *Phyllocladus* [4.7], *Podocarpus* [2.6], *Prumnopitys* [2.9] and *Cyathea smithii* type[2.1]. *Cyathea dealbata* type [63.4] is extremely over-represented.

Omahuta State Forest Site 3, Pukekohe Stream

Located on a steep spur, this site is about 20 metres above the Pukekohe Stream and about 100 metres from site 2. The dominant canopy tree is *Nothofagus truncata* (61.5), with *Agathis* (2.5) and *Podocarpus hallii* (7) also present. The sub-canopy is dominated by *Weinmannia* (14.1) and *Caldcluvia* (5), with *Hedycarya* (2), *Phyllocladus* (0.6) and *Elaeocarpus* (1.7). Lesser amounts of *Olearia rani* (0.5) and *Cyathea dealbata* (1.5) contribute to the understorey.

Fuscospora [72.2] is clearly the chief pollen type, being slightly over-represented. *Weinmannia* [2.2] is very under-represented, as is *Podocarpus hallii* [1.5] and *Agathis* [0.9], whilst *Caldcluvia* is not recorded at all. *Phyllocladus* [2.2] is over-represented, and other podocarp trees, though not present at the site, record low frequencies. *Cyathea dealbata* type is very over-represented.

Warawara State Forest

The Warawara site is dominated by *Beilschmiedia tarairi* and *B. tawa* (16.1), *Phyllocladus trichomanoides* (14.9), *Knightia* (11.9) and *Prumnopitys ferruginea* (6.8). *Weinmannia silvicola* (9.4) dominates the sub-canopy along with *Olearia rani* (2.9), and *Pseudopanax ferox* (0.7). *Coprosma arborea* (24.5) is the dominant understorey taxon contributing significantly to the total basal area of the plot, and *Dicksonia fibrosa* (11.9) is also abundant. *B. tarairi* and *B. tawa* saplings are common.

Phyllocladus pollen [88.2] swamps the palynoflora and is extremely over-represented, whilst *Beilschmiedia*, *Prumnopitys* and *Olearia* are not recorded. *Knightia* [0.4], *Coprosma* [7.4] and *Weinmannia* [0.1] are extremely under-represented. Of the tree ferns, *Cyathea dealbata* type [9.3], though abundant, is not present at the site and *Dicksonia fibrosa*, though common on site, is not recorded.

Puketi State Forest, Headquarters Site

The forest at this site is dominated by *Weinmannia silvicola* (37) in a well aspected locality near the margin of the forest. There are appreciable amounts of *Podocarpus hallii* and *P. totara* (13.3), *Cyathea dealbata* (11.7), *Prumnopitys ferruginea* (9.3), *Dacrydium cupressinum* (9.2), *Dysoxylum spectabile* (8.2) and *Hedycarya arborea* (4.9). Scattered individuals of *Beilschmiedia tawa* (1.8), *Coprosma arborea* (2), *Dacrycarpus dacrydioides* (1.4), *Olearia arborescens* (0.5) and *Rhopalostylis sapida* (0.6) occur. The forest floor cover consists of numerous seedlings of the above as well as various ground ferns such as *Blechnum* sp. and *Asplenium* sp., including *A. bulbiferum* and *A. polyodon.*

The most notable feature of the pollen spectrum at this site is the poor representation of *Weinmannia* [7.7], even though it is the chief taxon. *Prumnopitys ferruginea* [0.3] is also very under-represented. This may in part be due to over-representation of *Phyllocladus* [16.5], *Knightia* [4.3] and *Metrosideros* [5.8], (which are absent from the site but present nearby), *Cyathea dealbata* type [26.6] and *Dacrydium* [19]. Ferns, many of which were either forest floor species or not large enough to be included in the basal area measurements, comprise a third of the total pollen sum. *Podocarpus* [7.8] is under-represented, while *Coprosma* [3.8] is slightly over-represented, and *Rhopalostylis* [0.6] is proportional. *Dysoxylum*, *Hedycarya* and *Beilschmiedia* are not recorded.

	Omahuta 1		Omahuta 2		Omahuta 3		Warawara		Puketi 1		Puketi 2		Waipoua		L. Tauanui		Orere Res.		Omaha		Rangitoto Is.	
	B. A.	**P. %**	**B. A.**	**P. %**	**B. A.**	**P. %**	**B. A.**	**P. %**	**B. A.**	**P. %**	**B. A.**	**P. %**	**B. A.**	**P. %**	**B. A.**	**P. %**	**B. A.**	**P. %**	**B. A.**	**P. %**	**B. A.**	**P. %**
Agathis	83.7	27.0	-	2.6	2.5	0.9	-	0.2	-	1.7	75.9	14.0	87.9	35.3	-	-	-	0.3	-	0.3	-	0.3
Beilschmiedia	2.7	-	2.3	-	3.4	-	15.8	-	1.8	-	-	-	6.2	-	9.7	-	2.9	-	-	-	-	-
Caldcluvia	0.3	-	19.4	3.2	5.0	-	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	-	-
Corynocarpus	-	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	0.4	1.9	-	11.7	1.7	-	-
Dacrycarpus	-	0.6	-	2.0	-	0.7	-	0.2	1.4	1.2	-	2.8	-	1.1	0.7	0.8	-	1.0	42.3	27.3	-	-
Dacrydium	-	11.9	-	2.0	-	0.5	-	0.5	9.2	19.0	-	13.1	-	2.0	-	3.1	-	-	-	4.7	-	1.1
Dysoxylum	-	-	9.8	0.3	-	-	-	-	8.2	-	0.9	-	-	-	0.5	-	2.4	-	-	-	-	-
Elaeocarpus	1.0	0.6	-	0.3	1.7	0.2	-	-	-	3.0	-	1.8	-	3.1	-	-	-	-	-	-	-	0.9
Fuscospora	-	1.7	-	7.8	61.5	72.0	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	-	0.6
Halocarpus	-	2.4	-	0.3	-	0.4	-	0.1	-	-	2.9	0.7	-	2.8	-	1.1	-	-	-	-	-	-
Hedycarya	-	-	2.2	-	2.0	-	-	-	4.9	-	-	0.2	-	-	-	-	-	-	-	-	-	-
Knightia	-	1.1	12.3	4.6	-	1.2	12.0	0.4	-	4.3	4.1	4.2	-	1.7	20.2	6.1	-	0.3	-	0.3	-	-
Laurelia	-	-	-	-	-	-	-	-	-	-	0.3	1.2	-	0.3	-	-	-	0.3	-	1.1	-	-
Metrosideros	-	2.2	2.8	3.5	-	2.7	-	0.3	-	5.8	-	7.6	-	3.6	-	1.9	-	0.7	-	2.5	97.1	61.1
Phyllocladus	-	2.8	-	4.6	0.6	2.2	15.1	88.2	-	16.5	-	2.8	-	0.6	-	1.9	-	-	-	1.1	-	0.9
Podocarpus	6.9	7.8	-	2.6	7.0	1.5	-	0.2	13.3	7.8	-	2.3	-	5.6	-	9.5	80.1	47.9	-	1.9	-	0.9
Prumnopitys f.	4.8	3.2	-	2.9	-	1.1	6.9	-	9.3	3.3	-	1.4	1.0	3.9	-	3.8	-	-	-	0.3	-	0.9
Prumnopitys t.	-	2.4	-	2.9	-	1.1	-	0.7	-	4.5	-	4.8	-	14.0	-	8.8	-	1.4	-	1.9	-	-
Syzygium	-	-	-	-	-	-	-	0.1	-	0.2	7.6	4.2	-	0.3	-	-	-	-	-	0.3	-	1.7
Vitex	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	58.6	3.1	-	0.7	11.3	0.6	-	-
Weinmannia	-	0.6	29.3	29.6	14.1	2.2	9.4	0.1	37.0	7.7	5.3	5.5	2.5	2.2	-	-	-	-	-	-	-	-
Coprosma	-	1.9	-	2.9	-	1.1	25.1	7.4	2.0	3.8	-	0.9	0.1	0.6	-	0.4	4.2	2.1	-	3.3	-	-
Cordyline	-	-	-	-	-	-	-	0.2	-	0.7	-	0.2	-	-	-	2.3	-	2.1	19.7	5.0	-	0.3
Melicytus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	-	-	-	-	-	2.9	-
Myrsine	-	0.2	-	-	-	0.1	-	-	-	0.2	-	0.2	-	0.3	3.8	0.8	-	-	-	1.1	-	4.0
Olearia	-	-	-	-	0.5	-	2.9	-	0.5	-	-	0.2	-	-	-	-	-	-	-	-	-	-
Pseudopanax	-	0.2	-	0.9	-	0.4	0.7	0.4	-	1.2	-	0.5	-	-	-	-	-	-	-	0.3	-	-
Rhopalostylis	-	-	2.5	-	-	-	-	-	0.6	0.5	0.2	3.0	-	-	4.6	3.8	-	0.7	13.8	2.8	-	0.3
Toronia	0.1	0.6	-	1.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cyathea d. type	-	5.7	16.4	63.3	1.5	9.2	-	9.3	11.7	26.6	2.7	22.0	0.3	20.0	-	14.0	8.6	25.6	1.2	2.0	-	1.1
Dicksonia fibrosa	-	-	-	2.1	-	0.4	12.0	-	-	0.3	-	0.1	0.8	-	-	-	-	-	-	-	-	-
Dicksonia sq.	0.6	4.7	3.1	0.8	-	0.9	-	-	-	-	0.2	6.0	1.0	6.7	0.5	1.0	-	1.1	-	-	-	-

Table 3.2. Total basal area (B. A. m^2) and pollen percentages (P. %) for tree types at forest sites.

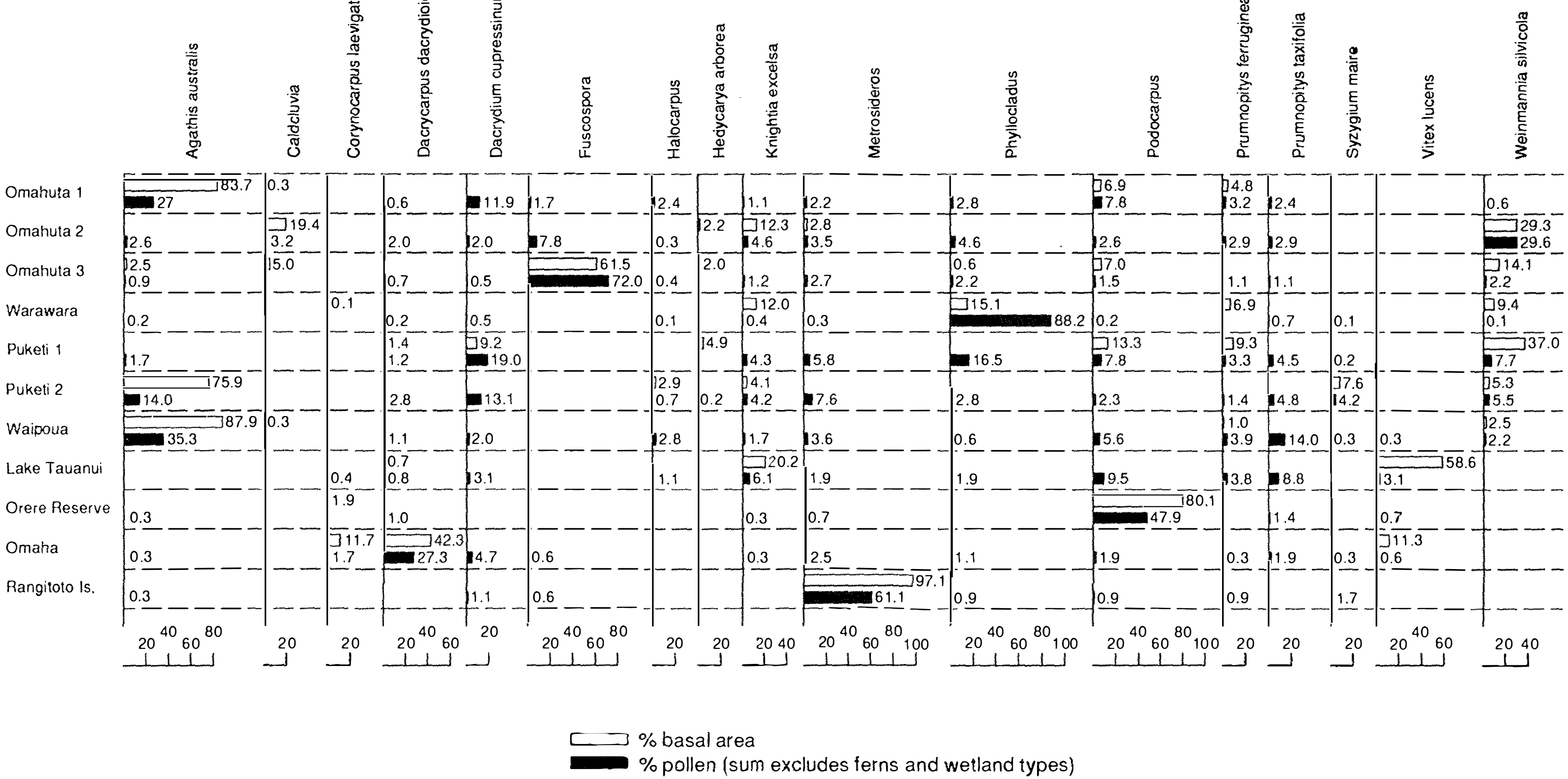

Figure 3.2 Relationship between pollen rain and forest composition for main tree types.

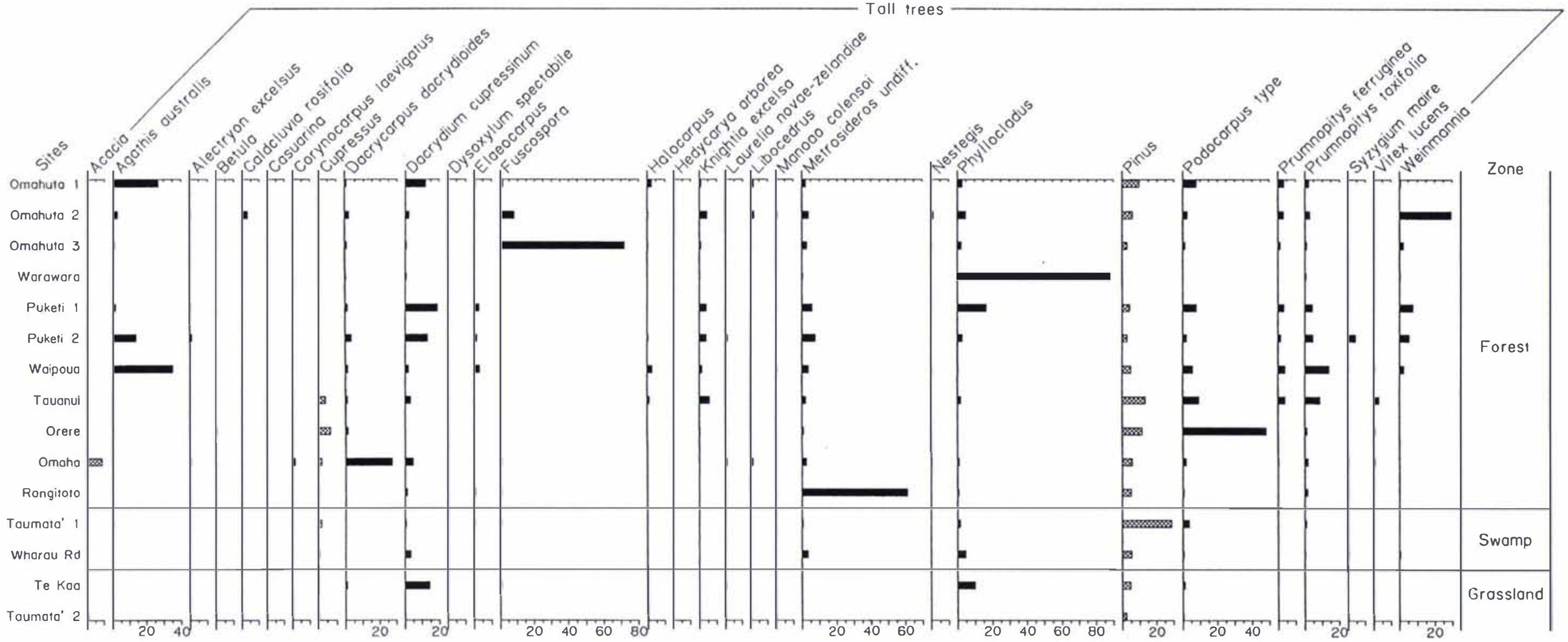

Figure 3.3a Pollen percentage diagram for tall trees; introduced taxa shown as hatched pattern.

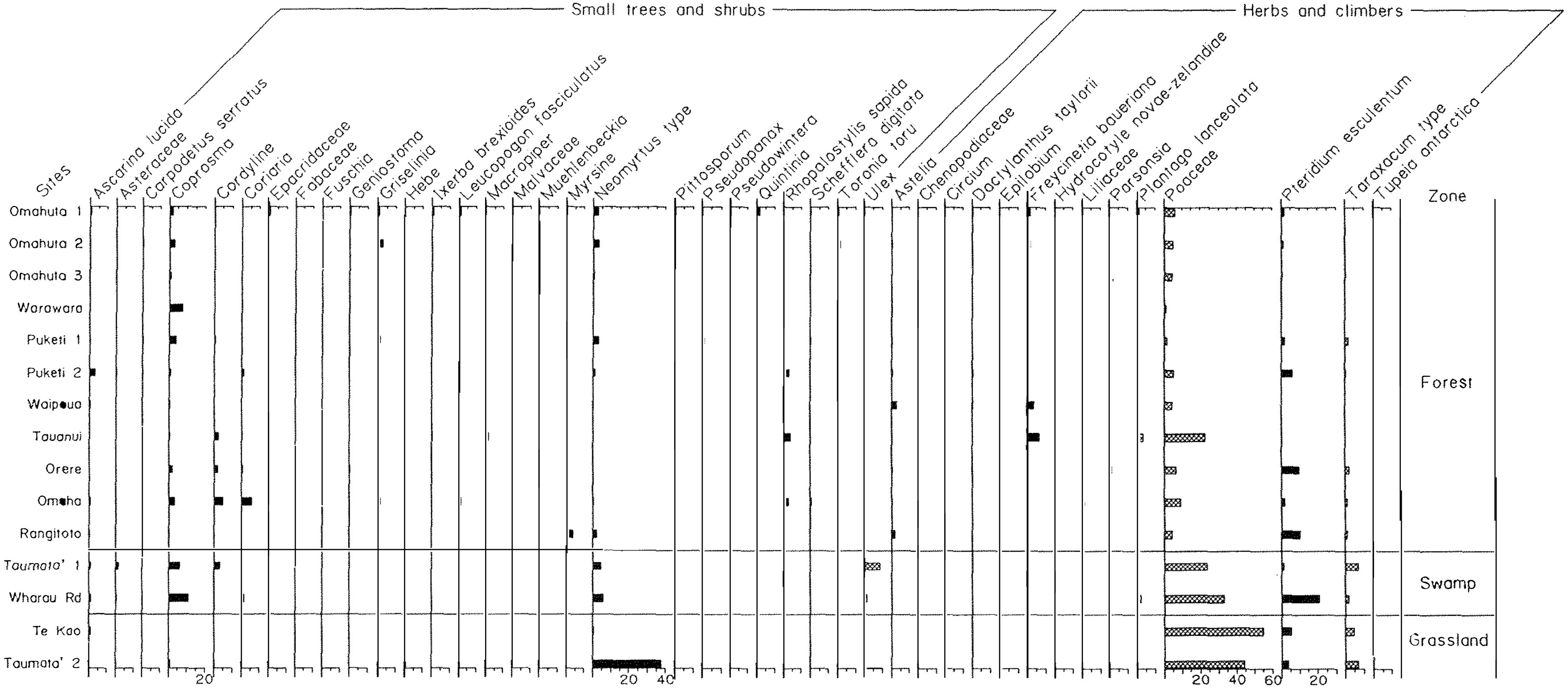

Figure 3.3b Percentage pollen diagram for small trees, shrubs, herbs and climbers; introduced taxa shown as hatched pattern.

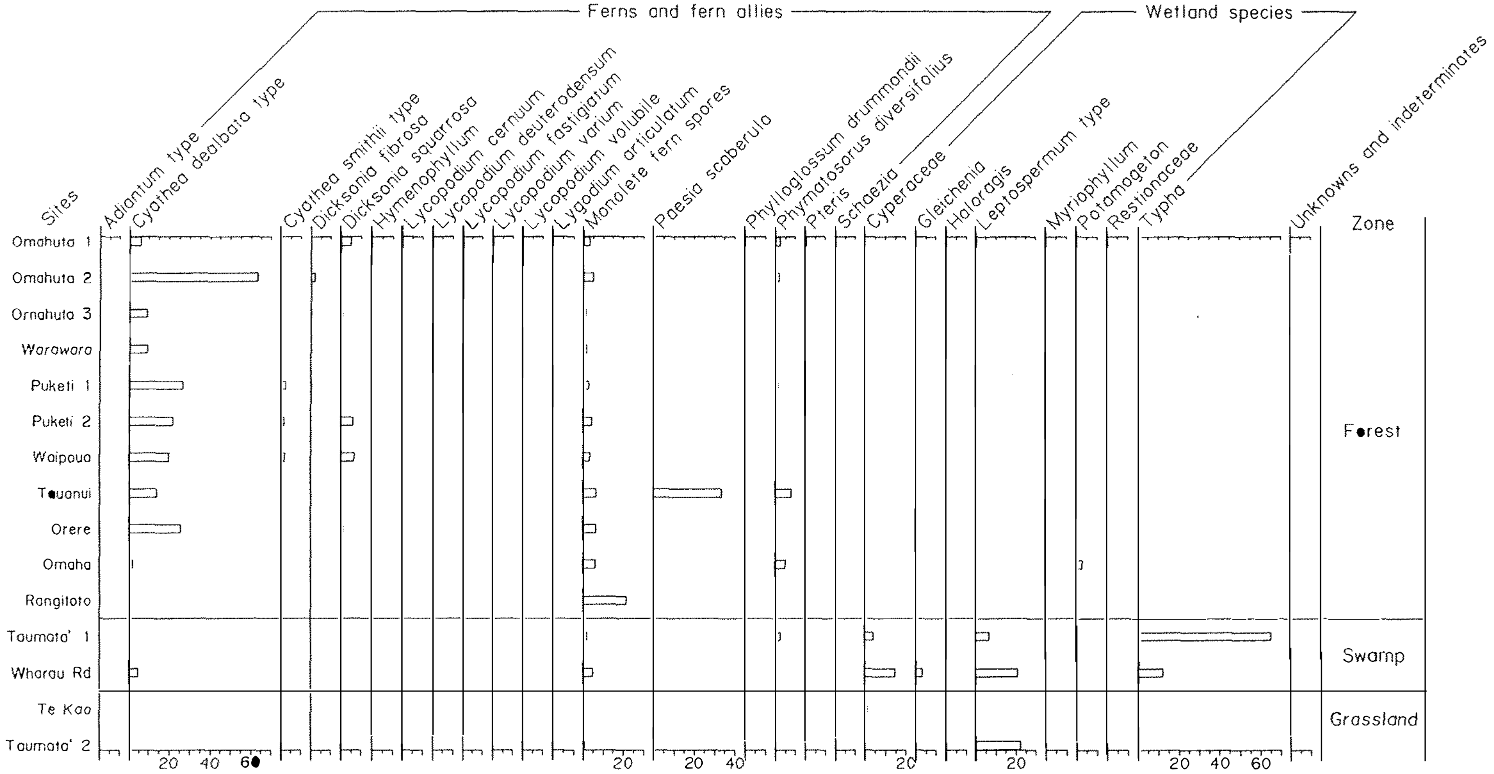

Figure 3.3c Percentage pollen diagram for ferns, fern allies, and wetland species, excluded from the pollen sum.

Puketi State Forest, Manginanginga Scenic Reserve Site

Swampy ground occurs in the lower third of the plot. The canopy is dominated by *Agathis australis* (75.9). Under this enormous single tree are scattered individuals of *Weinmannia silvicola* (5.3), *Syzygium maire* (7.6), *Knightia excelsa* (4.1), and one *Halocarpus kirkii* (2.9), a relatively uncommon tree. *Cyathea dealbata* (2.7) is common. Also present are *Dysoxylum* (0.9), *Laurelia novae-zelandiae* (0.3), *Rhopalostylis* (0.2), and *Dicksonia squarrosa* (0.2). The forest floor is rich in bryophytes, pteridophytes, especially *Blechnum* and *Asplenium* sp., as well as many tree seedlings, and scattered individuals of *Ripogonum scandens*.

The low pollen frequency for *Agathis* [14] illustrates strikingly the under-representation of this species. The over-representation of *Dacrydium* [13.1], and *Metrosideros* [7.6] in particular, but also *Dacrycarpus* [2.8], *Phyllocladus* [2.8], and *Podocarpus* [2.3], none of which are recorded on the site, tend to mask the *Agathis* pollen count. *Weinmannia* [4.2] is slightly under-represented, while *Syzygium* [5.5] and *Knightia* [4.2] are proportional. *Halocarpus* [0.7] is under-represented. *Laurelia* [1.2] and *Rhopalostylis* [3] are over-represented. Tree ferns, *Cyathea dealbata* type [22.5] and *Dicksonia squarrosa* [6.1], are very over-represented.

Waipoua State Forest

The Waipoua site is notable for a marked dominance by *Agathis* (87.8) with appreciable amounts of *Beilschmiedia* (6.2) and *Weinmannia silvicola* (2.5). Also present are *Prumnopitys ferruginea* (1), *Caldcluvia* (0.3) and *Coprosma arborea* (0.1). Tree ferns, though not abundant, are represented by *Cyathea dealbata* (0.3), *Dicksonia fibrosa* (0.8) and *D. squarrosa* (1).

Agathis pollen [35.3] is again, under-represented. *Beilschmiedia* is not recorded, and *Weinmannia* [1.5] is also under-represented. Tree ferns, *Cyathea dealbata* type [20.1] and *Dicksonia squarrosa* [6.7], are very over-represented. *Prumnopitys ferruginea* [3.9] is over-represented. Of the tree pollen types, significant values are recorded for numerous taxa in spite of their absence from the site, including *Prumnopitys taxifolia* [14], *Podocarpus* [3.7], *Metrosideros* [2.4] and *Halocarpus* [1.9].

Lake Tauanui

This site is on the crest of a small island in the lake and is dominated by *Vitex lucens* (58.6), *Knightia* (20.2) and *Beilschmiedia tarairi* (9.7). The understorey mostly consists of *Rhopalostylis* (4.6), *Myrsine australis* (3.8) and *Melicytus ramiflorus* (2). Small trees of *Dacrycarpus* (0.7), *Dysoxylum* (0.5) and sapling *Podocarpus totara* are present. *Dicksonia squarrosa* (0.5) is recorded, and *Cyathea medullaris* is present in adjacent bush. Ground cover includes abundant *Paesia* *scaberula* in forest openings along with *Pteris macilenta*. *Collospermum hastatum* is a common epiphyte, and *Metrosideros robusta* occurs as juvenile lianes.

The notable feature of the pollen spectrum is the poor representation of *Vitex* [3.1]. *Knightia* [6.1] and *Myrsine* [0.8], are also under-represented. Most of the tall forest trees which are not present on site record significant pollen values (*e.g. Dacrydium* [3.1], *Prumnopitys ferruginea* [3.8] and *P. taxifolia* [8.8]). *Podocarpus* [9.5], though not recorded as part of the basal measurements, is present in the form of numerous small poles which may account for its over-representation here. *Rhopalostylis* [3.8] is more or less proportionately represented, as is *Dacrycarpus* [0.8]. *Cyathea dealbata* type [14.0] is over-represented, but this tree fern type is commonly present in adjacent forest. Introduced taxa are significant, including grasses [22.5], *Pinus* [13.0] and *Cupressus* [3.8].

Orere Reserve

The Orere Reserve site is predominantly *Podocarpus totara* (80.1), with significant amounts of *Cyathea dealbata* and *C. medullaris* (8.6), *Coprosma arborea* (4.2), *Dysoxylum* (2.4), *Beilschmiedia tarairi* (2.9) and *Corynocarpus* (1.9). The understorey along with numerous seedlings of the above also includes abundant *Macropiper excelsum*, *Melicytus ramiflorus*, *Myrsine australis* and ground ferns, including *Phymatosorus diversifolius* and *Adiantum hispidulum*.

Podocarpus [47.9], though under-represented, dominates the pollen spectrum. *Coprosma* [2.1] is also under-represented, while *Beilschmiedia*, *Corynocarpus* and *Hedycarya* are not recorded. *Cyathea dealbata* type [25.6] is over-represented. Exotic taxa contribute significantly to the pollen rain, including *Pinus* [11.2], *Cupressus* [6.6] and grasses [6.6].

Omaha Kahikatea Bush Remnant

The site lies in what was probably a former back-dune swamp, and *Dacrycarpus dacrydioides* (42.3) is the most common tree species. Within this dense assemblage there are significant amounts of *Cordyline australis* (19.7), *Rhopalostylis* (13.8), *Corynocarpus* (11.7) and *Vitex* (11.3). *Cyathea dealbata* (1.2) is also present. The understorey vegetation is diverse and includes various fern and *Coprosma* species. *Leucopogon fasciculatus*, *Leptospermum scoparium*, *Kunzea ericoides*, *Myrsine australis*, *Pseudopanax crassifolius*, and immature *Dacrydium cupressinum*, *Podocarpus totara* and *Agathis australis*, are present in adjacent bush.

Dacrycarpus [27.3], though it is the chief pollen type, is under-represented. *Corynocarpus* [1.7] and *Vitex* [0.6] are very poorly represented. *Cordyline* [5.0] and *Rhopalostylis* [2.8] are also under-represented. Significant contributors to the pollen rain, though not recorded at the site are *Dacrydium* [4.7], *Coriaria* [5.8], *Pinus* [5.5] and grasses [9.1]. *Coprosma* pollen contributes 3.3 %.

Rangitoto Island, McKenzie Bay Site

The vegetation at this site is almost entirely *Metrosideros excelsa* (97.1). The remainder is *Melicytus ramiflorus* (2.9). The understorey consists largely of *Myrsine australis*. *Griselinia lucida* is present nearby. The location is notable for a lack of soil development and xeric conditions. *Metrosideros* [61.1] is under-represented even though it dominates the pollen spectrum. *Pinus* [4.9], *Myrsine* [4.0] and *Pteridium esculentum* [10.3] are significant.

Swamp Sites

Taumatawhana Swamp

Typha orientalis (85) is the dominant species in this swamp site. Significant cover is also given by *Eleocharis acuta* (10), a sharp spike-sedge of the Cyperaceae family. The remaining significant cover is provided by *Gleichenia dicarpa* (3) and *Phormium tenax* (2). Other swamp tolerant plants recorded as a trace are *Conyza canadensis*, *Hypochaeris radicata* and *Isachne globosa*. The swamp and its drier margins is surrounded by *Leptospermum* scrub, with scattered *Cordyline australis* and *Coprosma tenuicaulis*. The enclosing dunes are in pasture dominated by *Anthoxanthum odoratum* and *Pennisetum clandestinum*.

The pollen of many of the herbaceous and sub-aquatic taxa are not readily identifiable to generic or specific level. Nevertheless, it can be seen from the low Cyperaceae [4.2] pollen value that *Eleocharis* is under-represented, as is *Typha* [65]. *Phormium* is not recorded. The high influx of grass pollen [23.6] and *Taraxacum* type [6.7], from the adjacent pasture is significant. Other wetland taxa, though not recorded in the plot, are significantly represented, including *Coprosma* [6.2], *Cordyline* [3.4] and *Leptospermum* [6.5].

Wharau Road Swamp

Wharau Road Swamp is an extensive valley-dammed wetland with a diverse flora. Surrounding hillsides are mostly in pasture with patches of gorse (*Ulex europaeus*) and *Leptospermum* scrub. The site is dominated by *Eleocharis acuta* (55), but *Typha* (20), and swamp tolerant shrubs *Leptospermum scoparium* (10), *Coprosma tenuicaulis* (8) and *Cordyline australis* are common. Other species recorded are *Gleichenia dicarpa* (1), *Isachne globosa* (1), and traces of *Calystegia silvatica*, *Conyza canadensis*, *Crepis capillaris* and *Senecio minimus*.

As with the Taumatawhana site many pollen types are only identifiable to family level. Cyperaceae pollen [14.7] indicates that *Eleocharis* is very under-represented. *Typha* [12.2] is also under-represented, and *Cordyline* was not recorded. Of the other shrubs, *Leptospermum* [21.1] is markedly over-represented, and *Coprosma* [10.8] is more or less proportional. *Gleichenia* [3.3] is over-represented. The most significant pollen input comes from the grasses [32.9], probably derived from the surrounding farmland. *Pteridium esculentum* [20.8] is also highly significant.

Grassland-shrubland Sites

Te Kao

The grassland-shrubland heath at Te Kao is dominated by grasses (89.3). The remainder of the cover comprises *Hypochaeris radicata* (4), *Juncus tenuis* (2), *Isolepis* sp. (2), and traces of *Gnaphalium subfaculatum*, *Lotus suaveolens*, *Plantago lanceolata*, *Pratia* sp., *Rumex acetosella*, and *Anagallis arvensis*. Grasses [54.7] dominate the pollen spectrum, yet are under-represented. *Taraxacum* type [4.6] is proportional, but Cyperaceae [0.9] are under-represented, and Juncaceae not recorded. A feature of the pollen rain is the deposition of pollen from outside the sampling site. While some is local, such as *Pteridium* [5.3], much is from more distant sources *viz.* *Dacrydium* [14.3], *Phyllocladus* [9.9] and *Pinus* [4.6].

Taumatawhana Pa Site

Grasses (86.5) dominate the Taumatawhana Pa site. *Pteridium esculentum* (7.8), *Juncus* sp. (3.2), *Hypochaeris radicata* (1.0), and *Lepidosperma laterale* (1.0) comprise the rest of the ground cover. Poaceae [44.3] is the commonest pollen type but is poorly represented, and *Pteridium* [3.8] is also under-represented. Juncaceae is not recorded and *Taraxacum* type [7.0] is over-represented. Pollen deposition from elsewhere is recorded in the form of *Neomyrtus* type [37.7] and *Leptospermum* type [22.3]. These shrubs are common in the nearby scrub. Notably tree pollen and fern spores are poorly represented.

DISCUSSION

Dacrydium cupressinum is generally over-represented in the pollen spectra, and is recorded even when absent from the sample plots. This supports earlier studies by Moar (1970) and Mildenhall (1976), who noted long distance transport of *Dacrydium* pollen in the South Island and on Chatham Island respectively. Therefore, the presence of *Dacrydium* in the pollen spectra cannot necessarily be seen as evidence of local occurrence. *Dacrydium* is found throughout Northland forests. It is common in all types of *Agathis australis* (kauri) forest, and is a characteristic dominant in podocarp-*Beilschmiedia tarairi* associations though seldom abundant (Franklin, 1968). However, the results in this study imply (Omahuta-Puketi Forest) that high frequencies are indicative of local or extra-local representation. *Dacrydium* is capable of producing large quantities of pollen which are widely dispersed. Most studies indicate the taxon to be well or over-represented in the pollen record (*i.e.* Macphail and McQueen, 1983; Bussell, 1988; McGlone, 1982; McGlone and Wilson, 1996).

Table 3.3. Percentage cover of recorded species at swamp sites.

	Taumatawhana Swamp	**Wharau Road Swamp**
Coprosma tenuicaulis	-	8
Leptospermum scoparium	-	10
Conyza canadensis	+	+
Crepis capillaris	-	+
Hypochaeris radicata	+	-
Scenic minimus	-	+
Isachne globosa	+	1
Cordyline australis	-	5
Eleocharis acuta	10	55
Phormium tenax	2	-
Typha orientalis	85	20
Gleichenia dicarpa	3	1

Table 3.4. Plant group representation, and their respective pollen percentages for swamp sites.

[a] Taraxacum type.

	Taumatawhana Swamp		**Wharau Road Swamp**	
	% Cover	**% Pollen**	**% Cover**	**% Pollen**
Coprosma	-	6.2	8	10.8
Cordyline	-	3.4	5	-
Leptospermum	-	6.5	10	21.1
Asteraceae[a]	+	6.7	+	1.7
Convolvulaceae	-	-	+	-
Cyperaceae	10	4.2	55	14.7
Poaceae	+	23.6	1	32.9
Phormium	2	-	-	-
Typha	85	65.0	20	12.2
Gleichenia	-	-	1	3.3

Table 3.5. Percentage cover of recorded species for grassland-shrubland sites,

(+ = less than 1%; ❀ = presence recorded).

	Te Kao	Taumatawhana
Agrostis capillaris	4.9	-
Anagallis arvensis	+	-
Anthoxanthum odoratum	74.1	27.9
Axonopus affinis	10.3	-
Briza minor	-	+
Centella uniflora	❀	-
Coprosma sp.	-	❀
Cyathodes junipera	-	❀
Dactylis glomerata	-	1.0
Gnaphalium subfaculatum	+	-
Hypochaeris radicata	4.3	1.0
Isolepis sp.	2.0	-
Juncus sp.	2.0	3.2
Lepidosperma laterale	-	1.1
Leucopogon fraseri	❀	-
Lolium sp.	-	+
Lotus suavolens	+	-
Muehlenbeckia complexa	-	+
Paspalum dilatatum	+	2.0
Pennisetum clandestinum	-	54.3
Phleum pratense	-	1.3
Plantago lanceolata	+	-
Pomaderris phylicifolia	-	❀
Pratia sp.	+	-
Prunella vulgaris	❀	-
Pteridium esculentum	-	7.8
Rumex acetosella	+	-
Sacciolepis indica	+	-
Schoenus maschalinus	❀	-
Sysyrinchium iridifolium	+	-

Table 3.6. Plant group representation and their respective pollen percentages for grassland-shrubland sites.

	Te Kao		Taumatawhana	
	% Cover	% Pollen	% Cover	% Pollen
Asteraceae[a]	4.3	4.6	1.0	7.0
Epacridaceae	+	0.7	-	-
Leguminosae	+	-	-	-
Lobeliaceae	+	-	-	-
Plantago sp.	+	-	-	-
Polygonaceae	+	-	-	-
Poaceae	89.3	54.7	86.5	44.3
Cyperaceae	2.0	0.9	1.0	0.0
Juncaceae	2.0	-	3.2	-
Pteridium esculentum	-	5.3	7.8	3.8

[a](*Taraxacum* type)

Prumnopitys ferruginea (miro) representation is variable. At some sites (Pukekohe Stream, Lake Tauanui and Omaha) it is recorded in the pollen rain even though it is absent from the site, implying its presence in the nearby forest, but at other sites the tendency is for under-representation. At Warawara no miro pollen is recorded in spite of its significant presence at the site. This may be due to the upland nature of the site and exposure to prevailing westerly winds carrying pollen away from the sample site. Pocknall (1978) reports under-representation of this species from Westland forest, although Newnham (1990) considers miro tends to be over-represented. Results here indicate that deposition of miro pollen may be quite variable depending on local factors, though the general tendency is for under-representation.

Dacrycarpus dacrydioides, when present, is always under-represented. This finding is in agreement with that of Pocknall (1978, 1980) who argues that this is due to low pollen production. The Omaha result shows that high frequencies of *Dacrycarpus* pollen indicate local presence. Other sites often record low values in spite of its absence from basal area analyses. This suggests that although the taxon may be a low producer, it is capable of wide dispersal.

Podocarpus totara type is generally well represented in the pollen spectra but this does not always reflect its importance in the local vegetation. In Orere Reserve, where *Podocarpus totara* is the dominant tree, the pollen values under-represent its occurrence in the local forest. At

Omahuta, in the *Nothofagus truncata* plot, *Podocarpus hallii* is very under-represented. At the Puketi Forest Headquarters site, where mixed populations of *P. hallii* and *P. totara* occur, pollen values also indicate under-representation. Pocknall (1982) and McGlone and Wilson (1996) have suggested that *P. hallii* pollen has poor dispersal, but it is represented roughly proportionally when present locally. These results tend to support that conclusion *e.g.* Omahuta site 1. Other sites where it is present in the pollen spectra but not recorded in the basal area analyses reflect its widespread occurrence throughout Northland, both in forest and as open woodland on farmed landscapes.

Phyllocladus is generally well to over-represented. The results from Warawara are clearly an extreme case. Pocknall (1982) describes similar pollen dominance from Westland samples and argues such results could occur where there is a lack of air circulation under the canopy. This may be the case for this site, and at the Puketi HQ site where high values are also recorded. Elsewhere *Phyllocladus* is generally well represented given its common occurrence in Northland forests, especially in association with *Agathis australis*. It is less well represented farther from source indicating that its pollen is not widely dispersed. This finding is at variance with Newnham (1990) who suggests *Phyllocladus* is widely dispersed, but consistently under-represented.

Agathis australis, though it may dominate the pollen spectrum, is almost invariably under-represented, sometimes extremely so. Even where this taxon constitutes nearly 90 % of the basal area it does not achieve more than about one third of the pollen sum. When *Agathis* is not present, or comprises only a small part of the local vegetation, the pollen values range from zero to low. The results imply that when pollen values exceed 5-10 %, *Agathis* is common in the local/extra-local vegetation. Results also suggest that *Agathis* is an abundant pollen producer but has limited dispersal ability. This agrees with observations made by Newnham (1990) at Waipoua.

Weinmannia silvicola is well represented when present locally, but pollen values decline rapidly with distance from source or when its presence is only a small proportion of the local vegetation. This indicates that though it is an abundant producer, *Weinmannia* has poor dispersal power. Pocknall (1980), McGlone (1982) and Newnham (1990) report similar results.

Pollen of *Elaeocarpus dentatus* is generally quite indicative of its representation in the vegetation, though it can be over-represented when locally abundant. Like *Weinmannia*, it produces copious pollen but has limited dispersal.

Knightia excelsa is a common tree in Northland forests, particularly in secondary regrowth areas where it can be a dominant successional tree. The recent pollen spectra indicate that it can be well represented when locally common but generally *Knightia* is under-represented. In some cases, even where the tree is common, pollen is scarce. So although high values are possible where it is locally abundant, it is otherwise under-represented, and has poor dispersal.

Metrosideros pollen (cf. *M. robusta*) tends to be proportional to its presence where it is recorded in the basal area analyses, but otherwise is generally over-represented. McGlone (1988) describes the genus as an abundant producer with poor dispersal characteristics. Its frequent occurrence in Northland pollen spectra suggest that the over-representation may be due to the importance of *Metrosideros* lianes and their abundance in the flora, although they are under-represented in basal area analyses. Because the differential identification of *Metrosideros* pollen is not readily achieved, pollen counts may include a number of species (*M. albiflora*, *M. carminea*, *M. colensoi*, *M. diffusa*, *M. fulgens*, *M. perforata*, and *M. robusta*). Many of these species are commonly found in northern forests, and *M. robusta* which begins life as a liane, eventually becomes an emergent tall tree. Newnham (1990) records similar results.

Nothofagus truncata is well to over-represented at Omahuta. The genus is a prolific pollen producer and capable of long-distance dispersal (Mildenhall, 1976). Newnham (1990) reports that, even with localised distribution in Waipoua forest, *Fuscospora* pollen is recorded in 4 of 12 samples. He argues that the pollen is regionally dispersed and consistently over-represented. Bussell (1988) found that *Fuscospora* pollen masks pollen of other taxa when locally abundant. However, the results in this study generally show that pollen values fall sharply with distance from source. At Omahuta Site 3 where *Nothofagus truncata* dominates the vegetation (61.5%) *Fuscospora* pollen reaches 72%, yet Omahuta Site 2 (only some 50-100 m from Site 3) records only 7.8% *Fuscospora* pollen. The Omahuta Site 1 pollen rain has only 1.7% *Fuscospora* pollen. Although high values of beech pollen have been recorded elsewhere in spite of local absence (e.g. McGlone and Wilson, 1996), in Northland when values exceed 5 % it is likely that the *Nothofagus* is locally present.

Coprosma, is generally well to over-represented at most sites. The genus is anemophilous and a high pollen producer. Pocknall (1978) recorded the genus as being over-represented. The Warawara sample greatly under-represents its importance at the site. This is probably due to the masking effect of *Phyllocladus* discussed above.

Pollen percentages for *Dysoxylum spectabile*, *Hedycarya arborea*, *Syzygium maire*, *Beilschmiedia tarairi* and *B. tawa* do not reflect their importance in Northland forests. *Beilschmiedia* pollen is almost never recorded, even from litter on and beneath the tree (Macphail, 1980). The results in this study confirm that finding. Low pollen production (*e.g. Beilschmiedia*), entomophily, ornithophily, and extremely local dispersion (*e.g. Syzygium*) may account for this.

Cyathea dealbata type and *Dicksonia squarrosa* are consistently over-represented, which is typical of tree fern representation reported elsewhere (Moar, 1970; Dodson, 1976; Pocknall, 1978). However, their dispersal power appears to be limited. Ground ferns are often extremely over-represented when locally common *e.g. Paesia scaberula*, but may be scarce when the sample site is distant from source. *Pteridium esculentum* spores record low frequencies at most forest sites. The exceptions are the Puketi 2 [6.3] (Manginangina Reserve), Orere [9.8] and Rangitoto [10.3] sites. At these sites bracken is common on the forest margins providing a local source for spores. At the grassland sites bracken is underrepresented at Taumatawhana where it is a common local element, but at Te Kao scores 5.3% where it was absent from the site. The Te Kao abundance may be derived extra-locally from nearby scrubland. The swamp sites also gave contrasting results. Wharau Road recorded almost 21%, yet Taumatawhana gave only 1%. The abundance of spores at Wharau Road is probably derived from scrubland surrounding the swamp, both local and extra-local. Wilmshurst (1995) has reported similar variable results for *Pteridium esculentum.*

The non-forest sites show markedly different pollen spectra, and the comparison between the vegetation composition and the pollen frequencies is necessarily somewhat subjective. Grass pollen is always well represented, though it under-represents the proportion of grass in the grassland-shrubland sites. At Taumatawhana, shrub pollen forms an important component of the pollen sum. This is represented mainly by large amounts of *Neomyrtus* type and *Leptospermum* type pollen. These pollen types both represent genera belonging to the Myrtaceae family. They are prolific pollen producers but have low dispersal ability. The pollen source for these groups is quite local. At Te Kao much of the non-herbaceous pollen is derived from trees, particularly *Dacrydium* and *Pinus*, demonstrating their wide dispersal characteristics. The records for *Pinus* in most samples including the forest sites, reflect the widespread occurrence of this exotic species throughout the country, its high pollen productivity, and wide dispersal.

The swamp sites indicate a general tendency for emergent species such as *Typha* to be under-represented. The swamp-tolerant woody taxa, such as *Leptospermum* and *Coprosma*, tend to be over-represented. Poaceae pollen records high frequencies in swamps but the source for this pollen is mostly from the surrounding slopes in pasture, and this feature indicates that grasses are high producers.

CONCLUSIONS

The pollen of anemophilous taxa are generally proportionately represented or over-represented when compared to the entomophilous and ornithophilous taxa. However, there are some exceptions, most notably *Agathis australis*, which is typically grossly under-represented. This finding is also reported by Newnham (1990) and Newnham *et al.* (1993), and may be explained by poor dispersal and low pollen production. Other anemophilous taxa that form important components of Northland forests which are often under-represented are *Prumnopitys ferruginea* and *Dacrycarpus dacrydioides*. Pocknall (1978) reports similar findings from Westland, and concludes that a low frequency of these species is not necessarily indicative of rarity in the vegetation. *Podocarpus* is regularly under-represented even when it is the dominant forest tree, particularly where *P. hallii* is common. McGlone and Wilson (1996) report *P. hallii* being under-represented in Stewart Island spectra.

The angiosperm elements of Northland forests are generally very poorly recorded The exception to this is *Metrosideros*. This pollen type is either well or over-represented. Although there are many species belonging to this pollen group, much of this pollen is probably *Metrosideros robusta* which becomes an emergent tree upon maturity and is common in Northland forests. Like its southern equivalent, *M. umbellata*, *M. robusta* bears many flowers producing abundant pollen, whilst other *Metrosideros* species are less common or scarce and may also bear fewer flowers *e.g. M. diffusa* (McGlone and Wilson, 1996). *Weinmannia* and *Elaeocarpus* may form significant proportions of pollen spectra, but only when close to source. *Knightia excelsa* is consistently under-represented. Its presence in pollen spectra indicates local occurrence. Other angiosperm taxa are either recorded only sporadically, *e.g. Dysoxylum spectabile* and *Hedycarya arborea*, or not recorded at all *e.g. Beilschmiedia* spp. The extreme under-representation of the angiosperm vegetation in general is a major problem for New Zealand Quaternary pollen analyses.

Tree ferns and ground ferns are often over-represented, particularly when the sample site is close to source *e.g. Dicksonia squarrosa* and *Paesia scaberula*. Most produce vast numbers of spores, but most of these fall to ground close to source and dispersal is reduced with distance. Some writers report under-representation of fern spores, particularly *Cyathea dealbata* type, *Dicksonia* spp. and *Pteridium esculentum* (*e.g.* Macphail and McQueen, 1983), while others describe them as either well or over-represented (*e.g.* Dodson 1976; Bussell, 1988; McGlone 1982). Wilmshurst (1995) has suggested a number of explanations for the contradictory reports of bracken spore representation, including variable fertility and spore production of bracken colonies. The age of a moss polster and therefore the duration of pollen accumulation in it may influence pollen and spore preservation. The importance of wind dispersal at exposed sites may also be a factor, carrying spores over long distances from source. This study suggests that fern spores in general are well to over-represented on a local scale, but only adequately to under-represented on an extra local to regional scale.

Poaceae pollen are generally represented at less than 5% in forest spectra despite large areas of pasture land in surrounding areas. Similar observations are made by Pocknall (1978) and Randall (1990), suggesting that local vegetation may inhibit rainout of regional pollen. Where sample sites are in more open situations, such as the swamp sites and Lake Tauanui, grass pollen influx is considerably greater.

In general the pollen profiles presented here are reflective of their respective plant communities. Results are comparable with other modern pollen studies (Moar, 1970; Dodson, 1976; Pocknall, 1978, 1980; Macphail, 1980; McGlone, 1982; McGlone and Wilson, 1996; Randall, 1990; Wilmshurst, 1995). McGlone (1982) has commented on the extreme under-representation in New Zealand of *Phormium tenax*, the good representation of *Dactylanthus taylori*, and the excellent dispersal of *Pteridium esculentum.* This study confirms these features.

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Chapter 4

LAKE TAUMATAWHANA

Introduction

This chapter and the two which follow form part of a study undertaken in the Department of Geography - "Identification of the location and date of first Maori colonisation of Northland and Auckland using palynological and sedimentological evidence for environmental change". Chapters 4, 5 and 6 derive from three of the sites studied in the "Northland project" during the first year of this PhD programme. They are presented here as multi-author papers which are now published in internationally refereed journals. The following establishes the contribution of the various authors to these papers:

Michael B. Elliot: Directed and carried out all field work with help from the other authors and those acknowledged. Carried out all palynological analyses, including pollen preparation, microscopy, and interpretation of results. Wrote all manuscripts and integrated sediment analyses and their interpretation.

Bernd Striewski: Assisted with some field work (Lake Tauanui). Carried out all sedimentological analyses and their interpretation.

John Flenley: Supervised research as Principal "Investigator" of the FRST-funded programme. Provided editorial advice for the manuscripts and assisted with some field work at Lake Tauanui.

Doug Sutton: Supervised research as Associate "Investigator" of the FRST-funded programme. Provided editorial advice for the manuscripts and assisted with field work at Lake Taumatawhana and Wharau Road Swamp.

John Kirkman: Supervised sedimentological research as PhD supervisor to B. Striewski.

Palynological and sedimentological evidence for a radiocarbon chronology of environmental change and Polynesian deforestation from Lake Taumatawhana, Northland, New Zealand. *Radiocarbon* 37(3): 899-916.

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Abstract

We present pollen diagrams and sedimentological analyses from a lake site within an extensive dune system on the Aupouri Peninsula, Northland. Five thousand years ago, a regional *Agathis australis*-podocarp-broadleaf forest dominated the vegetation, which became increasingly dominated by the conifer species. Climate was cooler and drier than present. From *ca.* 3400 BP, warmth-loving species such as *A. australis* and drought-intolerant species, *Dacrydium cupressinum* and *Ascarina lucida*, became common, implying a warm and moist climate. The pollen record also suggests a windier climate. The most significant event in the record, however, occurred after *ca.* 900 BP (800 cal BP) when anthropogenic deforestation commenced. A dramatic decline in forest taxa followed, accompanied by the establishment of a *Pteridium esculentum*-dominated community. Fire almost certainly caused this, evidenced by a dramatic increase of charcoal. Sedimentological evidence for this site indicates a relatively stable environment before humans arrived and an increasingly unstable environment with frequent erosional events after human contact.

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Plate 4.1 Lake Taumatawhana. Arrow marks coring site.

Introduction

Although much is now known of the late Holocene vegetation history and archaeology of early settlement of southern regions in New Zealand, little is known of the archaeology of the early settlement of the north (Bulmer, 1988). The vegetational history remains sketchy, although several pollen diagrams cover this period (Kershaw and Strickland, 1988; Dodson, Enright and McLean, 1988; Enright, McLean and Dodson, 1988; Newnham, 1992). The debate over when first settlement of New Zealand occurred continues to be marked by controversy and remains poorly defined. None of the published palynological investigations from Northland addresses this contentious issue, although discussion in the archaeological literature has been vigorous (Sutton, 1987, 1988; Enright and Osborne, 1988; Anderson and McGovern-Wilson, 1990; McGlone, Anderson and Holdaway, 1994). The most preferred position in this argument has been that first human settlement occurred at or around 1000 BP (Davidson, 1984); more recently the date has been brought forward to 700 BP (Anderson, 1991; McFadgen, Knox and Cole, 1994). The evidence for this derives from dated archaeological sites. However, the effect of Polynesian settlement on the vegetation of New Zealand has been profound, and palynological analyses from more southern regions of New Zealand have provided evidence of this human impact (McGlone, 1978; McGlone, Mark and Bell, 1995; Mildenhall, 1979; Bussell, 1988; Newnham, Lowe and Green, 1989). Elsewhere in the Pacific and Southeast Asia, evidence from pollen records, charcoal influx and sedimentological analyses has been used to define the onset and extent of human impact on the environment (*e.g.*, Flenley, 1988; Flenley *et al.*, 1991; Newsome and Flenley, 1988; Kirch, Flenley and Steadman, 1991; Kirch *et al.*, 1992). We present here similarly derived evidence for one of the first chronologically secure records of human impact on the environment in northern New Zealand.

Descriptive background

Lake Taumatawhana is about halfway between Houhora and Te Kao on the west of the Far North Road (Figure 4.1). The lake occupies an area < 1 ha on a block of land administered by the Department of Conservation within which, adjacent to the lake, is a 9.8-ha parcel of land designated as proposed historic reserve (Maingay, 1991). A well-preserved double pa (Maori fort) site (Figure 4.1) overlooks both the lake on the southern side and an extensive area of early Maori gardens which lies to the north (Maingay, 1991).

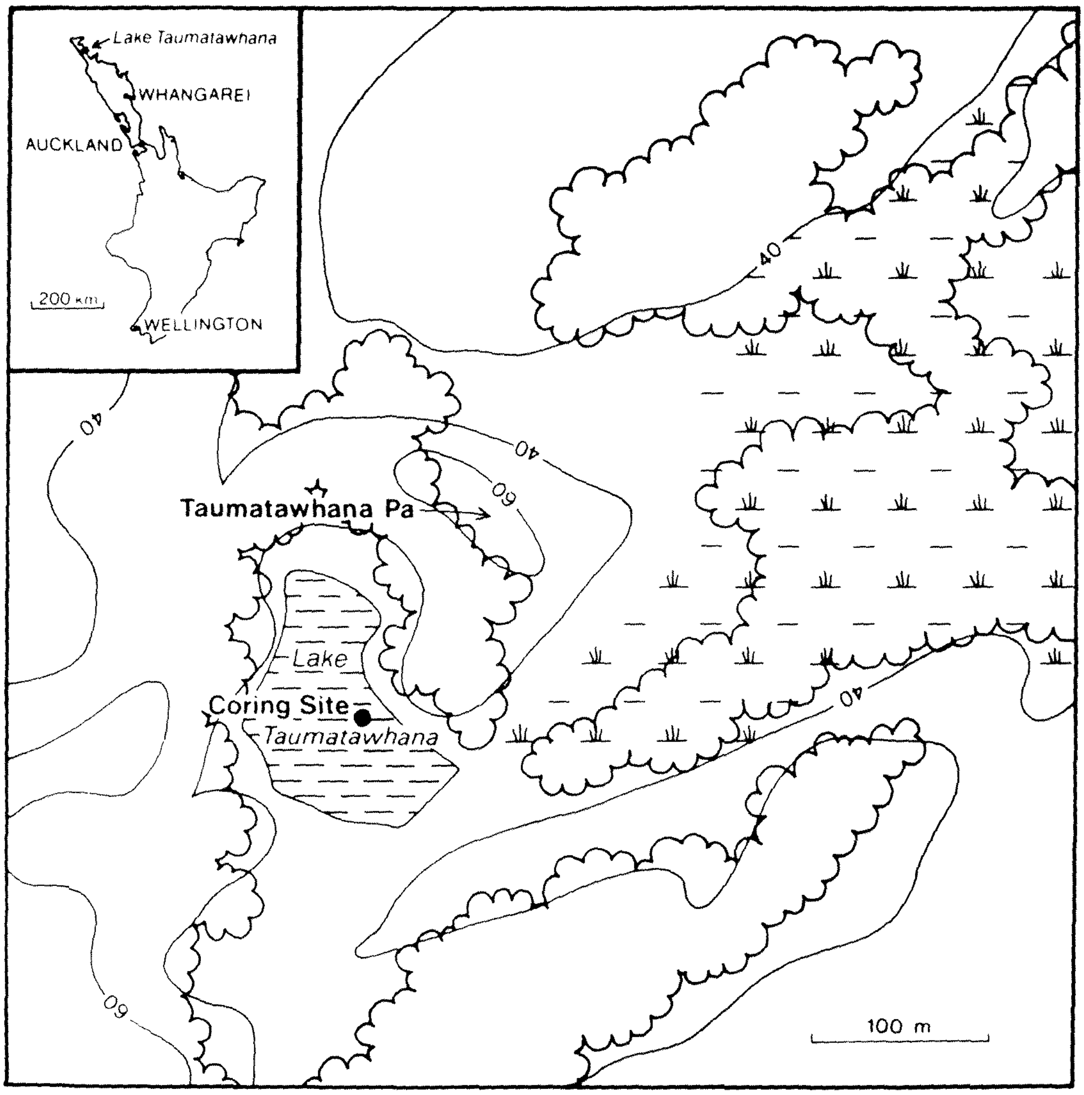

Figure 4.1. Lake Taumatawhana, Onepu, Northland.

The lake is *ca* 30 m asl and formed as part of coastal progradation processes that followed the postglacial rise in sea level. Prevailing westerly winds formed dunes and created the Aupouri Peninsula, a large tombolo linking the northern archipelago to mainland Northland. Numerous small lakes and peat swamps formed in the trailing arms of parabolic dunes and also between such dunes where drainage has been impeded. Lake Taumatawhana is one such lake in this system, and at its eastern end, drains by seepage into a larger peat swamp lying within a large parabolic dune. ^{14}C dating of basal sediments for both the lake and adjacent swamp yielded ages of 4883 ± 64 BP (NZA-3486) and 4792 ± 70 BP (NZA-2808), respectively (Table 4.1).

Table 4.1. ^{14}C Dating of Samples.

Depth (m)	**NZA-no.**	**^{14}C (yr BP)**	**δ ^{13}C‰**	**Cal range BP (2σ)**	**Material dated**
Lake Taumatawhana					
0.29-0.34	3920	1434 ± 77	-29.34	1491-1089	Treated gyttja
0.29-0.34	3823	1741 ± 83	-29.97	1803-1409	Treated gyttja
0.96-1.00	3882	686 ± 72	-27.11	684-521	Treated gyttja
1.10-1.16	3819	913 ± 65	-28.24	912-675	Treated gyttja
1.56-1.61	3820	1928 ± 68	-28.84	1979-1624	Treated gyttja
1.86-1.91	3821	2612 ± 72	-29.51	2784-2368	Treated gyttja
3.06-3.11	3822	2976 ± 67	-29.41	3262-2876	Treated gyttja
4.05-4.10	3486	4883 ± 68	-32.14	5725-5332	Treated gyttja
Taumatawhana Swamp					
2.35-2.40	2808	4792 ± 70	-25.3	5640-5325	Twigs

Leptospermum scrub with numerous small *Coprosma* and *Pomaderris* shrubs, scattered *Cordyline australis* and exotic wattles surround the lake. The margins of the lake, in many parts overhung with *Leptospermum,* support a variety of restiads and sedges, as well as clumps of *Phormium tenax*, *Typha orientalis* and numerous aquatic species, including *Myriophyllum*, that extend out into the water body forming a fringe floating mat. *Typha orientalis* dominates the adjacent swamp in the wetter areas, and *Leptospermum* the outer, drier zones. *Phormium tenax* and *Cordyline australis* trees are also present. *Gleichenia dicarpa* and *Blechnum minus* are common and a number of swamp-tolerant forbs persist. Pasture grasses, the commonest species of which are *Anthoxanthum odoratum* and *Pennisetum clandestinum*, cover adjacent sand dunes. There are several plantations of *Pinus* in the surrounding district, including the extensive Aupouri Forest in the west.

A sediment core 4.46 m long was recovered below 6.5 m of water from the deepest part of the lake, using a modified piston mud sampler (Walker, 1964) operated from a raft. This core consists of three broad stratigraphic units (Figure 4.2).

METHODS

Palynology

Samples were taken at 0.10-m intervals to a depth of 3.95 m. Only one sample was taken from the upper 0.30 m as this part of the core was loose and possibly liable to mixing. Laboratory preparation for pollen analysis of these samples followed standard alkali and acetolysis treatments (Fægri and Iversen, 1989). *Lycopodium* marker spore tablets were added at the onset of chemical treatment for absolute pollen-frequency calculations (Stockmarr, 1971). Charcoal counts were made by counting all fragments across a traverse in the size range of pollen grains and spores until 10 *Lycopodium* spores had also been counted. Pollen percentages are based on a pollen sum of all dryland plants including ferns and fern allies. In almost all cases, counts exceeded 250 dryland types. Preservation of pollen and spores was generally good. Plant nomenclature follows Allan (1961), Moore and Edgar (1976), Connor and Edgar (1987), and Molloy (1995).

Sedimentology

The sediments were analysed to a core depth of 3.00 m. All investigations required the same basic sample preparation. First, X-ray photographs were taken to identify any laminar structures present (Baker and Friedman, 1969). The variation in laminar structures resulted in the choice of different sample lengths; between 0 and 1.00 m the sample length ranged from 0.04 to 0.135 m; between 1.00 and 2.00 m sample lengths varied from 0.09 to 0.15 m. The entire section from 2.00 to 3.00 m was sampled at 0.10-m intervals. Dry samples were pestled and sieved at 2.0 mm to separate coarse (>2.0 mm) and fine (< 2.0 mm) sediment (Loveland and Whalley, 1991).

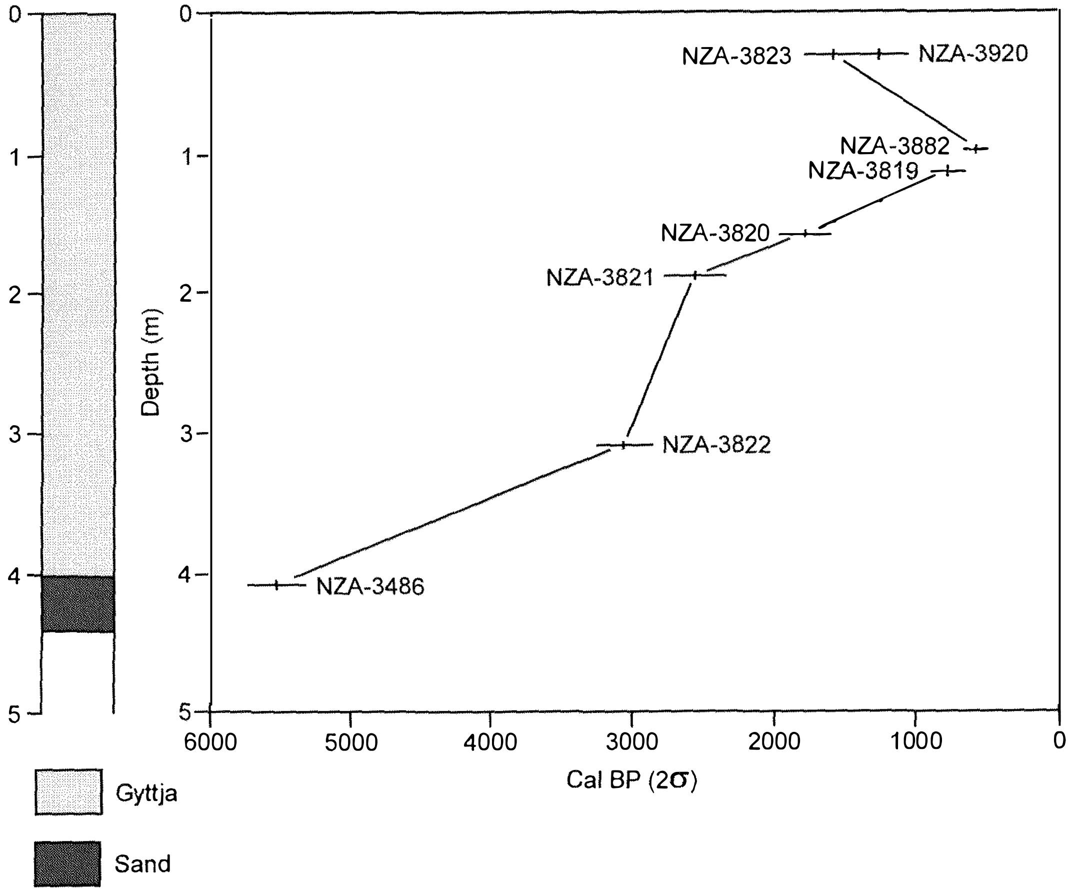

Figure 4.2 Stratigraphy of core, and age-depth graph for Lake Taumatawhana. Lithology from top to bottom: black gyttja (organic mud); black gyttja with sand; and sand. The uppermost 0.30 m of the core consists of loose black gyttja. Below this loose layer, black gyttja persists to a depth of 4.00 m. From 4.00 m to 4.11 m the black gyttja contains a trace of sand. The horizontal bars represent the range of uncertainty on the calibrated date chronologies (2σ), and the vertical bars the length of the core sediment used.

Sediment texture was analysed through the grain-size distribution. Samples were oxidised in 30% hydrogen peroxide (H_2O_2) (Day 1965 in Gee and Bauder, 1986; Kunze and Dixon, 1986). We used a particle size analyser to analyse the silt and clay fractions ("Sedigraph": Micromeritics, 1991; Risberg, 1989; Berezin and Voronin, 1981). The sand fraction (62.5 µm-2.0 mm) was separated from the bulk sample by wet sieving and determined separately. Grain-size-distribution classes chosen for the sedigraph analysis correspond with the Wentworth scale (Heim, 1991). A further subdivision of the sand fraction (62.5 µm-2.0 mm) was not carried out as the sample weight for this fraction was too small (average sample weight < 1.00 gram) for a sieve test on a nest of standard sieves with a frame diameter of 200 mm. Instead, the entire sand fraction obtained by wet sieving was regarded as an individual fraction.

Organic content was determined by loss-on-ignition (after Kretzschmar, 1989). Correction factors were applied to these data as organic substances and also some chemically bound water and void compounds are known to evaporate (Håkansson and Jansson, 1983). As the bulk of the clay minerals occur in the clay fraction ($<1.95\mu m$), Schlichting and Blume (1966) suggested subtracting 0.1% weight per 1.0% weight of clay content from the result of the organic matter content obtained by loss-on-ignition.

Bulk sediment chemistry was analysed by Inductively Coupled Plasma Emission Spectrometry (ICP-AES) providing data for 23 elements (Al, As, B, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Se, Si, Sn, Sr and Zn). The analyses were performed on liquid digest. Sample digestion involved a 1:1 concentrated hydrofluoric acid/concentrated nitric acid (HF/HNO_3) solution treatment in combination with 30% H_2O_2 oxidation to destroy the organics of the samples, and hydrochloric acid (2 M HCl) extraction.

We investigated the sediment mineralogy for two different grain-size fractions - the mud fraction (silt and clay fraction - material $< 62.5\ \mu m$) and the sand fraction (material $> 62.5\ \mu m$) - at 0.20-m intervals to a depth of 2.80 m. Samples were treated with 30% H_2O_2 solution and wet-sieved at 62.5 μm to separate the two fractions. The mineralogy of the mud fraction was analysed by X-ray diffraction (XRD). Mineralogical constituents of the sand fraction were investigated by petrographic microscopy.

RESULTS

Dating

Seven samples from the lake and an additional sample from the adjacent swamp were radiocarbon-dated by accelerator mass spectrometry (AMS) (Table 4.1, Figure 4.2) at the Rafter Radiocarbon Laboratory, Lower Hutt, New Zealand. The material dated was bulk sediment obtained from 0.05–0.06 m-length core segments. No dateable plant macrofossils were present. The basal samples from the lake and swamp sediments yielded ages of 4883 ± 68 BP (NZA-3486) and 4792 ± 70 BP (NZA-2808), respectively. The uppermost two dates (NZA-3920 and -3823) appear to have been contaminated by older carbon following deforestation and pasture establishment by European farmers within the lake catchment (*e.g.* Pennington *et al.*, 1976). Non-contemporary forest litter and humic compounds were probably incorporated into the lake sediments. The appearance of introduced species in the pollen record supports this hypothesis. The $\delta\ ^{13}C$ values from the anomalous dates are dissimilar to those immediately below, and similar to those from older material in the core, which further supports this interpretation.

Palynology

Figures 4.3 and 4.4 show the pollen diagrams displayed as relative frequency and pollen concentration data, respectively. The charcoal data displayed on both of these figures is shown as absolute charcoal influx in grains/cm^3. The pollen spectra are divided into five zones.

1. Zone Ta 4: 4.00-3.30 m depth; ca. *5000 - 3400 BP*

The terrestrial pollen is dominated by arboreal pollen, the most abundant elements of which are *Agathis australis*, *Dacrycarpus dacrydioides*, *Dacrydium cupressinum*, *Libocedrus*, *Nestegis*, *Phyllocladus*, *Podocarpus*, *Prumnopitys taxifolia*, *Ascarina lucida*, *Coprosma* and *Leptospermum/Kunzea*. Ferns, herbs and aquatics record only low frequencies and charcoal influx is also low. The steady increases in *A. australis* and *A. lucida* are notable.

2. Zone Ta 3: 3.30-1.90 m depth; ca. *3400 - 2600 BP*

Like the previous zone, this is characterised by an arboreal dominance with a similar composition of species. At the onset of this zone is a very sharp and short-lived decline in *A. australis*, followed by a steady increase before again declining at the top. The curves for *D. cupressinum*, *Libocedrus*, *P. taxifolia* and *A. lucida* show similar, though less pronounced, trends. Herbs, ferns and aquatics are again only weakly represented, although the ferns assume slightly more importance than previously.

3. Zone Ta 2: 1.90-1.12 m depth; ca. *2600 - 900 BP*

As with Zones Ta 3 and 4, a strong dominance is maintained by the arboreal taxa over the relative paucity of herbs, ferns and aquatics. *A. australis* rises steadily upward from a starting point of low abundance through the zone to achieve a significant peak at the top. A similar trend is observed in the *D. cupressinum* curve, but other podocarps do not demonstrate the same pattern although they generally maintain a strong presence. *A. lucida* maintains high abundances throughout, and most other forest taxa are well represented.

4. Zone Ta 1b: 1.12-0.30 m depth; ca. *900 - (?)250 BP*

This sub-zone is characterised by several significant changes in the pollen spectra. Initially, a short, sharp increase in ferns is observed, attributable chiefly to *Pteridium esculentum.* The arboreal pollen declines in tandem with the above change. This event is followed by an equally brief reverse trend followed by a significant decline in forest taxa. All tree, small tree and shrub taxa other than *Coprosma* and *Coriaria* exhibit dramatic decreases in abundance. Herbs, though still relatively unimportant, increase in abundance, particularly Poaceae members. The *P. esculentum* curve dominates the pollen spectra; other herbaceous ferns represented by the curve for monolete fern spores increase noticeably, and the frequencies for Cyperaceae and Restionaceae members are also increased. The charcoal influx mirrors the *P. esculentum* curve.

5. Zone Ta 1a: 0.30 m depth to sediment surface; ca. ?250 BP - present

This sub-zone is characterised by low frequencies for almost all arboreal pollen types. Herbs are clearly the dominant pollen group, in particular, Poaceae members and *Taraxacum* type. Exotic European pollen types appear for the first time, notably *Cupressus* and *Pinus*; it is likely that the increases in herb pollen, *i.e.*, Poaceae and *Taraxacum*, are also attributable to introduced European species, but conclusive differential identification is not possible.

Sedimentology

Texture

The grain-size distribution is characterised by two peaks in the sand fraction (Figure 4.5). The first peak (35%) occurs at 1.12 m. Prior to this, the sand content is consistently low, averaging 10%. The second peak occurs between 0.61 m and the sediment surface, with an initial value of 14% at 0.61 m, which increases sharply to 27.2% at 0.54 m and achieves a maximum value of 87.2% between 0.13 m and the surface. Low values for clay fractions are coincident with these peaks in sand fractions. Between 0.53 and 0.13 m, clay fraction values range from 29% to 4.3% compared with an average value of 46% for the remainder of the core. Other grain-size fractions remain almost entirely unaffected throughout the core.

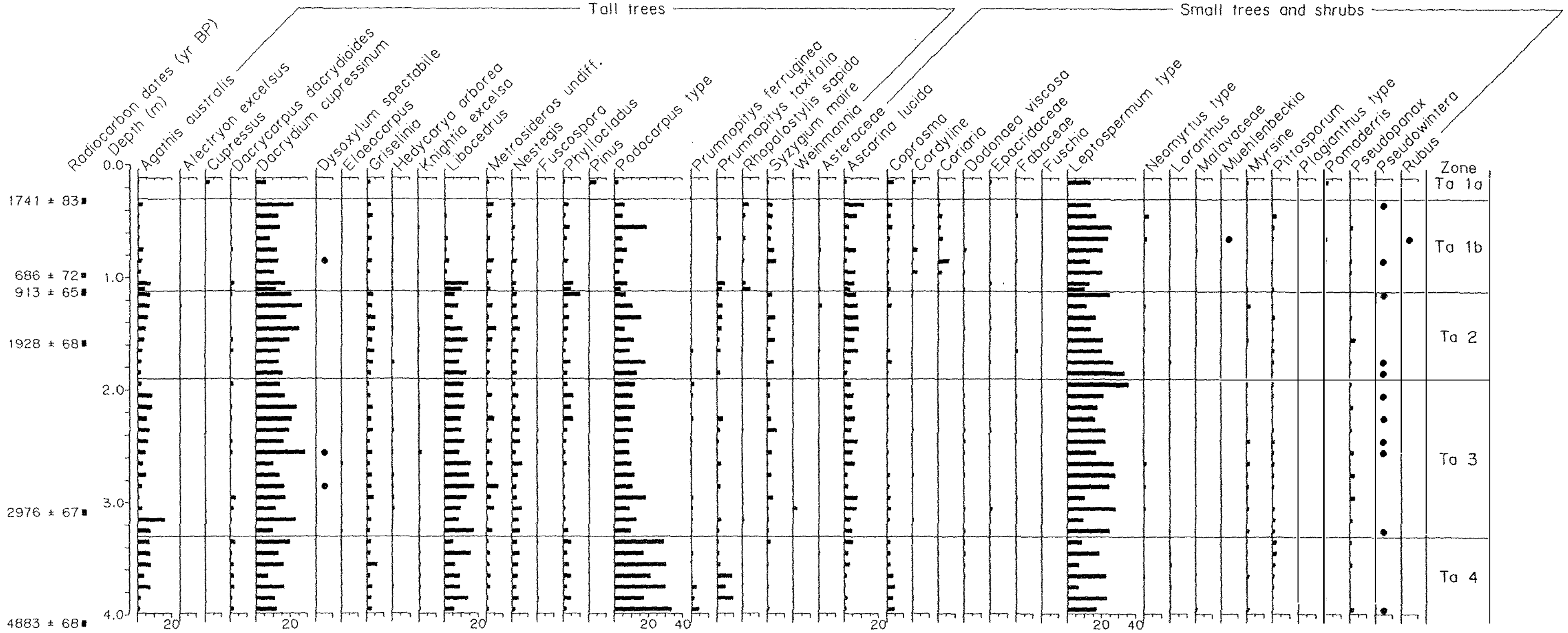

Figure 4.3 Lake Taumatawhana pollen percentage diagram. A: Trees, small trees and shrubs.

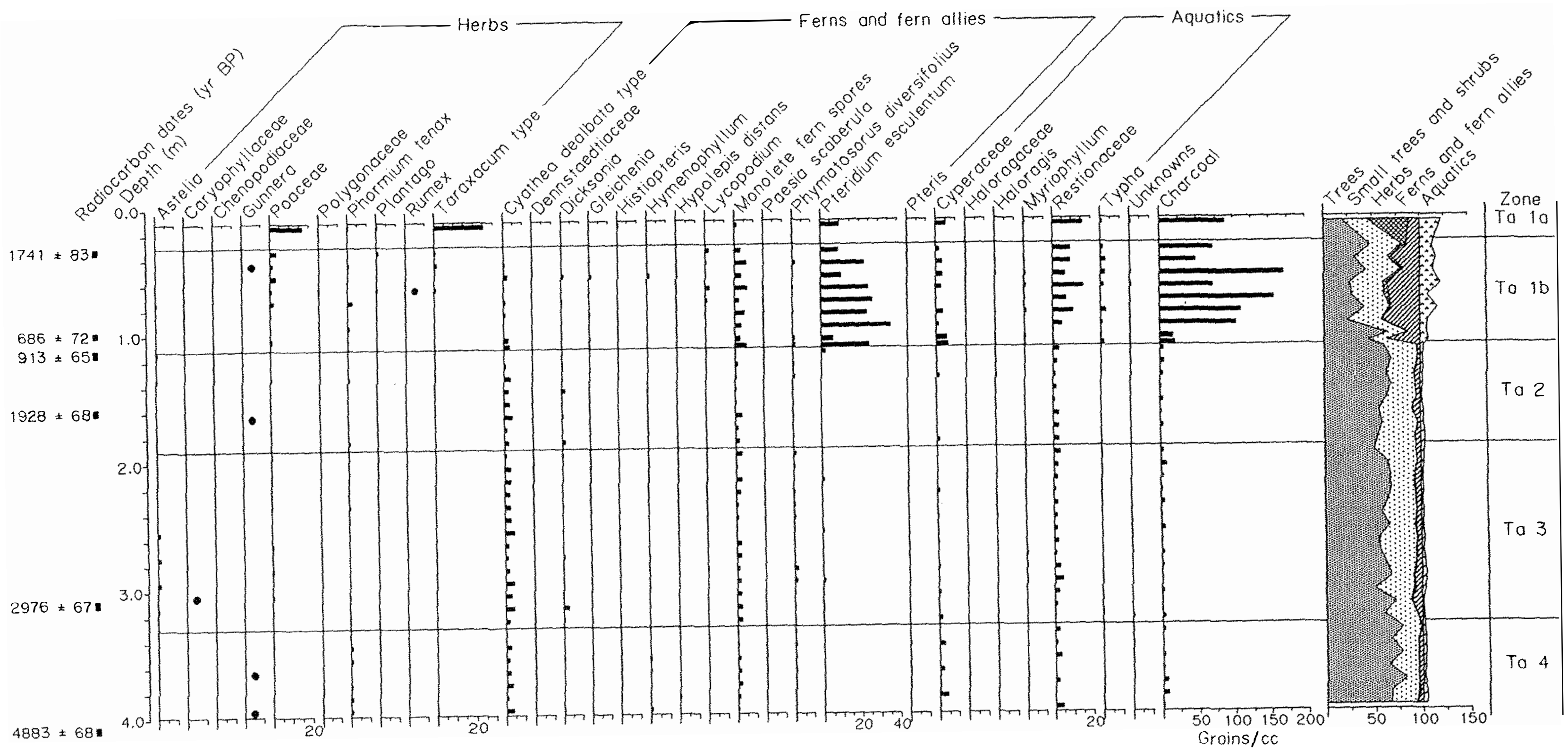

Figure 4.3 Lake Taumatawhana pollen percentage diagram. B: Herbs, ferns, fern allies and aquatics.

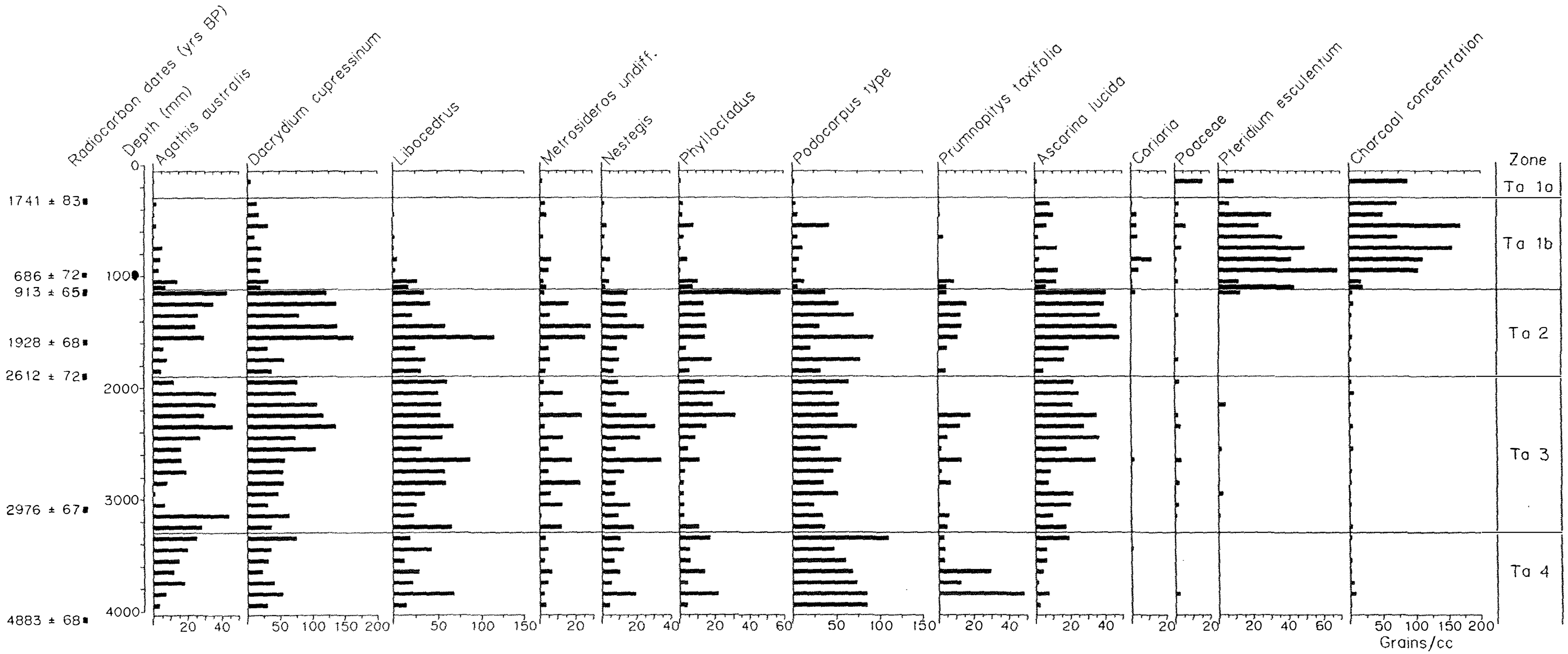

Figure 4.4 Lake Taumatawhana pollen concentration diagram, selected taxa only.

Organics

Typically, the organic matter content is *ca* 50% (by dry weight) throughout the core (Figure 4.5). However, a sharp decrease occurs from 0.61 m to the surface (0.00 m) where the organic content is only 6.5%. Lower-than-average values are also noted between 1.12 and 0.61 m (39.3%), and also at 3.00 and 2.00 m.

Mineralogy

The inorganic portion is characterised by only three minerals throughout the core: quartz, feldspar and a mineral that is amorphous to X-ray radiation. In the XRD patterns, quartz is identified by its 1st- and 2nd-order peaks at 24° 2Θ (= 0.43 nm) and 31° 2Θ (= 0.33 nm), respectively, and feldspar is indicated by its 1st-order peak at 33° 2Θ (= 0.31 nm) (Figure 4.6). The amorphous material, which is most probably amorphous silica gel (J. Kirkman, personal communication 1995), is indicated by a "hump" in the XRD pattern. The apex of this hump lies in the vicinity of 26° 2Θ (Figure 4.6). Most of the core appears to consist of this material, as its XRD pattern shows a distinct trend with depth. The exception to this pattern occurs in the uppermost section of the core from 0.40 m - 0.00 m, where there is almost no amorphous material. Here the dominant minerals are quartz and feldspar (peaks at 24° 2Θ, 31° 2Θ and 33° 2Θ; see Figure 4.6) coincident with extremely low values in the clay fraction (clay content between 0.30 m and 0.00 m of 3.6 - 4.3%; see Figure 4.5). Apart from these three minerals, no other minerals were detected in the XRD patterns despite the relatively high clay content of the core material (Figure 4.5). The clay content of the sediment seems to be associated with the amorphous material. From 0.80 - 0.40 m, the clay content decreases steadily from 36.3% - 12.9% with a concurrent decrease in the amount of amorphous material reflected in a steadily declining hump in the XRD patterns. Further minor fluctuations in the clay content (Figure 4.5) are mirrored by the XRD patterns for amorphous material. Microscopic investigation, by point counting, of the sand fraction also revealed an apparent dominance of quartz. The shape of these grains ranges from angular to well-rounded. Apart from quartz, a few iron oxides (probably hematite or magnetite) were also noted. There were also a few feldspars, but in contrast to the mud fraction, their abundances were extremely low; plagioclase feldspars were totally absent.

Chemistry

The elemental assays (Figure 4.7) are placed in two main groups, major and minor elements (after Håkansson and Jansson, 1983; Mackereth, 1965, 1966). Major elements comprise Al, K, Mg, Na and Si. The minor elements are further subdivided into heavy metals elements (As, Co, Cd, Cr, Cu, Mo, Ni, Pb, Sn, and Zn), carbonate elements (Ca and Mg), nutrient elements (P), mobile elements (Fe, Mn and S) and others (B, Se and Sr).

The five major elements show an almost identical distribution pattern of generally consistent "background" concentrations from the base upwards to a depth of 0.75 m. At this depth, increases in concentrations are seen, dramatically so from 0.58 m (Mg excepted) to the surface.

Calcium exhibits several concentration peaks throughout the profile. Peaks are registered between 0 and 0.42 m, at 0.88 m, 1.79 m and 2.39 m. Of the nutrient elements, only phosphorus can be analysed by ICP-AES. The record for P is stable from the base of the core up to *ca.* 0.70 m depth, from which a rise in concentration is noted, peaking at 0.42 m. Thereafter levels decline. Of the mobile elements, both Fe and Mn show peaks at 0.17 m and 0.42 m. Below this depth, these two elements show reduced but fluctuating concentrations, although Fe has a major peak at 2.99 m. Sulphur behaves somewhat differently. No clear trend is apparent, but peaks in concentration are noted at 0.17 m, 0.42 m, 1.36 m, 2.26 m and 2.99 m. Substantial declines are seen between 0.58 - 0.75 m, at 1.93 m and 2.86 m.

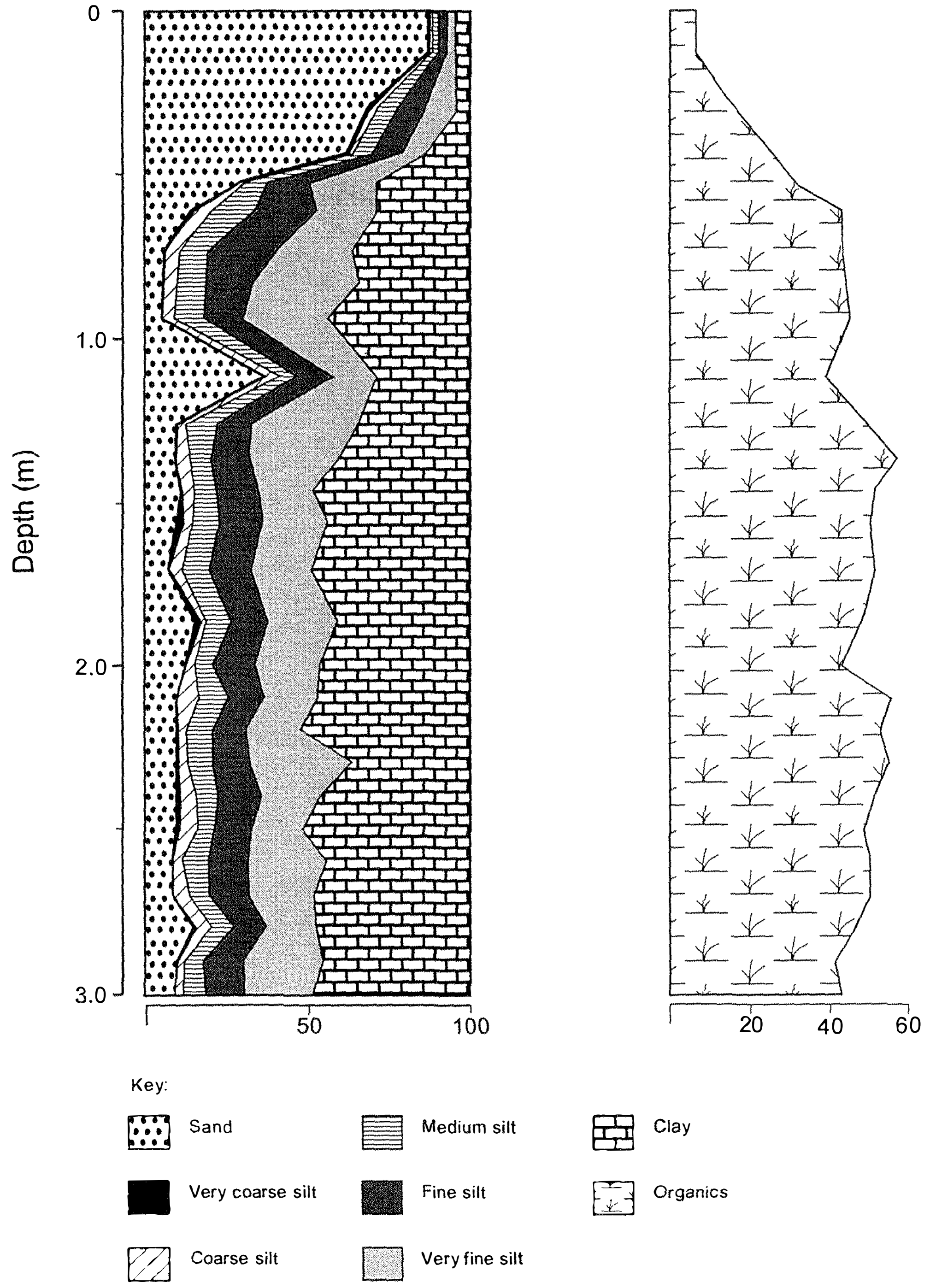

Figure 4.5 Grain-size classes and organic matter shown as percentages, Lake Taumatawhana.

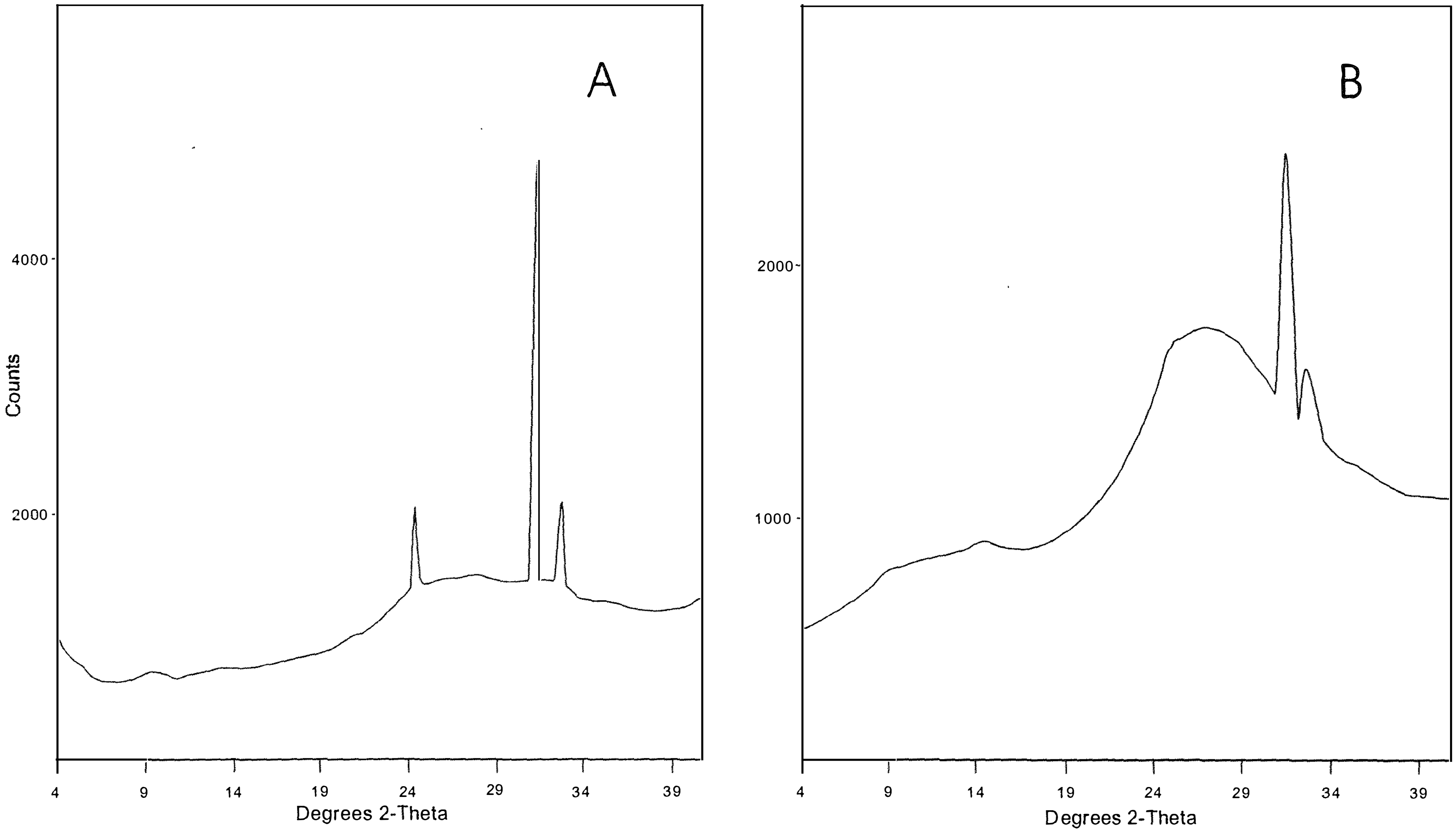

Figure 4.6 Smoothed XRD patterns for sediment mineralogy at 0.40 m (A) and 1.40 m (B), Lake Taumatawhana.

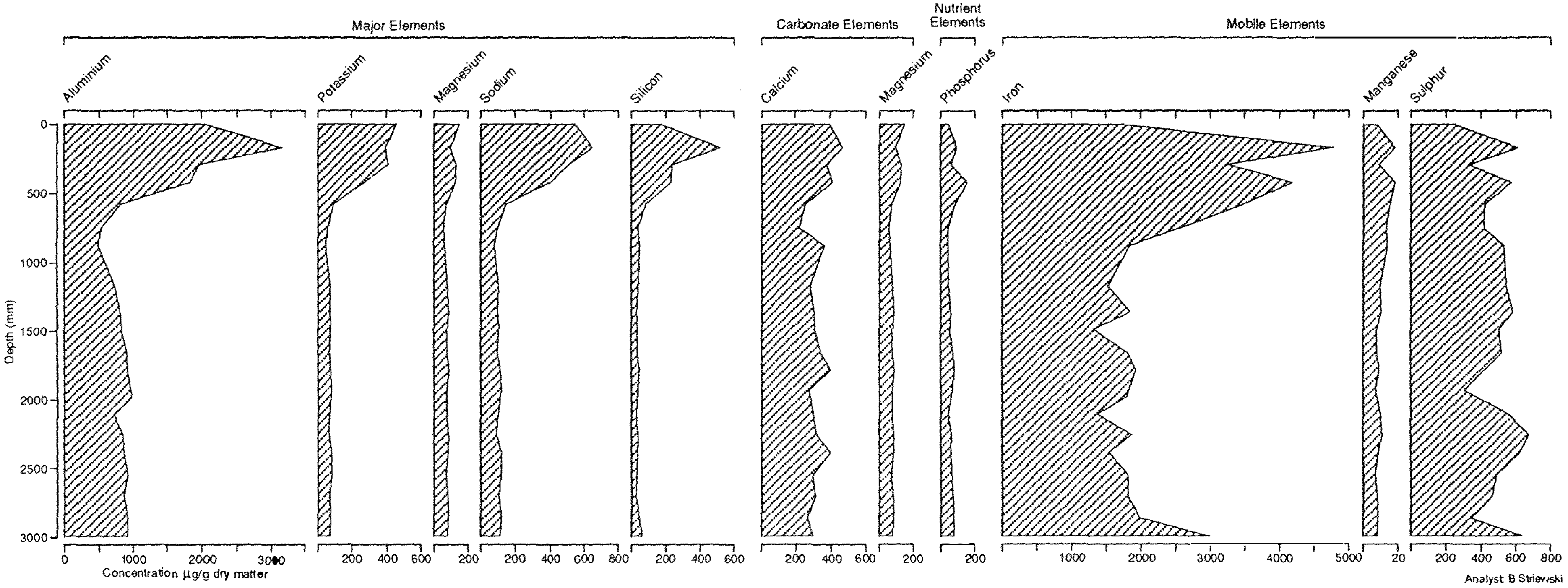

Figure 4.7 Chemical stratigraphy for selected elements, Lake Taumatawhana.

DISCUSSION

Palynology

The pollen record for Lake Taumatawhana extends from *ca.* 5 ka to the present and provides evidence for significant paleoecological changes over that time both locally and extra-locally. These are summarised in Table 2. Lake formation relates to dune activity and drainage impedance following the attainment of sea level close to present level at *ca.* 6500 BP (Gibb, 1986), and the lake has existed for *ca.* 5500 years. Immediately following lake formation and onset of organic deposition at *ca.* 5 ka, a regional *Agathis australis*-podocarp-hardwood forest dominated the vegetation. This community included all the tall podocarp trees, the most important of which were *Dacrydium cupressinum*, *Phyllocladus* sp., *Podocarpus totara* type and *Prumnopitys taxifolia*. *Libocedrus* sp. and *Nestegis* sp. were also significant, and *A. australis* became increasingly dominant from an initial low value. The development of a conifer-hardwood forest through the lower zone is a consequence of increasing stability of the dune environment following sea-level stabilisation. Similar trends for *A. australis*, *D. cupressinum* and *Podocarpus* sp. are reported by Kershaw and Strickland (1988) from a coastal inter-dune bog in Northland. *D. cupressinum* was a common emergent of the regional forest, and *Podocarpus totara* type was a commonly occurring tree. *A. australis* is regularly under-represented in pollen records (Newnham, 1990; Newnham, Ogden and Mildenhall, 1993) and thus, its good representation in the present study is significant.

McGlone and Topping (1977) describe postglacial climate changes that have some features in common with Zones Ta 4 and Ta 3. After 5 ka BP, northern sites (of the North Island) indicate that *Podocarpus* and *Prumnopitys* became more abundant, responding to a generally harsher climate. This trend is reversed between 3500 and 1800 BP to a more *Dacrydium-cupressinum*-dominated phase (McGlone and Topping, 1977). A similar trend can be observed in the Taumatawhana record. The reversion in importance of *D. cupressinum* and *Podocarpus* is accompanied by an increase in abundance of *A. lucida*. McGlone and Moar (1977) report that *A. lucida* was common in the postglacial period from 10-5 ka BP, after which a decline in abundance was noted. A period of recovery occurred between 3500 and 1800 BP, when *A. lucida* again became common (McGlone and Moar, 1977). This trend is similar to that observed for Taumatawhana and supports the evidence provided by the *D. cupressinum* and *Podocarpus* curves, although these taxa persist for somewhat longer in the time scale. Other Northland pollen diagrams (Kershaw and Strickland, 1988; Dodson, Enright and McLean, 1988; Enright, McLean and Dodson, 1988; Newnham, 1992; Newnham, Ogden and Mildenhall, 1993) provide a less distinct trend for *A. lucida*. It is likely that drought rather than cold was the limiting factor in the Onepu district given its northern location and the susceptibility of the sand dune communities to moisture deficit.

Drought is also implicated in the cyclic curve of *A. australis*, which requires a rainfall regime between 1000 and 2500 mm per annum for optimum growth (Ecroyd, 1982). Windthrow by hurricane(s) during droughtier and windier times could be more devastating on the sand-dune country and could account for the destruction of hundreds of kauri (*Agathis australis*) trees at a time (Ecroyd, 1982). Under such circumstances, mass synchronous regeneration of *A. australis* under the cover of *Leptospermum/Kunzea* scrub could lead to even-aged stands (Ecroyd, 1982; see also Ogden, 1985 and Ogden *et al.*, 1992). Evidence for drier and windier conditions in far northern New Zealand during this period has been advanced by Enright, McLean and Dodson (1988), and Dodson, Enright and McLean (1988).

The most significant change in the pollen record occurs at the boundary between Zones Ta 2 and Ta 1b. A decline of all arboreal taxa is observed, accompanied by sharp rises in the curves for *Pteridium esculentum*, the aquatic species of the Cyperaceae and Restionaceae families, as well as *Typha*. The charcoal influx follows the same trend as *P. esculentum*. Elevated values for *Coriaria* at this time are also significant. This shrub is considered to be an aggressive, early coloniser of fire-cleared landscapes (Wardle, 1991). Features of this nature have been recorded at many other sites in New Zealand (Mildenhall, 1979; McGlone, 1978; McGlone, Mark and Bell, 1995; Chester, 1986). The association between Polynesian deforestation and these features in pollen records is now well-established (McGlone, 1983, 1989). McGlone, Anderson and Holdaway (1994) propose that such widespread deforestation began *ca.* 600 years ago with a small number of sites dated between 700 and 800 BP. Few sites have been dated rigorously to provide an unambiguous chronology. Analysis of ^{14}C dates associated with moa hunting (Anderson, 1989, 1991; Anderson and McGovern-Wilson, 1990) suggests human presence after 800 BP. A few dates before 1 ka BP are considered questionable by these authors. ^{14}C dates (NZA-3819 and -3882) bracketing this event in our study indicate that significant anthropogenic disturbance first occurred some time after *ca.* 900 BP (800 cal BP), and by *ca.* 700 BP (600 cal BP), major forest clearance had taken place from which the local/extra-local vegetation has never recovered.

Table 4.2. Summary of Palynology and Inferred Regional Vegetation since *ca.* 5000 BP

Pollen zone	**Yr BP**	**Key pollen taxa**	**Regional vegetation**	**Climate**
Ta 1a	150(?)	Exotics	Pasture	?
	250 (?)	*Pteridium*-charcoal	Fernbrake	
	700	*Pteridium*-charcoal	Fernbrake	?
Ta 1b		*Dacrydium*	Podocarp-hardwood forest	
	900			
Ta 2		*Dacrydium*, *Agathis*, *Libocedrus*, *Ascarina*	Kauri-podocarp-hardwood forest	warm, moist
	2600			
Ta 3		*Dacrydium*, *Agathis*, *Libocedrus*, *Ascarina*	Kauri-podocarp-hardwood forest	warm, moist, windy
	3400			
Ta 4		*Podocarpus*, *Phyllocladus*, *Agathis*, *Coprosma*	Kauri-podocarp-hardwood forest	Cooler, drier
	5000			

The possibility of old soil carbon inwash is likely to occur after forest clearance (Pennington *et al.*, 1976). This is probably shown in the dating inversion exhibited by NZA-3920 and -3823 when compared with NZA-3882 (Figure 4.2). The dates provided by NZA-3819 and -3882, which indicate the period of first human impact, are not considered to be contaminated in this way.

Sedimentology

The granulometric composition of the Lake Taumatawhana sediments shows two distinct changes in the sand fraction (Figure 4.5). The first peak occurs at 1.12 m and the second between 0.61 m and the sediment surface. The coarse granulometric nature of these peaks indicates the high energy level of the depositing medium (Reineck and Singh, 1975). Thus, the constituent particles of these peaks must have been deposited during periods of increased erosion.

Pollen data from Zone Ta 1b 1.12-0.30 m and Zone Ta 1a 0.30 m to surface (Figures 4.3, 4.4) suggest that these periods of increased erosion can be attributed to human influence in the form of deforestation. This contention is also supported strongly by the trend of the organic matter content down the core (Figure 4.5). Organic-matter content declines sharply at 1.12 m, and also between 0.61 m and the sediment surface. This is thought to represent deforestation accompanied by an increased inwash of (coarse) inorganic matter. Dawson (1990) attributed similar features to periods of increased erosion in lake sediments on Mangaia, Central Polynesia.

The relative abundance of the amorphous material throughout this core is considered a pedological rather than a human-induced feature. The amorphous material forms in the silica-rich sandy parent material of the dune system within which this site is located. Under complete saturation, silica dissolves, and, on reaching the solubility product, it precipitates as amorphous material (J. Kirkman, personal communication 1995). The general tendency of a high content of amorphous material varies only at depth ranges that show markedly higher sand and lower clay contents (Figure 4.5).

The chemical stratigraphy of the Taumatawhana core can best be explained if the inorganic fraction of the sediment is regarded as a sequence of soils derived from the lake catchment. The composition of the residues finally reaching the lake bed reflects erosional activity within the catchment or in the lake itself (Mackereth, 1966). The chemical composition of the sediments in general does not appear to be subject to alterations due to in-lake processes, although some elements are more or less susceptible to post-depositional modification or pre-depositional leaching processes within the soils of the catchment, especially phosphorus, sulphur, iron, manganese and calcium (Mackereth, 1966).

Elements showing a firm association with the soil and sediment mineral matter seem to reflect the erosive processes within the catchment, eventually leading to the deposition of material into the lake. Because of their abundance in mineral matter, the distribution of major elements (Al, K, Mg, Na and Si) in the lake sediments seems to best reflect the erosional history of the catchment. Of those elements in particular, sodium and potassium are clearly associated with the mineral fraction of the sediment rather than with the organic material (Mackereth, 1965, 1966). Both elements show sharply rising concentration values from 0.58 m to the water-sediment interface. The strong relation between the mineral content of the sediment and the Na-K concentration implies that these features are directly proportional to the intensity of erosion to which the catchment was exposed when the sediments were deposited. Thus, the high concentration of K and Na immediately below the surface suggests a period of extremely high erosion within the catchment which continues into the present.

This contention is strongly supported by the chemical stratigraphy of aluminium, magnesium and silicon which also belong to the group of major elements. Apart from a few minor fluctuations in element concentration within the range from 2.99 - 0.58 m, their overall pattern is almost identical to Na and K. Increased values for phosphorus in the upper 0.60 m of the core coinciding with the major elements may also be related to more intensive erosion, although P is often implicated in biological activity.

The chemical stratigraphy suggests that the erosional history at this site can be divided into two main periods. A period of relatively stable conditions reflected by low rates of erosion existed throughout much of the history of the lake. This is characterised by low elemental concentrations in the sediments. With decreasing depth, the concentration of all major and many other elements increases markedly. While the stratigraphic position of this onset of increasing concentration values is not uniform, the trend is generally initiated between 0.75 and 0.58 m. Thus it is here interpreted that 0.75 m marks the boundary between a change from stable to unstable conditions characterised by intense erosional activity.

CONCLUSION

Palynological analysis of sediments from the Lake Taumatawhana site indicates that this region of northern New Zealand has been sensitive to environmental and climate changes throughout the late Holocene. Pollen spectra indicate that while warmer and wetter conditions prevailed from *ca.* 3400 to at least 2000 BP, increased windiness was also a feature of the regional climate. However, the most significant event of the late Holocene has been that of human impact commencing after *ca.* 900 BP (800 cal BP). The coincidence of forest decline, a sharp rise in the incidence of *P. esculentum* and charcoal influx together with related changes in the sedimentological history, which are not evident prior to deforestation, provide the strongest argument for major human-induced environmental change. The date of *ca.* 900 BP (800 cal BP) is somewhat earlier than 700 BP suggested previously.

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Chapter 5

LAKE TAUANUI

A late Holocene pollen record of deforestation and environmental change from the Lake Tauanui catchment, Northland, New Zealand.

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Plate 5.1. Lake Tauanui. Arrow indicates location of pollen core.

Abstract

Late Holocene pollen and sediment records from the Lake Tauanui catchment, northern New Zealand, indicate that the lake formed about 5500 years ago following a series of volcanic events in the Tauanui Volcanic Centre. These volcanic events initiated a volcanosere resulting in a mixed conifer-hardwood forest. *Dacrydium cupressinum* was the dominant tree. *Agathis australis* was always present.

Changes similar to those registered in other Northland pollen diagrams are apparent. At *ca* 4000 yr B.P., when the climate became cooler and drier than before, a fire occurred in the catchment area causing erosion of the surrounding slopes and some destruction of forest. Fluctuations in abundance of many forest species, including *Ascarina lucida, Agathis australis* and *D. cupressinum,* from *ca* 3500 yr B. P. indicate repeated disturbance, increasingly so after 1600 yr B. P. Summer droughts and increased frequency of cyclonic winds are suggested as the cause.

Major anthropogenic deforestation events defined by palynology occurred across many parts of the New Zealand landscape at *ca* 700 yr B.P. At Lake Tauanui anthropogenic forest disturbance, radiocarbon dated to *ca* 1000 yr B.P., is indicated by significant decline in all tree and shrub elements with concomitant increase in pteridophytes, especially *Pteridium esculentum.* Charcoal concentration increases steadily from the onset of disturbance, and in the final phase after the arrival of Europeans, major clearance of vegetation is indicated. Herbs increase markedly in this period, in diversity and abundance.

Introduction

The vegetation of New Zealand has varied during the late Quaternary as a result of climate change. In particular, the effects of the Last Glacial Maximum for most of New Zealand are well documented south of latitude 37°S. At the height of the Last Glacial (*ca* 18,000 years ago) all areas south of Auckland were dominated by grass and shrub communities (McGlone *et al.*, 1993). Forest persisted only in microclimatically favoured sites. Reafforestation commenced in a progressively southward direction from *ca* 14,500 yr B. P. (McGlone, 1988; McGlone *et al.*, 1993). However, north of Auckland (37°S, 175°E) less is known about this period, although two pollen diagrams indicate that forest cover persisted throughout the Last Glacial Maximum (Newnham, 1992; Dodson *et al.*, 1988).

The most dramatic changes in the late Holocene environment resulted from human impact (Molloy, 1969). There has been much debate as to the timing of the earliest human settlement.

The orthodox view, based on archaeological interpretations, places this event at around 1000 years ago (Davidson, 1984), while some suggest it may have occurred up to 2000 years ago (Sutton, 1994). Others contend that first settlement took place *ca* 700 calendar years before present (Anderson, 1991; McFadgen *et al.*, 1994). Arguments for later settlement are based on radiocarbon ages of archaeological material. Support for earlier settlement rests chiefly on palynological and archaeological chronologies of the settlement of tropical Polynesia, demographic extrapolations, and the anticipation that current palynological and associated sedimentological research will support this position (see Flenley, 1994).

McGlone (1983, 1989) demonstrated the strong association in pollen records between deforestation, fire intensity and frequency, bracken (*Pteridium esculentum*) abundance and Polynesian impact. These features are identified in a number of New Zealand pollen records (see *e.g.* McGlone, 1978; McGlone *et al.*, 1995; Mildenhall, 1979; Bussell, 1988; Newnham *et al.*, 1995; Elliot *et al.*, 1995).

This study is part of a larger multi-disciplinary project using lake sediments and peat deposits to reconstruct the timing of first human disturbance in northern New Zealand. In this paper we report results of pollen analysis carried out on a core taken from Lake Tauanui in northern New Zealand. Environmental change is inferred from the palynological record which suggests that this locality was first disturbed much earlier than other similar New Zealand sites.

Study area

Geomorphology

Lake Tauanui is situated in the central Bay of Islands district of northern New Zealand at latitude 35° 30' 06"S and longitude 175° 51' 32"E (Figure 5.1). Its altitude is *ca* 230 m above sea level. Lake formation was a consequence of runoff water from the Mangakahia Range being trapped in two conjoint explosion craters forming part of the Tauanui Volcanic Centre (Elliot and Neall, 1996). The lake has a surface area of approximately 10 ha that varies as water level fluctuates (between approx. 4-6.5 m at the deepest parts). A small cone forms an island within the lake which may be connected to the shore at times of low water level. There are no inflow or outflow streams; water is lost via seepage at the south-western end. Regenerating bush extends to the southern margins of the lake. On the northern side, including Tauanui Cone and its flanks, vegetation is mostly improved pasture with scattered individual trees, mostly

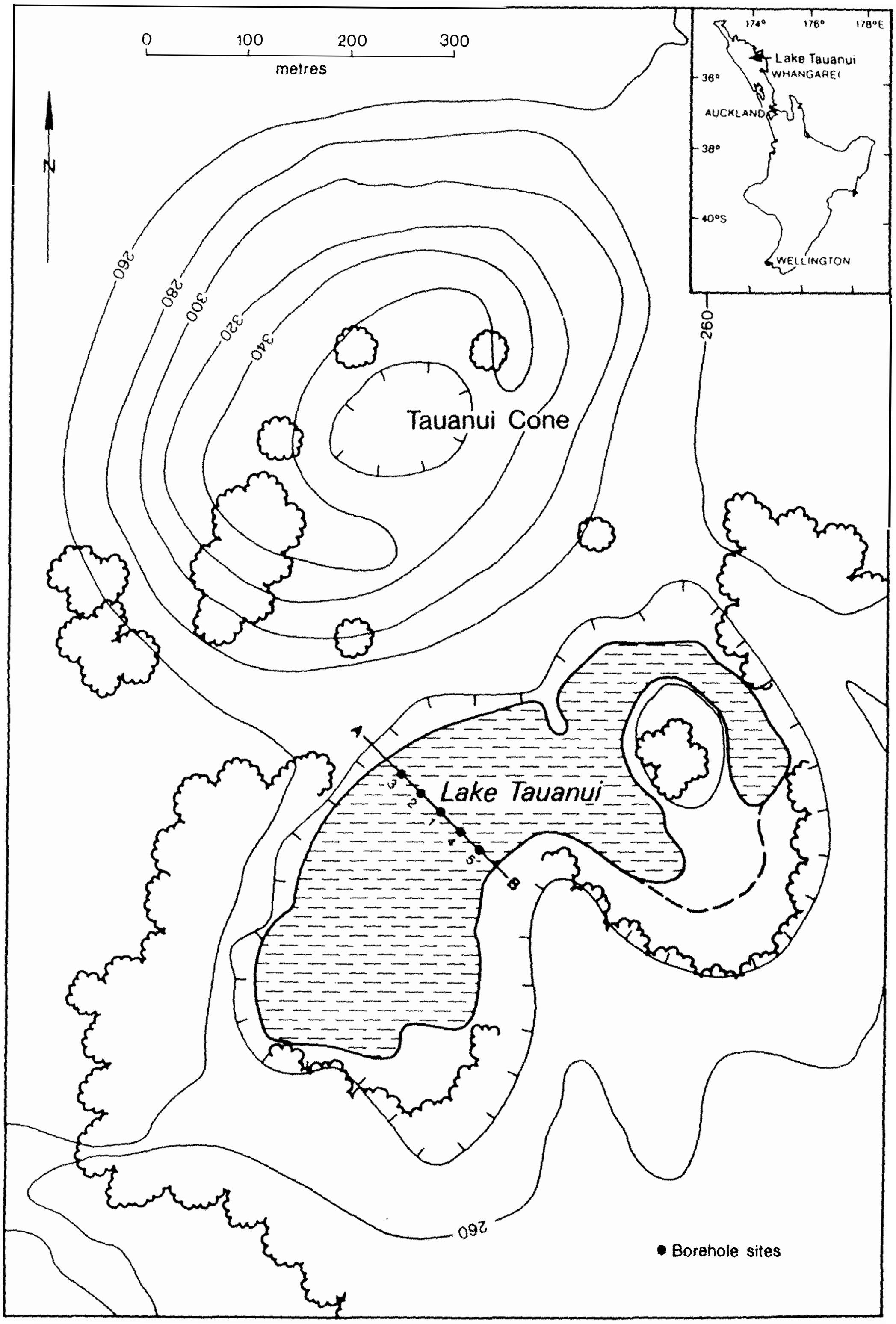

Figure 5.1 Location of the study site, Lake Tauanui, showing its physiography and Tauanui Cone.

Beilschmiedia tarairi (A. Cunn.) Benth. et Hook. f. ex Kirk and *Podocarpus totara* G. Benn ex D. Don. A dense stand of *Dacrycarpus dacrydioides* (A. Rich.) Laubenf lies some 400 metres north-east of the lake.

Climate

In general the climate of Northland is characterised by warm, humid summers and mild winters. Many parts have only a few light frosts each year and some areas are frost-free most years. Inter-annual rainfall in Northland varies greatly. The Kaikohe district has a mean annual rainfall (1941-1970) of 1766 millimetres (Moir *et al.*, 1986). Dry spells occur, usually in late summer or early autumn. Most parts of Northland receive *ca* 2000 hours of bright sunshine per year. Based on temperature records from various parts of Northland (Moir *et al.*, 1986), mean annual temperature for Lake Tauanui is estimated to be *ca* 14.5°C. Northland is one of the least windy parts of New Zealand (Moir *et al.*, 1986). Airflow is predominantly from the south-west, especially in winter and spring (Tomlinson, 1975). Occasionally tropical cyclones reach Northland, but hurricane force winds are rare. Other storms of tropical origin affect Northland, usually once or twice a year between December and April. They bring heavy rain and strong easterly winds.

Field and laboratory methods

A transect was established across the deepest part of the lake (see Figures 5.1 and 5.2). Working from a raft, five cores were retrieved using a modified Vallentyne mud sampler (Walker 1964). Cores were examined in the field and described according to the Tröels-Smith (1955) system. Boreholes 2 - 5 did not penetrate the entire lacustrine sediment owing to the stiff nature of the basal mud. Seven samples from borehole 1 of 5 cm length were dated by Accelerator Mass Spectrometry (AMS) at the Rafter Radiocarbon Laboratory, Lower Hutt, New Zealand. The material was bulk dated except for the lowermost sample which was dated for two fractions, a twig fraction and a humin fraction.

Palynology

Pollen analysis was carried out on the longest (4.00 m) core, from borehole 1. Samples at 10 cm intervals were prepared using the standard acetolysis techniques (Fægri and Iversen, 1989), and mounted in silicone oil for microscopy. *Lycopodium* marker spore tablets were added for pollen concentration calculations (Stockmarr, 1971). Pollen preservation was generally excellent. Taxonomic nomenclature follows Allan (1961), Moore and Edgar (1970), Connor and Edgar (1987), and Molloy (1995). Charcoal concentrations were estimated following Bush *et al.* (1992).

Results of pollen analysis are presented in a pollen percentage diagram (Figure 5.4), and a pollen concentration figure (Figure 5.5). The pollen sum includes all dryland taxa.

RESULTS

Sediment Stratigraphy

Cores from the lake exhibited no laminations. However, several stratigraphic sequences were identified (Figure 5.2) in the core from borehole 1. The uppermost sequence comprised a soft, dark grey/brown gyttja, consisting of 2 parts *Argilla* to 1 part each of *Limus detrituosus* and *Substantia humosa*, to a depth of 2.93 m, which became firmer and drier with increasing depth. This sequence was followed by a grey, clay horizon from 2.93-2.97 m, consisting of 4 parts *Argilla*. The upper and lower boundaries of this horizon were clearly defined. The sequence from 2.97 -3.74 m consisted of dark brown gyttja, comprising *Limus detrituosus* and *Substantia humosa* in a ratio of 2:2. Below this sequence sediments from 3.74 - 4.0 m consisted solely of grey clay (*Argilla*).

Dating

Results from AMS dating are presented in Table 5.1 and Figure 5.3. All dates used in this paper are reported as radiocarbon years B. P. normalised to an average of -25‰ $\delta^{13}C$ per individual sample (after Stuiver and Polach, 1977). The basal sample from borehole 1 was dated for two fractions: a twig fraction which returned a date of 5385 ± 81 yr B. P. (NZA-2806), and a humin fraction which returned a date of 5439 ± 73 yr B. P. (NZA-2807). These dates provide an age for onset of lacustrine deposition in Lake Tauanui. The age/depth line (Figure 5.3) suggests that the slow rate of sedimentation between 5385 ± 81 yr B. P. (NZA-2806) and 4084 ± 72 yr B. P. (NZA-3017) was followed by a more rapid rate between 4084 ± 72 yr B. P. and 2101 ± 65 yr B. P. (NZA-3019). From 2101 ± 65 yr B. P. sedimentation increases noticeably until 1396 ± 64 yr B. P. (NZA-3020). Thereafter the sedimentation rate declines.

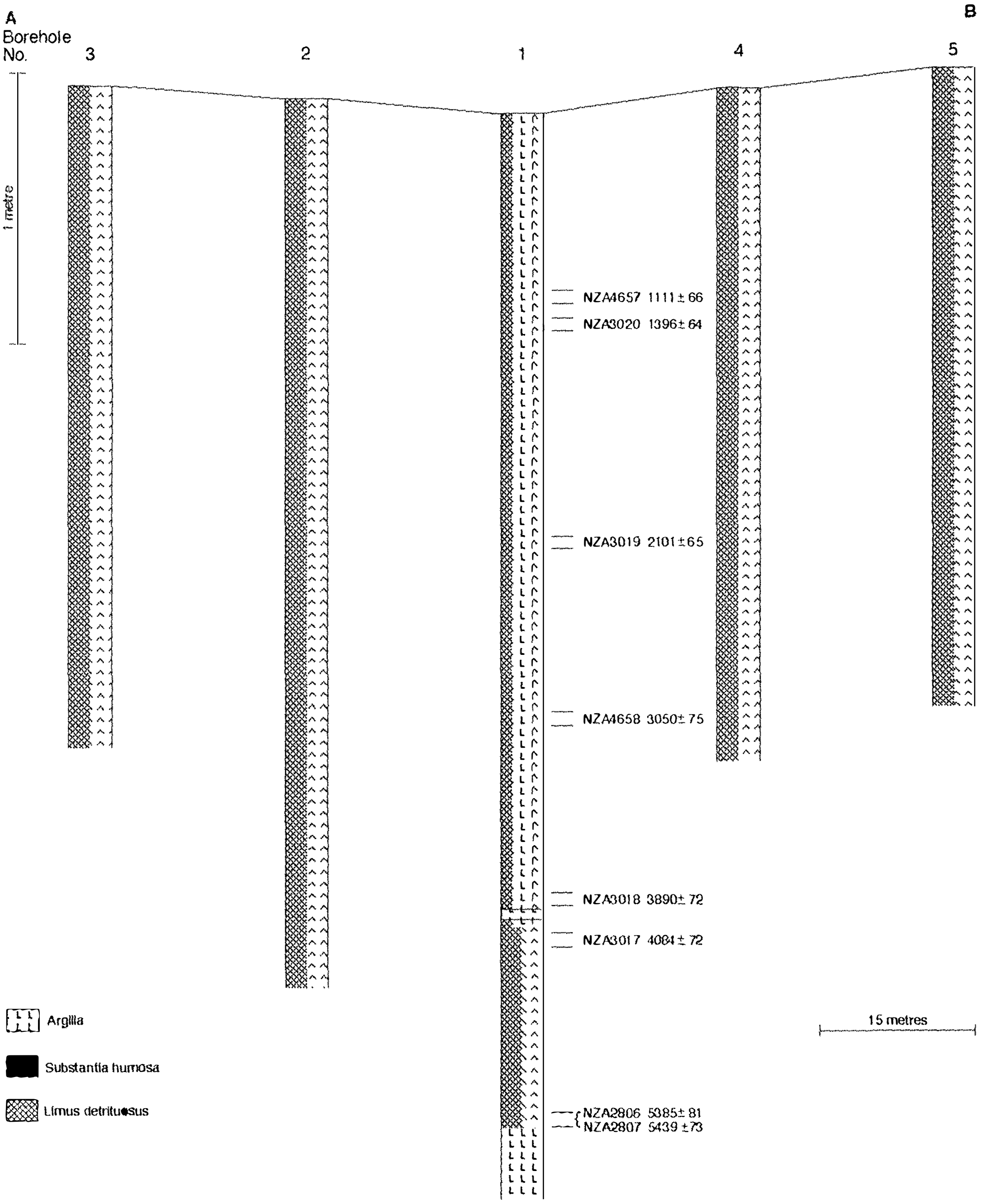

Figure 5.2 Lake stratigraphy of boreholes 1 - 5 showing ^{14}C chronology.

Table 5.1 Radiometric dating of borehole 1. Ages reported are normalised to an average -25‰ δ^{13}C per individual sample.

Borehole 1

Accession No.	Sample Material	Depth (m)	Age ^{14}C yr. B. P.	δ^{13}C‰
NZA-4657	treated gyttja	0.65-0.70	1111 ± 66	-31.63
NZA-3020	treated gyttja	0.75-0.80	1396 ± 64	-30.80
NZA-3019	treated gyttja	1.55-1.60	2101 ± 65	-30.90
NZA-4658	treated gyttja	2.21-2.26	3050 ± 75	-31.14
NZA-3018	treated gyttja	2.87-2.92	3890 ± 72	-32.12
NZA-3017	treated gyttja	3.02-3.07	4084 ± 72	-30.76
NZA-2806	twig fraction	3.69-3.74	5385 ± 81	-27.40
NZA-2807	humin fraction	3.69-3.74	5439 ± 73	-28.90

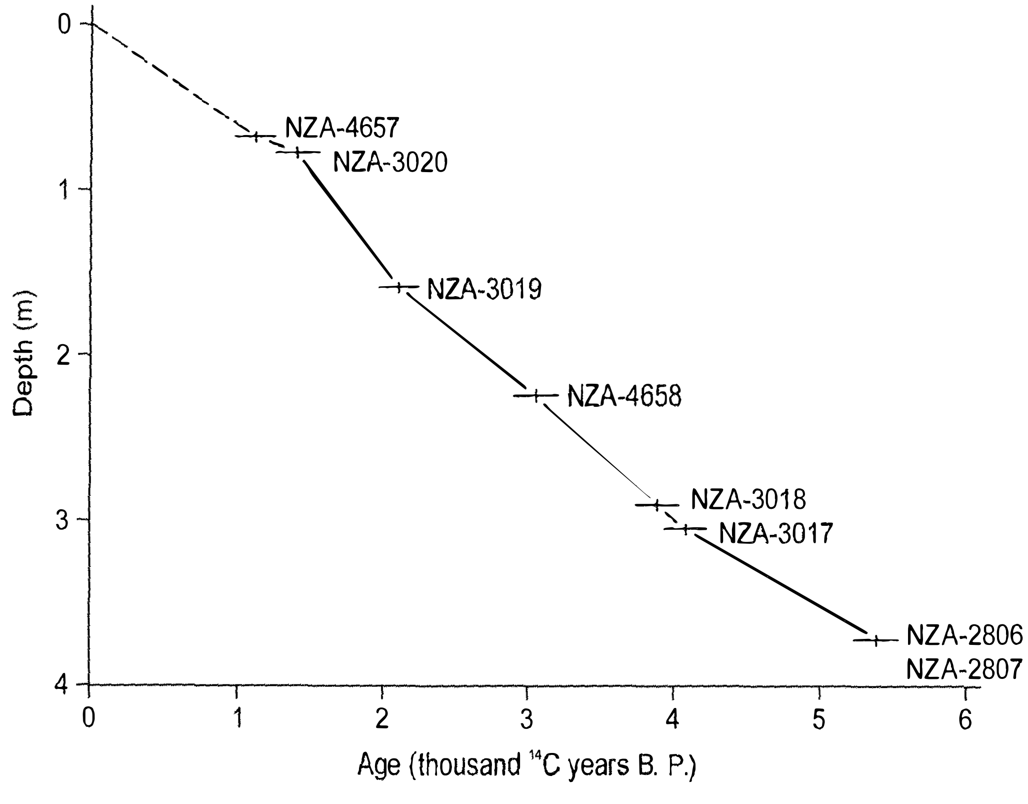

Figure 5.3 Age-depth graph for the core from Lake Tauanui. The horizontal bars represent the magnitude of error on the ^{14}C ages (2 SD), and the vertical bars the length of the core sediment dated.

Palynology

Three pollen zones are recognised (Figures. 5.4 and Fig. 5.5) based on cluster analysis shown on the CONISS dendrogram (Grimm, 1991a, 1991b). The dendrogram is produced by stratigraphically constrained cluster analysis, a multivariate method used to provide quantitative definition of stratigraphic zones (Grimm, 1987). Zone 1 is further subdivided into 1a and 1b. The resulting zones are as follows:

Zone T3 3.85-3.15 m ca 5400-4300 yr B. P.

Initially *Cyathea* spores are abundant. Very few of these spores are corroded. From 3.60 m pollen of *Dacrydium cupressinum* Lamb. and *Podocarpus* dominates the zone. Also present are *Agathis australis* Salisb., and significant amounts of *Ascarina lucida* Hook. f. Abundant, but fluctuating levels of *Metrosideros* occur throughout this zone. Pollen of several other angiosperm trees, including *Knightia excelsa* R. Br., and *Syzygium maire* Sykes et Garnock-Jones, is present in significant amounts. A small peak in charcoal concentration occurs at the base of this zone.

Zone T2 3.15-1.25 m ca 4300-1850 yr B. P.

The most important elements of this zone are *Agathis australis, Dacrydium cupressinum, Libocedrus, Knightia excelsa, Metrosideros, Podocarpus* and *Prumnopitys taxifolia* (D. Don.) Laubenf. *Ascarina lucida* is present throughout. Fluctuations in tall forest trees are evident in the upper part of the zone accompanied by elevated charcoal concentrations. *Paesia scaberula* (A. Rich.) Kuhn, a ground fern, is common from the middle of the zone. *Cyathea* is abundant throughout. A small peak in charcoal concentration occurs at the base of this zone.

Zone T1b 1.25-0.65 m ca 1850-1100 yr B. P.

Frequencies of ground ferns are elevated through this period, particularly *Paesia scaberula* which becomes increasingly significant toward the top of the zone. While *Agathis australis* maintains a strong presence, many of the other major tree taxa, particularly the podocarps, continue to fluctuate in abundance. Toward the top of the zone grass pollen begins to increase slightly.

Zone T1a 0.75-0.00 m ca 1000 yr B. P.- present

Most tree and some shrub taxa decline markedly from this time with a concomitant sharp increase in herb taxa, ferns and some shrubs. The rise in herbs is dominated by grasses and

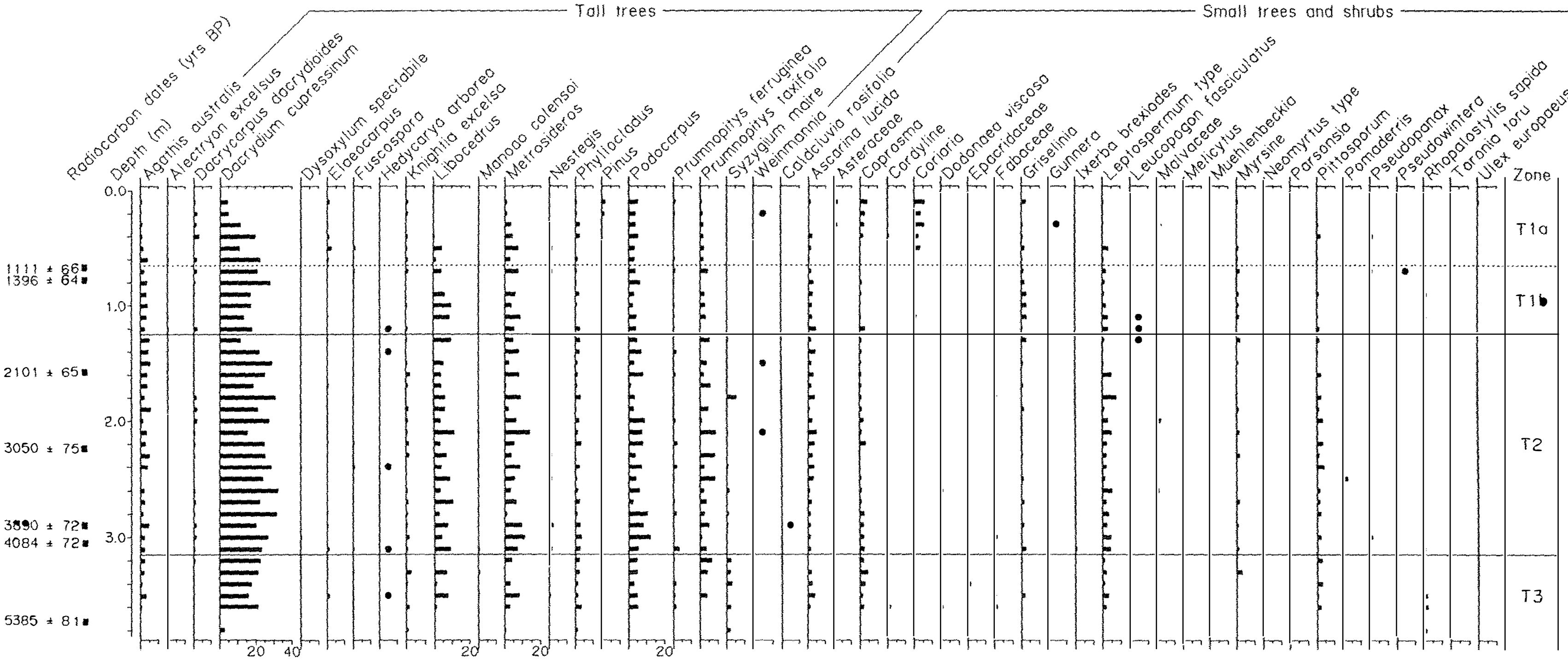

Figure 5.4a Pollen percentage diagram for borehole 1 from Lake Tauanui. Tall trees, small trees and shrubs. Pollen sum includes all dryland pollen and spores. Charcoal concentrations are shown as grains cm^{-3}.

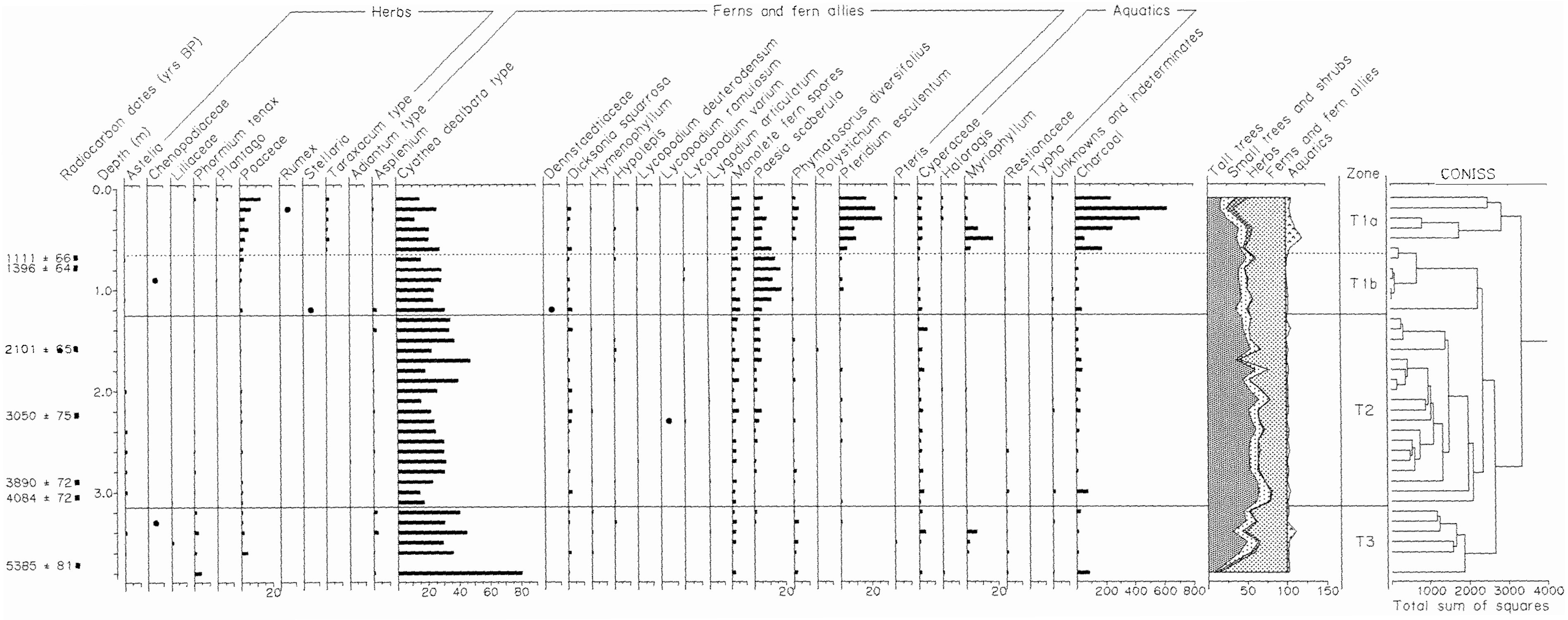

Figure 5.4b Pollen percentage diagram for borehole 1 from Lake Tauanui. Herbs, ferns, fern allies and aquatics. Pollen sum includes all dryland pollen and spores. Charcoal concentrations are shown as grains cm^{-3}.

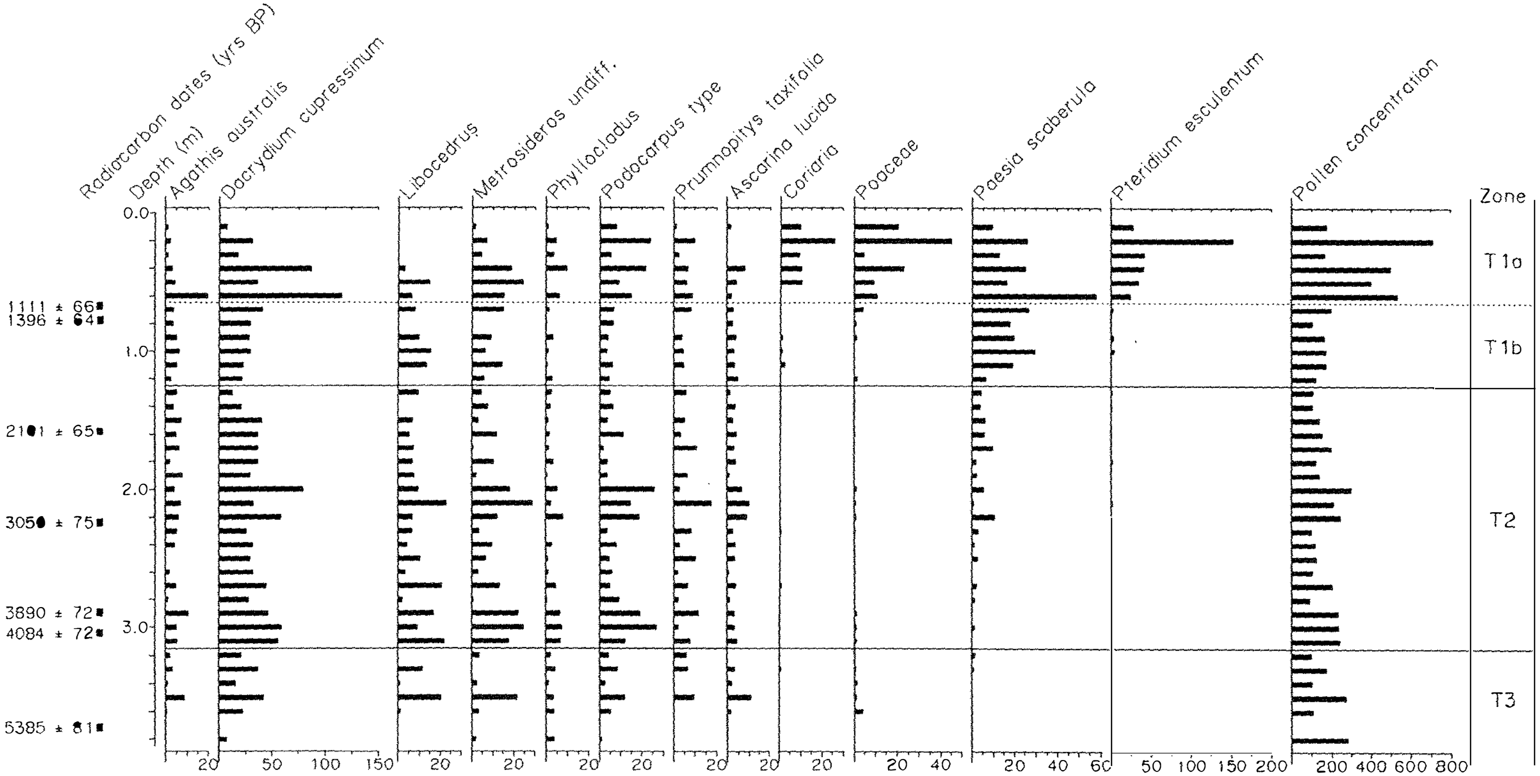

Figure 5.5 Pollen concentration diagram for borehole 1, data expressed as grains cm^{-3}.

also accompanied by significant amounts of *Taraxacum.* Ferns remain significant including tree ferns, *Cyathea* and *Dicksonia*; ground ferns, especially *Paesia scaberula* and *Phymatosorus diversifolius* (Willd.) Pichi. Serm., are particularly important. *Pteridium esculentum* rises sharply from the base of the zone accompanied by similar increases in charcoal concentration. The decline in tree taxa is most marked by reductions of *Agathis australis, Dacrydium cupressinum, Libocedrus, Metrosideros* and *Prumnopitys taxifolia.* Shrubs increase, including Asteraceae, *Coprosma* and *Coriaria,* while introduced European taxa first appear toward the top of the zone including *Pinus* and *Ulex europaeus* L. Aquatic and wetland species are more frequently recorded, in particular *Myriophyllum* .

DISCUSSION

The sediment record for Lake Tauanui extends back about 5400 radiocarbon years and reveals a number of major palaeoecological events of both a local and extra-local nature. The lake formed as a result of volcanic activity within Tauanui Volcanic Centre. Two eruption craters that formed *ca* 5500 years ago trapped runoff water from the flanks of the Mangakahia Range producing Lake Tauanui (Elliot and Neall, 1996). This volcanic event probably affected the local plant community and may have initiated fires that destroyed much of this vegetation. Immediately following the onset of organic deposition on the lake bottom *ca* 5400 yr B.P., few trees or shrubs were present in the pollen source area. The most important members of the plant community were tree ferns, especially *Cyathea.* Most of the fern spores enumerated were not corroded suggesting they were produced by local plants and not secondarily deposited. All tree ferns are capable of resprouting following fire (Wardle, 1991). Early vegetation succession at L. Tauanui was similar to volcanoseres in New Guinea (Taylor, 1957), Krakatau (Richards, 1964; Flenley and Richards, 1982), and other parts of the Pacific (Burrows, 1990). A similar trend was observed at Mount Tarawera (near Rotorua, New Zealand) following the 1886 eruption (Burrows, 1990). At Tauanui the fern-dominated vegetation gave way to an increasingly tree- and shrub-dominated community in which *Dacrydium cupressinum* was the dominant tree and *Cyathea,* though much reduced, was still important. This trend is suggestive of a type of volcanosere. *Libocedrus, Metrosideros, Phyllocladus, Podocarpus, Agathis australis, Dacrycarpus dacrydioides, Prumnopitys ferruginea* (D. Don.) Laubenf. and *P. taxifolia* were also represented in this forest.

A fire in the lake catchment is inferred from a charcoal concentration peak at 3.00 m *ca* 4 kyr B. P., and is followed immediately by inwash of clay sediment assumed to be the result of catchment erosion. Shortly after this a decline in many tree taxa is noted, though *Dacrydium cupressinum* appears to increase. This increase of *D. cupressinum* probably relates to influx of extra-local pollen. This taxon tends to be over-represented in the pollen record because of high production and wide dispersal (Moar, 1970; Mildenhall, 1976).

A trend of oscillating peaks and troughs in the forest taxa occurs throughout pollen zone T2. Initially *Ascarina lucida* is less common, but toward the middle of zone T2 (*ca* 3.4 kyr B. P.) becomes more abundant. Hardy podocarps, *Podocarpus* and *Prumnopitys taxifolia*, are more abundant throughout the lower half of zone T2, though levels fluctuate. McGlone *et al.* (1993, 1996) have described increased cyclonic activity in northern New Zealand during the mid-to-late Postglacial. High winds and high-intensity, heavy rain characterise cyclonic storms generated to the north of New Zealand which lose intensity as they travel south (McGlone *et al.*, 1996). Pollen diagrams from other parts of northern New Zealand (*e.g.* McGlone and Moar, 1977; McGlone, 1988) indicate that the climate deterioration of the mid-to-late Postglacial was interrupted by a brief period of climate amelioration between *ca* 3.4-1.8 kyr B. P. (McGlone and Moar, 1977). At Tauanui increases in abundance for *Agathis australis* and *Ascarina lucida* are apparent from 4000 yr B.P. *A. lucida* is a small, frost and drought sensitive tree endemic to New Zealand. Increased frequency of this tree elsewhere in New Zealand Holocene records has been interpreted as a change to milder, wetter climate (McGlone and Moar, 1977). Elliot *et al.* (1995) argue for cooler/drier conditions at Lake Taumatawhana (*ca* 90 km north of Lake Tauanui) from 5 - 3.4 kyr B.P. followed by a period of warm, moist and windy conditions. However, changes in *A. lucida* values at Tauanui are only slight, and together with fluctuations in other taxa such as *Knightia* are more suggestive of seral trends associated with forest disturbance than significant climate change. Similar trends can be seen in other Northland pollen diagrams (*e.g.* Kershaw and Strickland, 1988; Enright *et al.*, 1988; Dodson *et al.*, 1988).

The period that follows, *i.e.* from 1850 yr B. P., marks a change from dominance of mature forest to one where understorey trees, shrubs and ferns are more abundant, especially *Paesia scaberula*, and emergent trees are less common. *P. scaberula* has a known ecological preference for open disturbed habitat (Brownsey and Smith-Dodsworth, 1989). The combination of increased understorey and shrub taxa with increased frequencies for ferns is suggestive of disturbance in the catchment. No significant changes occur in charcoal concentration, which remains low. This disturbance could be due to increased cyclone activity, and is consistent with climatic variability described by McGlone *et al.* (1993, 1996) in the late Postglacial. A change from moist, cloudy summers and dry, clear winters to a cool, wet winter-dry summer regime has been argued for mid-to-late Holocene times (McGlone *et al.*, 1993). Drier conditions could have been severe in their effects on the local vegetation at Lake Tauanui given the free-draining nature of the volcanic soils. The possibility of this disturbance being human-induced should not be entirely discounted. However, the absence of *Pteridium esculentum* (bracken) spores and microscopic charcoal which are typically associated with Polynesian deforestation (McGlone, 1983, 1989) does not support this hypothesis.

Major forest decline is clearly evident from the top of zone T1b dated at *ca* 1100 yr B.P. All trees other than *Podocarpus* show significant decline. Shrubs show significant increase, particularly Asteraceae, *Coprosma* and *Coriaria*. *Coriaria* is described by Wardle (1991) as being a vigorous pioneer species, particularly in secondary succession. Various *Coprosma* species are also able to take advantage of disturbed ground, especially where some protection is afforded, for example by *Kunzea/Leptospermum* stands. Grasses become increasingly more common from the beginning of this period accompanied by other herbs, particularly *Taraxacum*. However, the most significant feature of the uppermost pollen zone is the rise to prominence of *Pteridium esculentum* and the associated rise in charcoal concentration. This is a feature of many other New Zealand pollen diagrams (*e.g.* McGlone, 1978, 1983; Chester, 1986; Newnham *et al.*, 1995; Elliot *et al.*, 1995), and is attributed to Polynesian deforestation (McGlone, 1983, 1989). This deforestation event occurred shortly after 1100 yr B. P., and probably between 980 - 1240 yr B. P. The lack of major changes in organic/inorganic sedimentation suggests that the ^{14}C chronology is not significantly affected by inwash of old soil carbon (*sensu* Pennington *et al.*, 1976). This is in contrast to the Lake Taumatawhana site further north where erosion is correlated with inwash of old soil carbon and inversion of radiocarbon dates (Elliot *et al.*, 1995). The presence of exotic taxa, such as *Pinus*, *Ulex europaeus* and *Plantago*, in the uppermost samples marks the arrival and influence of Europeans in the Tauanui catchment.

CONCLUSIONS

A chronological sequence of climate change and anthropogenic disturbance can be determined from the pollen and sediment records at Tauanui. This can be summarised as follows:

1. Lake Tauanui formed *ca* 5500 yr B. P. and organic sedimentation began *ca* 5400 yr B.P. A volcanosere developed in the catchment *ca* 5400 yr B. P. and was initially dominated by tree ferns, particularly *Cyathea*.
2. At *ca* 4000 yr B. P. high concentrations of charcoal indicate a fire. The fire event was followed closely by marked catchment erosion associated with forest instability. Forest disturbance occurred repeatedly throughout the following 2.0 - 2.5 kyr and catchment erosion is also evident during this period. This variability may reflect increased occurrence of summer drought and the effects of cyclones.
3. Increased forest disturbance is initiated at *ca* 1850 yr B. P. More catastrophic disturbance occurred after *ca* 1100 yr B. P. which is almost certainly attributable to human impact, marking the first anthropogenic environmental effects in this locality. This is in turn followed by the arrival of Europeans marked by the appearance of introduced taxa.

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Chapter 6

WHARAU ROAD SWAMP

A 4300 year palynological and sedimentological record of environmental change and human impact from Wharau Road Swamp, Northland, New Zealand.

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Plate 6.1 The Wharau Road Swamp.

Abstract

The palynology and sedimentology of the late Holocene Wharau Road Swamp, Northland, are described. Organic sediment began accumulating *ca* 4300 yr B.P. in a valley as a result of damming by a basaltic lava flow from nearby Mount Te Puke. Mixed conifer-hardwood forest dominated the region until major anthropogenic forest clearance dated by radiocarbon at *ca* 600 yr B.P. *Dacrydium cupressinum* was the dominant taxon. *Agathis australis* was always present until European clearance, with peaks in the pollen record at inferred ages of *ca* 3700 yr B.P. and *ca* 1800 yr B.P. Climate changes similar to those registered in other pollen diagrams from northern New Zealand are evident, and suggest that climate was wetter and warmer than at present before 4000 yr B.P. From about 2600 yr B. P. the climate became drier and cooler, indicated by a decline in *Ascarina lucida* and *D. cupressinum.* A period of milder and wetter climate from *ca* 2000 yr B. P. is suggested by increases in *D. cupressinum, A. lucida* and *Cyathea.* Major forest disturbance at *ca* 600 yr B. P. is recorded by a sharp decline in all tree and shrub taxa accompanied by increases in herbs and pteridophytes, and a coincident sharp rise in charcoal influx. Also of particular importance at this time is the dramatic rise in the curve for *Pteridium esculentum* (bracken), which is associated with Polynesian land clearance and cultivation. The date for forest clearance is much later than the widely accepted date of *ca* 1000 yr B.P. for first settlement.

Sedimentological evidence, in particular changes in grain-size distribution, supports palynological inferences of anthropogenic disturbance of local vegetation and associated soil instability. Increased rates of erosion are indicated by sharp rises in coarse grain-size fractions from *ca* 700 yr B. P. These granulometric trends are accompanied by changes in sediment chemistry, especially potassium and sodium, which show increased concentrations.

Keywords: palynology, sedimentology, pollen diagram, forest clearance, Holocene, Wharau Road Swamp, charcoal, climate change, *Agathis australis, Dacrydium cupressinum, Pteridium esculentum*

Introduction

Investigation of the vegetational history of many parts of New Zealand has indicated that Postglacial climate change can be identified in pollen records. One of the most widely documented changes has been that of the *Ascarina lucida* decline (McGlone and Moar, 1977). However, the most significant feature of the Holocene has been the late and severe human impact on the environment. It has been widely accepted that human settlement first occurred at around 1000 radiocarbon yr B. P. (Davidson, 1984), or soon after (Anderson and McGovern-Wilson, 1990). The evidence for this derives largely from dated archaeological sites. More recently, assessments of radiocarbon dates by Anderson (1991), McGlone *et al.* (1994) and McFadgen *et al.* (1994) suggest that first settlement occurred nearer 700 yr B. P.

The effect of Polynesian settlement on the vegetation of New Zealand has been profound. Large areas of forest were cleared, chiefly by fire, for a variety of reasons including agriculture, travel, hunting and settlements (McGlone, 1983). Perhaps one of the more important reasons for clearance of forest was to promote bracken growth - bracken (*Pteridium esculentum*) was a major carbohydrate food source for Maori in prehistoric New Zealand (Best, 1942). The concordance of evidence from pollen records, charcoal fragments and sediment analyses indicates that forest clearance was often rapid and it is now well established that the sharp rises in the curves for *Pteridium esculentum* and charcoal influx are firmly associated with anthropogenic modification of the landscape (McGlone, 1983, 1989; Newnham *et al.*, 1989). This paper presents a radiocarbon-dated pollen profile and sedimentological data from Wharau Road Swamp, extending from approximately 4300 yr B. P. to the time of European settlement, recording pre-human environmental change and deforestation of that region.

Despite previous work, there remains controversy as to the dating, amplitude and nature of these climatic and anthropogenic changes, and especially as to their date in northern New Zealand. The present paper is an attempt to apply the palynological technique in an area where there are traditions of long Maori occupancy, and where previous work by Chester (1986) had found possible evidence of early forest clearance. In addition, integration of sedimentology (especially grain-size analysis and sediment chemistry) with pollen analyses permits the correlation of erosive events with vegetation disturbance. This work forms part of a larger multi-disciplinary project using peat deposits and lake sediments from Holocene sites in the Northland peninsula aimed at reconstructing the timing of first human disturbance in northern New Zealand (see Elliot *et al.*, 1995).

Description of the Wharau Road site

The Wharau Road Swamp is located just south of the Hauparua Inlet, an arm of Kerikeri Inlet, west of Onewhero Bay in the Bay of Islands (Figure 6.1, NZMS 260 GR P05/052635; Plate 6.1). The peat swamp from which the cores were extracted covers approximately 17.5 hectares, and includes an ephemeral lake at its western end. The surrounding hills are of low relief, nowhere exceeding 100 m a.s.l., comprising Triassic-Jurassic greywacke basement rocks of the Waipapa Series (Kear and Hay, 1961). The swamp slopes gently to the west and is enclosed in a valley basin partially dammed by a basaltic lava flow from Mount Te Puke (Ferrar, 1925).

Volcanic bombs presumed to derive from nearby Mount Te Puke (Wellman, 1962), and which stratigraphically underlie Taupo Pumice (Pullar *et al.*, 1977), indicate that the formation of the swamp pre-dates the Taupo eruption of *ca* 1850 yr B. P. (Froggatt and Lowe, 1990). This assumes that damming of the swamp occurred at the same time as the formation of Mount Te Puke, which is thought to have formed from a single eruption (Chester, 1986). Although Smith *et al.* (1993) dated Te Puke basalts by K/Ar to 140,000 ± 60,000 yr B. P., earlier work using the K/Ar method (Stipp and Thompson, 1971) indicated a much younger age for Te Puke of 17,000 ± 6,000 yr B. P. Stipp and Thompson concluded that, whilst K/Ar dating of these rocks could not be accepted with any great confidence, there was little doubt that Te Puke basalts were late Quaternary and probably Holocene.

The modern, undisturbed vegetation of the swamp is relatively rich floristically. Numerous shrubs and small trees tolerant of high water tables are present; especially abundant are *Cordyline australis*, *Leptospermum scoparium* and *Coprosma tenuicaulis*. *Typha orientalis* is common, and the sedge *Eleocharis acuta* is widespread. Many small herbs occur as scattered individuals, including *Isachne* sp., an aquatic grass. The swamp margin is fringed in many places by *Acacia* species. The extra-local vegetation includes the Waitangi State Forest, which is planted in exotic trees, mainly *Pinus* sp. Elsewhere the land is either cleared and in pasture or supports shrubby vegetation, chiefly *Leptospermum scoparium* and *Ulex europaeus*.

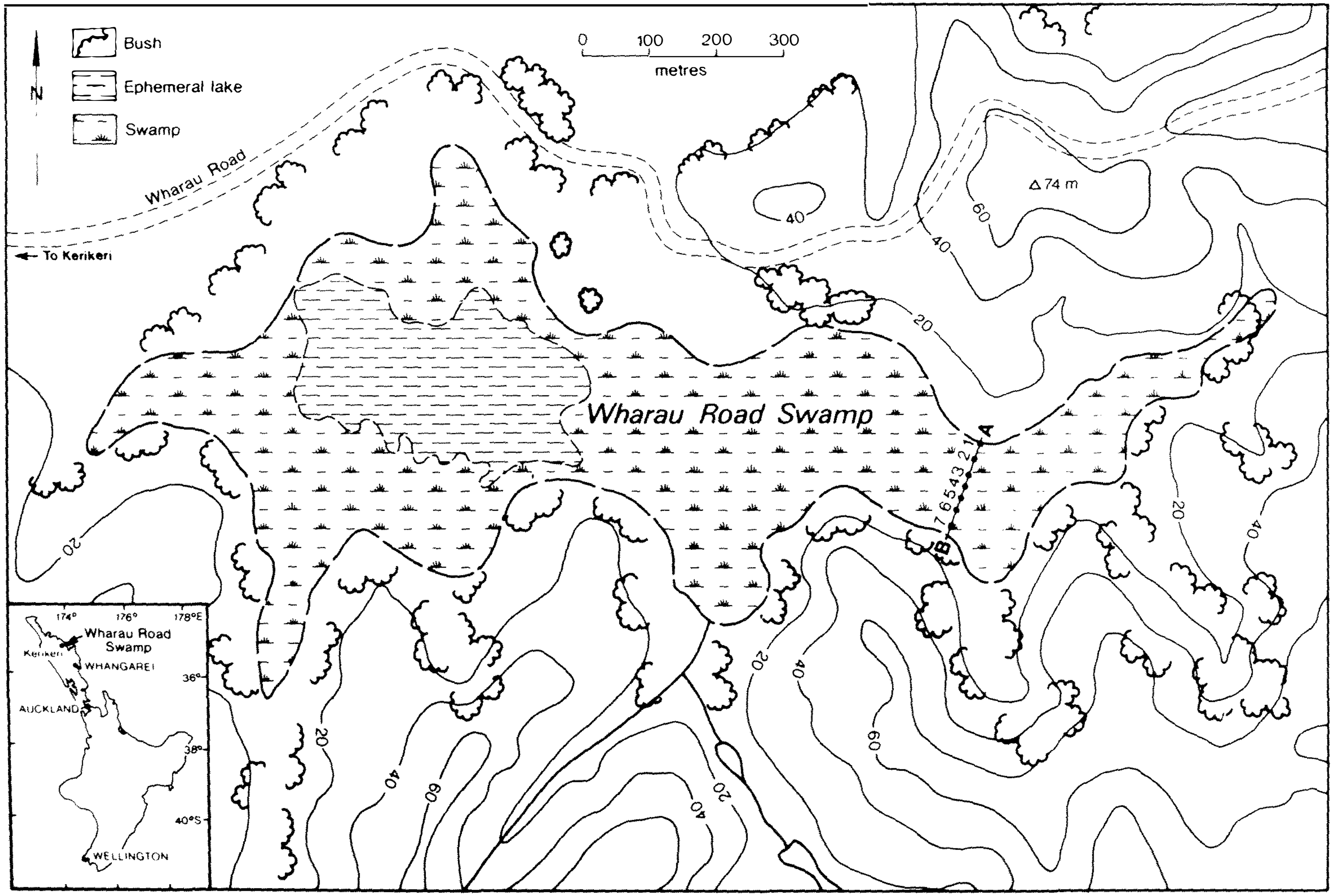

Figure 6.1 Location and physiography of the Wharau Road Swamp, Bay of Island. Values are elevations (in metres). A—B line shows coring transect across swamp.

MATERIALS AND METHODS

Stratigraphy

Using a D-section sampler (Jowsey, 1966) a series of boreholes was made along a transect across the swamp (Figure 6.1). This transect location was chosen because of its relatively undisturbed state. Much of the lower, western parts of the swamp have been drained and cleared for farming. Borehole 5 was selected for pollen analysis because it provided the longest sequence of organic deposition. This core can be divided from top to bottom into six broad stratigraphic units (Figure 6.2): loose peaty mud; coarse peat; organic mud (gyttja); coarse peat; organic mud; and a substratum of sandy clay. The adjacent boreholes (4 and 6) have similar stratigraphy. Field descriptions of borehole 5 following the Tröels-Smith (1955) system are discussed below.

The uppermost unit extends to a depth of 0.33 m, the top 0.20 m of which was too loose to be retained in the sampler. This dark brown material was made up of *Argilla, Grana* and *Substantia humosa* in a ratio of 2:1:1. The second unit extends to 1.60 m and can be subdivided into two sub-horizons. The uppermost sub-horizon, between 0.33 and 0.50 m, consists of dark brown *Detritus herbosus* and *Substantia humosa* in a ratio of 2:2. The lowermost sub-horizon, between 0.50 and 1.60 m, consists of red-brown *Detritus herbosus* and *Substantia humosa* in a ratio of 3:1. The third unit, between 1.60 and 1.74 m, consists of a brown gyttja made up of *Detritus herbosus*, *Substantia humosa* and *Argilla* in a ratio of 2:1:1. A transition, extending from 1.74 to 1.88 m, includes equal amounts of *Argilla, Grana, Limus detrituosus* and *Detritus herbosus.* The upper and lower boundaries of this unit are not well defined, and transitions are noted in the field records. From 1.93 to 2.46 m the fourth unit consists of dark brown/black *Detritus herbosus* and *Substantia humosa* in a ratio of 3:1. The fifth unit, extending from 2.46 to 3.51 m, consists of brown *Limus detrituosus, Argilla, Grana* and *Detritus herbosus* in equal parts. The lowermost unit, from 3.51 m to the base (4.00 m), comprises *Argilla* and *Grana* in a ratio of 3:1.

Palynology

Pollen slides for microscopic examination were prepared using standard alkali and acetolysis procedures (Fægri and Iversen, 1989). At the onset of the chemical preparation *Lycopodium* marker spore tablets were added for absolute pollen frequency calculations (Stockmarr, 1971). Where necessary, hydrofluoric acid treatment was used to remove sand and fine silt; sodium pyrophosphate was used to deflocculate clay-rich samples (Bates *et al.*, 1978); and oxidation of some samples was necessary to remove lignic material. Samples were then mounted in silicone oil (Andersen, 1960) and examined under a Zeiss Axiophot photomicroscope. Counts of pollen and spores were continued until at least 200 grains of dryland taxa were included. Taxonomic nomenclature used follows Allan (1961), Moore and Edgar (1970) and Connor and Edgar (1987). Charcoal counts were obtained by counting across a centre traverse until at least ten *Lycopodium* spores had been counted (after Bush *et al.*, 1992). From these counts estimates were obtained of charcoal concentration.

Sedimentology

Sedimentological analyses were carried out for grain-size, mineralogy, chemistry, and organic content. Cores 1–3 were used for determination of grain size and organic matter measurements (a total of 69 samples), core 7 for sediment mineralogy (a total of 30 samples) and core 5 for sediment chemistry (a total of 33 samples). Additional grain-size analyses were carried out on core 5 but these were restricted to coarse (>60 µm) and fine (<60 µm) fractions because of the limited amount of sediment remaining after pollen and chemical analyses. All these investigations required the same basic sample preparation. Samples were subdivided and oven-dried at 40°C. The sub-sample slices ranged from 0.04 m to 0.145 m in length depending on the lithology. Sections of the cores rich in organics (such as gyttja and peat layers) required longer sub-samples than more silty and clay-rich sections to yield sufficient inorganic material for the above-mentioned analyses. Dry sub-samples were gently pestled to break down aggregates, and dry sieved at 2.0 mm to separate coarse and fine sediment (Loveland and Whalley, 1991). All of the compositional analyses were made on the fine sediment fraction (< 2.0 mm).

For grain-size analysis, samples were oxidised with hydrogen peroxide (after Kretzschmar, 1989). Sample size ranged from 5.0 to 14.0 g, and silt and clay fractions were analysed using a particle size analyser ("Sedigraph"). The sand fraction (62.5 µm to 2.0 mm) was separated from the bulk sample by wet sieving and determined separately as an individual fraction.

Organic content was measured by loss-on-ignition (after Kretzschmar, 1989). Sediment chemistry was analysed by Inductively Coupled Plasma Emission Spectrometry on liquid digest. Sample digestion involved a 1:1 concentrated hydrofluoric acid/concentrated nitric acid solution treatment in combination with hydrogen peroxide (30%) oxidation to destroy the organics of the sub-samples and hydrochloric acid (2 M) extraction.

The mineralogy of the silt and clay fraction was investigated by X-ray diffraction (XRD). Preparation for this method was identical to that required for determination of grain size apart from sample drying at 40°C. Instead, the samples were treated with hydrogen peroxide for organic matter destruction at their field moisture in order to avoid a collapse of certain clay minerals through drying.

RESULTS

Dating

Seven samples were radiocarbon dated by accelerator mass spectrometry (AMS) at the Rafter Radiocarbon Laboratory, Lower Hutt, New Zealand (Table 6.1). An age-depth graph is shown in Figure 6.3. The lowermost and oldest sample was dated for two fractions: a plant fragment fraction which returned a date of 4241 ± 70 yr B. P. (NZA-2804), and a humin fraction which returned a date of 4448 ± 74 yr B. P. (NZA-2805). These dates are in good agreement and afford a high degree of confidence in their accuracy. Using an error weighted mean of the two ages provides a chronology for onset of organic deposition beginning *ca* 4300 yr B. P. Initially the rate of sedimentation is relatively slow (*ca* 0.55 mm/yr), but the rate increases sharply after *ca* 750 yr B. P. Because sedimentation is still continuing, the line in Figure 6.3 would be expected to pass through the origin, and to be progressively steeper near the origin because either the upper sediments are less compacted than lower ones, or the sedimentation rate increases owing to increased erosion. This gives the dotted line shown in Figure 6.3. NZA-3146 and 3607 are therefore probably slightly too old for the expected sedimentation rate. If so, this may be due to inwash of old soil carbon into the swamp during forest clearance (cf. Pennington *et al.* 1976). Age estimates for events occurring between dated samples are interpolated from the age-depth curve in Figure 6.3. A rhyolitic ash was observed in borehole 2 at 1.11-1.13 m and identified by electron microprobe analysis of glass as Kaharoa Tephra. The same tephra correlates with NZA-3606 of core 5 (756 ± 62 yr B. P.)

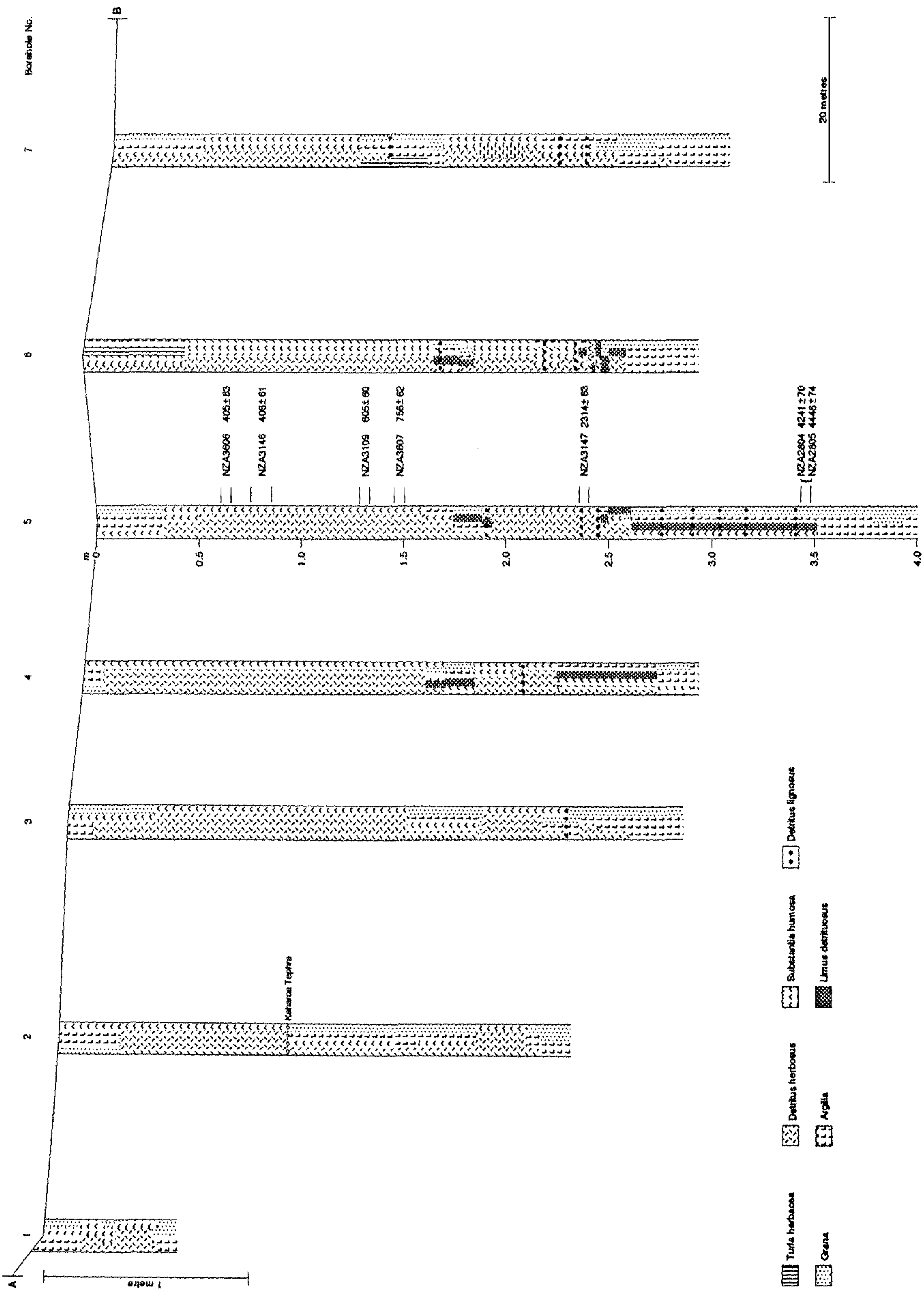

Figure 6.2 Core stratigraphy for boreholes 1-7 (terminology after Tröels-Smith, 1955) showing radiocarbon chronology and position of Kaharoa Tephra.

Table 6.1 Radiocarbon dating of samples from core 5

Depth (m)	Material dated	Conventional ^{14}C age [a]	NZA # [b]	δ^{13}C (‰)
0.60-0.65	litter	405 ± 63	3607	-25.67
0.75-0.80	treated peat	406 ± 61	3146	-26.60
1.28-1.33	treated peat	605 ± 60	3109	-27.10
1.45-1.50	litter	756 ± 62	3606	-27.13
2.35-2.40	treated peat	2314 ± 63	3147	-29.80
3.43-3.48	plant fragments	4241 ± 70	2804	-28.50
3.43-3.48	humin fraction	4448 ± 74	2805	-29.20

[a] In yr B. P. ± 1 s. d. based on old T½ after Stuiver and Polach (1977)

[b] Accession number for Rafter Radiocarbon Laboratory, Lower Hutt, N.Z.

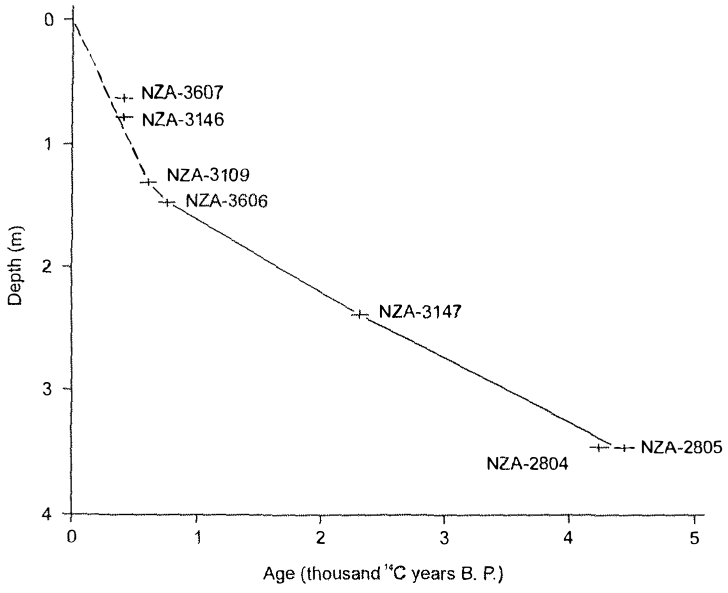

Figure 6.3 Age-depth curve for core 5. The horizontal bars represent the magnitude of statistical counting error on the ^{14}C dates (2 SD); the vertical bars are sample slice thicknesses.

Palynology

The pollen sum includes all dryland pollen and spores. The results are displayed as relative frequency (Figure 6.4) and absolute data (Figure 6.5), and in both diagrams charcoal data are displayed as charcoal concentration in grains/cm^3. Three pollen zones are recognised on the basis of cluster analysis (Grimm, 1987). Dates for zone boundaries are interpolated from the sedimentation rate (Figure 6.3).

Zone W3: 3.55-2.60 m, ca 4300 - ca 2600 yr B. P.

The terrestrial pollen is dominated by *Dacrydium cupressinum* and *Cyathea*. *Ascarina lucida* and *Coprosma* are also well represented. *Metrosideros* rises sharply towards the top of this zone, but then falls away abruptly. *Podocarpus*, though common in the early stages of this zone, is significantly reduced in the latter stages. Pollens of numerous other tree taxa are present, but generally at lower percentages than subsequently, *e.g. Agathis australis*, *Phyllocladus*. High values of the aquatic genus *Myriophyllum* are recorded initially; other wetland pollen types include Cyperaceae and Restionaceae. Grasses are also significant in the upper part of the zone, but these may also include aquatic types.

Zone W2: 2.60-1.20 m, ca 2600 - ca 600 yr B. P.

Cyathea declines sharply towards the middle of the zone, while *Dacrydium cupressinum* rises to a mid-zone peak. Thereafter *Dacrydium* remains the dominant tree taxon, though less important than formerly, and the curve for this taxon exhibits a number of peaks and troughs. *Agathis australis* pollen is abundant and *Phyllocladus* rises to a peak at the top of the zone. *Coprosma* rises steadily throughout the zone to a peak at the top, and *Leptospermum* is very abundant in the lower part of the zone. *Ascarina lucida*, from low initial values, increases in abundance at the top of the zone. Herbs and pteridophytes are less abundant than previously. *Cyathea* still maintains a strong presence, but declines markedly in the upper stages. Restionaceae and Cyperaceae pollens are abundant throughout this zone. An overall decline in the curve for trees with coincident increase of small trees and shrubs is noted in the latter stages. The decline in pollen from large trees is mainly due to reduced abundance of the conifer species.

Zone W1: 1.20-0.30 m, ca 600 yr B. P. - present

This zone is notable for a sharp decline in all trees and shrubs. *Dacrydium cupressinum* is still the dominant tree taxon and *Leptospermum*, though somewhat reduced in abundance, maintains a strong presence. Pteridophytes rise sharply, especially *Pteridium esculentum*, which becomes important for the first time. *Gleichenia* is also common. Cyperaceae pollen continues to

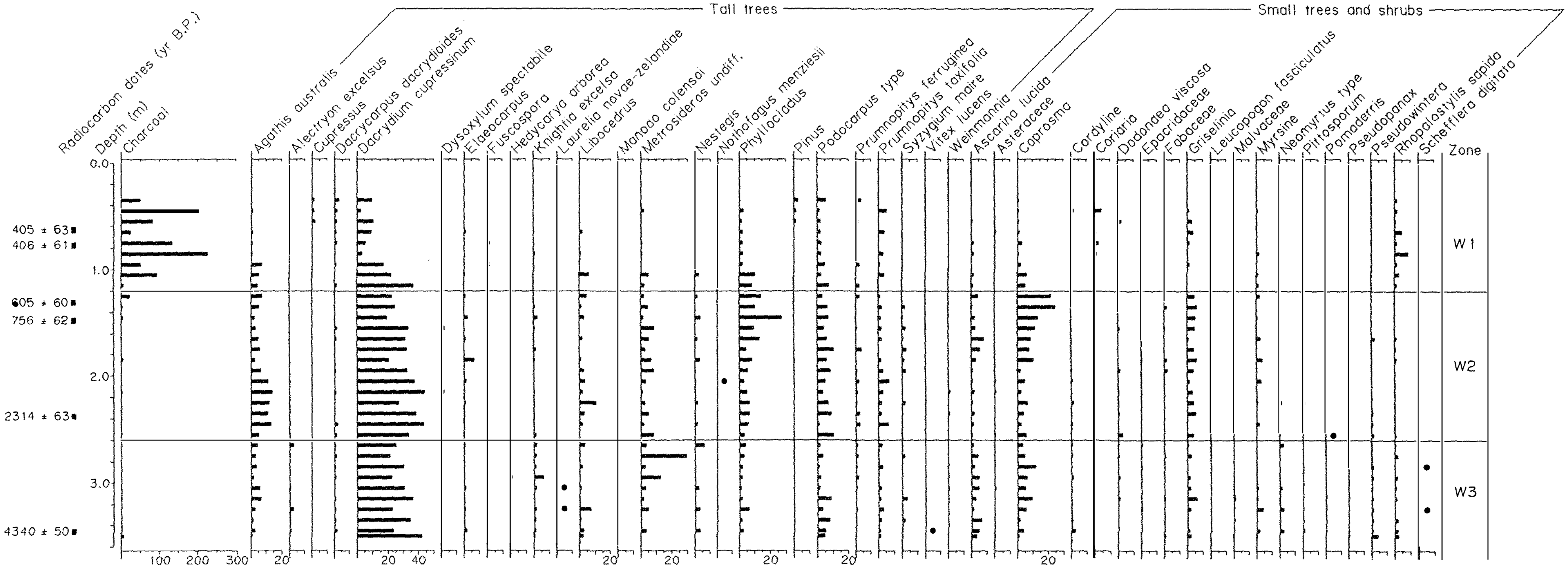

Figure 6.4a Percentage pollen diagram, core 5 – tall trees, small trees and shrubs. The pollen sum includes all dryland taxa. Charcoal concentration is shown in grains cm^{-3}.

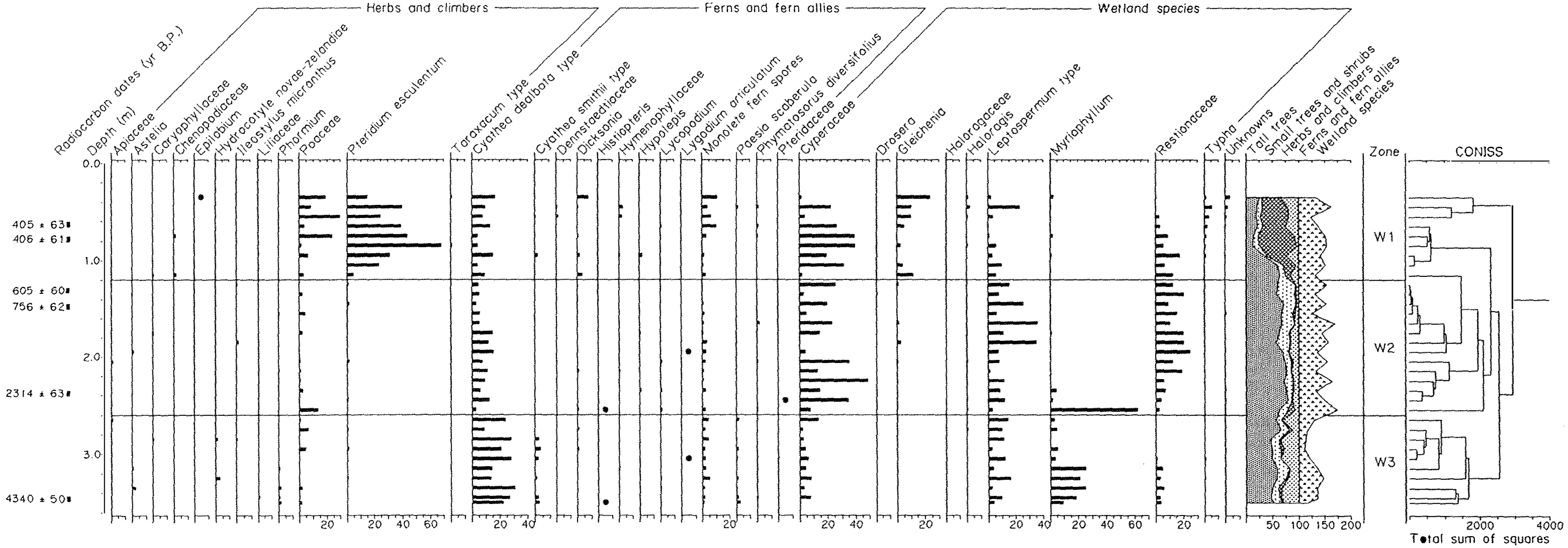

Figure 6.4b Percentage pollen diagram, core 5 – herbs, climbers, ferns, fern allies and wetland species.

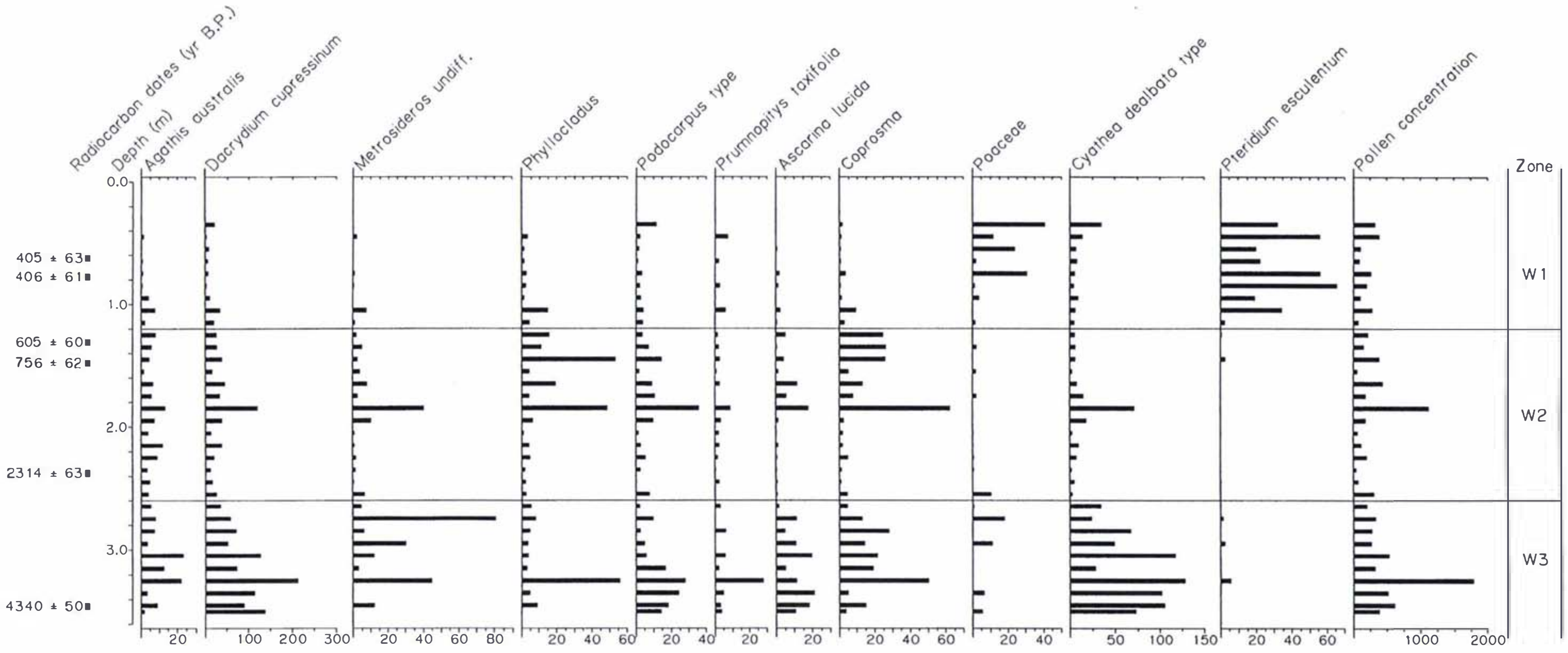

Figure 6.5 Pollen concentration diagram, core 5 – selected taxa only. Pollen data are expressed as grains cm^{-3}.

increase in abundance. Charcoal concentration, from a negligible background level, rises sharply to a peak in the middle of the zone. From this point the frequencies for trees and shrubs remain steady but low, and the profile is dominated by high frequencies of Poaceae pollen and fern spores, particularly *Cyathea*, *Gleichenia* and *P. esculentum*. The importance of aquatics declines significantly, although Cyperaceae pollen is still abundant. The charcoal concentration maintains high values.

Sedimentology

Grain size

Cores 1-3 and 5 (Figure 6.6) were analysed for their grain-size distribution. Borehole 3, with an overall length of 3.00 m was analysed to a depth of only 2.00 m, and borehole 2 was missing the first 0.30 m from the top because this section was lost during coring. Despite their different overall length (borehole 1, 0.85 m; borehole 2, 0.30 to 2.50 m; borehole 3, 3.00 m, analysed to a depth of 2.00 m; borehole 5: 4.00 m, analysed to a depth of 3.00 m), the cores all show an almost identical grain-size distribution pattern with depth. Cores 1-3 are characterised by high clay content (average 50-60%) throughout; this trend is interrupted only by a sudden increase in the sand fraction from values below 1% up to 15%. This increase occurs at the expense of the clay fraction. The clay fraction is reduced by almost half to an average 25-30%. In cores 2 and 3 the reduced clay content is located from 1.30 m to 0.72 m and 1.42 m to 0.84 m, respectively, and in core 1 from the base to 0.28 m.

The content of the finer silt fractions for cores 1 and 2 (*i.e.* very fine, fine, and medium silt) remains largely unaffected by the increase of sand (where sand is present). However, core 3 shows a strong increase in these fractions (also cumulative values) from 21% (bottom) up to 43 % (top). Of the coarse silt fractions, initial values of 3% (core 2) and 5% (core 3) were observed which remain quite stable up to 1.30 m and 1.42 m, respectively. The total content of these fractions then rises abruptly to a maximum of 24% and 31%, respectively, and then declines sharply from about 0.60 m. Core 1 shows a similar trend. The proportion of coarse to fine sediments in core 5 follows a very similar pattern to the grain-size distribution for cores 2 and 3. A sharp rise in the sand fraction occurs at 1.32 m (20 %) and remains elevated until 1.07 m before declining.

Organic content

Cores 1-3 are all dominated by a high organic matter content with maximum values of 50-60%. In core 1 (Figure 6.6) the organic matter rises from a low value of 0.5% at the base to a peak of

49% at 0.47 m, then declines sharply from 0.39 m to a low of 11% between 0.35 and 0.31 m. A sharp rise to 30% occurs at 0.28 m, followed by a more gradual increase to 52% at the top. Cores 2 and 3 (Figure 6.6) show similar trends for their organic content, *i.e.* steadily increasing organic content from the base upward, marked only by minor fluctuations in this trend until the surface is approached where both cores exhibit declines from about 0.40 m depth.

Sediment mineralogy

XRD analysis of mineral species in the clay and silt fraction of core 7 revealed major amounts of halloysite and smectite, and lesser amounts of mica (probably biotite) and vermiculite throughout the core. Trace amounts (<5%) of quartz and feldspar are also present in the silt fraction. The NaF test for allophane (Fieldes and Perrott, 1966) indicated that small amounts of this short range order mineral are present in the clay fraction. Halloysite and smectite are the dominant clay mineral species, and show a distinct pattern of distribution throughout the core. From the base of the core to 2.56 m depth, smectite dominated over halloysite. Thereafter to the top of the core, halloysite and smectite were present in approximately equal amounts.

Sediment chemistry

The results for Al, Ca, Fe, K, Mg, Mn, Na, S and P for core 5 are plotted as a concentration versus depth graph (Figure 6.7). Elements (or cations) such as Al, Ca and Mg show an irregular concentration distribution with depth without any conspicuous peaks. Fe and P show an increasing tendency from low values at the bottom of the core (Fe approximately 200 mg/g dry matter, and P 25 mg/g dry matter) to comparatively high values at the top of the core (Fe approximately 1250 mg/g dry matter, and P approximately 475 mg/g dry matter). Potassium and sodium show sharp rises in concentration from 1.50 m and then decline sharply at about 0.75 m. Manganese follows a similar trend.

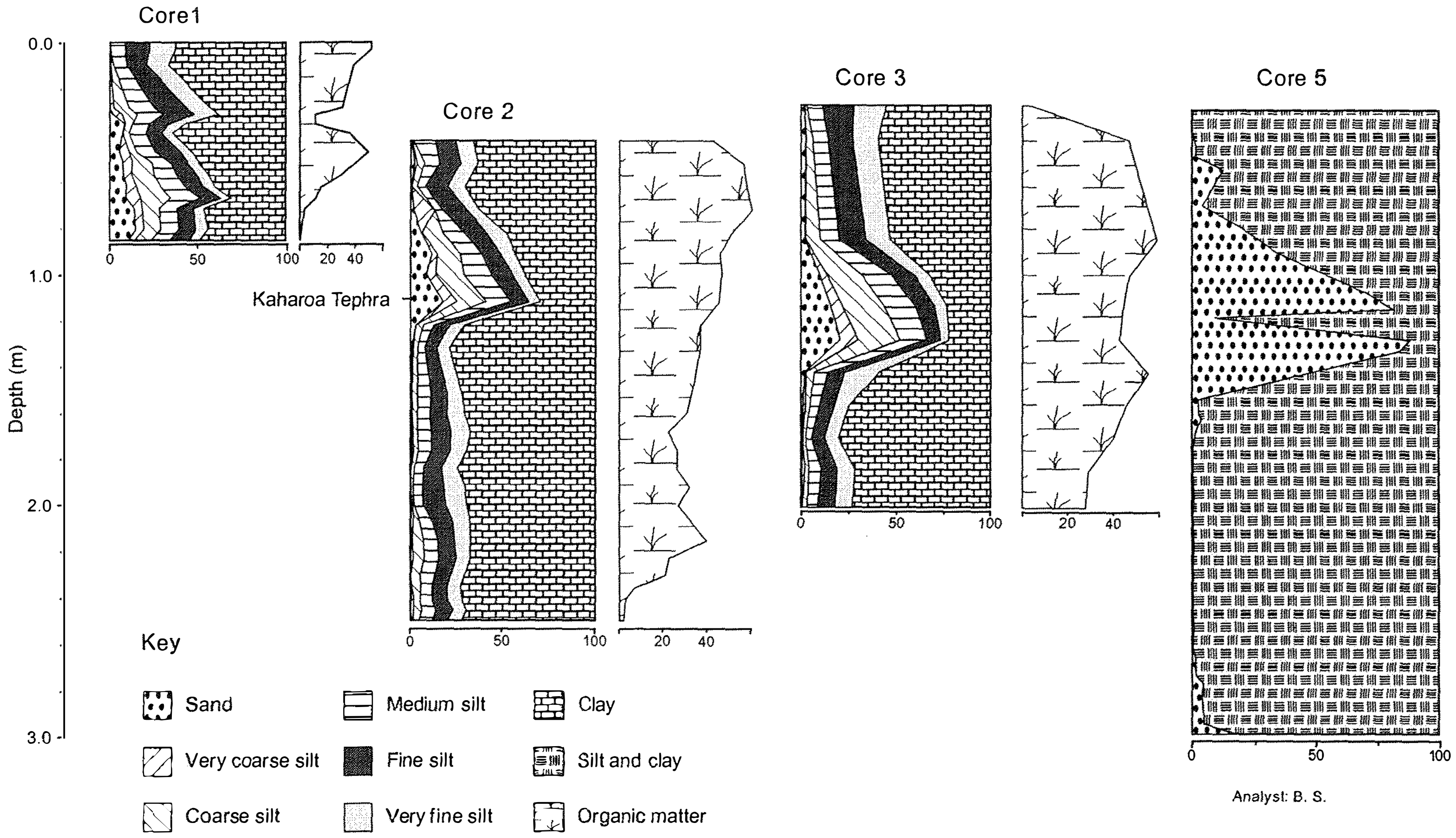

Figure 6.6 Grain-size classes and organic matter, cores 1-3 and 5. Core 5 shows only proportion of coarse (sand) to fine (silt-clay-size) sediment. Sand fraction values for core 5 are exaggerated 5x.

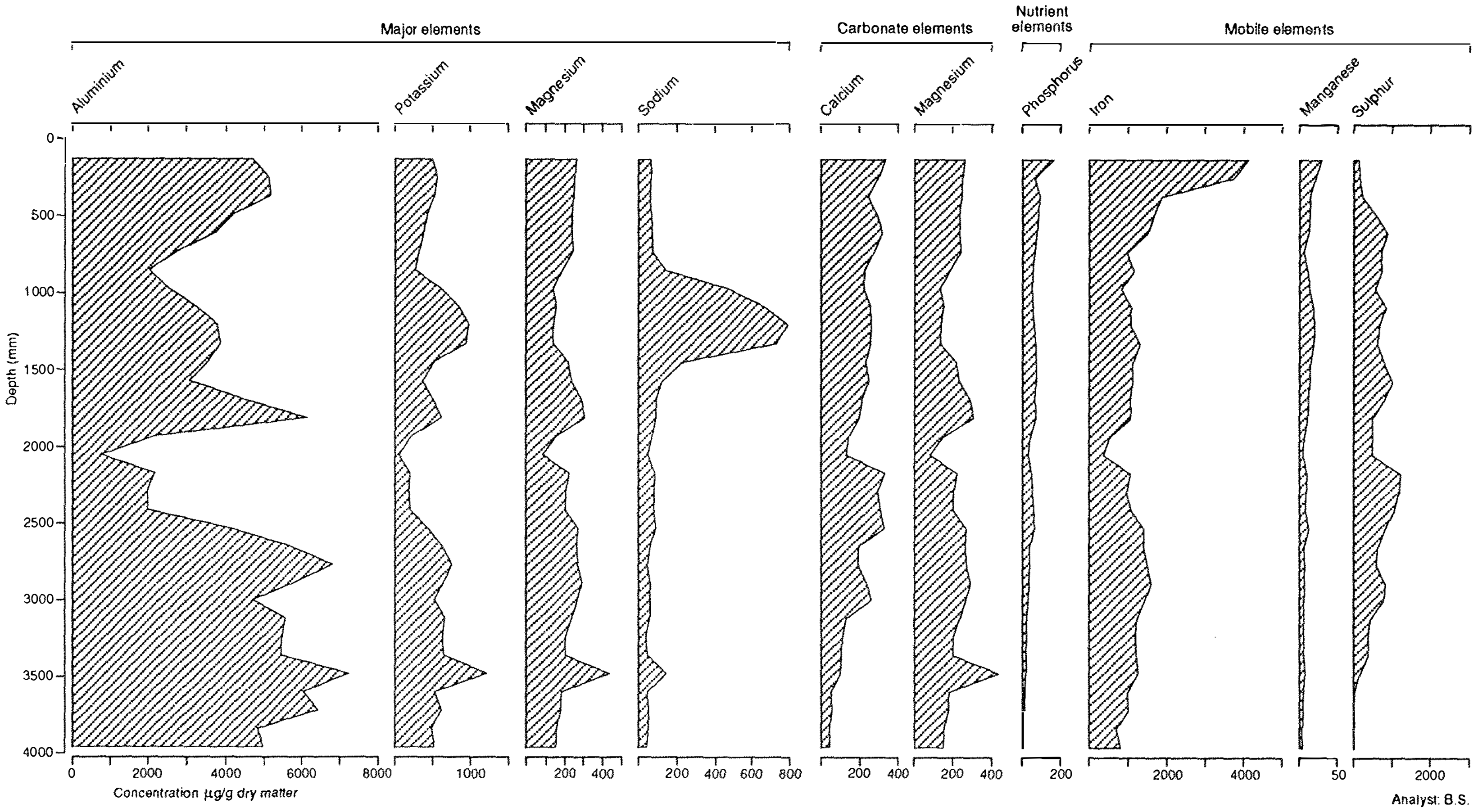

Figure 6.7 Sediment chemistry, core 5.

DISCUSSION

Dating

The regression in Figure 6.3 shows that an initial fairly slow rate of sedimentation (approx. 0.56 mm/yr) between NZA-2805/2804 and NZA-3606 was followed by a more rapid rate (approx. 2.0 mm/yr), especially after NZA-3109 (*ca* 600 yr B. P.). The Kaharoa Tephra found in borehole 2 at 1.11-1.13 m has been assigned an age of *ca* 700 yr B. P. on the basis of four new radiocarbon ages (Lowe and Hogg, 1992). This tephra was not found in borehole 5, the core analysed for pollen, but it is not unusual for distal tephras to concentrate in pockets in swamp deposits (V. E. Neall, pers. comm. 1994). Its presence in borehole 2 allows the age of Kaharoa Tephra to be correlated with the lower part of pollen zone W1, and also with changes in grain-size distribution in borehole 2.

Palynology

The pollen record for Wharau Road Swamp extends back about 4300 radiocarbon years. We consider the swamp to have formed as the result of volcanic activity at nearby Mount Te Puke that produced a lava flow damming the valley (Ferrar, 1925). The stratigraphic data indicate that an initial phase of shallow open water persisted through pollen zone W3. This contention is supported by high values for *Myriophyllum*, a perennial aquatic genus. Restionaceae and Cyperaceae species are also important at this time, probably growing in the marginal parts of the bog. The dryland vegetation patterns from this time indicate a regional vegetation of mixed conifer-angiosperm forest similar to those reported in other pollen records from mid-Northland at Otakairangi (Newnham, 1992) and McEwan's Bog (Kershaw and Strickland, 1988): *Dacrydium cupressinum*, *Podocarpus*, *Agathis australis*, *Phyllocladus* and *Metrosideros* were the chief taxa.

Dacrydium cupressinum, though always the dominant tree, declines from an initial high peak at the base of the core, then rises again in zone W2 before declining again. McGlone (1980) reports a decline of *D. cupressinum* in many North Island forests in the late Postglacial period. Comparison with other Northland pollen diagrams from Te Werahi Swamp (Dodson *et al.*, 1988; Enright *et al.*, 1988) and McEwan's Bog (Kershaw and Strickland, 1988) indicates similar trends in the late Holocene. At the Wharau Road site fluctuating abundance of many taxa – including *Phyllocladus*, *Agathis australis*, *Coprosma*, *Metrosideros*, *Podocarpus*, Poaceae, and *Cyathea* – follows trends comparable with these Northland records. The pollen evidence suggests that Northland, like many other parts of New Zealand, experienced climatic deterioration of a variable nature in the late Postglacial, though somewhat later than sites further south (McGlone *et al.*, 1984; Newnham *et al.*, 1989, 1995a, 1995b). At Wharau Road, from *ca* 4300 yr B. P., a wet and mild climate prevailed which became slightly drier and cooler. High levels of *Ascarina lucida* in zone W3 decline upward from *ca* 2600 yr B. P. The greatest frequencies for *Agathis australis* and other tree conifers are coincident with this decline of *Ascarina*, which increases again from *ca* 1400 yr B. P. along with other small trees and shrubs such as *Knightia excelsa*, *Phyllocladus* and *Coprosma*, and grasses. This trend may indicate a seral response to disturbance due to increased frequency of cyclonic activity. McGlone *et al.* (1993) propose more vigorous "cyclogenesis" in the late Postglacial. Similar observations are reported by Elliot *et al.* (1995) from an interdune lake north of Kaitaia between 3400 and 2600 yr B. P.

The total tree and shrub components throughout zones W3 and W2 are always high, suggesting that regional forest cover was persistent, though composition varied. However, declining values for tree pollen and coincident rises for small trees and shrubs cannot be entirely dismissed as being due to natural causes. The rise in secondary taxa, such as *Leptospermum* and tree ferns of *Cyathea* species, could also be indicative of low levels of anthropogenic disturbance. The absence of charcoal fragments or coincident rise in abundance of *Pteridium esculentum* does not lend strength to this argument. *Agathis australis* achieves its greatest importance from *ca* 2400 to 1700 yr B. P. but is present throughout the record. Modern pollen studies indicate that *A. australis* is consistently under-represented, and its regular occurrence in the pollen profile until the base of zone W1 implies that it was an important component of the regional vegetation.

The base of zone W1 marks the most significant transition in the pollen record where all major tree and shrub elements decline. Concomitantly the curve for *Pteridium esculentum* rises dramatically, and is matched by an equally impressive rise for charcoal concentration. Features of this nature have been recorded at many other sites in New Zealand (Mildenhall, 1979; McGlone, 1978, 1983, 1989; Chester, 1986; Bussell, 1988; Newnham *et al.*, 1989, 1995a; McGlone *et al.*, 1995; Elliot *et al.*, 1995). The association between Polynesian deforestation and these features in pollen records is now well established (McGlone, 1983, 1989), and we consider that at this site these changes are also attributable to human agency. A coincident rise in herbs and pteridophytes is also suggestive of vegetation response to clearance/disturbance. The sharp increase in sedimentation rate shown in Figure 6.3 suggests that significant deforestation by humans was initiated *ca* 600 yr B. P. (NZA-3109).

From *ca* 400 yr B. P. (0.90 m depth) the pollen record is characterised by significant amounts of Poaceae pollen. Trees and shrubs form a much reduced proportion of the vegetation and ferns, particularly *Cyathea*, all show sharp increases. *Cupressus* and *Pinus* make their first appearances in the upper part of this zone, and *Taraxacum* occurs at the top. Clearly the arrival of introduced taxa marks the onset of European influence in the area, which is known to have been about 1814 A. D. following the establishment of the mission at Waimate (Nicholas, 1817; Elder, 1932). Pollen of *Agathis australis* is recorded in only trace amounts, and this tree may have been eliminated from the Wharau Road locality. *Dacrycarpus dacrydioides* shows an increase from its previous low levels. *Leptospermum* values remain significant; much of this may have been growing on the swamp. Restionaceae pollen declines markedly, but Cyperaceae continues to be abundant. Charcoal influx declines from a peak in the middle of zone W1 but remains high. The activities of people in the region have clearly had significant continuing impacts since the beginning of major forest disturbance.

Sedimentology

The changes in the physical and chemical constituents of the sediment cores seem to indicate significant events in the environmental history of the catchment. Stratigraphic evidence for these events is given by the conspicuously altered granulometry of the cores. These changes in grain-size distribution occur in borehole 1 from the base up to 0.28 m, in borehole 2 from 1.30 to 0.72 m, in borehole 3 from 1.42 to 0.84 m, and in borehole 5 from 1.32 to 1.90 m (Figure 6.6). These depth ranges appear to give evidence of a period of increased erosion within the catchment as the granulometry shows an abrupt increase in coarse grain-size fractions such as sand, very coarse silt and coarse silt. The reason for this could be anthropogenic destruction of forest, leading to soil instability which results in erosion and sedimentation (McGlone, 1983). Kirch *et al.* (1992) found similar evidence of erosive events and forest disturbance in the form of clay bands in a lake on Mangaia, Polynesia. Whether these clay bands resulted from human activity or from natural causes (*e.g.* tropical cyclones, El Niño events) is unknown. Flenley *et al.* (1991) believe that a unit of silt, sand and gravel in a lake on Easter Island provides evidence for human-induced soil erosion.

The coincidence of changes in grain-size distribution with a reduction in organic matter in the above-mentioned depth ranges of boreholes 1, 3 and 5 also supports this contention. This is thought to represent the deforestation which results in an increased inwash of inorganic matter into the swamp site. Following this the vegetation cover appears to have recovered, which is reflected by an increasing value of organic matter and a decreasing input of coarser sediment particles into the site. Using such associations, Dawson (1990) recognised two main periods of erosion in lake sediment on Mangaia. This tendency is clearly evident in boreholes 1 and 3. Only borehole 2 does not show any conspicuous reduction in organic matter coincident with an increase in the sand fraction. The decrease in organic matter immediately below the top of boreholes 2 and 3 suggests a second deforestation with the same consequences, namely soil erosion and sedimentation. The decline of organic matter close to the top of the cores indicates that deforestation must have been most recent, and is probably of European origin. The only reason why the reduction in organic matter towards the top of borehole 2 is not as obvious as in borehole 3 is the fact that the first 0.30 m of this core are missing. Borehole 1 is also missing a distinct drop in organic content at the top. The reason for that could be its marginal location within the site. Such locations may receive more growth-promoting nutrients as a result of erosion than those which occupy a more central position (*e.g.* boreholes 2 and 3).

Further evidence of a major erosive event in the swamp catchment is provided by the results of the sediment chemistry for borehole 5. In particular, the elements potassium (K), sodium (Na) and manganese (Mn) support this contention as they show a distinct peak in their concentration profile from 1.50 m to 0.75 m. This depth range corresponds with the depth ranges of borehole 2 (1.30-0.72 m), borehole 3 (1.42-0.84 m) and borehole 5 (1.32-0.90 m), where increased erosion is indicated by changes in their stratigraphy. There is no obvious correspondence between the stratigraphic data of borehole 1 and the chemical results of borehole 5. The reason for this is probably the marginal position of borehole 1, which has experienced a different environmental history. The high concentration levels of K, Na, and Mn within the above-mentioned range can be attributed to an increased rate of inwash of freshly exposed soil during periods of reduced vegetation cover in the catchment due to deforestation. The decreased concentration levels of K, Na and Mn above the 0.75 m mark of borehole 5 indicate a recovery of the vegetation cover which resulted in a reduced erosion and decreased input of mineral matter into the site. These conclusions correspond with the stratigraphic evidence of boreholes 2, 3 and 5. Indications of a second deforestation event as in boreholes 2 and 3 (see above) are also evident at the top of borehole 5, but are not as distinct as in the depth range between 1.50 m and 0.75 m.

Our investigations of the clay mineralogy of borehole 7 reveal an increase in smectite and a decrease in halloysite with depth. As there are no obvious breaks in the mineralogy down the core, this general tendency does not constitute any evidence for an erosive event within the catchment. Rather the relative abundance of smectite in the lower parts of the core reflects poor drainage and an increased level of silica in solution, conducive to the formation of smectite, whereas the formation and persistence of halloysite in the upper parts of the core is a consequence of good drainage.

CONCLUSIONS

A summary of environmental change and regional vegetation history from the palynology and sedimentology of cores from Wharau Road Swamp is presented in Table 6.2. Pollen evidence indicates that the locality has experienced climatic trends similar to those registered in other parts of northern New Zealand in the late Postglacial period. A climate which may have been characterised by more intense cyclonic activity occurred from *ca* 4000 years ago, when conditions were perhaps slightly drier and cooler than present. Some amelioration of climate is indicated from *ca* 2000 to 1400 yr B. P. when wetter and milder conditions are thought to have existed. By far the most significant event of the late Holocene has been deforestation by Polynesian inhabitants.

Analysis of radiocarbon dates associated with moa-hunting (Anderson and McGovern-Wilson 1990) indicates human occupancy of New Zealand by 900-800 yr B. P. More recently, Anderson (1991), McGlone *et al.* (1994) and McFadgen *et al.* (1994) have assessed the onset of human occupation as beginning *ca* 700 B. P. Millener (1981) analysed coastal bird bone assemblages in far northern New Zealand and concluded that forest persisted to the coast until *ca* 1000 yr B. P., thereafter declining. Chester (1986) reported signs of early human activity at 1400-1350 yr B. P. from a site only a few kilometres west of the Wharau Road Swamp. It would appear that the Wharau Road Swamp site registers human disturbance in the pollen record much later than Chester's (1986) postulated forest clearance.

Results from analysis of grain-size distribution and sediment chemistry provide strong supportive evidence for anthropogenic deforestation as indicated by the pollen record, in particular the curves for *Pteridium esculentum* and charcoal concentration. The dating of this event provided by a radiocarbon chronology puts an age for human-induced deforestation at this site of *ca* 600 yr B. P. This is much later than the widely accepted age for early human occupancy of New Zealand at *ca* 1000 yr B. P. (Davidson, 1984), and thus no evidence from Wharau Road Swamp is found to support Chester's hypothesis (1986) of considerably earlier colonisation.

Table 6.2 Summary of vegetation/sedimentation history of Wharau Road Swamp and inferred regional climate over the past *ca* 4300 years.

Age (ka BP)	Pollen zone	Sediment phase	Regional vegetation	Climatic events
0	W1	Soil erosion	Forest clearance (*Pteridium*)	Polynesian deforestation
1 2	W2	Soil stability	Podocarp-hardwood forest (*Agathis*)	?Wet/mild Cooling/drying
3 4	W3	Soil stability	Podocarp-hardwood forest (*Dacrydium, Ascarina*)	?Increasing cyclonic activity Wet/mild

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Chapter 7

KAITAIA BOG

Late Quaternary pollen records of vegetation and climate change from Kaitaia Bog, far northern New Zealand. Submitted to *Review of Palaeobotany and Palynology.*

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Plate 7.1 Kaitaia Bog, location of borehole 3

Abstract

A vegetational history and palaeoclimatic changes are established for the last 25,000 years by pollen analysis of two peat cores from Kaitaia Bog, far northern New Zealand. Twelve AMS radiocarbon dates provide a chronology covering the Last Glacial Maximum to the late Holocene, *ca* 2,500 years ago.

Prior to 22,000 years ago a tall, complex, conifer-beech-hardwood forest dominated by podocarp trees covered the region. The most abundant of these was *Dacrydium cupressinum*. *Fuscospora* (*Nothofagus* cf. *truncata*) was also an important element. Other common emergent trees included *Podocarpus*, *Prumnopitys ferruginea*, *P. taxifolia*, *Dacrycarpus dacrydioides*, *Libocedrus*, and *Metrosideros*. From 22,000 - *ca* 14,000 yr B. P. regional forest was dominated by *Fuscospora*, and warm, moist elements such as *Ascarina lucida* and *Agathis australis* were scarce. This Last Glacial Maximum forest cover contrasts with the open grass and shrub communities which dominated landscapes south of Auckland. Cool climate species, such as *Fuscospora*, began to decline towards the end of the Lateglacial, and from *ca* 11,300 yr B. P. *Ascarina lucida* started to increase rapidly. Replacement of conifer-beech-hardwood forest with a conifer-hardwood association proceeded rapidly in the Postglacial as *Fuscospora* retracted sharply and *Dacrydium cupressinum* increased in abundance. The regional expansion of *Agathis australis* followed rapidly. Regional forest in the mid- to late Holocene consisted of a conifer-hardwood association dominated by *D. cupressinum*, *Podocarpus*, *Phyllocladus* and *Agathis australis*. A mid-Holocene decline for *Ascarina lucida* and coincident increased abundance of *P. taxifolia* suggests somewhat cooler conditions prevailed from this time. *Fuscospora*, though still present, assumed only a minor role as more favourable conditions allowed other species a competitive advantage.

Introduction

The evidence for substantial changes to the climate and vegetative cover of New Zealand during the Late Pleistocene is now reasonably well documented for most of the country south of Auckland. This evidence is derived mainly from pollen analysis of peats and lake sediments, but also from glacial activity (*e.g.* Burrows *et al.*, 1976), soil erosion and loess stratigraphy (*e.g.* Palmer and Vucetich, 1989), and ocean sediment studies (*e.g.* Wright *et al.*, 1995). During the Last Glacial Maximum (LGM) the mechanisms which influenced changes in plant communities were associated with drought, strong winds, and the advance of valley glaciers in southern regions, accompanied by invasion of cold maritime polar air masses. At 18,000 years ago, grass and shrub-dominant communities were widespread at least from south of Auckland (latitude

37°S) until *ca* 14,500 years ago when afforestation commenced in a progressively southward direction (McGlone *et al.*, 1993). Forest species south of 38°S only survived in small stands, in microclimatically favoured sites at inland locations, but may have been more extensive at the contemporary coast. North of Auckland, forest cover may have persisted throughout the Last Glacial Maximum, though only two published pollen diagrams cover this period. One of these presents a 30,000 year record from Otakairangi Swamp near Whangarei (Newnham, 1992) which has a problematic chronology owing to an inversion of dates. Nevertheless, Newnham suggests forest persisted at least as far south as Whangarei throughout the last 30,000 years. The second diagram is a pollen record spanning 17,000 yr B. P. to the present from the northernmost tip of mainland New Zealand (Dodson *et al.*, 1988) which reports *Agathis australis* podocarp-hardwood forest dominance throughout that period. Given that far northern New Zealand was the only inland region to maintain a forest cover throughout the Last Glacial Maximum, the composition of these forests remains inadequately described. This paper addresses this issue and evaluates how northern forests responded to ameliorating conditions as glaciers retreated in southern New Zealand.

Suggate and Moar (1970) define the Last Glaciation in New Zealand, the Otiran, as ending at 14,000 yr B. P., and the period that follows, from 14,000 yr B. P. to present, as the Aranuian. The terminology used here follows that of McGlone (1995) where the term "Last Glacial Maximum" (LGM) refers to the period 25,000 - 14,000 yr B. P., the "Lateglacial" to the period 14,000-10,000 yr B. P., and the "Postglacial" as 10,000 yr B. P. to present.

Study area

Kaitaia Bog is situated on the north-western margins of Kaitaia township (35° 06'S, 173° 12'E), at the southern end of Aupouri Peninsula, in far northern New Zealand (Figure 7.1). Aupouri Peninsula is a large tombolo consisting mainly of Pleistocene sand dunes which link former offshore islands of the "Northland Archipelago" to mainland Northland (Ballance and Williams, 1982). Cranwell (1953) described a number of New Zealand peat deposits and classified the Kaitaia Bog as an ombrogenous, raised bog, formerly dominated by *Sporadanthus traversii*, a massive, rush-like herb of the Restionaceae family. Most of the bog is now artificially drained and the dominant soils are Otonga loamy peats (Sutherland *et al.*, 1979a and b). It has a low-lying surface, mostly below 10 m a. s. l., and developed as a consequence of progressive sand dune encroachment on drainage from the Herekino Range in the south and lower hills to the east. The Herekino Range attains altitudes up to 300 m and comprises Cretaceous-Eocene marine volcanics. The low hills to the east rise up to 100 m, comprising Oligocene sandstones and calcareous siltstones (Kear and Hay, 1961; Hay, 1975). The northern and western margins are all bounded by late Quaternary sand dunes. The main natural drainage of the bog is now via the Awanui River, north-eastward into the Rangaunu Harbour.

Europeans first came to the Kaitaia locality in AD 1832, and Reverend W. Williams observed "The land...was, generally speaking, the most barren of the barren..." (Matthews and Matthews, 1940). Dieffenbach (1843) recorded most of the Aupouri Peninsula as having only scanty vegetation, chiefly low scrub (*Leptospermum scoparium*), fern (*Pteridium esculentum*) and scattered clumps of coarse, wiry "grass". Cheeseman (1896) and Carse (1910) made similar observations, and considered that the pre-European vegetation of far northern New Zealand was regularly fired. Since the establishment of European farming, clearance has been maintained both by firing and pastoral farming practices. Today sharp boundaries between cultural and semi-natural vegetation are apparent. Vestiges of swamp forest, including *Cordyline australis* and *Dacrycarpus dacrydioides*, persist on isolated patches of poorly drained soils, suggesting such forest was formerly widespread. Wilson (1921) reports the presence of burnt stumps and buried logs of *Vitex lucens*, *Manoao colensoi*, and *Agathis australis*, which indicate there was mature forest over the swamp in the past. Willow weed (*Polygonum aviculare*) has invaded partially drained areas, while *Typha orientalis* dominates margins of the large drains. Better drained, elevated tracts are often dominated by a shrubland of *Leptospermum scoparium* (Dick, 1950). Prior to European arrival large marginal areas were drained for gardening and flood protection by Polynesians (Wilson, 1921).

Northland is generally characterised by a mild, humid and rather windy climate. Few extremes occur owing to the modifying effect of extensive adjacent oceans, and also the relatively low latitudes. The Kaitaia region experiences warm, humid summers, and mild, frost-free winters. The mean annual temperature is *ca* 15.9°C (July mean 11.7°C; January mean 19.7°C), and annual sunshine usually exceeds 2000 hours. Annual rainfall is about 1450 mm yr^{-1}, most of which falls in the winter half year (Moir *et al.*, 1986).

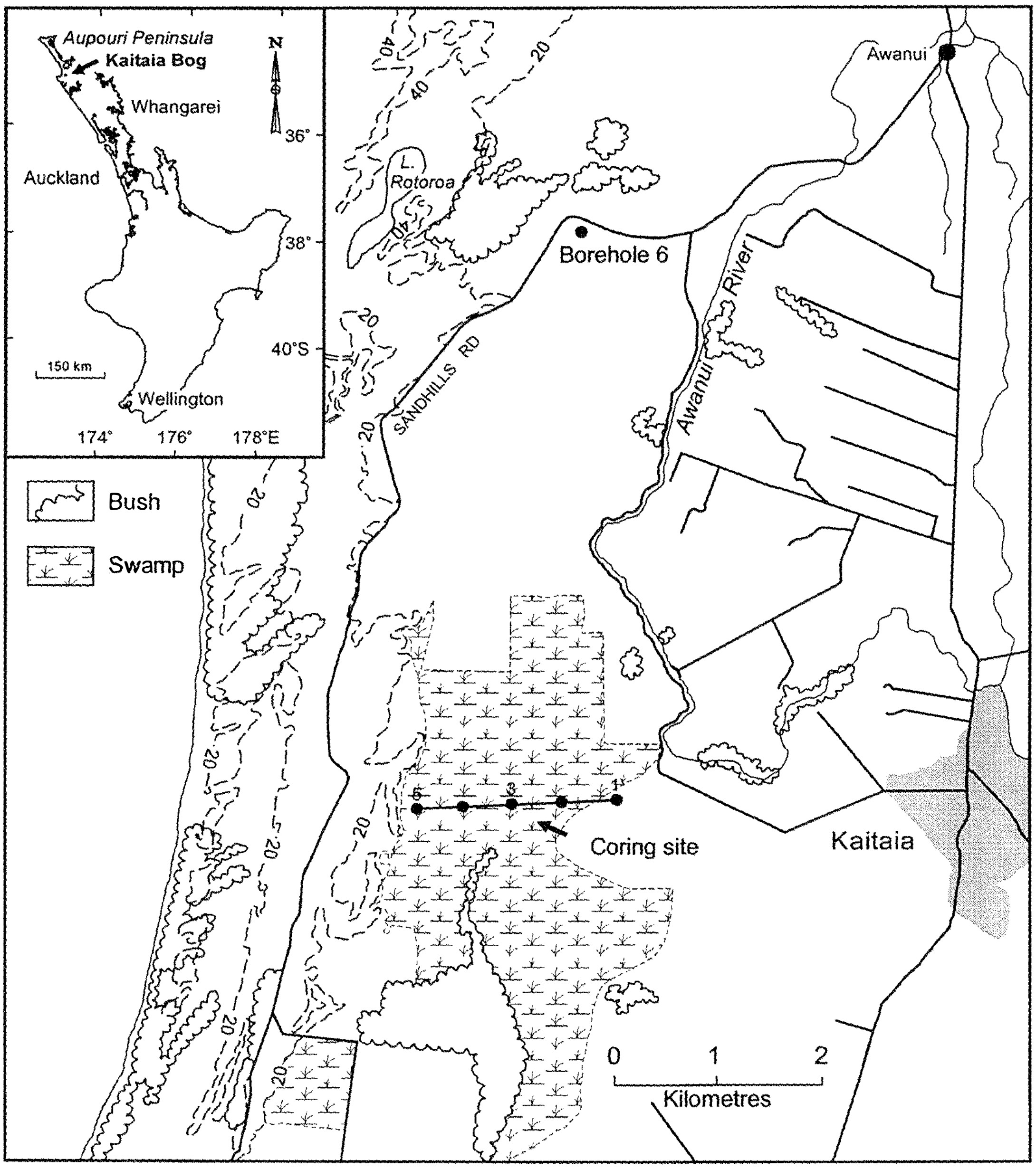

Figure 7.1 Physiography and location of the study site.

Methods

A number of cores have been recovered from the swamp using a d-section Russian peat sampler (Jowsey, 1966). A transect of 5 boreholes was made across the centre of the bog and one borehole on the northern margin (Figure 7.1). Sediments from boreholes 3 and 6 were analysed for pollen. Twelve samples of 5 cm length were submitted for AMS radiocarbon dating. Where coarse material such as fine rootlets occurred, this was removed by sieving. Otherwise the whole fraction of peat (treated by consecutive hot solutions of acid, alkali, and acid) was dated. A sampling interval of 10 cm was used for pollen analysis, except for borehole 3 between 4.55 and 5.45 m where samples were taken at 5 cm intervals. Preparation followed the standard palynological procedures (Moore *et al.*, 1991) of boiling in 10% KOH, sieving, acetolysis, digestion in 40% HF, and bleach. Samples were spiked with exotic *Lycopodium* spores, mounted in glycerine jelly, and counted under a light microscope at 450x magnification. Minimum counts of 200 dryland pollen types were made for each sample. Results are expressed as percentages, the pollen sum of which excludes wetland species, and as pollen concentration data. Charcoal was counted after the method used by Bush *et al.* (1992). Charcoal fragments were counted across a centre transect of the slide until at least 10 *Lycopodium* spores had been counted. From these counts estimates of charcoal influx were obtained. This is expressed as charcoal concentration independent of the pollen data. Taxonomic nomenclature follows that of Allen (1961), Connor and Edgar (1987) and Molloy (1995). *Nothofagus fusca* type pollen species are designated *Fuscospora* after McGlone *et al.* (1996).

Stratigraphy and dating

The stratigraphy of borehole 3 (see Figure 7.2) consists of an upper sequence, from the surface to 5.42 m, of dark brown peat which included a number of woody fragments and rootlets. Below this peat lies a narrow band of sandy organic mud to 6.0 m followed by sand interbedded with organic sands grading to a stiff basal grey clay at 6.5 m. Nine AMS radiocarbon dates provide a coherent chronology covering the Holocene and latter part of the Pleistocene (Table 7.1, Figure 7.2). The lowermost date at 5.49- 5.54 m of 22, 410 ± 450 yr B. P. suggests that the base is somewhat older. Extending the age-depth line in Figure 7.2 gives an age of at least 25,000 yr B. P. Plotting age *v.* depth it is apparent that there is either a hiatus in sedimentation or very *slow* sedimentation between the base and 11.6 ka. The age-depth curve also suggests an age at the ground surface of *ca* 2.4 ka. Borehole 6 consists of dark brown peat entirely of Holocene

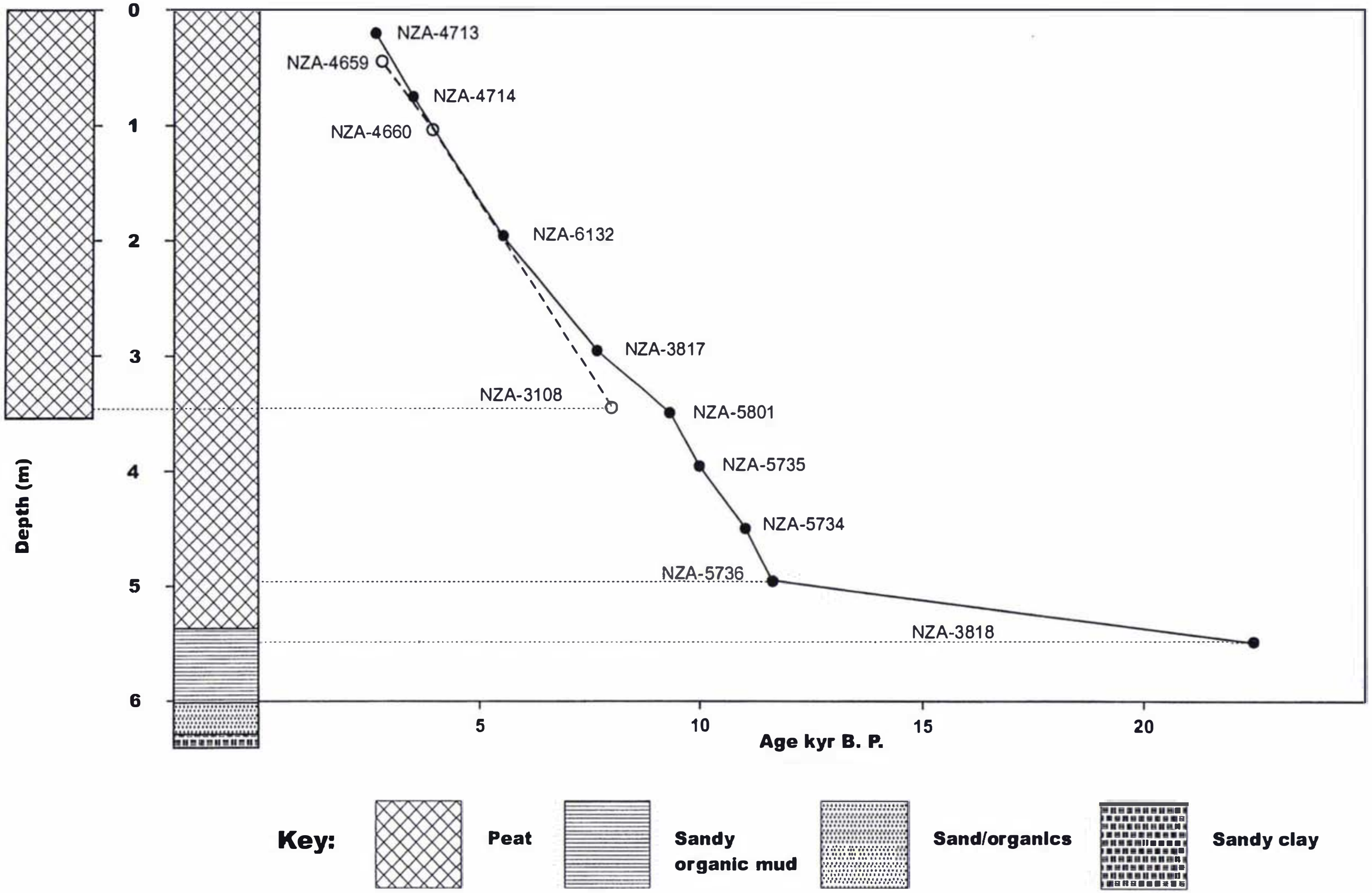

Figure 7.2 Stratigraphy and age depth graph of cores from boreholes 3 and 6, Kaitaia Bog See text for description of sediments. Dates for borehole 3 are shown as filled circles, and those for borehole 6 as open circles.

age, with a basal date of 7993 ± 66 yr B. P. (NZA-3108), and an uppermost date at 0.45-0.50 m of 2790 ± 73 yr B. P. (NZA-4659). The upper part of both peat records is missing; burning by Polynesians and later Europeans is the likely cause.

Table 7.1. Radiometric dating of Kaitaia Bog samples

Depth (m)	NZA#	Age ^{14}C yr B. P.	δ^{13}C‰	Material dated
Borehole 3				
0.20-0.25	4713	2639 ± 68	-25.51	sieved peat
0.75-0.80	4714	3505 ± 61	-23.90	sieved peat
1.95-2.00	6132	5521 ± 75	-26.20	treated peat
2.95-3.00	3817	7660 ± 100	-23.78	treated peat
3.49-3.54	5801	9357 ± 78	-27.50	sieved peat
3.95-4.00	5735	10011 ± 94	-27.20	treated peat
4.49-4.54	5734	11030 ± 110	-26.10	treated peat
4.95-5.00	5736	11640 ± 130	-26.90	treated peat
5.49-5.54	3818	22410 ± 450	-27.68	treated peat
Borehole 6				
0.45-0.50	4659	2790 ± 73	-26.07	sieved peat
1.06-1.13	4660	3968 ± 69	-26.11	sieved peat
3.43-3.48	3108	7993 ± 66	-26.90	treated peat

Palynology

The pollen diagrams (Figures 7.3 and 7.4) are displayed as percentage data (with the pollen sum including all dryland taxa). Four pollen zones are recognised based on cluster analysis (Grimm, 1987).

Borehole 3

Zone K4 6.00 - 5.50 m ca > 25 - 22,500 yr B. P.

High levels of *Dacrydium cupressinum* (35%+) and *Fuscospora* (probably *Nothofagus truncata*, hard beech) define this zone. Significant pollen frequencies are recorded by *Podocarpus*, *Prumnopitys ferruginea*, *P. taxifolia*, *Libocedrus*, *Dacrycarpus dacrydioides* and *Metrosideros*. Other podocarps recorded are *Halocarpus* and *Manoao colensoi*. Also present are *Phyllocladus*, *Nestegis*, *Coprosma*, *Myrsine* and various Myrtaceae genera. Tree ferns are significant, especially *Cyathea smithii* type which records its highest values here. *Ascarina lucida* and *Agathis australis* percentages are relatively low. *Elaeocarpus* is consistently recorded and *Laurelia novae-zelandiae* is present in two samples. Bog taxa are dominated by restiads and *Gleichenia*. Microscopic charcoal fragments are abundant.

Zone K3 5.50 - 4.20 m ca 22,500 - 10,500 yr B. P.

Fuscospora rises to high levels (30%+). Tree ferns decline along with *Dacrydium*, *Dacrycarpus* and *Libocedrus*. At about 5.20 m *Fuscospora* values peak. *Podocarpus*, *Prumnopitys taxifolia* and *Manoao* increase. Consistent, relatively low percentages of *Agathis* persist throughout the zone. *Ascarina*, initially scarce, and *Metrosideros* increase up the zone. Microscopic charcoal fragments are abundant but decline towards the top of the zone. *Dodonaea viscosa* first appears in the profile at 5.10 m and persists thereafter. *Nestegis* pollen is common. Initially the bog flora is dominated by sedges (Cyperaceae), but following a peak in charcoal concentration, *Leptospermum* and restiads increase sharply. *Lycopodium laterale* spores are common.

Zone K2 4.20 - 1.60 m ca 10,500 - 5000 yr B. P.

A sharp decline in *Fuscospora* values, rapidly so from *ca* 9.5 ka, and high levels of *Dacrydium*, rising to 40%, define this zone. *Ascarina* is abundant, particularly in the lower half of this zone, and *Metrosideros* sp. are common. From 3.75 m (*ca* 9.5 ka), levels of *Agathis* pollen increase markedly. This trend is matched by the curve for *Phyllocladus*. *Dacrycarpus* increases towards the top of the zone. Pollen of *Knightia excelsa* occurs throughout. *Elaeocarpus* and *Nestegis* are consistently present, and *Cyathea* is abundant. *Prumnopitys ferruginea*, *Halocarpus* and *Manoao* are less common than previously, but *Libocedrus* is consistently recorded. The bog flora is initially dominated by restiads and *Leptospermum*, but from mid-zone *Gleichenia* becomes increasingly important. Charcoal concentration is low throughout.

Zone K1 1.60 - 0.00 m ca 5000 - 2500 yr B. P.

This mid- to late Holocene zone is characterised by very high levels of *Dacrydium* (45-60%). *Phyllocladus*, *Podocarpus*, *Prumnopitys ferruginea* and *Agathis australis* are significant, and increased frequency of *Prumnopitys taxifolia* is recorded. *Ascarina* becomes less abundant than previously, and *Metrosideros* values also decline. *Halocarpus, Libocedrus* and *Manoao*, initially common, show declining abundances upward through the zone. Bog taxa are most strongly represented by *Gleichenia* and restiads. Microscopic charcoal fragments are scarce. The uppermost sample records a significant amount of *Pteridium esculentum* spores and Poaceae pollen, along with reduced tree pollen generally.

Borehole 6

Zone K2 3.40-1.70 m ca 8000 - 5000 yr B. P.

Significant, but low, values of *Fuscospora* decline abruptly from the base of the zone. Conifer pollen types are dominant, of which *Dacrydium* is the most common (35%+). High levels of *Libocedrus, Phyllocladus,* and *Podocarpus* are recorded. *Prumnopitys taxifolia*, from initially low values, and *Agathis* become increasingly abundant. Of the angiosperm taxa, only *Metrosideros* is common. Significant amounts of *Ascarina* are recorded, and *Dodonaea* is always present. Only low frequencies of ferns are recorded, of which *Cyathea dealbata* type is the most common. Bog species are initially dominated by sedges (Cyperaceae) and restiads, but *Gleichenia* becomes increasingly common as Cyperaceae declines. Restionaceae pollen records high values throughout. Charcoal concentration is high in the lower half of the zone, but is reduced in the upper half.

K1 1.70-0.00 m ca 5000-2500 yr B. P.

Agathis pollen is generally common. High frequencies of *Dacrydium* (40%+) are recorded throughout. *Libocedrus* and *Prumnopitys taxifolia* are less common than previously, but levels of *Podocarpus* increase. *Ascarina* is consistently recorded, but is generally less abundant. Values of *Dodonaea* and *Metrosideros* fluctuate. *Knightia excelsa* is significant in the lower part of the zone. Bog species are dominated by *Gleichenia* and restiads. Charcoal concentration is generally significant.

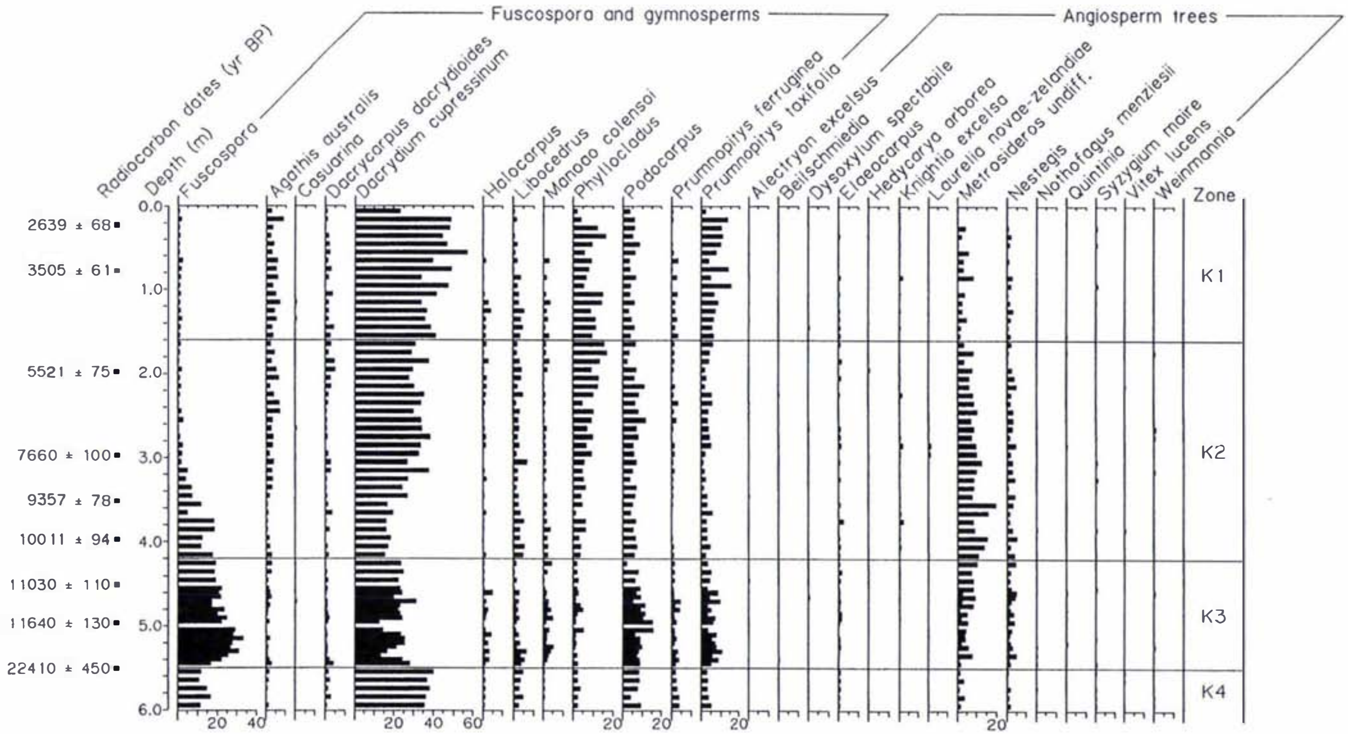

Figure 7.3a Percentage pollen diagram for borehole 3 showing *Fuscospora*, gymnosperms, and angiosperm trees. Pollen sum includes all dryland taxa.

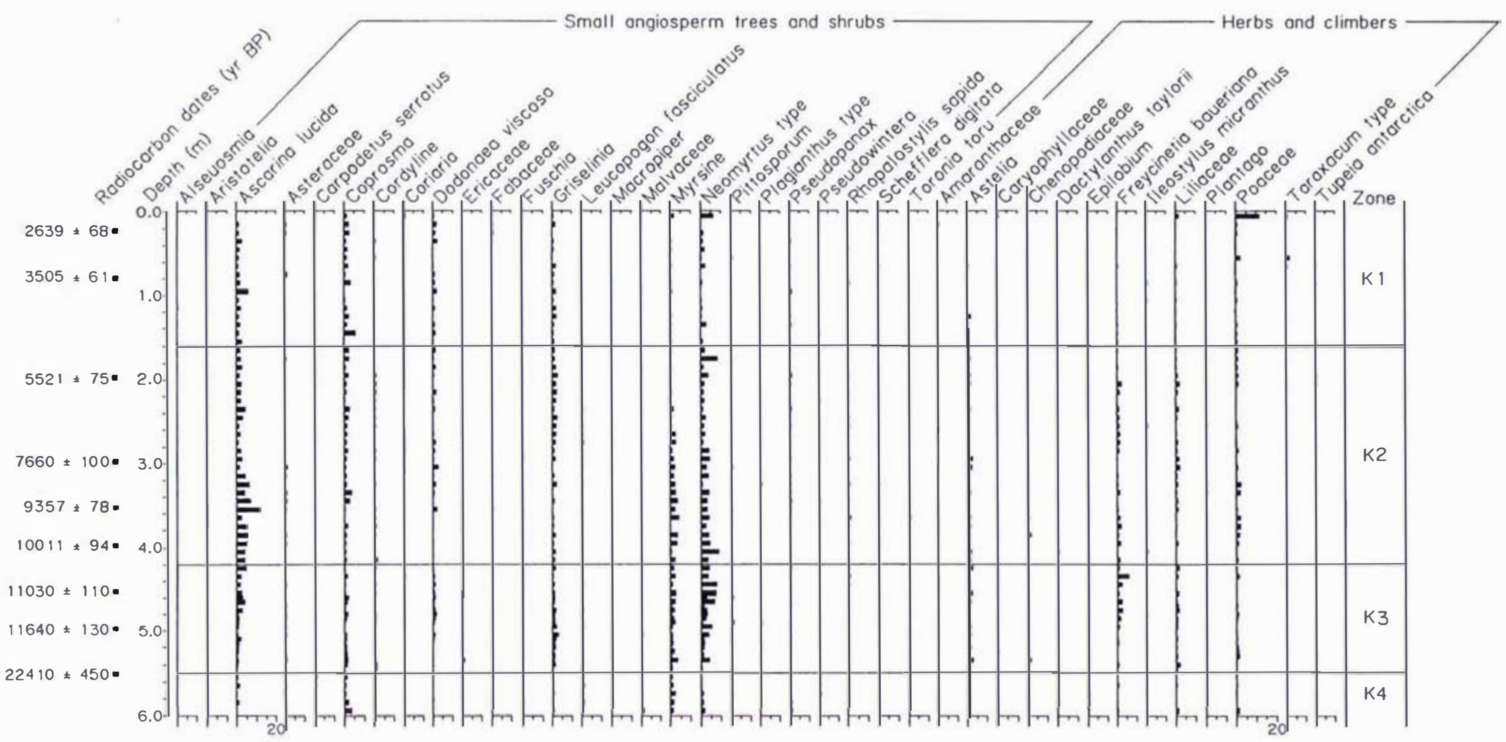

Figure 7.3b Percentage pollen diagram for borehole 3 showing small angiosperm trees, shrubs, herbs and climbers.

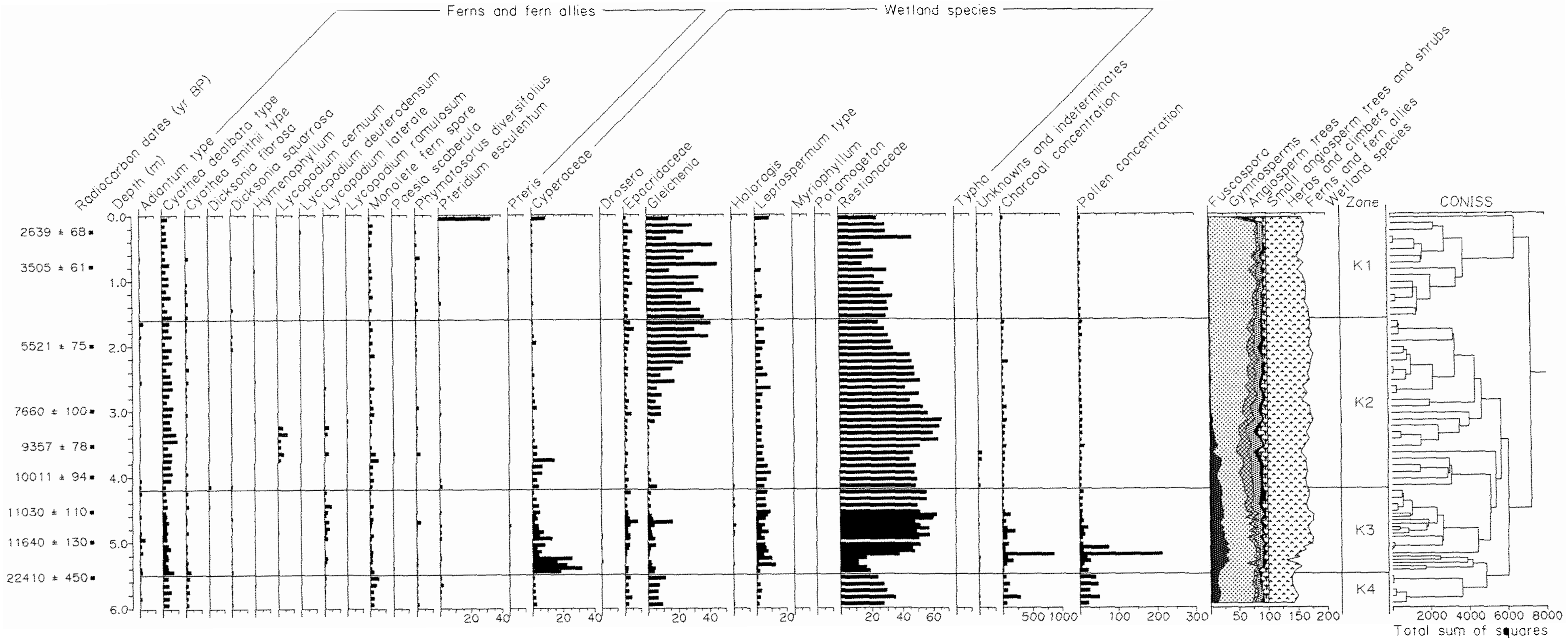

Figure 7.3c Percentage pollen diagram for borehole 3 showing ferns, fern allies and wetland species. Pollen concentration and charcoal concentration are shown in grains cm^{-3}.

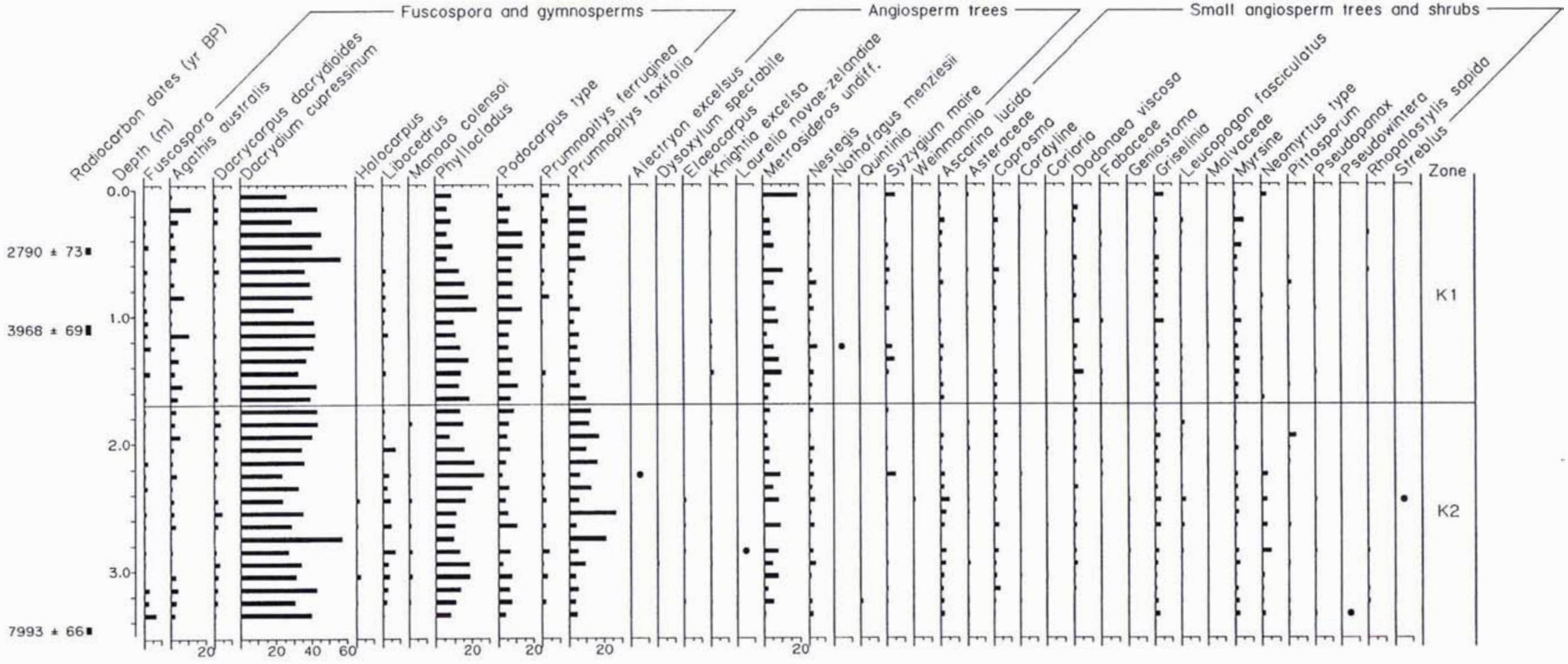

Figure 7.4a Pollen percentage diagram for borehole 6 showing *Fuscospora*, gymnosperms, and angiosperm trees, small trees and shrubs.

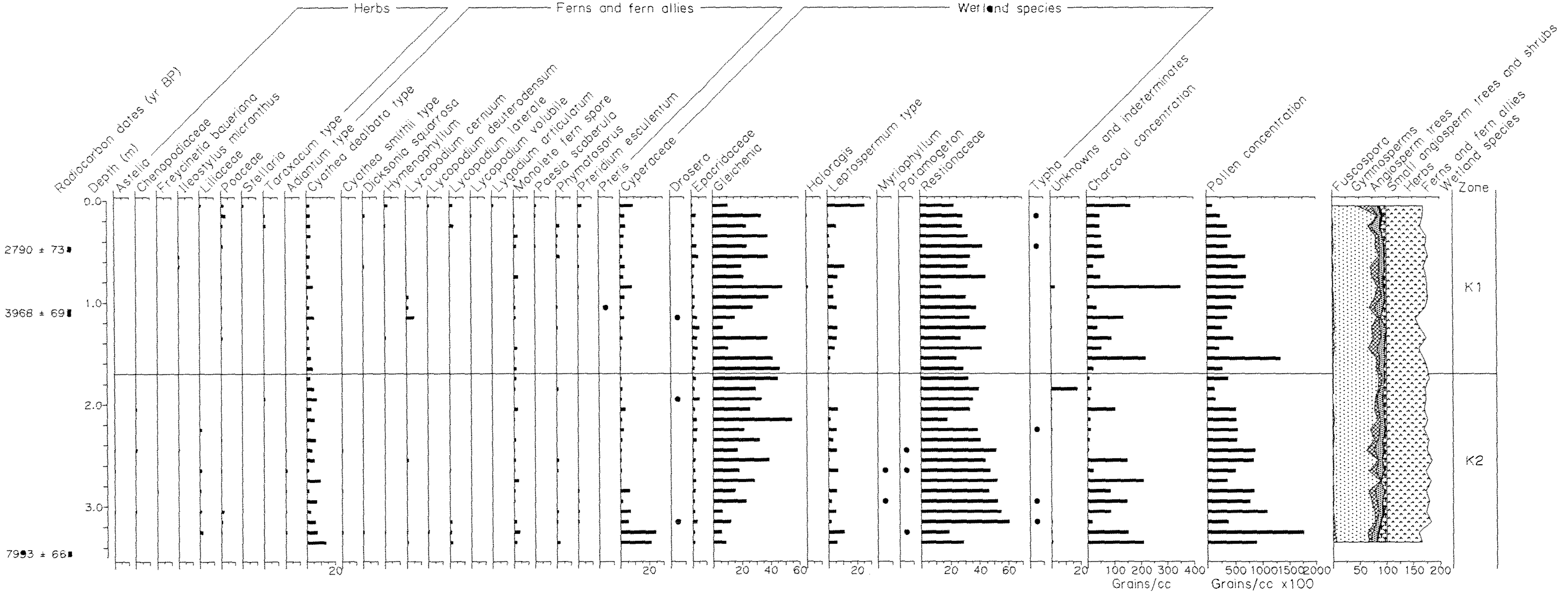

Figure 7.4b Pollen percentage diagram for borehole 6 showing herbs, ferns, fern allies and wetland species. Pollen concentration and charcoal concentration are shown in grains cm^{-3}.

Discussion

The inferred regional vegetation and palaeoclimates derived from the Kaitaia Bog pollen profiles are summarised in Table 7.2. Pollen zone K4 indicates that prior to the LGM, from *ca* 25 - 22.5 ka, a tall complex conifer-beech forest dominated by *Dacrydium cupressinum* and *Fuscospora* formed the principal vegetative cover of the Kaitaia region. Newnham (1992) concluded on the basis of aperture counts, and evidence of modern distributions and ecology, that *Fuscospora* pollen in far northern New Zealand is most likely to be *Nothofagus truncata*. Newnham's conclusion is accepted in this study. All conifers occurring in the region today are represented in this forest, though tree fern-rich conifer-hardwood forest was probably restricted at this time. Warmth-loving, drought-intolerant taxa such as *Agathis australis* and *Ascarina lucida*, are reduced in frequency when compared to more recent spectra. An abundance of charcoal fragments indicates that fires were frequent events. A predominance of large charcoal fragments (> 50 µm) over finer charcoal implies a local source suggesting direct disturbance of bog vegetation due to fire. The occurrence of *Laurelia novae-zelandiae* and *Syzygium maire*, typical swamp forest trees, suggests that the water table was high. *Cyathea smithii* type tree ferns are typical of cool, moist upland areas in Northland. Climate during this period is interpreted as being cool, moist and windy. Other evidence from south of Auckland (McGlone *et al.*, 1984a) indicates deterioration of climate from *ca* 28 ka.

Sharp changes in the regional vegetation occurred at the beginning of the LGM. *Nothofagus cf. truncata* dominated the forest flora. At the same time as *N. cf. truncata* was rising, tree ferns, *Dacrydium*, *Dacrycarpus* and *Libocedrus* declined in frequency, while the hardy podocarps, *Podocarpus*, *Prumnopitys taxifolia* and *Manoao*, increased. Leathwick (1995) correlates greatest abundance of these taxa with cooler/lower insolation environments. *Manoao* is frost-tolerant (Sakai and Wardle, 1978) and its increased abundance here suggests a cooler climate. In northern forests today it is found at frosty sites or on infertile swamp soils (Newnham, 1992). *Ascarina lucida*, a small understorey tree intolerant of frost and drought (McGlone and Moar, 1977), was scarce and only low percentages of *Agathis* are recorded. These features suggest conditions were not only cooler, but also probably much drier and windier than present with frequent fires in the catchment. Cranwell (1953) suggests that *Sporadanthus* may be favoured by frequent fires (see also McGlone *et al.*, 1984b). Certainly restiads, and also *Leptospermum*, increase following peak charcoal concentration. Climatic conditions appear to have been coolest and driest at about 5.25 m which, interpolated from the radiocarbon chronology (Figure 7.2), correlates to *ca* 18 ka. Dodson *et al.* (1988) do not record a similarly *Fuscospora*-dominant flora from their North Cape pollen site, and correlation with the Otakairangi pollen site (Newnham, 1992) is difficult owing to the dating problems. In present day Northland, *Nothofagus* forest is scarce. Small mixed podocarp-beech-hardwood stands covering only a few acres can be found in the Omahuta State Forest 30 km south of Kaitaia. Elsewhere, on mainland Northland, a few isolated trees remain in Waipoua State Forest and near Whangarei. Offshore, *Nothofagus truncata* occurs on Little Barrier Island (Wardle, 1984).

The end of the LGM is not readily identified in the record owing to the slow sedimentation rate from 5.49-5.00 m. However, the first *Dodonaea viscosa* pollen appears in the profile at 5.10 m, and interpolation from Figure 7.2 suggests this depth correlates to *ca* 14 ka. *Dodonaea* prefers warm sunny sites, and is confined largely to coastal locations south of Auckland. Its presence implies a transition to more equable conditions. From *ca* 11.3 ka this transition becomes more pronounced as *Ascarina* becomes more abundant. Its rise from the beginning of the Holocene has been well documented in more southern records (McGlone and Moar, 1977; McGlone and Neall, 1994; Newnham *et al*., 1989).

The Postglacial section of the Kaitaia Bog pollen record has many similarities to other Northland pollen records (MacDonald, 1984; Kershaw and Strickland, 1988; Elliot *et al*., 1995), as well as those of the Waikato, Tongariro, and Taranaki (McGlone, 1988). All include a regional vegetation of mixed conifer-hardwood forest of which *Dacrydium*, *Phyllocladus* and *Metrosideros* were the most prominent taxa. By 10 ka climate was warm and moist. Fires were still common but burning was much reduced. The finer nature of the charcoal fragments at this time implies a more distant source. At Kaitaia, *Nothofagus cf. truncata* declined sharply after 9.5 ka, and by *ca* 8 ka was only a minor component of the northern forest. From *ca* 9 ka *Agathis* pollen became more abundant whilst *Dacrydium* and *Metrosideros* sp. were the most common emergent taxa. The curve for *Phyllocladus* rises progressively through the early Holocene. This successional species is commonly associated with *Agathis* communities (Ecroyd, 1982). Thus the general trend for the early Holocene, is one of replacement of *Nothofagus*-podocarp-hardwood forest by an *Agathis australis*-podocarp-hardwood association. This community persists as the dominant vegetation type into the late Holocene. *Prumnopitys* sp., *Manoao* and *Halocarpus* are less common than previously, while *Libocedrus* becomes more abundant. These features in the record lend further support for a moister, milder early to mid-Holocene climate. *Ascarina* is most abundant from *ca* 10.5 to 7.6 ka suggesting that this period enjoys the warmest, most equable climate over the last 25 ka. Evidence from speleothem records suggests that early

Table 7.2. Vegetation and climate history of far northern New Zealand during the past 25,000 years

Pollen zone	**Timespan**	**Key pollen taxa**	**Regional vegetation**	**Climate**
K1	*ca* 2,500 to 5,000	*Dacrydium, Agathis, Prumnopitys taxifolia*	Kauri-podocarp-hardwood forest	Mild, summer drought
K2	*ca* 5,000 to 10,500	*Dacrydium, Agathis, Metrosideros, Ascarina*	Kauri-podocarp-hardwood forest	Warm, moist
K3	*ca* 10,500 to 14,000	*Ascarina, Dacrydium, Metrosideros, Prumnopitys taxifolia, Podocarpus, Fuscospora*	Podocarp-beech-hardwood forest	Cool-mild, moist, windy
	ca 14,000 to 22,500	*Fuscospora, Dacrydium, Podocarpus, Prumnopitys taxifolia,*	Beech-podocarp-hardwood forest	Cold, dry, windy
K4	*ca* 22,500 to > 25,000	*Dacrydium, Fuscospora, Podocarpus, Prumnopitys taxifolia, P. ferruginea*	Podocarp -beech-hardwood forest	Cool, moist, windy

Holocene temperatures were 1-2°C warmer than present (Hendy and Wilson, 1968). Pollen and macrofossil evidence from more southern regions also indicates milder and less frost-prone climates during the early Holocene (McGlone *et al.*, 1993). The Postglacial expansion of *Agathis* is noted in other Northland records from *ca* 8 ka (MacDonald, 1984; Newnham, 1992), and increased abundance of *Knightia excelsa* and *Phyllocladus* occurred during the early Postglacial from *ca* 7 ka at other northern North Island sites (McGlone, 1988; Newnham *et al.*, 1989). *Agathis* requires a climate which is generally warm and humid with a rainfall between 1000 and 2500 mm per annum (Ecroyd, 1982).

The mid- to late Holocene is characterised by significant rises in hardy podocarps, especially *P. taxifolia* and *Manoao*. *Metrosideros* sp., *Ascarina* and *Libocedrus* are less abundant. This is suggestive of some cooling or **drying** and may well indicate a more frequent occurrence of summer drought. McGlone *et al.* (1993) argue that drought was more common from 6000 yr B. P., and more frequent incursion of cool polar air masses brought cooler average temperatures overall. At Lake Taumatawhana a cooler, drier climate is suggested as having occurred between 5000 and 3400 yr B. P. (Elliot *et al.*, 1995).

The uppermost samples of both Kaitaia records are typical of pollen spectra associated with Polynesian deforestation (McGlone, 1983). These features are commonly seen in many late Holocene profiles (*e.g.* McGlone, 1978; Newnham *et al.*, 1995; Elliot *et al.*, 1995). The onset of Polynesian deforestation is generally accepted as having occurred at *ca* 700 B. P. (McGlone *et al.*, 1994). However, the proximity of these samples to the surface makes their dating ambiguous, and they may represent mixing of recent pollen with bog erosion.

Conclusions

At Kaitaia, forest cover has probably been continuously present throughout the last 25,000 years. The inferred regional vegetation of the Last Glacial Maximum was mixed beech-conifer-hardwood forest in contrast to the Postglacial, pre-human contact Northland forests which are typically conifer-hardwood associations. The persistence of forest cover through the LGM contrasts sharply with pollen records from more southern regions where forest was very restricted in extent, and grass-shrubland communities were widespread (McGlone, 1988; McGlone *et al.*, 1993). The Kaitaia record indicates a very diverse assemblage of conifer trees similar to that recorded by Newnham

(1992) from the Whangarei area. The most climate-sensitive forest taxa, though much reduced at the height of the LGM, were able to maintain a presence, presumably restricted to climatically favoured sites. Typical northern elements were always present. The major limiting factor for forest species in the north seems to have been available moisture. The similarity of forest composition (mixed podocarp-hardwood associations dominated by *Dacrydium cupressinum* and *Nothofagus truncata*), notwithstanding the presence of northern elements, to those of the present day northern South Island forests suggests that climate was probably similar to that of the Nelson Sounds area today, (*i.e.* annual rainfall *ca* 1000 mm, mean annual temperature *ca* 12.5°C). This contrasts sharply to the present day climate regime of about 1450 mm annual rainfall, and average annual temperature of *ca* 15.9°C. However, this is consistent with the reconstructions for lowered mean annual temperatures during the LGM estimated from snowlines (Soons, 1979).

The sharp rise in *Ascarina lucida* which commenced towards the end of the Lateglacial indicates a rapid transition from cool, dry to warm, moist climate. No detection of a cooling event synchronous with the Northern Hemisphere Younger Dryas is apparent in this record. However, dating resolution of the Kaitaia Bog profiles for this period is not good enough to rule it out. McGlone (1995) assessed the New Zealand pollen records for the Lateglacial and reached a similar conclusion. By the early Holocene *Nothofagus* was a minor element of the northern forests. A Postglacial expansion of *Agathis australis* from *ca* 9 ka is consistent with other Northland records (Newnham, 1992), and an early Postglacial climate of warm, moist conditions is in agreement with McGlone (1988).

A mid- to late Holocene climate which became slightly drier and cooler is consistent with interpretations advanced for other parts of New Zealand (McGlone *et al.*, 1993).

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Chapter 8

LAKE TANGONGE AND LAKE OHIA

Introduction

As yet few published pollen sequences of long records exist which span the Last (Otiran) Glacial. The best records to date are the deep sea core records of Wright *et al.* (1995), and Heusser and van de Geer (1994). These are integrated logs of palynology, sedimentology, $CaCO_3$ content, and isotopic data. That of Wright *et al.* has a reliable chronostratigraphy provided by dated silicic tephras and in this paper they describe palaeoclimates during the past 59 ka for northern New Zealand. However, long records of late Quaternary continuous sedimentary sequences from terrestrial sources in New Zealand are scarce. The interpretation of late Quaternary climates relies mainly on the correlation of numerous records from widespread studies throughout the region with the integrated logs from marine core studies (*e.g.* Stewart and Neall, 1984; Fenner *et al.*, 1992; Nelson *et al.*, 1994).

Land-based pollen records, together with marine core pollen and oxygen isotope analyses, indicate that terrestrial vegetation patterns in New Zealand closely match late Quaternary global climatic changes (Pillans, 1994). Beginning during oxygen isotope Stage 3 (59 - 24 ka) Wright *et al.* (1995) report Northland Peninsula as being fully covered by *Agathis australis*-podocarp-hardwood forest. Stage 3 is subdivided into two sub-stages, a warmer period from 59 - 43 ka, and a period of cooling from 43 - 24 ka. During Stage 2, from 24 - 12 ka, glacial climates prevailed, with full glacial conditions occurring between *ca* 22 - 18 ka. During this time (Stage 2) a beech forest (probably dominated by *Nothofagus truncata*), characteristic of cooler, more stressed conditions, spread into Northland (Wright *et al.*, 1995; Newnham, 1992). Elsewhere in New Zealand LGM forest cover was much reduced, so that south of Auckland grassland-shrubland communities predominated (Pillans *et al.*, 1993; McGlone *et al.*, 1984a). In Northland the distribution of warm northern elements, such as *Agathis* and *Ascarina lucida*, was severely restricted at this time. Instead hardy podocarps, such as *Prumnopitys taxifolia* and *Podocarpus*, became more widespread. Subsequent climate amelioration from glacial to postglacial conditions occurred rapidly as a resurgence of *Dacrydium cupressinum*-dominant forest, with abundant *Ascarina lucida* and tree ferns, re-established throughout Northland. This change in forest cover reflects the increasingly warm and moist climates of the early Holocene (McGlone,

Plate 8.1 The Lake Tangonge site, Kaitaia Bog.

Plate 8.2 The Lake Ohia site, Karikari Peninsula.

1988; Newnham, 1992; Newnham *et al.*, 1993). By the late Holocene increasing abundance of *Agathis australis* and *Phyllocladus*, along with the decline of *Ascarina* and tree ferns, is correlated with slightly cooler, more variable climates. In this study two terrestrial pollen records are described which, together with previous work, establish the composition of far northern forest over the past *ca* 100 ka. A core from "Lake Tangonge", in the Kaitaia Bog, provides a *ca* 68 ka record using a radiocarbon chronology and correlation with other well dated pollen records (*e.g.* Wright *et al.*, 1995; McGlone *et al.*, 1984a; Pillans *et al.*, 1993). Comparisons with other Northland pollen diagrams are made (Newnham 1992; Newnham *et al.*, 1993; Ogden *et al.*, 1993; Chapter 7, this study). A *ca* 26 ka record from Lake Ohia is also reported and correlated by palynostratigraphy to other dated profiles and the deep-sea ^{18}O chronostratigraphy of Martinson *et al.* (1987) to the period 100-74 ka.

Geology

"Lake Tangonge" (O04/302734; 35° 08' 35" S, 173° 12' 50" E) is part of the Kaitaia Bog complex (Figure 8.1) described in Chapter 7. Whilst not truly a lake, "Lake Tangonge' exists as a standing body of shallow water from time to time during periods of prolonged heavy rainfall. The lake is located on the southern margins of Kaitaia Bog approximately half way between Ahipara and Kaitaia, and receives drainage from the northern flanks of the Herekino Range which comprises Tangihua Volcanics of Palaeocene - Eocene age (Figure 8.2; Plate 8.1; Kear and Hay, 1961). Lake Ohia is also, strictly speaking, not a lake, but rather consists of a shallow, wide peat deposit. However, like Tangonge, surface ponding occurs during periods of prolonged heavy rainfall. Lake Ohia is situated at the southern end of Karikari Peninsula (O04/444911 ; 34° 59' S, 173° 22' E; Figure 8.1). The site is bounded on the west, north and east by late Quaternary sand dunes. To the south lie Miocene, siliceous claystones, and carbonaceous siltstones, and Eocene calcareous mudstones and greenstones (Figure 8.3, Plate 8.2; Hay, 1975).

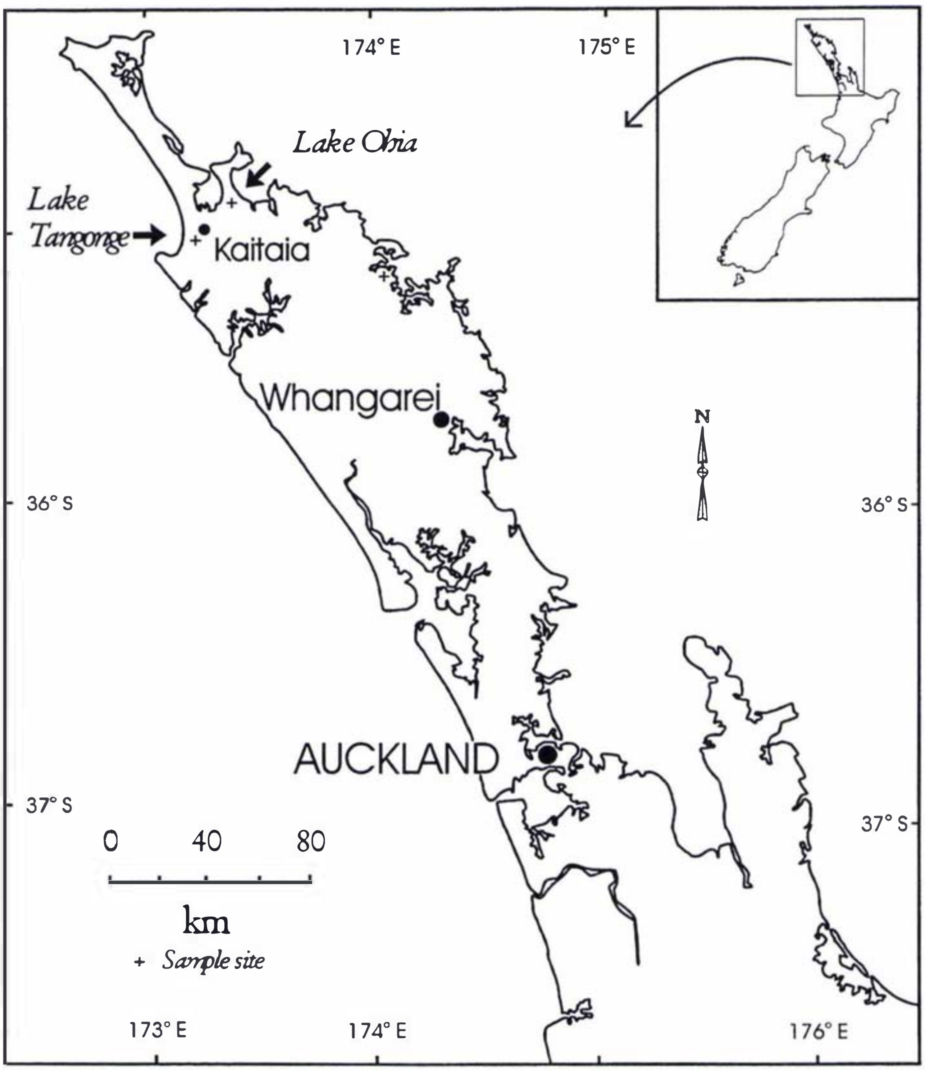

Figure 8.1 Location of Lake Tangonge and Lake Ohia sites in far northern New Zealand

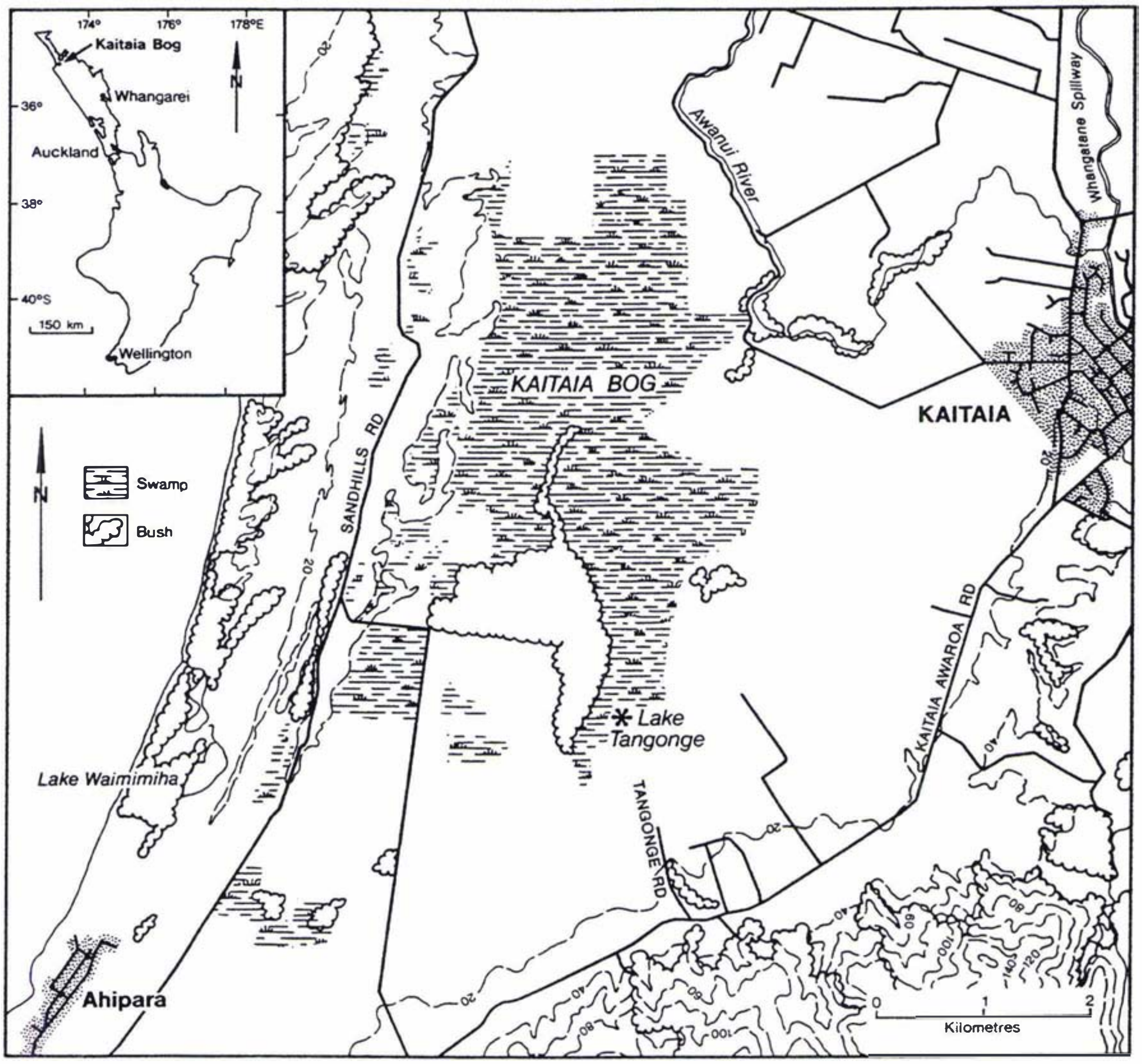

Figure 8.2 The Kaitaia Bog showing physiography and the Lake Tangonge coring site.

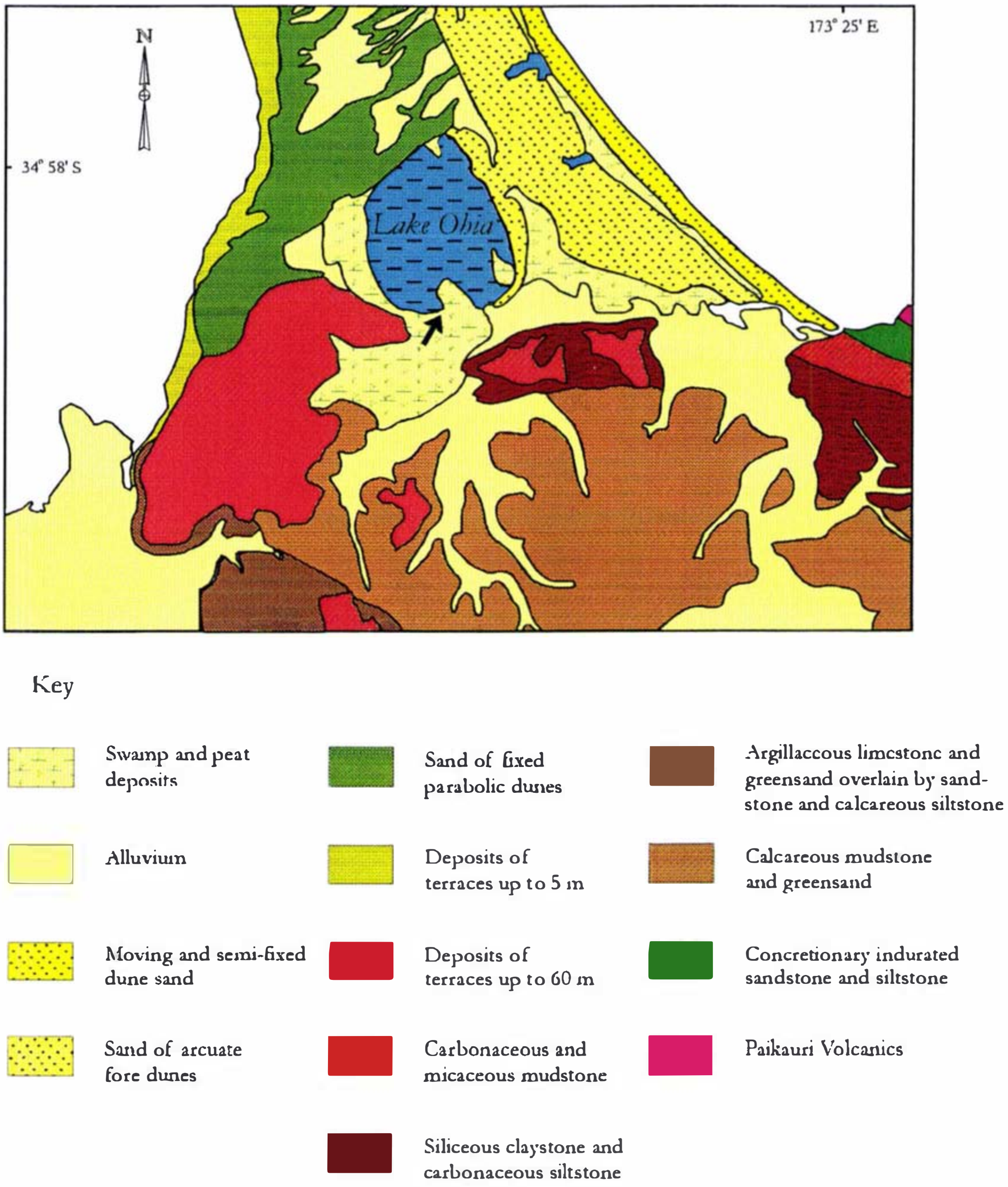

Figure 8.3 Lake Ohia geological map (after Hay, 1975). Arrow marks coring site.

Methods

A 4.5 metre long core from Lake Tangonge (Figure 8.2), and a 2.77 metre long core from Lake Ohia (Figure 8.3), were obtained using a d-section Russian corer (Jowsey, 1966). Core sediments for pollen analysis were prepared following standard palynological techniques (Moore *et al.*, 1991; see Chapter 2). A sampling interval of 10 cm was used throughout, except for Lake Tangonge between 1.0 - 1.5 m where samples were prepared at 5 cm intervals. Samples were stained and mounted in glycerine jelly for microscopic identification. Counts were made of *ca* 250-300 terrestrial-type pollen grains per sample. The results are presented as percentages of all woody plants and dryland herbs, but excluding wetland species and all fern spores excluding *Pteridium esculentum*. Fern spores are excluded because of their tendency to be over-represented. This is particularly likely at Lake Tangonge where inwash of soil spores may be a significant component of the pollen spectra. Charcoal concentration is derived after Bush *et al.* (1992) and described in Chapter 2. Pollen concentration is shown as grains cm^{-3} based on calculations using exotic *Lycopodium* spore markers (Stockmarr, 1971). Four samples of 4 -5 cm length from the Lake Tangonge core, and 6 from Lake Ohia, were submitted to the Rafter Radiocarbon Laboratory at Lower Hutt for Accelerator Mass Spectrometry (AMS) dating. Samples from the same levels as those used for pollen analysis from Lake Ohia were analysed for plant macrofossil remains by Dr. Mike Pole, Department of Botany, University of Queensland.

RESULTS

Lithostratigraphy and dating

The lithostratigraphy of the Tangonge core consists of a series of peats, clays, organic muds, and silty/sandy units (Figure 8.4). Numerous wood fragments occur through the core. A chronostratigraphy for the Tangonge core is established by AMS ^{14}C dating (Table 8.1), and correlation with other, well dated northern sequences (see Chapter 7 and Wright *et al.*, 1995). An uppermost date at 0.96 - 1.0 m provided an uncorrected age of 7160 ± 100 yr B. P. (NZA-6401), and a basal sample at 4.38 - 4.43 m gave an uncorrected age of 43,876 ± 1650 yr B. P. (NZA-3107). The date at 2.95 - 3.00 m (NZA-6088) was derived from a piece of wood. Particular care was taken in the pre- preparation of this wood sample, and the cellulose fraction was isolated for ^{14}C measurement.

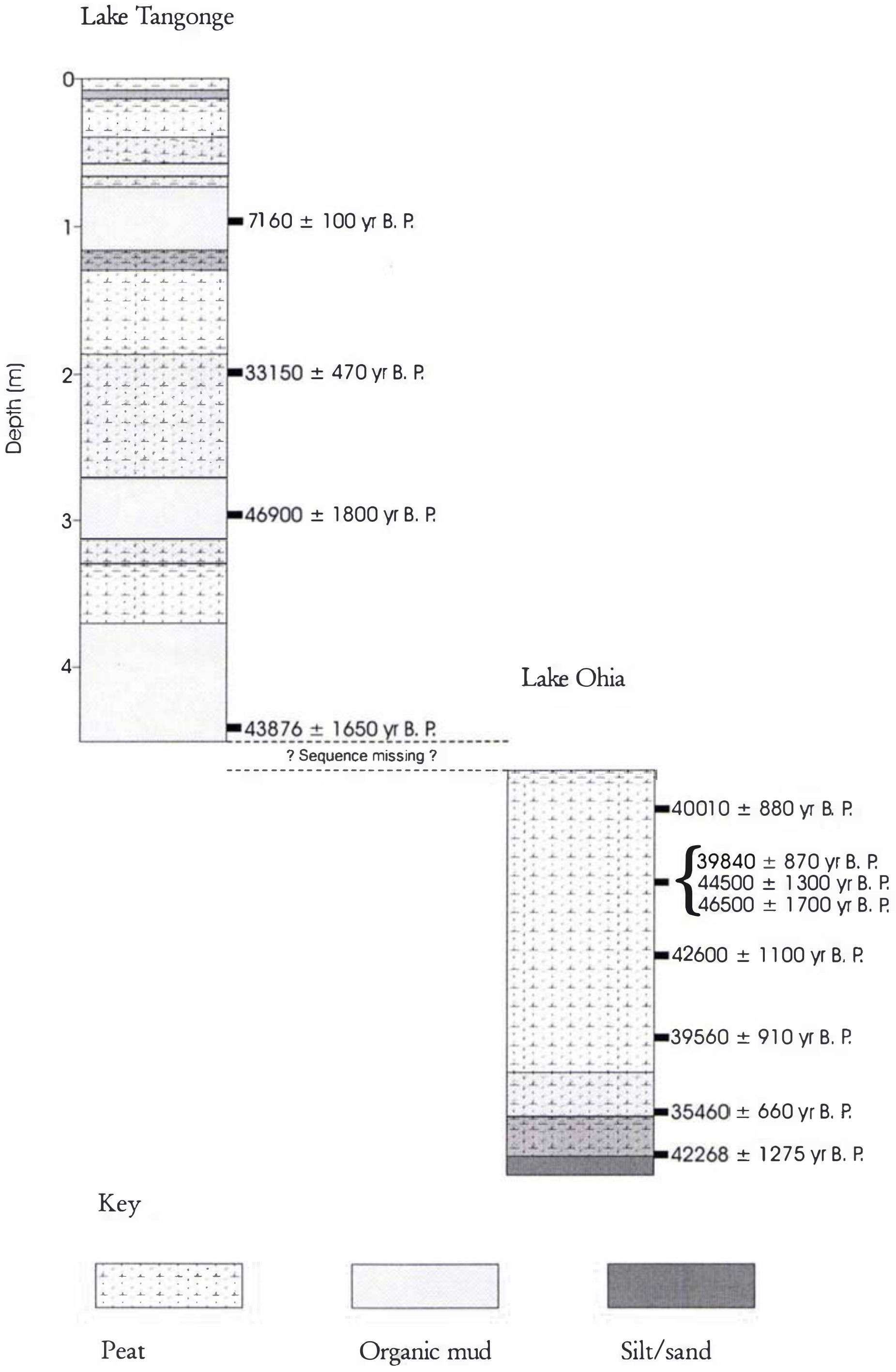

Figure 8.4 Lithostratigraphy of Lake Tangonge and Lake Ohia cores.

Cellulose dates on wood samples are considered to provide more accurate measurements, less prone to contamination from young carbon (N. Beavan, pers. comm. 1996).

The Ohia core consists of dark brown peat with traces of sand, increasingly so near the base (Figure 8.4). Carbon dating of wood reported by Hicks (1975) from trees near the surface suggested that the upper sediments might be *ca* 31 - 38 ka. AMS dating of a basal sample at 2.60 - 2.65 m yielded an age of 42,268 ± 1275 yr. B. P. (NZA-3488). Subsequently, 5 further samples were also dated by AMS (Table 8.1).

Table 8.1 Radiometric dating results

Depth (m)	NZA#	Age ^{14}C yr. BP	Material dated
Lake Tangonge			
0.96 - 1.00	6401	7160 ± 100	peat
1.96 - 2.00	6403	33150 ± 470	peat
2.95 - 3.00	6088	46900 ± 1800	wood cellulose
4.38 - 4.43	3107	43876 ± 1650	wood/peat
Lake Ohia			
0.25-0.30	6129	40010 ± 880	peat
0.75-0.80	6133	44500 ± 1300	peat/charcoal
0.75-0.80	6657	39840 ± 870	humic precipitate
0.75-0.80	6656	46500 ± 1700	peat
1.25-1.30	6130	42600 ± 1100	peat
1.81-1.86	6134	39560 ± 910	peat/seeds
2.31-2.36	6135	35460 ± 660	peat
2.60-2.65	3488	42268 ± 1275	twigs

The rationale for the ages assigned to the pollen zones for Lake Ohia and the lower part of the Lake Tangonge core is discussed on pages 211-212.

Plant Macrofossils

Table 8.2

Depth (m)	*Plant remains*
0.05	unidentified wood
0.15	Cyperaceae seeds, charcoal
0.25	Cyperaceae seeds, charcoal
0.35	roots, charcoal
0.45	? *Typha*, Cyperaceae seeds, charcoal
0.55	roots, reeds, Cyperaceae seeds
0.65	roots, ?Cyperaceae
0.75	charcoal, ?bark
0.85	reeds and fine roots, seeds
0.95	reeds and seeds
1.05	podocarp root nodules
1.15	podocarp root nodules
1.25	?leaves
1.35	roots, bark
1.45	*Agathis australis*, ?bark, dicot. fragments
1.55	charcoal, fusainised leaf, fruits, Cyperaceae seed
1.65	reeds, charcoal and seeds
1.85	podocarp root nodules
1.95	podocarp root nodules and resin
2.05	podocarp root nodules
2.15	podocarp root nodules
2.25	podocarp root nodules
2.35	podocarp root nodules
2.55	podocarp root nodules and resin

Palynology

The results of pollen analyses for Lake Tangonge and Lake Ohia are presented as percentage data in Figures 8.5 and 8.6 respectively. Pollen zones are based on stratigraphically constrained cluster analysis (Grimm, 1987). Variables were standardised to a mean of zero at one standard deviation and standardised Euclidean distance. At Ohia 2 major zones are recognised, the upper zone being subdivided into two; at Tangonge 4 major zones are recognised, zones 1 and 2 being subdivided into two.

Lake Ohia

Zone Oh 2, 2.60 - 1.80 m, ca100- 91 ka

The zone is dominated by *Dacrydium cupressinum*, *Agathis australis*, *Phyllocladus*, *Metrosideros* and *Quintinia*. *Agathis* declines in the upper part of the zone. *Ascarina lucida* is present in appreciable amounts. *Weinmannia* and *Elaeocarpus* also record notable values. Significant, though low, abundances of *Ixerba brexioides* are recorded in the upper half of the zone and traces of *Beilschmiedia* are recorded. Pollen of understorey trees and shrubs is dominated by *Myrsine* and *Neomyrtus* type. *Coprosma* and *Griselinia* are also present. *Tupeia antarctica* is common in the lower half of the zone. Tree ferns are not common generally, though significant amounts of *Cyathea smithii* type are present at the top of the zone. Pollen of typical bog species is not abundant, but sedges, restiads, *Gleichenia*, Epacridaceae, and *Leptospermum* are present. Charcoal concentration is low.

Zone Oh 1b, 1.80 - 1.00 m, ca 91 - 80 ka

At the onset of this zone a number of changes are apparent. Initially, sharp rises in *Podocarpus*, *Prumnopitys ferruginea*, and *P. taxifolia* are evident. *Dacrydium*, *Agathis* and *Ascarina* decline at this time, and traces of *Fuscospora* are first recorded at the zone boundary. *Gleichenia*, *Leptospermum*, and Restionaceae frequencies, as well as charcoal concentration are elevated in the lower part of the zone. Subsequently *Dacrydium* rises sharply, reaching almost 80 % of the pollen sum. All other gymnosperms are significantly reduced, except for *Agathis* which maintains a strong, though less dominant, presence than previously. *Metrosideros* is greatly reduced in frequency, but the curve for *Quintinia* follows a similar trend to that of *Dacrydium*. *Weinmannia* and *Elaeocarpus* are well represented throughout the zone. Pollen of *Ascarina lucida* is scarce. Charcoal concentration declines from elevated values in the lower zone and bog species are all reduced in abundance.

Zone Oh 1a, 1.00 - 0.00 m, ca 80 - 74 ka

In this upper zone *Dacrydium cupressinum* declines significantly. *Agathis australis* is well represented throughout, and all gymnosperms are common, particularly *Phyllocladus*, *Podocarpus* and *Prumnopitys taxifolia*. Increased frequencies of *Elaeocarpus* are notable. *Metrosideros* and *Nestegis* are markedly more common. A slight increase in *Ascarina* occurs in the lower part of the zone, but then declines to become scarce, and a number of other shrubs and understorey trees become more abundant. These include *Coprosma*, *Griselinia*, *Myrsine*, and *Neomyrtus*. Liliaceae and grass pollen are more common. Bog species are much more abundant. Restiads increase throughout the zone. Charcoal concentration is greatly elevated throughout the zone.

Lake Tangonge

Zone LT 4, 4.5 - 3.7 m, ca 67.5 - 56.5 ka

High levels of *Dacrydium cupressinum* (40 - 65 %) and *Dacrycarpus dacrydioides* define this zone. Significant, but low, amounts are recorded by all other gymnosperms. The most important of these are, *Phyllocladus*, *Podocarpus*, *Prumnopitys ferruginea* and *P. taxifolia*. Of the angiosperm trees, *Knightia excelsa* levels are highly significant, and *Metrosideros* pollen is common. Pollen of

Ascarina lucida is notably scarce, while that of *Pseudowintera* becomes increasingly common toward the middle of the zone, then declines upward. Also present are *Pittosporum* and *Leucopogon fasciculatus*. Asteliad pollen is significant, as is that of the parasitic shrub *Tupeia antarctica*. Ground ferns (represented by monolete fern spores) are common. Bog species are not well represented, but significant levels of *Coprosma* pollen suggest its widespread occurrence. Charcoal concentration is low.

Zone LT 3, 3.70 - 2.40 m, ca 56.5 - 39 ka

This zone is notable for the increased abundance of *Dacrycarpus dacrydioides* pollen (15 - 25 %), and the decline in importance of *Dacrydium cupressinum* which falls from *ca* 40 % down to *ca* 10 %. *Agathis australis* pollen shows a gradual increase up to about 5 %, but other gymnosperms show markedly reduced frequencies. *Elaeocarpus* pollen records consistent, but low, levels. *Knightia excelsa* is less prominent than previously. *Metrosideros* pollen is increasingly important, particularly in the upper part of the zone. Other angiosperm trees to record significant abundances are *Nestegis*, *Quintinia* and *Syzygium maire*. A greatly increased abundance of *Ascarina lucida* pollen is recorded from the base of the zone. Several other small angiosperm trees and shrubs register significant values through this zone. Of particular importance are *Griselinia*, *Myrsine*, *Neomyrtus/Lophomyrtus*, *Pittosporum*, and *Pseudopanax*. *Pseudowintera* frequency is much reduced. The woody liane *Freycinetia baueriana* is common throughout. *Phormium* is present in the lower part of the zone. Ground ferns, including *Phymatosorus*, are common throughout. Although significant amounts of bog species, such as the sedges (Cyperaceae), *Gleichenia*, *Leptospermum* and *Coprosma*, are present at the base of the zone, they are generally scarce thereafter. Charcoal concentration is low.

Zone LT 2b, 2.4 - 1.9 m ca 39 - 30 ka

A sharp decline in *Dacrycarpus dacrydioides* and *Ascarina lucida* pollen, accompanied by significant increase in *Agathis australis*, define this zone. *Dacrydium cupressinum* pollen is common throughout. *Libocedrus* and *Phyllocladus* increase upward to become abundant at the top of the zone. Tall podocarps, especially *Podocarpus* and *Prumnopitys taxifolia*, are more abundant than previously. *Elaeocarpus* pollen is consistently recorded, and *Metrosideros* is common. *Nestegis* and *Quintinia* record consistent, but low values throughout. *Weinmannia* is abundant but declines sharply at the top of the zone. Of the small tree and shrub elements *Griselinia* is notably less common, and *Neomyrtus* type pollen declines abruptly from initially high values. The woody liane, *Freycinetia baueriana*, is much less common than previously. The bog flora is dominated by sedges and *Leptospermum* which increases upward. Charcoal concentration is low, and total pollen concentration is much reduced.

Zone LT 2a, 1.90 - 1.20 m, ca 30 - 12 ka

This zone is defined by the abundance of *Fuscospora* and tall podocarps, *Podocarpus* and *Prumnopitys taxifolia*. *Fuscospora* (20-25%) and *Dacrydium cupressinum* (20-30%) dominate the tree pollen. *Agathis australis* and *Phyllocladus* decline at the base of the zone and record only low values thereafter. *Metrosideros* is initially scarce but increases sharply toward the top. *Ascarina lucida* increases in abundance especially toward the top of the zone. Asteraceae pollen, which was previously scarce, is common in the upper samples. Values for most other small trees and shrubs are reduced from their former importance, but many show small increases near the top of the zone *e.g.* *Cordyline* and *Neomyrtus* type. Grass pollen, though not common, is increased at the top of the zone. Ground ferns are scarce. Of the bog flora, sedges and *Gleichenia* are widespread, and *Leptospermum* pollen, though variable, is common. Restiads become common toward the top of the zone. Charcoal concentration increases markedly and in the upper 3 samples of the zone attains it's greatest values. Total pollen concentration is variable but generally low throughout this zone.

Zone LT 1b 1.20 - 0.90 m, ca 12 - 7 ka

This zone is notable for a rapid decline in *Fuscospora*. *Dacrycarpus dacrydioides* increases from low frequencies to become common by the top of the zone, and *Ascarina lucida* rises sharply to a mid-zone peak of almost 20 % of the pollen sum. *Agathis* shows slightly increased values towards the upper levels. *Podocarpus*, *Prumnopitys ferruginea*, and *P. taxifolia* decline significantly. *Metrosideros* pollen increases sharply from the base of this zone and is the dominant angiosperm pollen type. Other angiosperm trees which record significant, though low values are *Knightia excelsa*, *Laurelia novae-zelandiae*, *Quintinia*, *Rhopalostylis sapida* *Syzygium maire*. *Nestegis*, and Asteraceae shrubs, become less common than formerly. Liliaceae, grasses, asteliads, and *Pteridium esculentum* are more common than formerly. Tree ferns are more common in the upper samples, and ground ferns increase markedly. Bog species are initially dominated by sedges, restiads, *Gleichenia*, and the bog-tolerant shrub, *Leptospermum*. However, these types decline toward the top of the zone. Charcoal concentration is reduced from the previous high values.

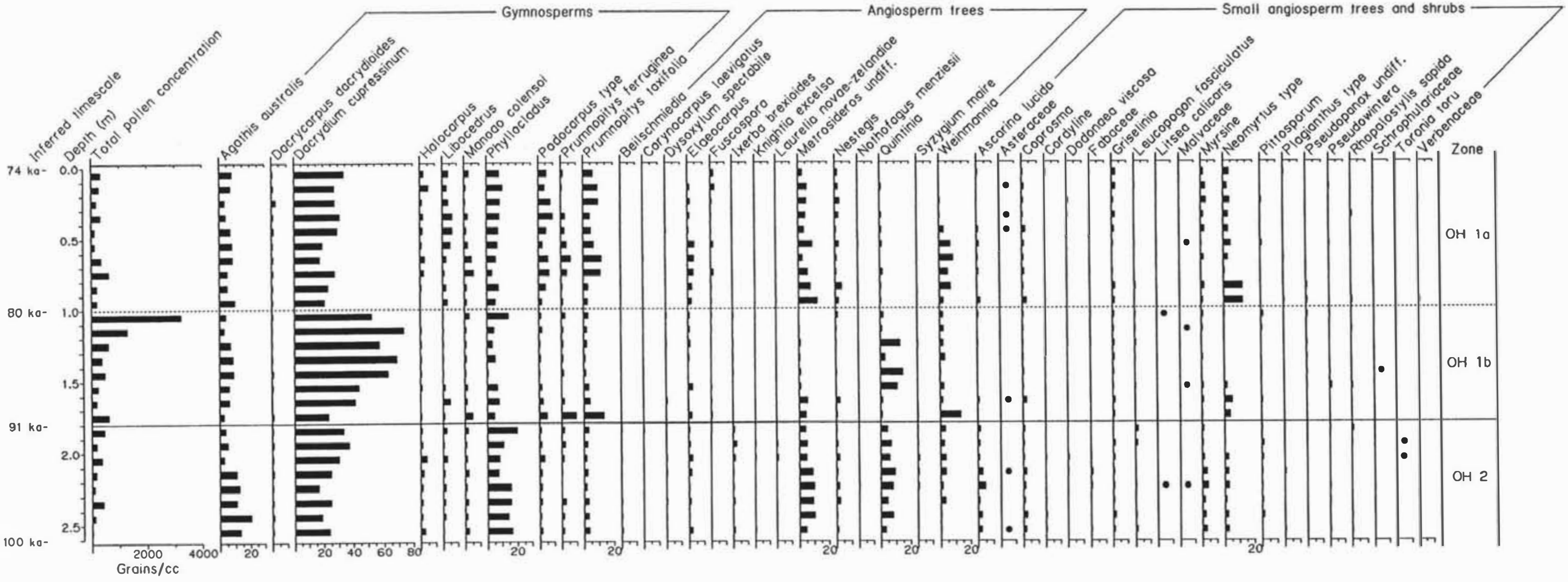

Figure 8.5a Percentage pollen diagram from Lake Ohia for gymnosperms, angiosperm trees, small trees and shrubs.

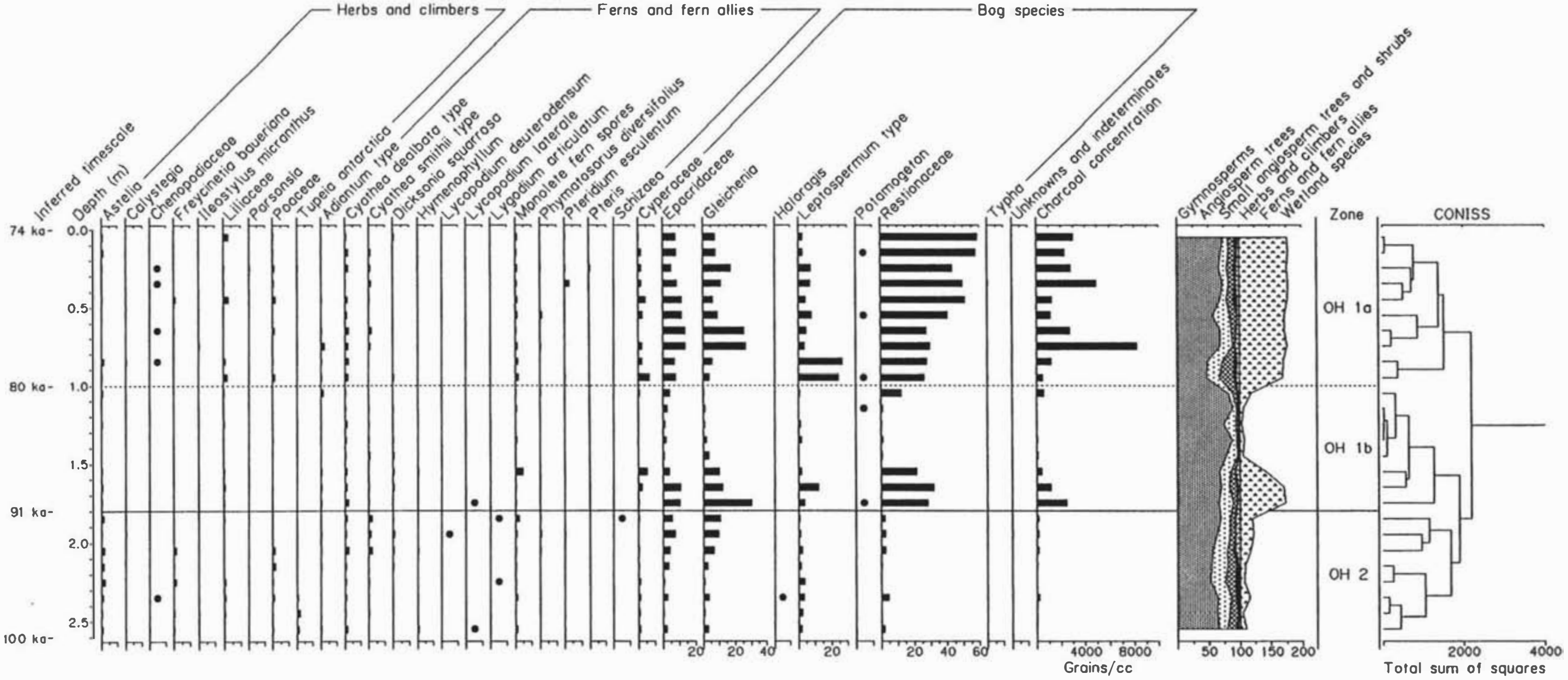

Figure 8.5b Percentage pollen diagram from Lake Ohia for herbs, climbers, ferns, fern allies, and bog species.

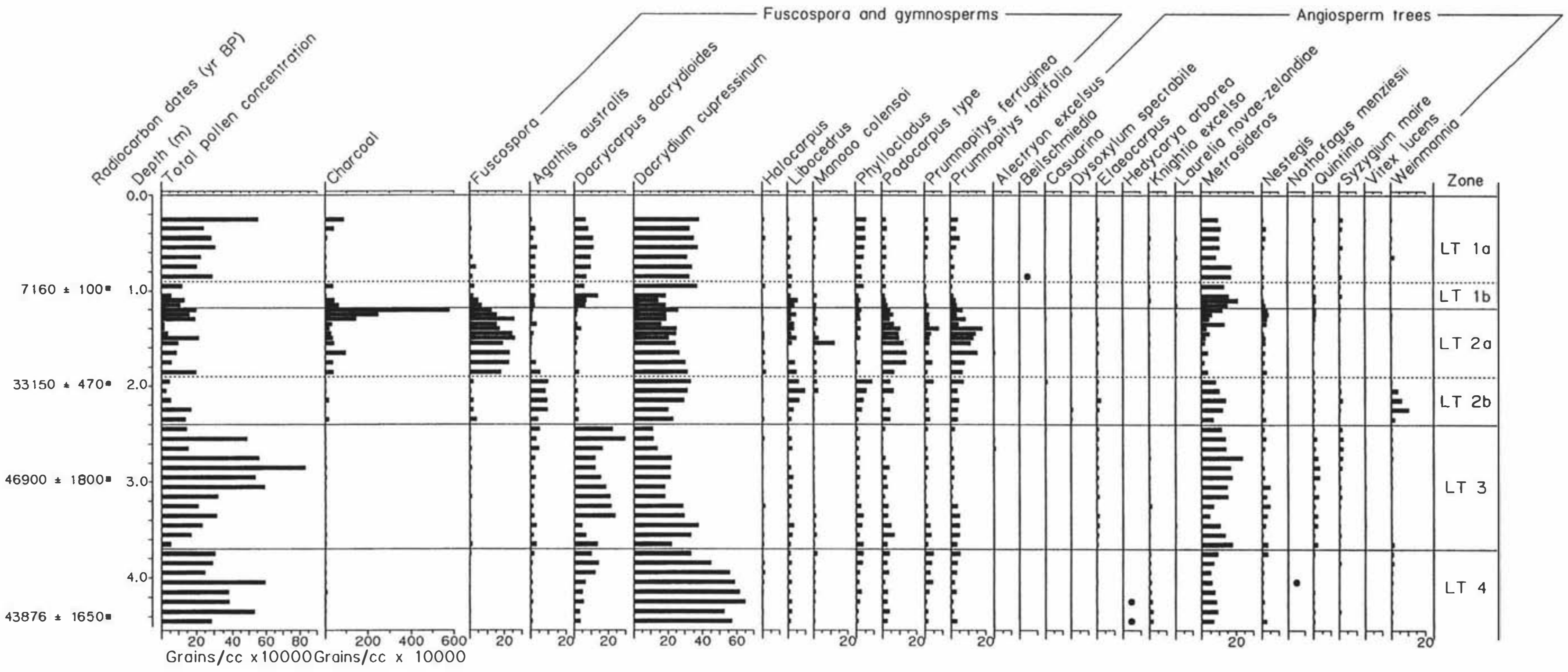

Figure 8.6a Percentage pollen diagram from Lake Tangonge for *Fuscospora*, gymnosperms, and angiosperm trees.

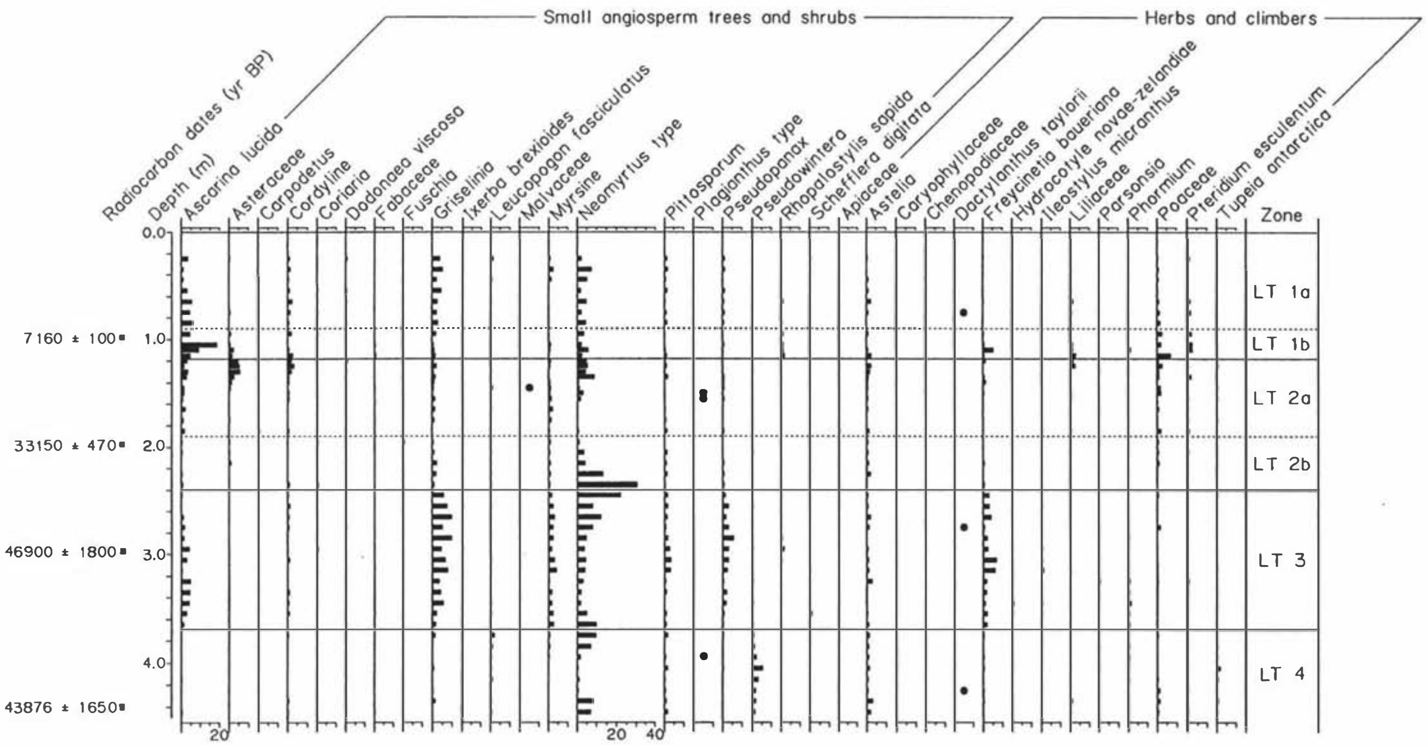

Figure 8.6b Percentage pollen diagram from Lake Tangonge for small angiosperm trees, shrubs, herbs and climbers.

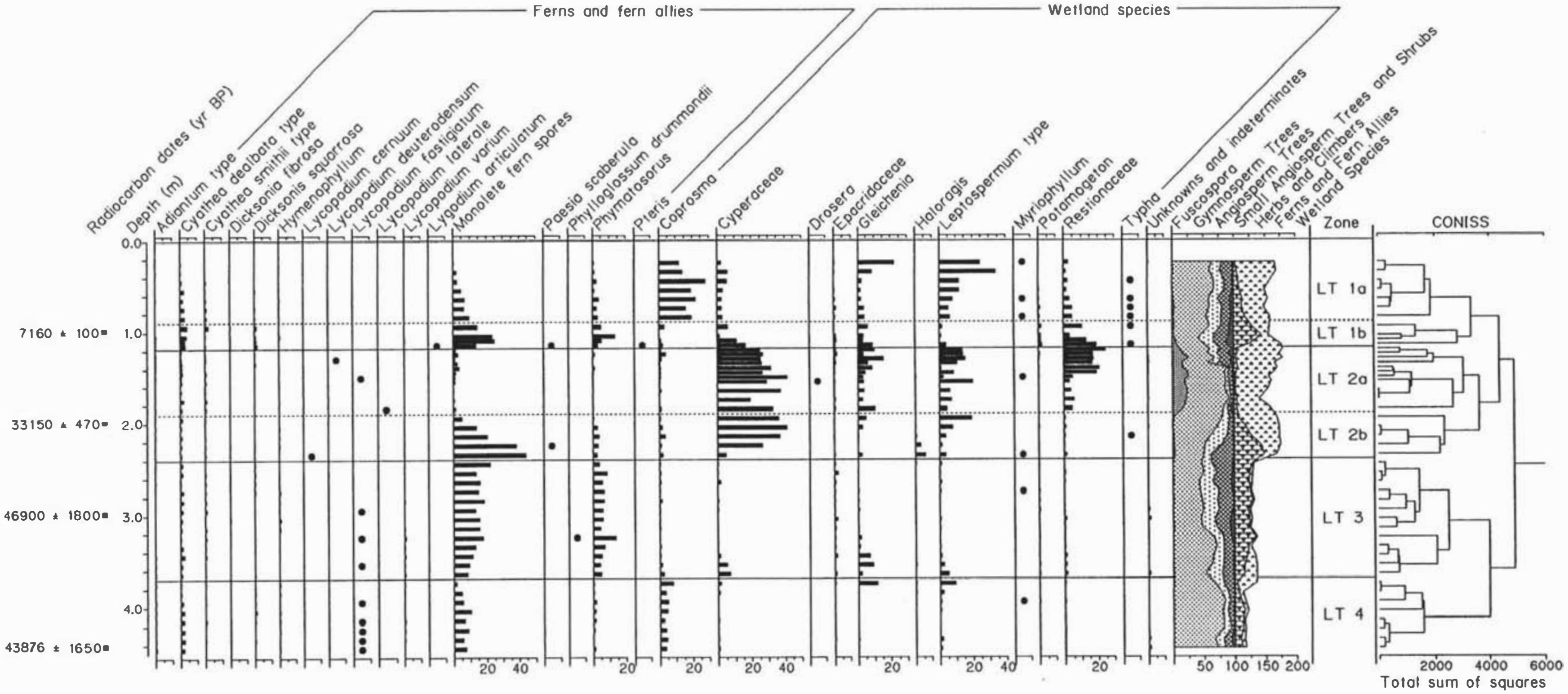

Figure 8.6c Percentage pollen diagram from Lake Tangonge for ferns and fern allies, and wetland species.

Zone LT 1a, 0.90 - 0.20 m, ca 7 - 3 ka

The uppermost zone is characterised by high levels of *Dacrycarpus*, *Dacrydium* and *Ascarina*. *Fuscospora* declines to become only a minor element, and *Libocedrus* is less common than previously. *Phyllocladus* and *Agathis* frequencies are consistently greater than before, though values are not high. Angiosperm tree pollen is predominantly *Metrosideros*, but consistent values are recorded for *Elaeocarpus*, *Knightia*, *Quintinia*, and *Syzygium*. *Vitex lucens* and *Laurelia* are also recorded in this zone. *Ascarina* declines toward the top of the zone. *Griselinia*, *Pittosporum* and *Pseudopanax* are significant understorey species. Grass pollen declines in importance, and ground fern spores become less abundant. The bog flora is dominated by high levels of *Coprosma* and *Leptospermum*. Sedges, restiads, and *Gleichenia* are present throughout the zone, though in reduced amounts. Charcoal concentration is low apart from the uppermost levels when it increases markedly.

Correspondence analysis (CA)

CA was undertaken on selected data sets from the Lake Ohia and Lake Tangonge pollen profiles. This statistical scaling technique is an analogue of principal components analysis (PCA) (Hill, 1974), but is more appropriate for count data than PCA. (Birks, 1985). CA is closely related to PCA but is performed in a sub-space of the variables of interest called a simplex, where all variables are rescaled as proportions. CA aids in the interpretation of stratigraphic geologic data by the detection of stratigraphic patterns and the establishment of relationships between different stratigraphic variables in the same sequence (Birks, 1987). The TILIA software package used here carries out CA which loosely follows the DECORANA program (Grimm, 1991). Only dryland pollen types which consistently attained >2-5% frequency were included. The components of axes which explain most variance between taxa were plotted against each other, and sample scores of these axes were plotted against each other and against depth. Taxa scores are divided into four groups, defined by lines $y = 0$ and $x = 0$.

Lake Ohia

Figure 8.7 plots the taxa scores for the first two axes. CA1 contrasts *Prumnopitys ferruginea*, *P. taxifolia*, *Podocarpus* and *Manoao colensoi* with *Dacrydium cupressinum* and *Quintinia*; CA2 contrasts *Agathis australis*, *Ascarina lucida* and *Metrosideros* with *Prumnopitys ferruginea*, *P. taxifolia*, *Podocarpus* and *Manoao colensoi*. The scores are divided into two main groups: the *+y/-x* quadrat contains a close cluster of taxa which dominated Zone OH 1a and are generally associated with cool/dry climates; those taxa in the *+y/ +x* quadrat are less closely clustered and tend to be most strongly associated with Zone OH 2, particularly those taxa with high CA2 values and low CA1 values. These taxa are associated with warm moist climates. One taxon is recorded in each of the other quadrats, clearly well separated from all other scores. *Quintinia* excels in waterlogged soils, and *Dacrydium cupressinum* is drought intolerant (Franklin, 1968). Thus CA1 separates taxa which thrive in more droughty environments from those which require wetter conditions. CA2 distinguishes those taxa which are more tolerant of cool climates from those which require milder temperatures. The close proximity of *Agathis australis* and *Phyllocladus* scores emphasises their affinity in northern forests.

Sample scores plotted on the first two axes (Figure 8.7) illustrate these distinctions clearly. Clusters of the sample scores are highly consistent with the pollen zones. Only one sample score from Zone OH 1b is an exception and plots with the OH 1a group. The stratigraphic plot of CA2 (Figure 8.8) indicates strong positive values in Zone OH 2 followed by a negative excursion into OH 1b. The following scores are generally negative or low positive. The strong environmental signal here is correlated to temperature, with mild-warm conditions in Zone OH 2 which subsequently decreased. The CA1 stratigraphic plot (Figure 8.8) is explained in terms of the moisture regime. A strong negative excursion occurs in Zone OH 1b, with strong positive excursions in Zone OH 1a and also at 1.75 m. It appears that CA1 is strongly influenced by *Dacrydium cupressinum* which dominates this zone. The total amount of variance explained by these two axes is only 25%. This is very low compared with other datasets from northern New Zealand (Newnham, 1990). This probably reflects the relatively unchanging pollen percentages.

Lake Tangonge

Taxa scores on the first and second components (Figure 8.9) separate the taxa which dominated Zone LT 2a, the *Fuscospora*-rich zone, from other trees. The clustering of *Prumnopitys taxifolia*, *Podocarpus* and *Manoao colensoi* in the *+y/+x* quadrat indicates a strong link between these taxa and glacial conditions. The *-y/+x* quadrat contains a cluster of taxa which were common both prior to the LGM and in the Postglacial; the *-y/-x* quadrat contains just two taxa, *Dacrydium cupressinum* and Phyllocladus *Dacrydium cupressinum* is a common regional element throughout the profile, and *Phyllocladus* is present in low amounts for most of the sequence except during the LGM when it is scarce. *Phyllocladus* scores close to Agathis, again emphasising the relationship between these taxa in northern forests. *Dacrycarpus dacrydioides* is locally abundant in Zones LT 4-3 and 1b-1a when *Fuscospora* is scarce. Thus it appears that CA1 separates dry elements from wet elements, and CA2 separates LGM elements from Postglacial and early LG elements.

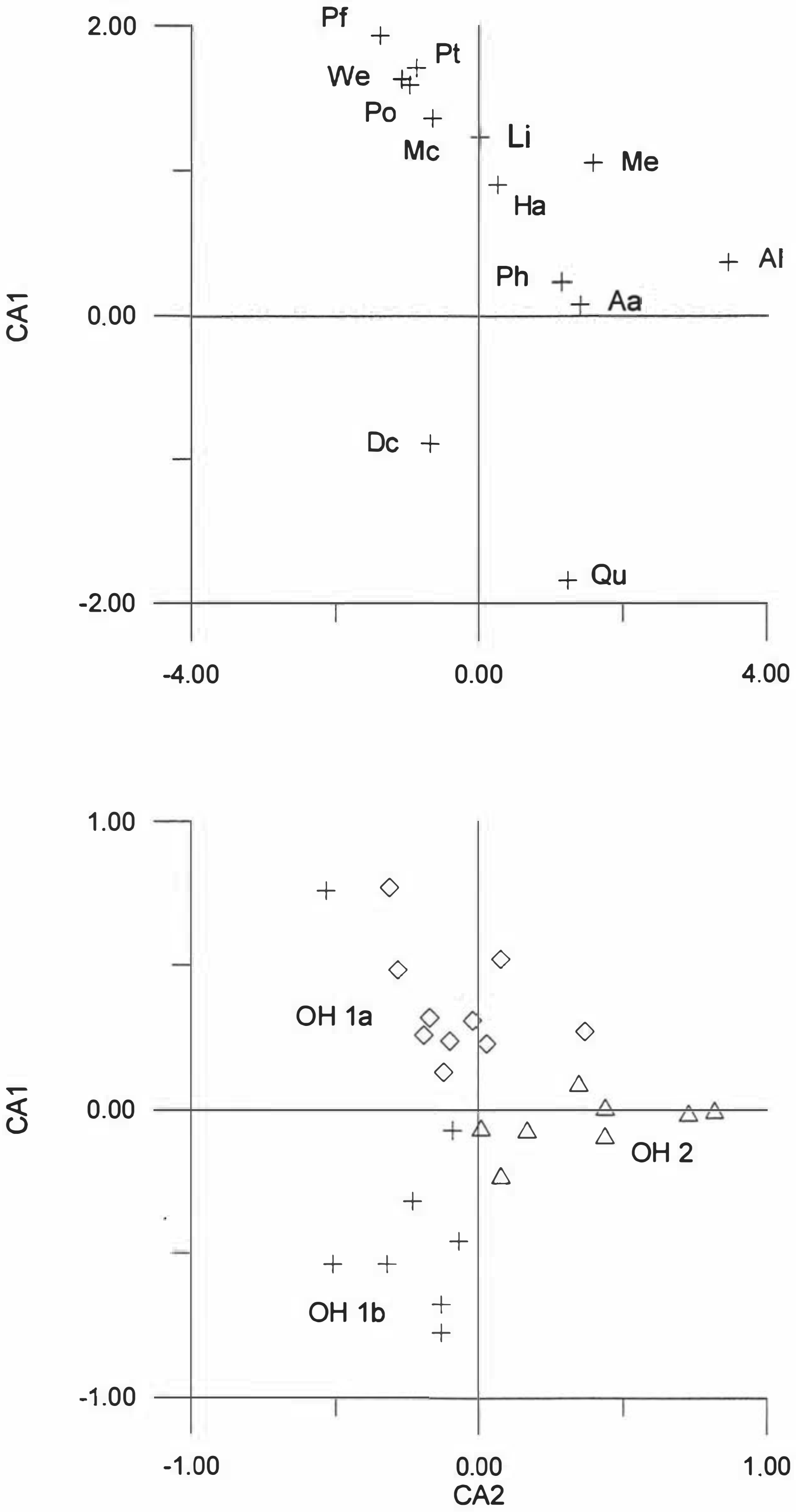

Figure 8.7 Lake Ohia Correspondence Analysis: plots of first two principal axes; taxa scores (above) and sample scores (below). Codes: Aa = *Agathis australis*, Dc = *Dacrydium cupressinum*, Ha = *Halocarpus*, Li = *Libocedrus*, Mc = *Manoao colensoi*, Ph = *Phyllocladus*, Po = *Podocarpus*, Pf = *Prumnopitys ferruginea*, Pt = *P. taxifolia*, Al = *Ascarina lucida*, Me = *Metrosideros*, Qu = *Quintinia*, We = *Weinmannia*.

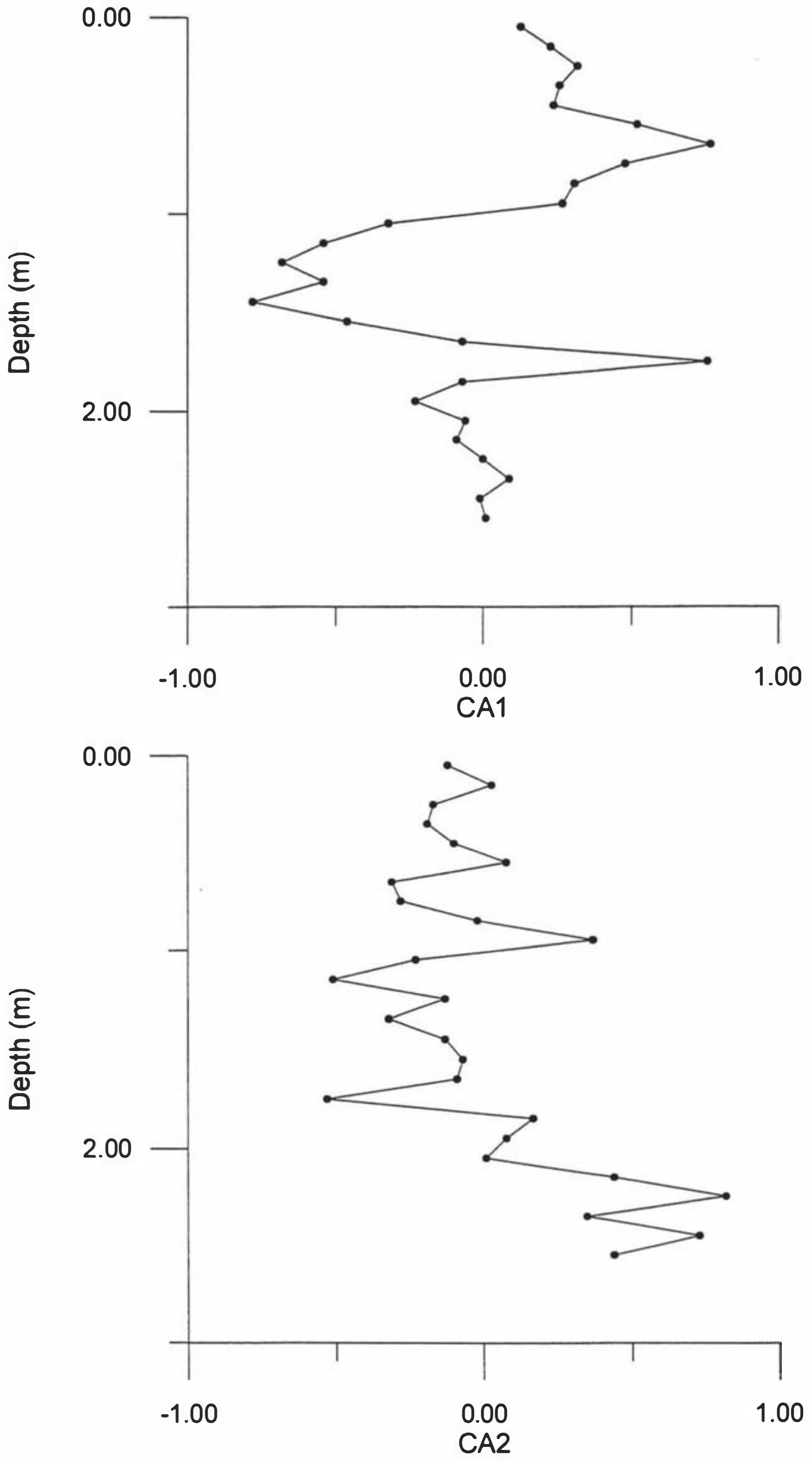

Figure 8.8 Lake Ohia Correspondence Analysis: stratigraphic plots of first two principal axes.

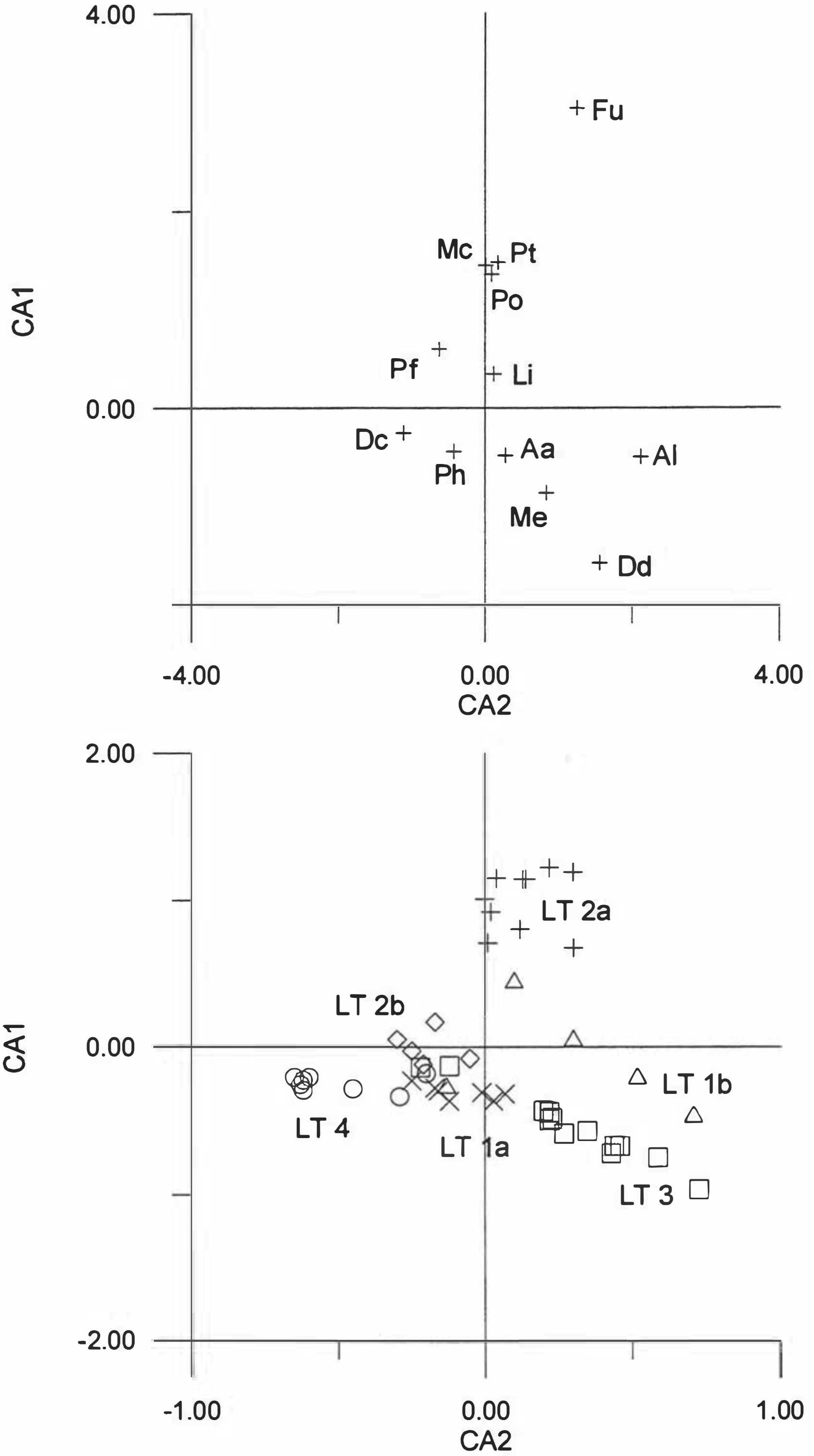

Figure 8.9 Lake Tangonge Correspondence Analysis: plots of principal axes; axis 1 *v.* axis 2, taxa scores above, and sample scores below. Codes as for Figure 8.7 plus Fu = *Fuscospora*, Dd = *Dacrycarpus dacrydioides*.

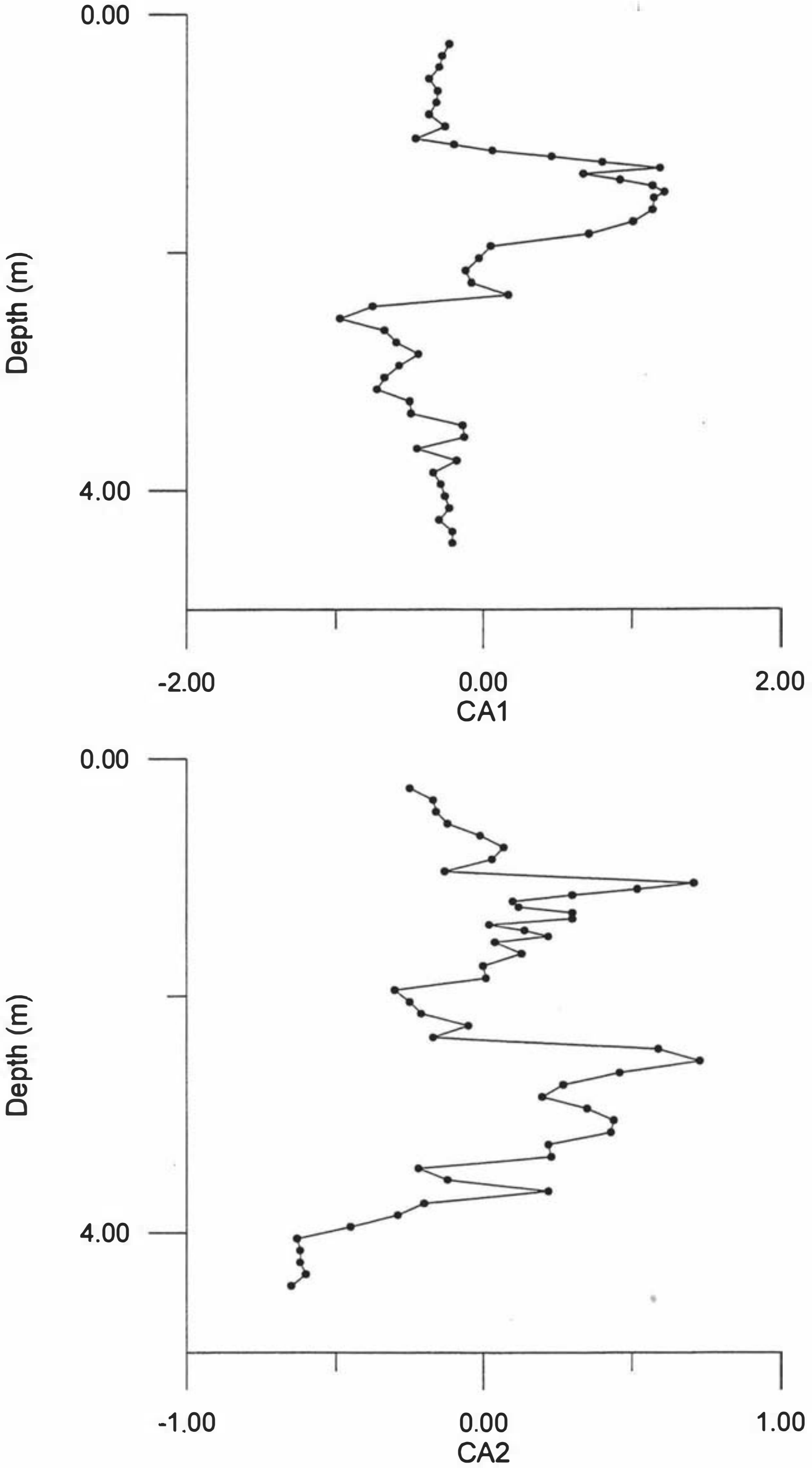

Figure 8.10 Lake Tangonge Correspondence Analysis: stratigraphic plots for first two principal axes.

The plots of samples scores for CA1 and CA2 (Figure 8.9) illustrate these distinctions. Clusters of samples are generally consistent with the pollen zonation defined on the basis of the CONNISS dendrogram. Samples from Zone LT 2a have high positive CA1 values. They are clearly distinguished from all other samples and illustrate the dominance of *Fuscospora* and the hardy podocarps during the LGM. The other CA2 zones form a strong cline with areas of overlap. They reflect the comparatively homogenous suite of dryland taxa throughout most of the profile apart from the LGM. It appears that Northland forest vegetation is relatively invariable for most of the LG and Postglacial, and only varies significantly when environmental conditions are extreme. Stratigraphic plots (Figure 8.10) for the first two axes also reflect these clusters of taxa and zone comparisons. The first two axes account for only 37% of total variance (Eigenvalues for CA1 and CA2 are 0.26323 and 0.10537 respectively). The third axis accounts for only a further 6% (Eigenvalue 0.05717). The comparatively low variance at L. Tangonge may be due to the long time interval of the profile and the relative persistence of most dryland taxa which vary only a little throughout the record.

DISCUSSION

Vegetation and climate history

A diverse mixed conifer-hardwood forest was present throughout the record at the Lake Ohia site. The pollen diagram is dominated by *Dacrydium cupressinum* pollen, but this cannot be taken to imply that *Dacrydium* forest was the dominant vegetation type. *D. cupressinum* produces large amounts of widely dispersed pollen (Mildenhall, 1976; Macphail and McQueen, 1983). Nevertheless, where high frequencies are recorded it is likely that this is evidence of local or extra-local abundance. The abundance of podocarp root nodules is strong evidence that podocarp trees were close by to the coring site. At the beginning of Zone OH 2 the local forest was dominated largely by angiosperm vegetation. The most important elements were *Beilschmiedia*, *Elaeocarpus*, *Ixerba brexioides*, *Metrosideros*, *Nestegis*, and *Quintinia*. The presence of low frequencies of *Beilschmiedia* pollen in this zone is a significant finding. This pollen type is rarely observed in fossil and modern pollen studies (Macphail, 1980). The genus is an extremely low producer (~15 - 60 grains per flower, M. S. McGlone pers. comm. 1996) and is poorly recorded in the late Quaternary vegetation of the North Island. This is in spite of its widespread occurrence throughout contemporary northern forests (Wardle, 1991). Of the two species, *B. tarairi* is the more common in the present day lowland forests of Northland, and it s southern limit of distribution is approximately 38° S (Wardle, 1991). *Ascarina lucida*, which is a frost- and drought-intolerant small understorey tree (McGlone and Moar, 1977), records its highest frequencies in this zone. The regional forest was dominated by anemophilous, tall conifers, chiefly *Agathis australis*, *Dacrydium cupressinum* and *Phyllocladus*. *Agathis* requires a warm, humid climate, and a rainfall regime of 1000 - 1500 mm year^{-1} (Ecroyd, 1982). *Dacrydium* is drought intolerant (Franklin, 1968). Low charcoal concentrations imply that fires were infrequent. A mild, moist climate is proposed for this zone with relatively stress free conditions.

From the latter stages of Zone OH 2 to the early part of OH 1b, warmth-loving, drought-intolerant species are noticeably reduced. Sharp, short-term rises in *Podocarpus*, *Prumnopitys taxifolia*, *Leptospermum*, Restionaceae and charcoal concentration occur at the zone boundary. These changes are interpreted as indicating a climate which became drier, and slightly more frosty. Subsequently, *Dacrydium* rose dramatically reaching almost 80% of the pollen sum. All other conifers were significantly reduced except for *Agathis* which maintained a strong, though less dominant, presence than previously. Charcoal concentration decreased, and wetland species were all but eliminated. The rise in *Dacrydium* is accompanied by a similar trend in the curve for *Quintinia*. This climate is interpreted as having been wet and cool. Invasion of *Dacrydium* onto the bog may have displaced most mire taxa. *Quintinia* was also able to exploit these conditions and became more abundant. Local forest elements, such as *Elaeocarpus*, *Metrosideros*, *Nestegis* and *Weinmannia*, diminished at this time.

In the upper zone, OH 1a, the local dominance of *Dacrydium cupressinum* declined. Typical bog species flourished. However, hardy podocarp species, such as *Manoao colensoi*, *Podocarpus* and *Prumnopitys taxifolia* increased. *Manoao* is frost-tolerant (Sakai and Wardle, 1978) and Leathwick (1995) relates increased abundance of these taxa to cooler/lower insolation environments. *Nothofagus* became a slightly more common element. The charcoal concentration curve indicates that fires were common. The peaks in charcoal concentration match those of bog taxa, especially Epacridaceae, *Leptospermum* and Restionaceae. The abundance of large charcoal fragments (> 50µm) over fine charcoal in most of the samples indicates a local source and implies direct disturbance of bog vegetation due to fire. Restiad bog vegetation is highly inflammable when dry (McGlone *et al.*, 1984c). These features imply that conditions became cooler and drier. Nevertheless, warm elements were still present. The onset of cooler climate in the central North Island with periods of severe erosion following the Otamangakau interstadial is reported by McGlone and Topping (1983) and McGlone *et al.* (1984b).

The Lake Tangonge profile indicates a regional forest cover comprising a diverse mixed conifer-hardwood forest assemblage existed throughout the history of pollen deposition at this site. Traces of *Casuarina* pollen occur in 5 samples at this site. These grains probably originated in Australia as this genus is not extant in the modern New Zealand flora. Newnham *et al.* (1993) have also recorded traces of *Casuarina* in pollen diagrams from this region. At the beginning of zone LT 4 *Dacrydium cupressinum* dominated the regional forest. Typical northern gymnosperm elements were also present in this forest, but in only low abundances. Warmth-loving species were scarce. The abundance of *Dacrydium* and increasing importance of *Dacrycarpus dacrydioides* imply a strong local presence of these tall conifers. *Dacrycarpus* has a preference for poorly drained, fertile alluvial soils (Wardle, 1991) where its continued presence is maintained by silt deposition. Its abundance here suggests there may have been recurrent surface flooding. High levels of *Pseudowintera* pollen and *Knightia excelsa*, described as a pioneering tree (Hinds and Reid, 1957), indicate a seral forest in the process of transition. *Pseudowintera* species are slender, fast growing, and short-lived small trees (Wardle, 1991). The absence of *Ascarina lucida* pollen from this zone implies that temperatures were sufficiently cool to restrict this species, given that moisture was not a limiting factor. Low charcoal concentrations imply that fires were infrequent. Climate throughout this zone is interpreted as having been cooler and moister than present. The forest and climate of the central West Coast South Island offers a partial modern day analogue to this environment. Similar climates are described from the beginning of the Last Glacial at Lake George in south-eastern Australia dated to 75 - 64 ka (Singh *et al.*, 1981). At Lynch's Crater in northern Queensland Kershaw (1976, 1978) provides evidence for similar climatic decline between 76 - 63 ka, characterised by high proportions of gymnosperm rainforest and significantly reduced rainfall (~ 50% of present).

The period that followed is characterised by an increased abundance of *Dacrycarpus*, and *Metrosideros* species. *Dacrydium* was a less common component of the regional forest, and other, hardy podocarp trees assumed only minor importance. The curve of *Agathis australis* shows a gradual increase, but *Agathis* was still only a minor element. Of more significance is the increase in angiosperm trees, particularly *Quintinia* and *Syzygium maire*. These two trees excel in water-logged soils. The pollen of these species is not widely dispersed, thus their occurrence in the pollen record implies a strong local presence as part of a swamp forest. Other broadleaf species also expanded at this time, particularly *Griselinia*, *Pittosporum* and *Pseudopanax* species. The high values of *Ascarina* recorded in most LT 3 samples imply that temperatures were much milder than previously. Charcoal concentration is low, indicating a low intensity fire regime.

The inferred climate through pollen zone LT 3 is one of mild, wet conditions, similar to north-west Nelson of today. Wright *et al.* (1995) report similar trends for Oxygen isotope Sub-stage 3b (59 - 43 ka) from deep sea core S803. For Northland they interpret this sub-stage was somewhat cooler and moister than present. Ogden *et al.* (1993) report on pollen and plant macrofossil evidence from Aupouri Peninsula which they believe indicates a mid-Otiran (41 - 34 ka) interstadial with cooler (2 - 3° C), cloudier and wetter conditions than present. Newnham *et al.* (1993) considered this period to be one of moist mild climates when a diverse mixed conifer-hardwood forest dominated the landscape of the Far North prior to the last advances of the Otiran Glaciation. McGlone *et al.* (1984a) describe similar interstadial climates further south in the Bay of Plenty and Gisborne areas between *ca* 50 - 30 ka which are interpreted as having been 3 - 4° C cooler than present.

From *ca* 39 ka (based on accumulation rates), the beginning of pollen zone LT 2b, expansion of *Agathis australis*-podocarp-hardwood forest occurred. *Dacrydium cupressinum* and *Libocedrus* were important elements of this forest. The rises in abundance of hardy podocarp trees, particularly *Podocarpus* and *Prumnopitys taxifolia* are significant. *Dacrycarpus* declined from its previous importance, and *Ascarina* was notably scarce. The first appearance of significant beech (*Fuscospora*) and microscopic charcoal fragments occur at the base of this zone. *Fuscospora*, which is tolerant of dry climates, has a competitive advantage over podocarps in areas where either soils or climate are less than optimal *e.g.* the uplands of the lower North Island axial ranges (McGlone *et al.*, 1984a). These features suggest the onset of a more seasonal climate characterised by drier summers and cooler winters. Locally important species included *Elaeocarpus* and *Weinmannia*. From *ca* 30 ka the climate became progressively colder, drier and windier, as *Fuscospora* expanded dramatically. Continued expansion of *Podocarpus*, *Manoao colensoi*, and *Prumnopitys taxifolia*, accompanied by declining abundance of *Phyllocladus* and *Agathis australis* mark the onset of full glacial climates of the Last Glacial Maximum (LGM). Fires became more frequent and conditions were generally harsh compared to the warm-temperate climates which typify modern day northern New Zealand. However, sheltered locations supported significant populations of some climate-sensitive taxa including *Ascarina*. Restiads and sedges were common throughout the LGM. Restiads have been suggested by Cranwell (1953) and McGlone *et al.* (1984c) to be favoured by a fire regime. Climatic deterioration from *ca* 38 - 28 ka is recorded in a number of other New Zealand pollen records (*e.g.* Moar and Suggate, 1979; McGlone and Topping, 1983; McGlone *et al.*, 1984a.; Wright *et al.*, 1995). In the central and southern North Island the LGM was characterised by widespread erosion of regolith, aggradation of river valleys, and deposition of loess. Pollen data indicate that tall forest was highly restricted (Pillans *et al.*, 1993). In the Waikato lowlands the period from 18 - 14 ka was windy, dry and cool (Newnham *et al.*, 1989). Whilst the Waikato region was largely unforested, tall podocarps were rare but not absent, and *Fuscospora* and *Libocedrus* levels were increased.

In the Lateglacial beech-conifer-angiosperm forest continued to dominate the far northern regional vegetation. The chronostratigraphic record indicates that there may be a paraconformity (*sensu stricto* Dunbar and Rodgers, 1957) in the sequence. This hiatus appears to be centred over the upper part of pollen zone LT 2b when climatic conditions were at their most severe. The peak in charcoal concentration at 1.2 m indicates a fire regime which reached its maximum intensity at this time. It is possible that peat growth was suspended, or greatly limited, at this time because of lower temperatures and a reduction in available moisture. Alternatively persistent firing of the vegetation may have removed part of the sequence. A similar observation is made for the other Kaitaia Bog profile described in Chapter 7. If one assumes that sedimentation was **not** interrupted during the LGM, but merely slowed down when conditions became too unfavourable to sustain mire species, then extrapolating between radiocarbon ages NZA-6401 and NZA-6403 gives a date of *ca* 12 ka at the time in the pollen record when the *Ascarina* and *Dacrycarpus* curves increase sharply, and *Fuscospora* and charcoal concentration drop sharply. This would correlate with the end of Oxygen Isotope Stage 2, by which time reafforestation had begun in more southern regions of New Zealand (McGlone *et al.*, 1993). In the Waikato region rapid reafforestation occurred from *ca* 14.5 ka (Newnham *et al.*, 1989). These early forests were dominated by *Prumnopitys taxifolia.* In Taranaki, McGlone and Neall (1994) describe a rapid transition beginning *ca* 12.5 ka from open grassland/shrubland to tall complex conifer-broadleaf forest of which *P. taxifolia* was the most abundant element.

The early Postglacial record is characterised by rapidly ameliorating climates as first, *Ascarina* increased significantly, and then expansion of *Agathis australis*-podocarp-hardwood forest replaced the beech association. The abundance of microscopic charcoal declined, and *Dacrycarpus* forest reoccupied the site locality. The warm moist climates of the early Holocene are identified by the abundance of *Ascarina lucida.* In Taranaki the last of the cool temperate elements was eliminated by *ca* 9.5 ka (McGlone and Neall, 1994). *Dacrydium cupressinum* replaced *Prumnopitys taxifolia*, and *Ascarina* was common. They compare this early Holocene climate with that of the present but climatic variability and extremes were much reduced. In the Far North by *ca* 5 ka *Ascarina* had declined significantly. This pattern has also been identified by McGlone and Moar (1977), and McGlone and Neall (1994). McGlone and Neall (1994) consider that summer droughts and vegetation disturbance were more common in the late Holocene and this suggestion is supported by Waikato data (Newnham *et al*., 1989) where increased droughtiness/frostiness is indicated after *ca* 5.5 ka. Similar observations have been made for the records from Lake Tauanui (Chapter 5), and Wharau Road Swamp (Chapter 6). The uppermost pollen samples have elevated charcoal concentrations and reduced abundance of *Agathis*. This may be evidence of increased windiness and frequency of fires, and this is also suggested in the Aupouri Peninsula from *ca* 3.4 - 2.6 ka (Elliot *et al*., 1995; see Chapter 4). The climate may have been drier and/or windier in the North Cape region between *ca* 2.6 - 2.1 ka (Dodson *et al*., 1988).

Chronology and correlations

The vegetation and climatic sequences derived from these profiles suggest that the Ohia peats were laid down during the closing stages of an interglacial or interstadial. The lack of control over the chronology for this site is problematical. The series of ^{14}C dates (Table 8.1) all indicate that the site is older than the limits of radiocarbon dating. The pollen flora of Zone OH 2 is of an interglacial type, though cooler than present. Moar and Suggate (1996) report a period of mild climate from the West Coast during Substage 5c. That of subsequent zones is indicative of generally cooler, drier climate, although a period of wet, cool climate is indicated in the latter stages of Zone OH 1b. A period of cool climate is recorded in South Taranaki by McGlone *et al*. (1984b) which they correlate with Substage 5b. The fact that *Fuscospora* remains only a minor element of the upper zone vegetation suggests that conditions were not greatly harsher than present *cf*. the cold interval of the LGM at Lake Tangonge and Kaitaia Bog (borehole 3, Chapter 7). Moar and Suggate (1996) have described climates of Stage 5 as fluctuating, but generally deteriorating towards the Otira Glaciation. The oldest parts of the offshore record for northern New Zealand covering oxygen isotope stages 1, 2 and 3 (Wright *et al*., 1995) do not match the Ohia record. It is unlikely that the sediments date to the previous glacial *i.e.* > 128 ka. Therefore on available evidence I conclude that this profile correlates to the Last Interglacial (Kaihinu), and possibly the early part of the Last Glacial (Otiran). Pollen zone OH 2 is here correlated with oxygen isotope sub-stage 5c commencing at *ca* 100ka or slightly after. The lower boundary of pollen zone OH 1b marks the boundary between sub-stage 5c and stage 5b *i.e. ca* 91 ka. The uppermost pollen zone, OH 1a, is correlated with the stage 5a. Thus the boundary between OH 1b and 1a is *ca* 80 ka and the top of the sequence may be *ca* 74 ka or later. The ages for these isotopic stages follow those of Martinson *et al*. (1987). If these age estimations are accepted then the palynostratigraphy of the Ohia profile is in broad agreement with those of

McGlone and Topping (1983), McGlone *et al.* (1984b) and Moar and Suggate (1996). The climatic inferences are also not dissimilar to those described for sites in eastern Australia (Singh *et al.*, 1981). The chronology for the lower part of the Lake Tangonge sequence rests in part on extrapolation of the accumulation rate, assuming a constant rate of sedimentation from 2.0 m to the base, and accepting the two ages (NZA-6403, NZA-6088; Table 8.1) as real dates. Quartz grains present at 4.0-4.15 m consist of highly angular fractured fragments, some with euhedral terminations, implying they have been deposited as direct airfall material. They show no evidence of saltation and are typical of rhyolitic sourced quartz (R. C. Wallace pers. comm. 1997). The most reasonable explanation for the source of volcanic quartz for this period is the Rotoehu Ash which was distributed across Northland. The currently accepted best age for the Rotoehu Ash is 64 ka (Wilson *et al.*, 1992; Lowe and Hogg, 1995) thus providing some independent support for the interpolated radiocarbon chronology. The inferred climates for pollen zones LT 3 and LT 4 are consistent with this chronology when compared with other New Zealand pollen sequences (*e.g.* McGlone *et al.*, 1984a; Ogden *et al.*, 1993; Wright *et al.*, 1995), and those Australian records reported by Singh *et al.* (1981). Strength is lent to this argument by comparing the well-dated Kaitaia Bog sequence with pollen zones LT 2a and 2b. There is no suggestion of any hiatus in the lower parts of the Tangonge profile which might weaken this line of argument.

Conclusions

Regional vegetation and climates over the past 100 ka for northern New Zealand are summarised in Table 8.3. The far north of the North Island was forested throughout the Last (Otiran) Glacial. However, the composition of this forest cover varied over time in response to changing climatic conditions related to the maximum extent of glaciation, drought, strong winds, and the incursion of cold maritime southerly air masses. The replacement of diverse kauri-podocarp-hardwood forest typical of modern day Northland with a beech-dominated podocarp-hardwood association is not, however, a new phenomenon. This trend is recorded at other times in the lower Pleistocene (Murray and Grant-Mackie, 1989), and it is likely that a cycle of beech-podocarp-hardwood forest/kauri-podocarp-hardwood forest has been part of the changing northern landscape throughout the climate changes of the Quaternary. The beech association is rare in present day northern forests, and refugial stands are only found in isolated locations such as the Omahuta-Puketi Forest stands (see Wardle, 1984). Kauri (*Agathis australis*) forest appears to have reached its maximum extent during oxygen isotope stages 5c and 3b indicating that the climates prevailing during these intervals were optimal for this taxon. *A.*

australis is favoured by dryish, warm summers (Ogden and Ahmed, 1989). Maximum cooling and harshest climatic conditions occurred between *ca* 30 - 14 ka. The peak of this cold interval, between *ca* 22-16 ka, may have been as much as 4° C cooler than present. This inference is consistent with the reconstructions of Soons (1979) for low mean annual temperatures during the LGM. However, it is likely that the most influential factor in the changing shape and composition of northern forests was effective precipitation.

The early Postglacial is characterised by a rapid expansion of warm-temperate conifer-hardwood forest dominated by *Dacrydium cupressinum* and *Metrosideros. Ascarina lucida* was a common understorey tree in lowland forest. *Fuscospora* became very much restricted in its distribution, and from *ca* 9 ka was only a minor element of far northern forests. Alluvial flats and poorly drained areas were dominated by *Dacrycarpus dacrydioides*, *Laurelia novae-zelandiae*, *Quintinia* and *Syzygium maire*. In the mid-to-late Postglacial, *Agathis australis* became a somewhat more common element of regional forest, but did not attain the same level of abundance it had enjoyed just prior to the LGM (*ca* 39 - 30 ka). Declining abundances of *Ascarina lucida* from *ca* 5 ka, accompanied by minor expansion of *Manoao colensoi* and *Prumnopitys taxifolia*, suggest slight climatic deterioration toward a more seasonal dry summer-wet, cool winter regime. This trend has been identified in other parts of the North Island (Newnham *et al.*, 1989, 1995; McGlone *et al.*, 1993).

Table 8.3 Vegetation and climate history of far northern New Zealand during the past *ca* 100,000 years.

Pollen zone	**Age (yr B. P.)**	**Key pollen taxa**	**Regional vegetation**	**Climate**
LT 1	3000 7000	*Dacrycarpus, Dacrydium, Ascarina*	Kauri-podocarp-hardwood forest	Mild, summer drought Warm, moist
LT 2a	14,000	*Dacrycarpus, Ascarina, Metrosideros*	Kauri-podocarp-hardwood forest	Warm, wet
	22,000	*Fuscospora, Podocarpus,* Asteraceae, *Prumnopitys taxifolia,*	Beech-podocarp-hardwood forest	Cold, dry, windy
LT 2b	39,000	*Fuscospora, Prumnopitys taxifolia, Podocarpus* *Agathis, Dacrydium, Libocedrus*	Beech-podocarp-hardwood forest Kauri-beech-podocarp-hardwood forest	Cooling, drying
LT 3	56,500	*Dacrycarpus, Dacrydium, Ascarina, Metrosideros, Agathis*	Kauri-podocarp-hardwood forest	Wet, mild
LT 4		*Dacrydium, Dacrycarpus, Knightia, Pseudowintera*	Podocarp-hardwood forest	Cool, moist
OH 1a	74,000	*Agathis, Prumnopitys taxifolia, Dacrydium, Phyllocladus, Podocarpus, Manoao colensoi*	Kauri-podocarp-hardwood forest	Cool, dry
OH 1b	80,000	*Dacrydium, Agathis, Quintinia, Weinmannia*	Kauri-podocarp-hardwood forest	Drying, cool
OH 2	91,000 100,000	*Dacrydium, Agathis, Phyllocladus, Quintinia, Ascarina, Metrosideros, Beilschmiedia*	Kauri-podocarp-hardwood forest	Mild, moist

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Chapter 9

THE VEGETATIVE COVER OF FAR NORTHERN NEW ZEALAND AND ITS CLIMATE IN THE LATE QUATERNARY: A SUMMARY OF THE LAST *CIRCA* 100,000 YEARS

Kaihinu Interglacial: ^{18}O Sub-stage 5a-c, 100 - 74 ka

Records derived from oxygen isotope stratigraphy of deep sea cores indicate that the period of time between *ca* 100 - 74 ka was part of an interglacial sequence referred to as ^{18}O Stage 5. This Last Interglacial is subdivided into sub-stages 5a-e, and the period from *ca* 100-74 ka comprises sub-stages 5a-c (Martinson *et al.*, 1987). In the New Zealand chronostratigraphic nomenclature the Last Interglacial is known as the Kaihinu Interglacial (Suggate, 1992). Proxy temperature curves based on δ^{18}O data indicate that succeeding warm intervals (5e, 5c, 5a) became progressively cooler and were separated by the cool intervals 5d and 5b (*e.g.* see Pillans, 1994). Sub-stage 5a was probably not as warm as the present (Aranuian) Interglacial. Pollen data (McGlone and Topping, 1983; McGlone *et al.*, 1984a) support the oxygen isotope evidence suggesting that sub-stage 5a climates in New Zealand were mild, and may have been 1 - 2°C cooler than present. Given that the age estimates are reasonable, the pollen data from Lake Ohia confirm the broader picture of New Zealand climates at this time. Regional vegetation of the Far North was dominated by kauri-podocarp-hardwood forest. The most important elements of this regional forest were *Agathis australis*, *Dacrydium cupressinum*, and *Phyllocladus*. The small, frost and drought-sensitive, understorey tree, *Ascarina lucida* was common. Coastal forests were dominated by angiosperm trees, the commonest of which were *Beilschmiedia*, *Metrosideros*, *Nestegis* and *Elaeocarpus*. *Quintinia* and *Ixerba brexioides* were common angiosperm trees of inland/upland forests, although *Quintinia* may also have been present on the bog at times.

Last (Otiran) Glacial:

1. ^{18}O Stage 4, 74 - 59 ka

The onset of the Otiran Glacial at *ca* 74,000 years ago is marked by a change from mild, warm conditions to a climate which became cooler and drier. Far northern regional vegetation was still dominated by a diverse conifer-hardwood assemblage, but warmth-loving species became more restricted in their distribution, particularly *Ascarina lucida*. Near Lake Tangonge *Agathis australis* was scarce. However, to the east, *A. australis* remained a significant element of regional forest, though less important than previously. *Dacrydium cupressinum* was a common emergent tree. Climate was generally cool and moist with increased incidence of winter frost in exposed areas. Other North Island pollen records (McGlone and Topping, 1983; McGlone *et al.*, 1984a, 1984b) indicate that the period following the end of the Kaihinu Interglacial was characterised by periods of severe erosion and cooler temperatures. Climatic decline has also been identified in eastern Australia during ^{18}O Stage 4 at Lake George in southern New South Wales, and at Lynch's Crater, northern Queensland (Singh *et al.*, 1981; Kershaw, 1976, 1978).

2. ^{18}O Sub-stage 3b, 59 - 43 ka

A period of relative warming and increased precipitation followed Stage 4 during what has been recognised as Sub-stage 3b (Wright *et al.*, 1995). Species associated with wetter conditions were more abundant during this interval in the far northern region, particularly *Dacrycarpus dacrydioides*, *Metrosideros* species, *Quintinia*, and *Syzygium maire*. Increased occurrence of *Ascarina lucida* also suggests temperatures were milder at this time. Regional forests were primarily podocarp-hardwood assemblages. *Agathis australis* was present in these forests, but not dominant. Other northern records which indicate mid-Otiran warming are reported by Ogden *et al.* (1993), and Wright *et al.* (1995). Elsewhere in New Zealand interstadial climates have been recognised in the Bay of Plenty (McGlone *et al.*, 1984b), Central North Island (McGlone and Topping, 1983), and southern Taranaki (McGlone *et al.*, 1984a).

3. ^{18}O Sub-stage 3a, 43 - 24 ka

After the warming of Sub-stage 3b, the cooling trend of the Otira Glaciation continued. As conditions in the far north became cooler and drier, kauri-dominated mixed conifer-hardwood forest expanded. Significant expansion of hardy podocarps *Podocarpus* and *Prumnopitys taxifolia* occurred at this time, and *Agathis australis* reached its greatest abundance since the Last Interglacial. *A. australis* is identified as warmth-loving and requiring a humid climate with rainfall between 1000-2500 mm (Ecroyd, 1982). It seems unlikely that the climate during this period was optimal for kauri. However, the cooler/drier conditions may have allowed it a competitive advantage over more drought intolerant taxa, especially *Dacrydium cupressinum*. *Ascarina lucida* was scarce and climate was characterised by drier summers and cooler winters. As glaciation in the south of New Zealand intensified, northern climates also became progressively colder, drier and windier, particularly from *ca* 30 ka. Data from δ^{18}O values in

Time ka	This study	Cape Reinga [a]	Otakairangi [b]	Aupouri Peninsula [c d]	Central North Island [e]	Bay of Plenty/ Gisborne [f]
0	Deforestation					
2	mild, moist					
5	cool, dry, variable	drying	moist		cool, dry	
7 10	Warm, moist	warm, wet	warm, wet	warm, moist	mild, wet	
14	warm, wet				cool dry	
20	cold, dry, windy	cool	cool, dry	cold, dry	cold, dry	cold, dry, windy
30	cooling, drying		moist		cool, dry	
40	cool, moist			cool, wet	cold, dry	
50	mild, wet					cool, wet, windy
60	cool, moist				mild, moist	mild, moist, windy
70	cool, dry					
80	drying, cool				cool, wet	
100	mild, moist					

Table 9.1 Summary diagram of regional climate change in northern New Zealand from this study over the past 100 ka compared with other studies in northern New Zealand. ([a] Dodson *et al*., 1988; [b] Newnham, 1992; [c] Newnham *et al*., 1993; [d] Ogden *et al*., 1993; [e] McGlone & Topping, 1983; [f] McGlone et al., 1984b).

cores between latitudes 30-45°S in the Tasman Sea indicate subtropical surface waters cooled little during the LG, probably <2°C (Nelson *et al*., 1993). This is in contrast to the results of CLIMAP (1981) whose maps show as much as 4°C cooling at this time. Wright *et al*. (1995) have identified marked cooling of surface waters off the east coast of northern New Zealand from 43 ka. Progressive cooling of surface waters, and later bottom waters, continued up to the onset of the full-glacial conditions of isotope stage 2 at 24 ka. The data of Wright *et al*. (1995) give cooler LG sea surface temperatures by about 2-3°C (and locally by as much as 5°C). However, Fenner *et al*. (1992) suggested that subtropical waters off the east of the North Island, like those of the Tasman Sea, also cooled relatively little. A possible explanation lies in prominent wind-induced upwelling of cool subsurface waters associated with stronger and persistent westerly winds during the LG (Stewart and Neall, 1984; Alloway *et al*., 1992; Wright *et al*., 1995). Increased frequencies of microscopic charcoal fragments indicate that fires were more common. The replacement of kauri-dominated conifer-hardwood forest with beech (*Fuscospora*) -dominated podocarp-hardwood forest followed rapidly. The deep sea core record of Wright *et al*. (1995) supports this vegetation reconstruction. In the Bay of Plenty McGlone *et al*. (1984b) argue that climate deteriorated from *ca* 28 ka.

4. ^{18}O Stage 2, 24 - 14 ka

By the Last Glacial Maximum, Northland forests as far north as Kaitaia were dominated by *Fuscospora* (Figure 9.1). Newnham (1992) has suggested that Northland beech was probably *Nothofagus truncata*. North of Kaitaia, on the Aupouri Peninsula, *Agathis australis* remained a common element in a conifer-hardwood association (Ogden *et al*., 1993), and there is no evidence to suggest that beech was part of this most northern assemblage (Dodson *et al*., 1988; Newnham *et al*., 1993; Ogden *et al*., 1993). From Kaitaia south all typically warm northern elements were restricted in their distribution. McGlone *et al*. (1993) have described the LGM landscape south of Auckland (south of 37°S) as being largely devoid of forest, except in microclimatically favoured areas where pockets of forest persisted. Elsewhere grassland/shrubland communities were common (Figure 9.2). In central and southern parts of New Zealand widespread erosion of regolith, aggradation of river valleys, and loess deposition typified the Glacial Maximum environment (Pillans *et al*., 1993). Temperatures are postulated to have been 4 - 5°C colder than present at the height of this cold interval (*ca* 18 ka) (McGlone *et al*., 1996). In the far north temperatures were probably lowered less owing to the moderating influence of the adjacent oceans. Although offshore records for northern New Zealand suggest that sea surface temperatures may have cooled relatively little (<2°C) during the LG (Wright *et* *al*., 1995), nearshore data indicate greater cooling (*e.g.* Hendy, 1995 in Wright *et al*., 1995). For Northland this may have translated to a maximum temperature depression by 3 - 3.5°C. The most limiting factor was probably available moisture with annual rainfall reduced to about 2/3 it s present level.

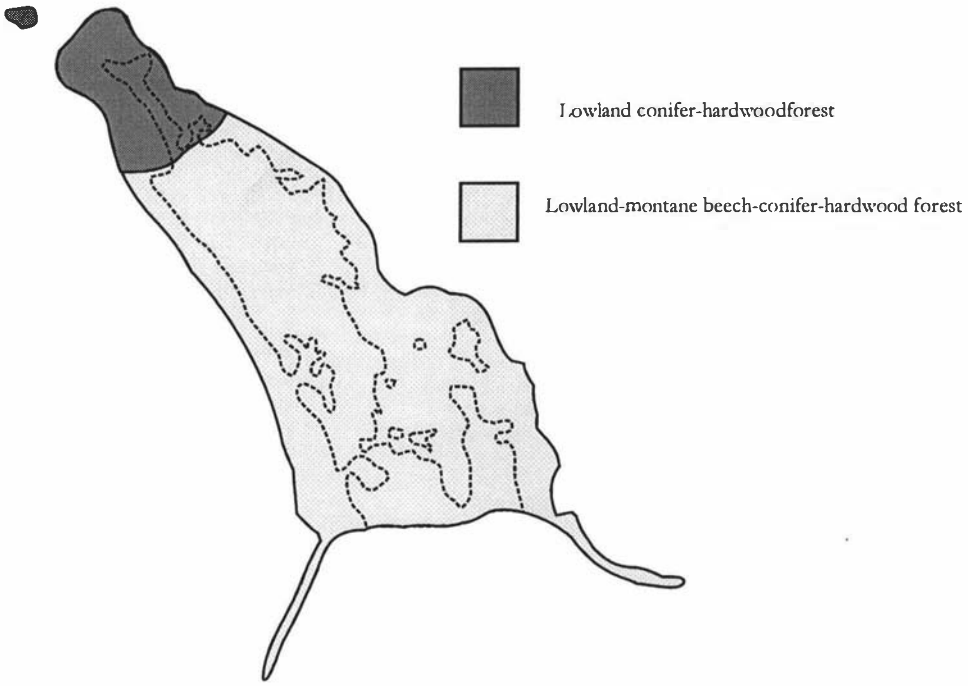

Figure 9.1 Northland forests at the Last Glacial Maximum

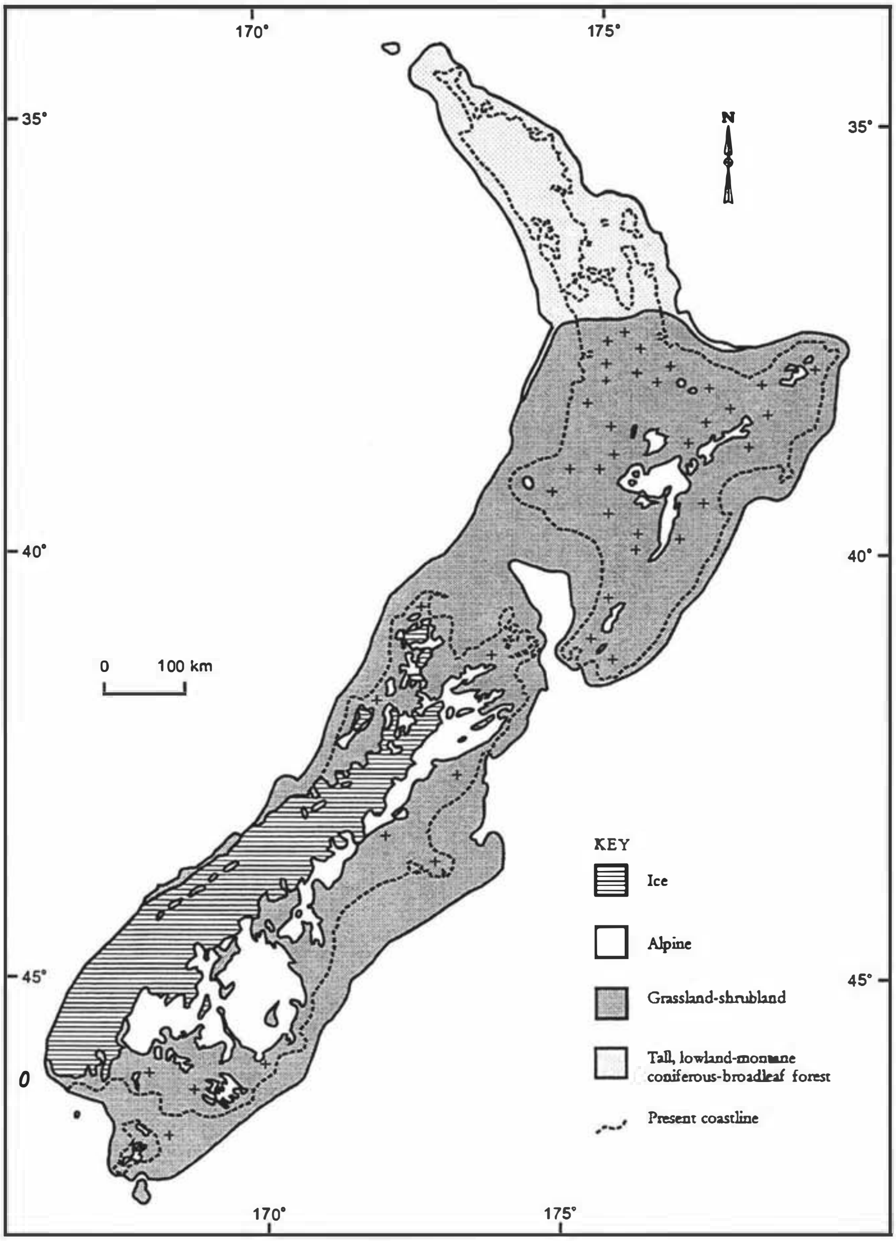

Figure 9.2 New Zealand vegetation at the Last Glacial Maximum (after McGlone *et al.* 1993)

5. The Lateglacial: 14- 10 ka

The Lateglacial is characterised by a transition to more equable conditions as warmth-loving species such as *Ascarina lucida* and *Dodonaea viscosa* increased in abundance. The abundance of *A. lucida* was more pronounced at the Lake Tangonge site where it may have been one of the most ubiquitous understorey trees of the lowland forest. Further north of Kaitaia, in the dune country, *A. lucida* and tree ferns were much less widespread, probably because of the proneness of the sandy soils to summer drought. Other taxa also expanded in response to ameliorating conditions, including *Dacrydium cupressinum* and *Dacrycarpus dacrydioides*. Trees, such as *Fuscospora*, *Podocarpus* and *Prumnopitys taxifolia*, which had expanded during the harsher climates of the LGM, became more restricted in their distribution. The Lateglacial transition is well recorded in other parts of New Zealand where it is generally characterised by reafforestation, as forest spread rapidly from their refugial stands in a progressively southward trend (Newnham *et al.*, 1989; McGlone, 1988).

The Holocene: Early Postglacial, 10 - 7 ka

From *ca* 10 ka the changes in forest composition progressed even more rapidly. Across the far northern region *Fuscospora*-podocarp-hardwood forest was rapidly replaced by an *Agathis australis*-podocarp-hardwood association. From 9 ka *Agathis australis* became more abundant. At *ca* 9.5 ka, *Fuscospora* declined sharply, and by *ca* 8 ka was very much restricted in its distribution. *Dacrydium cupressinum* dominated regional forests as climates became warm and moist. *Manoao colensoi*, *Podocarpus*, *Prumnopitys ferruginea* and *P. taxifolia* were less common than previously. *Ascarina lucida* reached it s greatest abundance between *ca* 10.5 - 7.6 ka suggesting that the early Postglacial enjoyed the warmest, most equable climates over the past 100 ka. Temperatures in the Kaitaia region may have been 1 - 2°C warmer than present (*i.e.* 17 - 18°C mean annual temperature). Proxy temperature records for the Holocene from speleothem analyses (Hendy and Wilson, 1968) support this hypothesis. McGlone *et al.* (1993) have also argued for mild and less frost-prone climates during the early Holocene.

Mid-to-late Postglacial: 7 - 3 ka

In the Far North *Ascarina lucida* declined significantly by *ca* 5 ka. Hardy podocarps, especially *Manoao colensoi* and *Prumnopitys taxifolia*, increased in abundance. At the same time *Metrosideros* sp., and *Libocedrus* became less common. These changes in forest composition were a consequence of climate becoming slightly cooler and drier as a more seasonal dry summer-wet, cool winter regime became established. Declining abundance of *A. lucida* was a widespread event in the mid-Holocene New Zealand landscape, and has been well documented (McGlone and Moar, 1977; McGlone and Neall, 1994; Newnham *et al.*, 1989). A mid-to-late Postglacial increase in summer droughts, winter frosts and vegetation disturbance has been reported from the Waikato Lowlands (Newnham *et al.*, 1989) and Taranaki (McGlone and Neall, 1994). McGlone *et al.*, (1993) have argued that more frequent occurrence of drought and incursion of cold polar air masses was a widespread phenomenon across most of New Zealand from *ca* 6 ka. Increased vegetation disturbance recorded in this study, and from elsewhere in northern New Zealand, may be a consequence of an increase in cyclonic activity. The Lake Taumatawhana record provides strong evidence of cooling/drying in the period from *ca* 5 - 3.4 ka. The pollen profile for *Agathis australis* from Taumatawhana (Figure 4.3) shows a repeating pattern of local kauri (*A. australis*) populations rising to a peak then crashing abruptly before recovering once more. Ecroyd (1982) has shown that kauri is prone to windthrow by hurricanes. Cyclonic storms generated to the north of New Zealand could account for the destruction of hundreds of kauri trees at a time. A period of recovery following such destruction would see mass, synchronous regeneration of *A. australis* leading to even-aged stands (Ecroyd, 1982; Ogden, 1985; Ogden *et al.*, 1992).

Late Holocene: 3 ka - present

This period is best divided into two parts: the pre-human period through to *ca* 1.2 - 0.8 ka, and the human settlement period which followed.

The pre-human, late Holocene from *ca* 3 ka continued to be marked by climatic variability. At Lake Taumatawhana *Ascarina lucida* became common after *ca* 3 ka. At Lake Tauanui it was common between *ca* 3.4 - 1.4 ka, but at Wharau Road Swamp *A. lucida* had a more variable occurrence, being most common between *ca* 4.3 - 2.6 ka. The Lake Tauanui and Wharau Road records indicate that forest composition was seldom stable. Emergent and canopy trees fluctuated in abundance, and forest disturbance was a common event. The period between *ca* 3.4 - 1.8 ka has been described as one of slight climate amelioration (McGlone and Moar, 1977), but the general pattern for the late Holocene has been one of climatic variability characterised by increased seasonality (McGlone, 1988).

The most significant event in the late Holocene has been that of Polynesian settlement (Molloy, 1969). Prior to the arrival of the Polynesians the New Zealand land surface was in approximately 78% forest cover (Figure 9.3). The commencement of human occupation remains ill defined. Davidson's (1984) arguments for a 1000 year history of human settlement remain the most widely accepted, but vigorous debate continues over this issue. Some authors argue for a more recent settlement (Anderson, 1991; McFadgen *et al.*, 1994; McGlone *et al.*, 1994), while others suggest an earlier date of first settlement is possible (Sutton, 1987, 1994; Flenley, 1994; Kirch and Ellison, 1994). Much of the problem in resolving this debate lies in matching environmental evidence with the archaeological record. Whilst a number of archaeological dates predate 1000 yr B. P., doubt has been cast on all those before 800 yr B. P. (Anderson and McGovern-Wilson, 1990). Analysis of radiocarbon dates has identified a "tail" of older dates which have been considered statistical outliers (McFadgen *et al.*, 1994). However, if only small populations of people were present in New Zealand prior to 1000 yr B. P. then one could reasonably expect few archaeological dates associated with early occupation. Recent dating of rat bones (*Rattus exulans*) imply early human contact with New Zealand as much as 2000 years ago (Holdaway, 1996), though these dates have been challenged (Anderson, 1996). The palynological evidence for the timing of deforestation is not conclusive. Anderson (1995) argues that caution should be exercised in using palynology to identify human colonisation.

> " Except in rare cases where cultigens or weeds that required human transportation are identified, there is nothing which can be specified as definitively cultural. The argument is dependent on estimation of whether the scale of change requires postulation of human intervention" (Anderson, 1995: 121).

Nevertheless, it is possible to identify Polynesian deforestation in New Zealand. The association of prolonged forest decline with significant increase in abundance of bracken spores and concentration of microscopic charcoal in late Holocene pollen records is unequivocally interpreted as anthopogenic modification of the landscape (McGlone, 1983, 1989). There are now many published New Zealand pollen diagrams which record such events (*e.g.* McGlone 1978; McGlone and Basher, 1995; McGlone *et al.*, 1995; Bussell, 1988; Mildenhall, 1979; Elliot *et al.*, 1995; Newnham *et al.*, 1995a). Anderson has further argued that...

> "The advocacy of palynologically defined cultural change does not take adequately into account the possible range and scale of natural disturbances" (Anderson, 1995:122).

and

> "Disturbance events of natural origin can produce a long signal in the [palynological] record, especially if a catastrophic event, such as severe hurricane damage and subsequent massive firing of flattened forest, produces a persisting, fire-prone seral community" (Anderson, 1995:122).

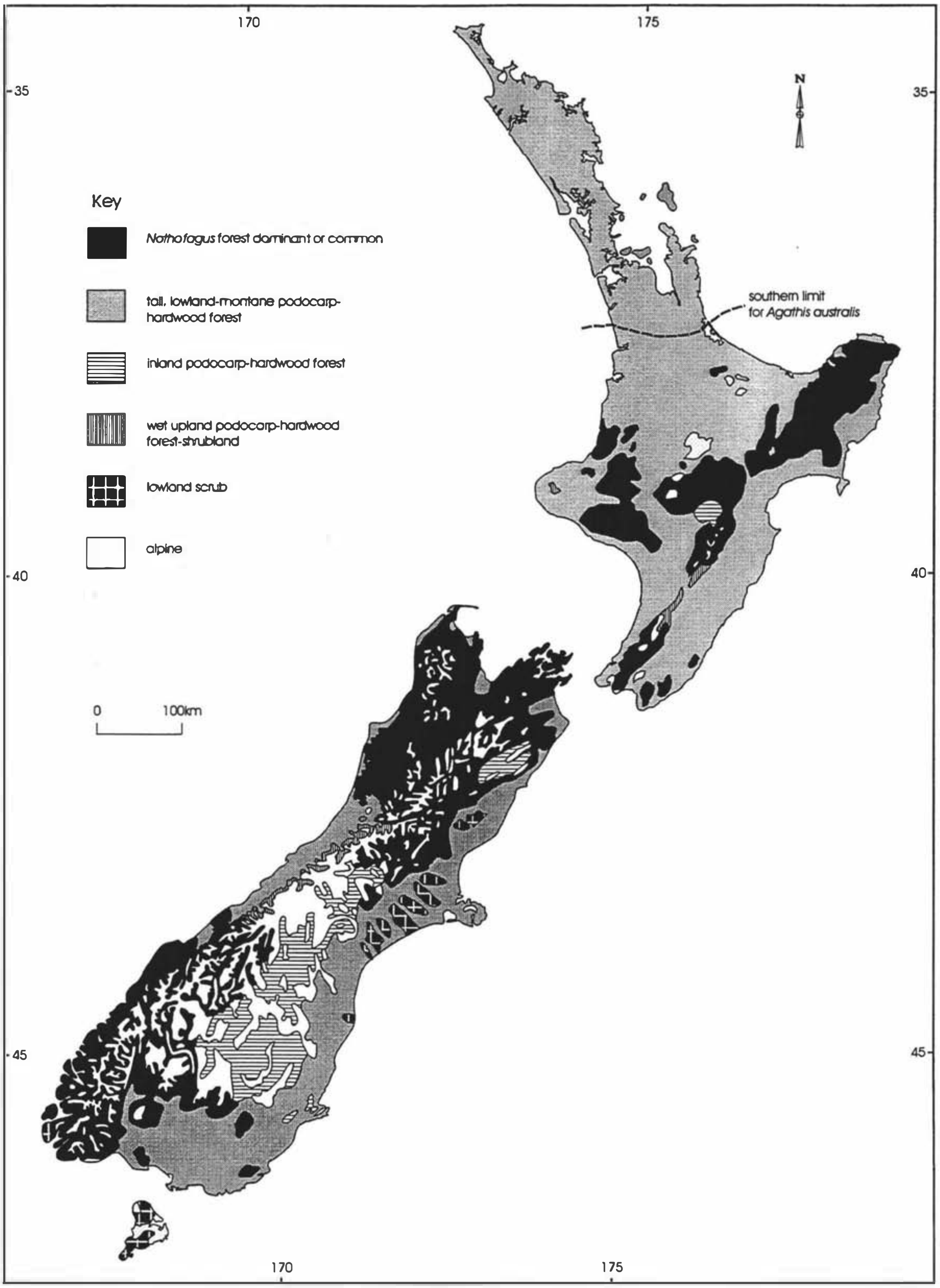

Figure 9.3 The vegetative cover of New Zealand before polynesian deforestation *ca* 1000 yr B. P. (after McGlone *et al*., 1993).

However, Wilmshurst and McGlone (1996) have shown that even such widespread deforestation as that which resulted from the massive 1850 yr B. P. Taupo eruption is followed by complete revegetation in 120-225 years, depending on local climate. There is no evidence in Northland for similar catastrophic forest destruction following major volcanic eruptions or other natural events. Even at Papamoa in the Bay of Plenty where 4 cm of Taupo Tephra was deposited only minimal forest damage is recorded (Newnham *et al.*, 1995b). Charcoal records of natural fires in the pollen diagrams in this study are not accompanied by coincident abundant bracken spores, or evidence of forest clearance. Those which have fire histories interpreted as anthropogenic in origin are all accompanied by prolonged deforestation and abundant bracken.

It is possible to pinpoint (notwithstanding confidence limits) the timing of major Polynesian deforestation for many parts of New Zealand. Whilst the dates are not synchronous, most deforestation events south of the Auckland region occurred between 800 - 600 yr B. P. (Bussell, 1988; McGlone and Basher, 1995; McGlone and Wilson, 1996; McGlone *et al.*, 1995; Mildenhall, 1979; Newnham *et al.*, 1989, 1995; Wilmshurst, 1995). The two lake records from this study indicate a somewhat earlier commencement of human impact than those typical, more southern dates. At Tauanui deforestation began just after 1100 yr B. P., and probably between 1240 - 980 yr B. P. (2 σ). Deforestation at Taumatawhana commenced just after *ca* 900 yr B. P. (1040 - 780 yr B. P. at 2 σ). However, the Wharau Road deforestation event appears to have occurred much later, *ca* 600 yr B. P. Whilst the date of forest clearance at Taumatawhana overlaps those in the 800 - 600 yr B. P. range at 2 σ (standard deviation), that of the Lake Tauanui record is much earlier. The Taumatawhana and Wharau Road records for deforestation are supported by significant erosion events which are clearly the result of soil instability following clearance. By the time of European settlement commencing in the early 1800s Polynesian deforestation had removed approximately one third of New Zealand's indigenous forest cover (Kelly, 1980). In the years that followed, European settlement and clearance soon reduced what remained by a further third (Figure 9.4), and by 1976 only 23.2 % of the country's native forest cover remained (Kelly, 1980). Most of the early human settlement, both Polynesian and European, was concentrated in the northern regions. Polynesian clearance by fire is considered to have been relatively modest in Northland when compared to the widespread conflagrations in the south (Newsome, 1987). The European impact can be traced in this study by the advent of exotic taxa, particularly *Cupressus*, *Pinus*, *Ulex europaeus*, and *Plantago lanceolata*.

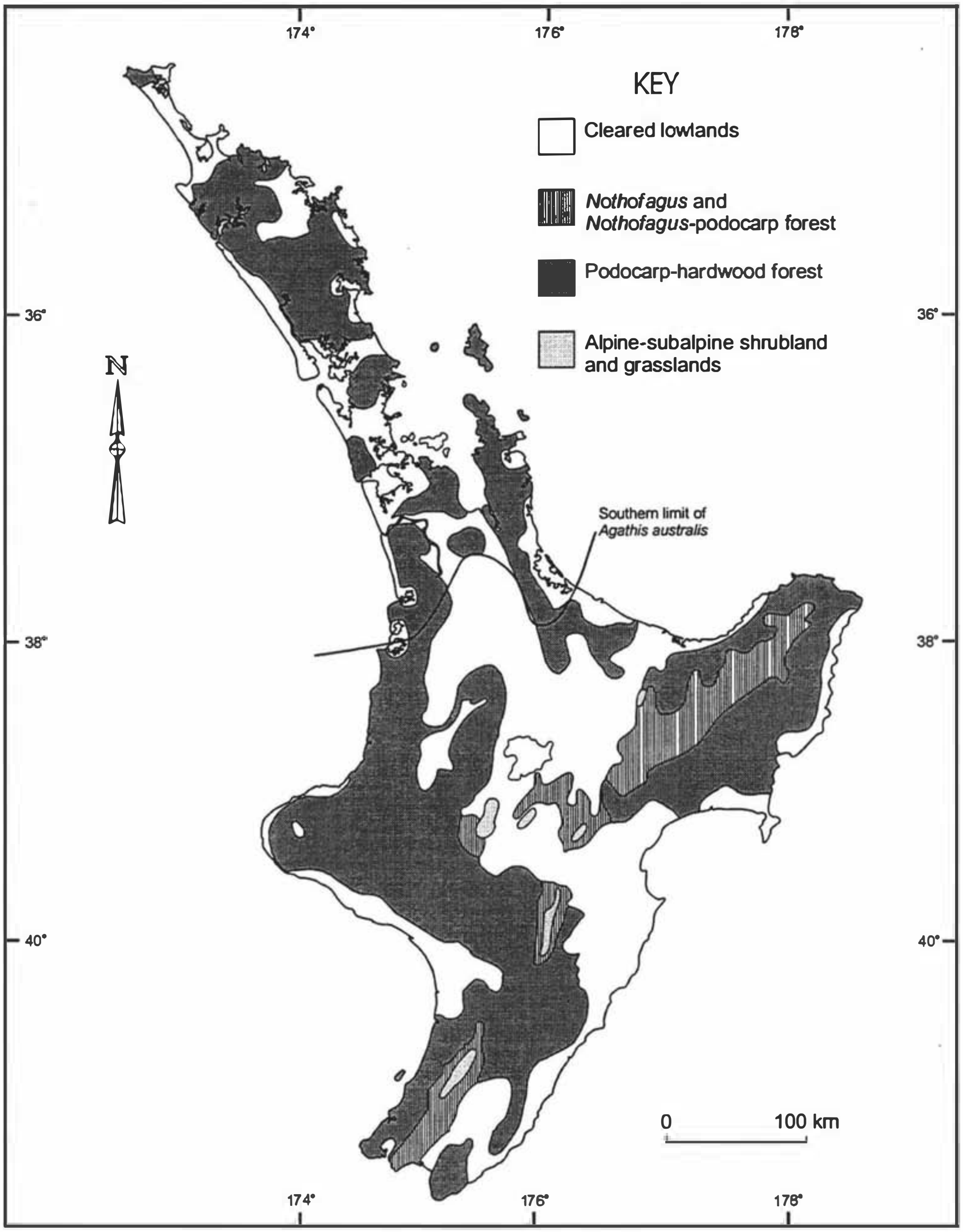

Figure 9.4 Vegetation cover of the North Island in AD 1840 following early European clearance (after McGlone, 1988 and Masters et al., 1957).

How the research objectives have been met

The pollen signatures of the late Holocene spectra from Lake Taumatawhana, Lake Tauanui and Wharau Road Swamp clearly identify the impact of human settlement in their respective localities. Anthropogenic deforestation is defined by the abrupt decline of forest species coincident with similarly sharp rises in charcoal concentration and abundance of bracken spores (*Pteridium esculentum*). These features have been identified in many other New Zealand Holocene records and are widely recognised as evidence of human impact. The evidence presented in this thesis implies that parts of Northland may have been settled and deforested earlier than other more southern areas of New Zealand.

The longer records from Kaitaia Bog and Lake Ohia demonstrate that far northern New Zealand remained forested throughout the Last Glacial including the LGM when most of New Zealand south of Auckland was deforested. The evidence suggests that temperatures during the LGM may have been as much as 3.5°C lower than present. Other, smaller temperature fluctuations during the preceding stadials/interstadials and subsequently in the Holocene are implied. Although far northern New Zealand remained forested throughout the LG the pollen records indicate that significant compositional changes occurred at the major climatic boundaries. This is most clearly indicated by the change from regional podocarp-hardwood forest to beech dominated podocarp-hardwood forest during the LGM, and then back to a podocarp-hardwood association in the Postglacial. Other more subtle vegetational trends are identified which reflect changes in precipitation regimes and cyclone frequency.

Plant distribution patterns during the late Quaternary and identified in this thesis show strong evidence for the influence of glacial climates on forest composition. In that respect the pollen records lend support for the glacial refuge hypothesis (Wardle, 1963, 1988). Comparison of the present-day distribution of *Nothofagus truncata* with Last Interglacial and LGM pollen spectra indicates that regional expansion of beech-dominated forest may have been a recurring feature of Quaternary glacial cycles. However, there is no suggestion in the pollen records presented here which shows major changes in the overall flora. None of the species present during the LG can be shown to have been eliminated from the region in the Postglacial (or vice versa). Thus changes seen in the pollen records are dominantly changes in abundance of species. Certainly the geological stability of Northland can be associated with its high proportion of endemism in higher plants. This would lend weight to the tectonic hypothesis (McGlone, 1985). However, the evidence in support of either hypothesis (glacial or tectonic) is not unequivocal and neither hypothesis can be said to be proven.

Further work

The question of when and where first colonisation occurred in Northland, and indeed New Zealand, cannot be said to have been resolved on the basis of only three sites studied here. Whilst it appears that Northland may well have been settled earlier than elsewhere in New Zealand the issue is clearly worthy of further study using fine resolution techniques. The best results in this study were obtained from lake sites and there are many other similar lake sites in Northland which have yet to be explored. Most of these lakes are situated in the dune country, either on the Aupouri Peninsula, or the bars which enclose the Kaipara Harbour. Fertile soils, which might have attracted early colonists, occur in the Waima Valley and alluvial flats inland from Doubtful Bay. These areas pose problems because of the difficulty in finding polliniferous deposits, and this is a limiting factor in resolving the colonisation question. The possibility of dating actual pollen grains to provide more precise dating of anthropogenic disturbance is currently being studied, and this technique would greatly aid definition of deforestation events in a debate which remains keenly argued.

The Last Interglacial and the early part of the Last Glacial palynological and palaeoclimatic records are not yet resolved for Northland, chiefly because of chronological uncertainties. Because the practical limits of ^{14}C dating are confined to the past approximately 30-40 ka, it is necessary to find pollen-bearing sediments which contain identifiable tephras such as the Rotoehu Ash on which a more rigid chronology can be pinned. The Kaipara area of Northland, where there are numerous deep peat deposits, and where Rotoehu Ash has previously been identified, may be a fruitful area for research.

The pollen signature for *Agathis australis* cycles in the Late Holocene, identified at Lake Taumatawhana, deserves further investigation. Cores from within the same locality which indicate similar trends would provide important information about the life cycle and ecology of one of New Zealand's largest and longest-lived trees. The Waipoua Forest area and south towards Dargaville have a long history of *Agathis australis* forests and may also yield further information about the past habits of this tree.

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APPENDIX 1

Modern pollen rain counts:

Site	**Omahuta 1**	**Omahuta 2**	**Omahuta 3**	**Warawara**	**Puketi 1**
Acacia	0	0	0	0	0
Agathis australis	125	9	10	3	10
Alectryon excelsus	0	1	0	0	1
Betula	0	0	0	0	0
Caldcluvia rosifolia	0	11	0	0	0
Casuarina	0	1	0	0	0
Corynocarpus laevigatus	0	0	0	1	0
Cupressus	0	0	0	0	2
Dacrycarpus dacrydioides	3	7	8	3	7
Dacrydium cupressinum	55	7	6	9	114
Dysoxylum spectabile	0	1	0	0	0
Elaeocarpus	3	1	2	0	18
Fuscospora	8	27	819	0	0
Halocarpus	11	1	5	1	0
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	5	16	14	7	26
Laurelia novae-zelandiae	0	0	0	0	0
Libocedrus	7	7	3	0	0
Manoao colensoi	0	2	0	0	1
Metrosideros undiff.	10	12	31	5	35
Nestegis	1	4	1	0	1
Phyllocladus	13	16	25	1736	99
Pinus	44	20	30	0	27
Podocarpus type	36	9	17	4	47
Prumnopitys ferruginea	15	10	12	0	20
Prumnopitys taxifolia	11	10	13	14	27
Syzygium maire	0	0	0	1	1
Vitex lucens	0	0	0	0	0
Weinmannia	3	102	25	1	46
Ascarina lucida	3	0	0	0	2
Asteraceae	0	0	0	0	0
Carpodetus serratus	1	1	0	0	1
Coprosma	9	10	12	146	23
Cordyline	0	0	0	3	4
Coriaria	0	0	0	0	1
Epacridaceae	2	0	0	0	0
Fabaceae	0	0	0	0	1
Fuschia	0	0	0	1	0
Geniostoma	2	0	1	0	0
Griselinia	3	9	3	5	9
Hebe	0	0	0	0	0
Ixerba brexioides	4	0	0	0	0
Leucopogon fasciculatus	5	1	13	0	0
Macropiper	0	0	0	0	0
Malvaceae	0	0	0	1	0
Muehlenbeckia	0	0	0	0	0
Myrsine	1	0	1	0	1
Neomyrtus type	13	11	8	2	18
Pittosporum	1	1	2	1	3
Pseudopanax	1	3	4	8	7
Pseudowintera	0	0	0	0	0
Quintinia	7	1	4	0	0

Site	**Omahuta 1**	**Omahuta 2**	**Omahuta 3**	**Warawara**	**Puketi 1**
Rhopalostylis sapida	0	0	0	0	3
Schefflera digitata	2	0	0	0	2
Toronia toru	3	5	0	0	0
Ulex	0	0	0	0	0
Astelia	2	1	0	0	2
Chenopodiaceae	0	1	0	0	0
Circium	0	0	0	0	0
Dactylanthus taylorii	2	0	0	0	1
Epilobium	0	0	1	0	0
Freycinetia baueriana	9	6	6	0	0
Hydrocotyle novae-zelandiae	0	0	0	0	1
Liliaceae	1	0	0	0	4
Parsonsia	0	0	0	0	0
Plantago lanceolata	6	0	2	1	4
Poaceae	28	17	51	16	10
Pteridium esculentum	8	4	4	0	11
Taraxacum type	0	0	1	0	11
Tupeia antarctica	0	0	4	0	0
Adiantum type	0	0	0	2	0
Cyathea dealbata type	32	834	121	207	244
Cyathea smithii type	1	1	2	5	20
Dicksonia fibrosa	0	27	5	0	3
Dicksonia squarrosa	26	10	12	0	0
Hymenophyllum	0	0	7	0	0
Lycopodium cernuum	0	0	1	0	1
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium fastigiatum	0	4	0	0	0
Lycopodium varium	2	3	2	0	0
Lycopodium volubile	0	1	0	0	0
Lygodium articulatum	0	0	0	0	1
Monolete fern spores	18	64	14	31	25
Paesia scaberula	0	3	5	2	4
Phylloglossum drummondii	0	0	0	0	0
Phymatosorus diversifolius	13	25	11	17	11
Pteris	1	0	0	0	4
Schaezia	0	0	0	0	0
Cyperaceae	0	0	0	0	0
Gleichenia	0	0	0	0	1
Haloragis	0	0	0	0	0
Leptospermum type	2	0	0	2	1
Myriophyllum	0	0	0	0	0
Potamogeton	0	0	0	0	0
Restionaceae	1	0	0	0	0
Typha	0	0	0	0	0
Unknowns	0	2	1	5	10

Site	**Puketi 2**	**Waipoua**	**Tauanui**	**Orere**	**Omaha**
Acacia	0	0	0	0	31
Agathis australis	79	126	0	1	1
Alectryon excelsus	6	0	0	0	2
Betula	0	0	0	1	0
Caldcluvia rosifolia	0	0	0	0	0
Casuarina	0	0	0	0	0

Site	**Puketi 2**	**Waipoua**	**Tauanui**	**Orere**	**Omaha**
Corynocarpus laevigatus	0	0	1	0	6
Cupressus	2	0	10	19	6
Dacrycarpus dacrydioides	16	4	2	3	99
Dacrydium cupressinum	74	7	8	0	17
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	10	11	0	0	0
Fuscospora	0	0	0	0	2
Halocarpus	4	10	3	0	0
Hedycarya arborea	1	0	0	0	0
Knightia excelsa	24	6	16	1	1
Laurelia novae-zelandiae	7	1	0	1	4
Libocedrus	0	0	0	1	6
Manoao colensoi	2	2	0	0	0
Metrosideros undiff.	43	13	5	2	9
Nestegis	0	1	0	0	1
Phyllocladus	16	2	5	0	4
Pinus	15	18	34	32	20
Podocarpus type	13	20	25	137	7
Prumnopitys ferruginea	8	14	10	0	1
Prumnopitys taxifolia	27	50	23	4	7
Syzygium maire	24	1	0	0	1
Vitex lucens	0	1	8	2	2
Weinmannia	31	8	0	0	0
Ascarina lucida	19	2	0	0	2
Asteraceae	1	0	0	0	0
Carpodetus serratus	1	0	0	0	0
Coprosma	5	2	1	6	12
Cordyline	1	0	6	6	18
Coriaria	7	0	1	2	21
Epacridaceae	0	0	0	0	1
Fabaceae	0	1	0	0	0
Fuschia	1	0	0	0	2
Geniostoma	0	0	0	1	0
Griselinia	4	4	1	0	5
Hebe	0	0	0	0	0
Ixerba brexioides	0	0	1	0	0
Leucopogon fasciculatus	0	0	0	0	5
Macropiper	0	4	4	0	0
Malvaceae	1	1	0	0	0
Muehlenbeckia	2	0	0	0	0
Myrsine	1	1	2	0	4
Neomyrtus type	7	1	0	0	1
Pittosporum	4	1	0	3	0
Pseudopanax	3	0	0	0	1
Pseudowintera	3	0	0	0	0
Quintinia	2	0	0	0	0
Rhopalostylis sapida	17	0	10	2	10
Schefflera digitata	1	0	0	0	3
Toronia toru	0	0	0	0	0
Ulex	2	0	0	1	0
Astelia	5	11	0	1	1
Chenopodiaceae	0	0	0	0	0
Circium	0	0	1	0	0
Dactylanthus taylorii	4	1	0	0	0

Site	**Puketi 2**	**Waipoua**	**Tauanui**	**Orere**	**Omaha**
Epilobium	0	0	0	0	0
Freycinetia baueriana	0	13	17	1	0
Hydrocotyle novae-zelandiae	0	0	0	0	0
Liliaceae	2	0	0	0	5
Parsonsia	0	0	0	3	0
Plantago lanceolata	3	4	9	3	0
Poaceae	30	16	59	19	33
Pteridium esculentum	36	0	0	28	7
Taraxacum type	2	0	0	6	4
Tupeia antarctica	0	0	0	0	0
Adiantum type	1	0	1	0	0
Cyathea dealbata type	199	108	102	112	9
Cyathea smithii type	14	10	4	4	1
Dicksonia fibrosa	1	0	0	0	0
Dicksonia squarrosa	54	36	7	5	0
Hymenophyllum	2	0	0	0	0
Lycopodium cernuum	2	0	0	0	0
Lycopodium deuterodensum	1	0	0	0	0
Lycopodium fastigiatum	0	0	0	0	0
Lycopodium varium	0	0	0	0	0
Lycopodium volubile	0	0	0	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	39	19	48	29	28
Paesia scaberula	1	3	246	0	1
Phylloglossum drummondii	0	0	0	0	0
Phymatosorus diversifolius	12	4	59	1	23
Pteris	9	0	0	0	5
Schaezia	0	0	0	0	2
Cyperaceae	0	0	0	0	4
Gleichenia	1	0	0	0	0
Haloragis	0	0	0	0	0
Leptospermum type	1	1	0	0	1
Myriophyllum	0	0	2	0	0
Potamogeton	0	1	0	0	12
Restionaceae	0	0	0	0	0
Typha	0	0	0	0	0
Unknowns	13	0	2	0	3

Site	**Rangitoto**	**Taumata' 1**	**Wharau Rd**	**Te Kao**	**Taumata' 2**
Acacia	0	0	0	0	2
Agathis australis	1	1	0	0	0
Alectryon excelsus	0	0	0	0	0
Betula	0	0	0	0	0
Caldcluvia rosifolia	0	0	0	0	0
Casuarina	0	0	0	0	0
Corynocarpus laevigatus	0	0	0	0	0
Cupressus	1	3	1	0	1
Dacrycarpus dacrydioides	0	0	0	3	0
Dacrydium cupressinum	4	1	8	62	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	3	1	0	0	0
Fuscospora	2	1	0	3	0

Site	Rangitoto	Taumata' 1	Wharau Rd	Te Kao	Taumata' 2
Halocarpus	0	0	0	0	0
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	0	0	0	0	0
Laurelia novae-zelandiae	0	0	0	2	0
Libocedrus	0	0	0	0	0
Manoao colensoi	0	0	0	0	0
Metrosideros undiff.	214	1	8	0	0
Nestegis	0	0	0	0	0
Phyllocladus	3	3	11	43	0
Pinus	17	51	12	20	7
Podocarpus type	3	7	2	6	1
Prumnopitys ferruginea	0	0	0	0	0
Prumnopitys taxifolia	6	2	1	0	0
Syzygium maire	0	0	1	0	0
Vitex lucens	0	0	0	0	0
Weinmannia	0	0	1	0	0
Ascarina lucida	1	2	2	4	0
Asteraceae	0	3	1	0	1
Carpodetus serratus	1	0	0	0	0
Coprosma	1	11	25	0	4
Cordyline	0	6	0	0	2
Coriaria	0	0	4	0	0
Epacridaceae	0	1	0	3	0
Fabaceae	0	0	0	0	0
Fuschia	0	0	0	0	0
Geniostoma	0	0	0	0	0
Griselinia	3	2	2	2	0
Hebe	0	0	0	0	3
Ixerba brexioides	0	0	0	0	0
Leucopogon fasciculatus	1	0	1	2	3
Macropiper	0	0	0	0	0
Malvaceae	0	0	0	0	0
Muehlenbeckia	0	0	0	0	0
Myrsine	14	0	1	1	0
Neomyrtus type	8	8	13	2	130
Pittosporum	1	0	1	0	0
Pseudopanax	0	1	0	0	0
Pseudowintera	0	0	0	0	0
Quintinia	0	0	0	0	0
Rhopalostylis sapida	1	0	0	0	0
Schefflera digitata	0	0	0	0	0
Toronia toru	0	0	0	0	0
Ulex	0	15	3	0	1
Astelia	7	0	0	0	0
Chenopodiaceae	1	0	0	0	0
Circium	0	0	0	0	0
Dactylanthus taylorii	0	0	0	0	0
Epilobium	0	0	0	0	0
Freycinetia baueriana	0	0	0	0	0
Hydrocotyle novae-zelandiae	0	1	0	0	0
Liliaceae	0	0	0	0	0
Parsonsia	0	0	0	0	0
Plantago lanceolata	1	1	5	0	0
Poaceae	16	42	76	237	153

Site	**Rangitoto**	**Taumata' 1**	**Wharau Rd**	**Te Kao**	**Taumata' 2**
Pteridium esculentum	36	2	48	23	13
Taraxacum type	4	12	4	20	24
Tupeia antarctica	0	0	0	0	0
Adiantum type	2	0	1	0	0
Cyathea dealbata type	5	9	30	2	0
Cyathea smithii type	2	0	0	0	0
Dicksonia fibrosa	0	0	0	0	0
Dicksonia squarrosa	0	0	1	0	0
Hymenophyllum	1	0	2	0	0
Lycopodium cernuum	0	0	0	2	0
Lycopodium deuterodensum	0	0	1	0	0
Lycopodium fastigiatum	0	0	0	0	0
Lycopodium varium	0	0	0	0	0
Lycopodium volubile	0	0	0	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	100	19	32	3	2
Paesia scaberula	0	3	4	1	1
Phylloglossum drummondii	0	0	0	1	0
Phymatosorus diversifolius	2	25	0	0	0
Pteris	1	0	0	0	0
Schaezia	0	2	0	0	0
Cyperaceae	0	42	93	4	0
Gleichenia	0	0	21	2	0
Haloragis	0	0	5	0	0
Leptospermum type	0	65	133	2	100
Myriophyllum	0	1	0	0	0
Potamogeton	0	0	0	0	0
Restionaceae	0	6	0	0	0
Typha	0	651	77	4	0
Unknowns	0	1	2	1	0

APPENDIX 2

Lake Taumatawhana pollen counts:

Depth (m)	**0.15**	**0.35**	**0.45**	**0.55**	**0.65**
Lycopodium spike	132	175	95	52	85
Spike concentration	13911	13911	13911	13911	13911
Agathis australis	1	6	1	2	1
Alectryon excelsus	0	0	0	0	0
Cupressus	5	0	0	0	0
Dacrycarpus dacrydioides	0	1	1	1	1
Dacrydium cupressinum	13	47	31	30	18
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	0	0	0	0
Fuscospora	0	1	0	0	0
Griselinia	4	4	7	2	6
Hedycarya arborea	0	0	1	0	1
Knightia excelsa	0	0	0	1	0
Libocedrus	0	0	2	0	3
Metrosideros undiff.	3	8	6	0	3
Nestegis	0	4	1	3	3
Phyllocladus	2	7	3	8	4
Pinus	9	0	0	0	0
Podocarpus type	4	12	10	40	9
Prumnopitys ferruginea	0	0	1	1	1
Prumnopitys taxifolia	0	1	1	0	5
Rhopalostylis sapida	0	8	4	0	4
Syzygium maire	2	6	7	5	4
Weinmannia	0	0	0	0	0
Asteraceae	1	1	0	0	1
Ascarina lucida	3	25	17	6	3
Coprosma	8	6	4	6	3
Cordyline	4	1	0	2	0
Coriaria	0	2	5	3	6
Dodonaea viscosa	0	0	0	0	0
Epacridaceae	2	0	0	0	0
Fabaceae	0	0	2	0	0
Fuschia	0	0	0	0	0
Ileostylus micranthus	0	0	0	0	0
Leptospermum type	29	29	39	55	53
Malvaceae	0	0	0	0	0
Muehlenbeckia	0	0	0	0	1
Myrsine	2	1	0	0	0
Neomyrtus type	0	0	6	0	3
Pittosporum	0	0	5	2	1
Plagianthus type	0	0	0	0	0
Pomaderris	6	2	0	0	4
Pseudopanax	0	0	1	3	1
Pseudowintera	0	2	0	0	0
Rubus	0	0	0	0	1
Astelia	0	0	0	0	0
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Gunnera	0	0	1	0	0
Poaceae	37	7	3	6	2
Polygonaceae	0	0	0	0	1

Depth (m)	**0.15**	**0.35**	**0.45**	**0.55**	**0.65**
Phormium	1	0	1	0	0
Plantago lanceolata	1	2	0	0	1
Rumex	0	0	0	0	1
Taraxacum type	55	1	3	0	2
Cyathea dealbata type	0	0	2	4	1
Dennstaedtiaceae	0	0	0	0	0
Dicksonia	0	1	0	2	0
Gleichenia	0	0	0	2	0
Histiopteris	1	0	0	0	0
Hymenophyllum	0	0	0	2	0
Hypolepis distans	0	0	0	0	0
Lycopodium	0	4	1	0	5
Monolete fern spores	3	7	14	7	15
Paesia scaberula	0	0	0	0	1
Phymatosorus diversifolius	0	1	3	0	1
Pteridium esculentum	21	19	52	22	56
Pteris	0	0	0	0	0
Cyperaceae	15	4	9	8	8
Haloragaceae	0	0	0	0	1
Haloragis	0	0	1	1	0
Myriophyllum	1	0	1	2	3
Restionaceae	44	23	26	16	47
Typha	2	3	7	5	4
Unknowns	2	0	0	1	2
Charcoal concentration	88.5	71.8	49.6	168.6	72.1

Depth (m)	**0.75**	**0.85**	**0.95**	**1.05**	**1.1**
Lycopodium spike	63	68	66	86	91
Spike concentration	13911	13911	13911	13911	13911
Agathis australis	6	5	4	22	12
Alectryon excelsus	0	0	0	0	0
Cupressus	0	0	0	0	0
Dacrycarpus dacrydioides	2	1	1	6	2
Dacrydium cupressinum	25	28	24	51	34
Dysoxylum spectabile	0	1	0	0	0
Elaeocarpus	0	0	0	0	0
Fuscospora	0	0	1	0	0
Griselinia	2	6	4	2	2
Hedycarya arborea	0	1	1	1	1
Knightia excelsa	0	0	1	1	0
Libocedrus	2	6	3	42	29
Metrosideros undiff.	0	8	6	3	6
Nestegis	1	6	2	7	3
Phyllocladus	1	6	1	17	13
Pinus	0	0	0	0	0
Podocarpus type	14	10	6	22	10
Prumnopitys ferruginea	0	0	0	1	0
Prumnopitys taxifolia	0	0	0	14	8
Rhopalostylis sapida	0	2	0	6	13
Syzygium maire	8	11	1	1	0
Weinmannia	0	0	0	0	0
Ascarina lucida	14	3	15	18	10

Depth (m)	**0.75**	**0.85**	**0.95**	**1.05**	**1.1**
Asteraceae	2	0	0	0	2
Coprosma	2	2	2	3	5
Cordyline	6	1	7	0	0
Coriaria	0	14	5	1	1
Dodonaea viscosa	2	0	1	0	1
Epacridaceae	0	0	0	2	1
Fabaceae	0	1	0	0	0
Fuschia	0	0	0	0	0
Ileostylus micranthus	0	0	0	0	0
Leptospermum type	42	28	45	38	29
Malvaceae	1	0	0	0	0
Muehlenbeckia	0	0	0	0	0
Myrsine	1	1	0	0	2
Neomyrtus type	0	0	0	0	0
Pittosporum	0	1	0	0	2
Plagianthus type	0	0	0	0	0
Pomaderris	0	3	0	0	0
Pseudopanax	0	2	2	0	0
Pseudowintera	0	1	0	0	0
Rubus	0	0	0	0	0
Astelia	1	0	0	0	0
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Gunnera	0	0	0	0	0
Poaceae	4	1	1	3	0
Polygonaceae	0	0	0	0	0
Phormium	5	0	2	1	0
Plantago lanceolata	0	0	0	0	0
Rumex	0	0	0	0	0
Taraxacum type	0	0	0	0	0
Cyathea dealbata type	2	2	0	8	9
Dennstaedtiaceae	0	0	0	0	0
Dicksonia	1	0	0	0	0
Gleichenia	0	1	0	1	1
Histiopteris	0	0	0	0	0
Hymenophyllum	0	0	0	0	0
Hypolepis distans	0	0	0	0	0
Lycopodium	2	0	0	0	0
Monolete fern spores	5	11	7	8	17
Paesia scaberula	1	1	0	0	1
Phymatosorus diversifolius	0	1	0	3	4
Pteridium esculentum	56	51	81	18	71
Pteris	0	0	0	0	0
Cyperaceae	0	9	3	17	19
Haloragaceae	0	0	0	0	0
Haloragis	0	0	0	0	0
Myriophyllum	1	3	0	2	1
Restionaceae	16	29	12	1	2
Typha	0	7	2	1	5
Unknowns	0	0	0	0	0
Charcoal concentration	156.6	111.3	104.5	17.5	20

Depth (m)	**1.15**	**1.25**	**1.35**	**1.45**	**1.55**
Lycopodium spike	22	24	30	25	15
Spike concentration	13911	13911	13911	13911	13911
Agathis australis	17	15	14	11	8
Alectryon excelsus	0	1	0	0	0
Cupressus	0	0	0	0	0
Dacrycarpus dacrydioides	2	1	0	1	3
Dacrydium cupressinum	48	59	43	62	44
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	0	0	0	0
Fuscospora	0	0	0	0	0
Griselinia	9	7	12	11	7
Hedycarya arborea	0	0	1	1	0
Knightia excelsa	1	0	0	1	0
Libocedrus	14	18	12	26	31
Metrosideros undiff.	1	7	3	13	7
Nestegis	6	6	8	11	4
Phyllocladus	23	6	8	7	4
Pinus	0	0	0	0	0
Podocarpus type	15	23	38	14	25
Prumnopitys ferruginea	0	1	0	0	1
Prumnopitys taxifolia	2	7	7	6	3
Rhopalostylis sapida	0	0	1	1	1
Syzygium maire	7	1	11	4	9
Weinmannia	0	0	0	0	0
Ascarina lucida	16	17	20	21	13
Asteraceae	0	4	0	1	0
Coprosma	2	5	1	1	1
Cordyline	1	0	0	0	0
Coriaria	1	0	0	0	0
Dodonaea viscosa	0	0	0	1	0
Epacridaceae	0	0	1	1	0
Fabaceae	0	0	0	1	0
Fuschia	0	0	0	0	0
Ileostylus micranthus	0	0	0	0	0
Leptospermum type	58	24	40	33	47
Malvaceae	0	0	0	0	1
Muehlenbeckia	0	0	0	0	0
Myrsine	1	5	2	1	2
Neomyrtus type	0	2	0	1	0
Pittosporum	0	1	3	1	1
Plagianthus type	0	0	0	0	0
Pomaderris	0	2	1	1	0
Pseudopanax	1	1	2	0	7
Pseudowintera	1	0	0	0	0
Rubus	0	0	0	0	0
Astelia	1	0	1	0	0
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	1	0	0
Gunnera	0	0	0	0	0
Poaceae	0	0	1	0	0
Polygonaceae	0	0	0	0	0
Phormium	0	0	1	0	0
Plantago lanceolata	0	0	0	0	0

Depth (m)	**1.15**	**1.25**	**1.35**	**1.45**	**1.55**
Rumex	0	0	0	0	0
Taraxacum type	0	0	0	0	0
Cyathea dealbata type	0	2	9	6	7
Dennstaedtiaceae	0	0	0	0	0
Dicksonia	0	0	0	5	1
Gleichenia	0	0	0	0	0
Histiopteris	0	0	0	0	0
Hymenophyllum	0	0	0	1	0
Hypolepis distans	0	0	0	0	0
Lycopodium	1	0	0	0	0
Monolete fern spores	1	3	2	2	1
Paesia scaberula	1	0	0	0	0
Phymatosorus diversifolius	0	2	3	0	1
Pteridium esculentum	5	0	0	0	0
Pteris	0	0	0	0	0
Cyperaceae	0	1	3	1	0
Haloragaceae	0	0	0	0	0
Haloragis	0	0	1	0	0
Myriophyllum	0	0	0	0	0
Restionaceae	7	4	2	4	2
Typha	0	0	0	0	0
Unknowns	0	0	1	0	0
Charcoal concentration	4	5.3	3.1	1.4	3.9

Depth (m)	**1.65**	**1.75**	**1.85**	**1.95**	**2.05**
Lycopodium spike	56	27	47	23	38
Spike concentration	13911	13911	13911	13911	13911
Agathis australis	6	4	4	5	25
Alectryon excelsus	0	0	0	0	0
Cupressus	0	0	0	0	0
Dacrycarpus dacrydioides	4	0	0	4	1
Dacrydium cupressinum	32	28	33	32	51
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	1	0	1	0	0
Fuscospora	1	0	0	0	0
Griselinia	11	8	5	3	7
Hedycarya arborea	0	3	0	0	0
Knightia excelsa	1	0	0	0	1
Libocedrus	25	18	27	25	34
Metrosideros undiff.	5	3	3	1	9
Nestegis	9	5	6	4	11
Phyllocladus	4	9	5	6	18
Pinus	0	0	0	0	0
Podocarpus type	21	38	28	27	32
Prumnopitys ferruginea	3	0	0	4	3
Prumnopitys taxifolia	5	0	4	0	0
Rhopalostylis sapida	2	0	0	1	0
Syzygium maire	1	8	0	4	4
Weinmannia	0	0	1	0	0
Ascarina lucida	19	8	4	9	17
Asteraceae	2	0	0	0	0
Coprosma	4	6	1	1	4
Cordyline	0	0	0	0	0

Depth (m)	**1.65**	**1.75**	**1.85**	**1.95**	**2.05**
Coriaria	0	0	0	0	0
Dodonaea viscosa	0	0	0	0	1
Epacridaceae	0	1	0	0	0
Fabaceae	3	0	0	0	2
Fuschia	0	0	0	0	0
Ileostylus micranthus	0	2	0	0	1
Leptospermum type	47	56	71	82	64
Malvaceae	0	0	0	0	0
Muehlenbeckia	0	0	0	0	0
Myrsine	0	0	1	2	1
Neomyrtus type	1	0	1	0	1
Pittosporum	3	2	1	2	2
Plagianthus type	0	0	0	0	0
Pomaderris	0	0	1	0	0
Pseudopanax	0	2	0	2	0
Pseudowintera	0	1	1	0	1
Rubus	0	0	0	0	0
Astelia	0	0	0	0	0
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Gunnera	1	0	0	0	0
Poaceae	0	1	0	1	0
Polygonaceae	0	0	0	0	0
Phormium	0	0	1	0	0
Plantago lanceolata	0	0	0	0	0
Rumex	0	0	0	0	0
Taraxacum type	0	0	0	0	0
Cyathea dealbata type	10	3	5	2	10
Dennstaedtiaceae	0	0	0	0	0
Dicksonia	2	0	4	1	0
Gleichenia	0	0	0	0	1
Histiopteris	0	0	0	0	0
Hymenophyllum	0	0	0	0	1
Hypolepis distans	0	0	0	0	0
Lycopodium	0	0	0	0	0
Monolete fern spores	8	3	4	7	1
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	1	0	0	3	1
Pteridium esculentum	0	0	0	0	0
Pteris	0	0	0	0	0
Cyperaceae	0	0	3	0	0
Haloragaceae	0	0	0	0	0
Haloragis	0	0	0	0	0
Myriophyllum	0	0	0	0	0
Restionaceae	7	6	6	8	6
Typha	0	0	0	0	0
Unknowns	0	0	0	0	0
Charcoal concentration	1.9	3.3	0.3	3.1	7.2

Depth (m)	**2.15**	**2.25**	**2.35**	**2.45**	**2.55**
Lycopodium spike	26	30	18	43	35
Spike concentration	13911	13911	13911	13911	13911
Agathis australis	17	16	15	21	10

Depth (m)	**2.15**	**2.25**	**2.35**	**2.45**	**2.55**
Alectryon excelsus	0	0	0	0	0
Cupressus	0	0	0	0	0
Dacrycarpus dacrydioides	2	2	0	5	3
Dacrydium cupressinum	50	63	44	57	66
Dysoxylum spectabile	0	0	0	0	1
Elaeocarpus	0	0	1	0	0
Fuscospora	0	0	1	2	1
Griselinia	7	8	8	7	8
Hedycarya arborea	0	1	2	1	1
Knightia excelsa	1	0	0	1	3
Libocedrus	25	28	22	42	20
Metrosideros undiff.	1	13	1	10	3
Nestegis	4	14	10	17	5
Phyllocladus	9	17	5	7	3
Pinus	0	0	0	0	0
Podocarpus type	25	28	24	31	20
Prumnopitys ferruginea	0	3	0	2	0
Prumnopitys taxifolia	0	10	4	4	1
Rhopalostylis sapida	0	0	1	0	0
Syzygium maire	2	6	12	1	6
Weinmannia	0	0	0	0	0
Ascarina lucida	10	19	9	28	11
Asteraceae	0	0	0	0	1
Coprosma	2	1	1	2	2
Cordyline	0	0	1	0	0
Coriaria	0	0	0	0	0
Dodonaea viscosa	1	0	1	3	1
Epacridaceae	0	1	1	1	0
Fabaceae	0	1	0	1	0
Fuschia	0	0	0	0	0
Ileostylus micranthus	0	0	0	0	0
Leptospermum type	37	49	51	80	39
Malvaceae	0	1	0	1	0
Muehlenbeckia	0	0	0	0	0
Myrsine	0	2	1	8	0
Neomyrtus type	0	0	0	1	0
Pittosporum	1	0	1	5	2
Plagianthus type	0	0	0	0	0
Pomaderris	0	0	0	0	0
Pseudopanax	4	0	2	0	5
Pseudowintera	0	2	0	1	1
Rubus	0	0	0	0	0
Astelia	0	0	0	0	3
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	1	0	0	0
Gunnera	0	0	0	0	0
Poaceae	0	1	1	0	0
Polygonaceae	0	0	0	0	0
Phormium	0	0	1	0	0
Plantago lanceolata	0	0	0	0	0
Rumex	0	0	0	0	0
Taraxacum type	0	0	0	0	0
Cyathea dealbata type	7	8	7	11	12
Dennstaedtiaceae	0	1	0	0	0

Depth (m)	**2.15**	**2.25**	**2.35**	**2.45**	**2.55**
Dicksonia	0	0	1	0	1
Gleichenia	0	0	0	0	0
Histiopteris	0	0	0	0	0
Hymenophyllum	0	0	0	0	0
Hypolepis distans	0	0	0	1	0
Lycopodium	0	0	0	0	0
Monolete fern spores	6	7	2	4	0
Paesia scaberula	0	1	0	0	0
Phymatosorus diversifolius	0	2	2	3	0
Pteridium esculentum	2	0	0	0	1
Pteris	0	0	0	0	0
Cyperaceae	0	4	0	1	0
Haloragaceae	0	0	0	0	0
Haloragis	0	0	0	2	0
Myriophyllum	0	0	0	0	0
Restionaceae	4	3	4	5	3
Typha	0	0	0	0	0
Unknowns	0	0	0	0	0
Charcoal concentration	2.5	1.4	4.5	0.8	5

Depth (m)	**2.65**	**2.75**	**2.85**	**2.95**	**3.05**
Lycopodium spike	34	35	49	44	58
Spike concentration	13911	13911	13911	13911	13911
Agathis australis	10	12	7	1	7
Alectryon excelsus	0	0	0	0	0
Cupressus	0	0	0	0	0
Dacrycarpus dacrydioides	1	0	0	7	6
Dacrydium cupressinum	35	34	48	38	34
Dysoxylum spectabile	0	0	1	0	0
Elaeocarpus	3	0	0	0	0
Fuscospora	0	0	1	0	1
Griselinia	7	8	8	9	4
Hedycarya arborea	0	2	1	2	3
Knightia excelsa	0	0	1	0	1
Libocedrus	53	36	51	28	28
Metrosideros undiff.	11	3	20	5	13
Nestegis	21	8	7	6	17
Phyllocladus	7	2	2	2	3
Pinus	0	0	0	0	0
Podocarpus type	34	29	31	41	26
Prumnopitys ferruginea	0	0	0	2	2
Prumnopitys taxifolia	8	1	6	0	1
Rhopalostylis sapida	0	0	0	1	0
Syzygium maire	2	6	0	7	1
Weinmannia	0	0	1	0	7
Ascarina lucida	21	5	6	17	21
Asteraceae	0	0	0	0	0
Coprosma	1	4	4	4	6
Cordyline	1	2	0	0	0
Coriaria	1	0	0	0	0
Dodonaea viscosa	1	1	0	0	1
Epacridaceae	0	0	1	0	3

Depth (m)	**2.65**	**2.75**	**2.85**	**2.95**	**3.05**
Fabaceae	0	0	0	1	0
Fuschia	0	0	0	1	0
Ileostylus micranthus	0	0	0	0	0
Leptospermum type	94	71	72	22	85
Malvaceae	0	0	0	0	0
Muehlenbeckia	0	0	0	0	0
Myrsine	7	2	4	1	4
Neomyrtus type	5	0	2	0	2
Pittosporum	4	2	2	0	3
Plagianthus type	2	0	0	0	0
Pomaderris	0	0	0	0	0
Pseudopanax	0	7	0	6	0
Pseudowintera	0	0	0	0	0
Rubus	0	0	0	0	0
Astelia	0	4	0	3	0
Caryophyllaceae	0	0	0	0	2
Chenopodiaceae	0	0	0	0	0
Gunnera	0	0	0	0	0
Poaceae	2	0	2	0	2
Polygonaceae	0	0	0	0	0
Phormium	0	0	0	0	1
Plantago lanceolata	0	0	0	0	0
Rumex	0	0	0	0	0
Taraxacum type	0	0	0	0	0
Cyathea dealbata type	7	3	6	10	11
Dennstaedtiaceae	0	0	0	0	0
Dicksonia	1	2	0	0	1
Gleichenia	0	0	0	0	0
Histiopteris	0	0	0	0	0
Hymenophyllum	0	1	0	0	0
Hypolepis distans	0	0	0	0	0
Lycopodium	0	0	1	0	0
Monolete fern spores	8	6	4	4	7
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	0	1	6	3	1
Pteridium esculentum	0	0	0	2	0
Pteris	0	0	0	0	0
Cyperaceae	1	0	2	0	3
Haloragaceae	0	0	0	0	0
Haloragis	1	0	0	0	0
Myriophyllum	1	2	1	0	0
Restionaceae	7	2	8	10	7
Typha	0	0	0	0	0
Unknowns	0	1	0	0	0
Charcoal concentration	0.8	2.2	1.7	0.8	2.5

Depth (m)	**3.15**	**3.25**	**3.35**	**3.45**	**3.55**
Lycopodium spike	63	45	35	57	64
Spike concentration	13911	13911	13911	13911	13911
Agathis australis	50	23	16	20	17
Alectryon excelsus	0	0	0	0	0
Cupressus	0	0	0	0	0

Depth (m)	**3.15**	**3.25**	**3.35**	**3.45**	**3.55**
Dacrycarpus dacrydioides	2	1	7	3	4
Dacrydium cupressinum	73	30	47	37	37
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	2	1	0	0
Fuscospora	0	0	1	0	0
Griselinia	8	6	6	6	14
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	1	1	0	1	1
Libocedrus	26	53	12	43	14
Metrosideros undiff.	1	10	2	5	3
Nestegis	11	15	7	13	8
Phyllocladus	3	9	11	6	7
Pinus	0	0	0	0	0
Podocarpus type	40	30	69	48	70
Prumnopitys ferruginea	1	2	0	3	0
Prumnopitys taxifolia	7	4	2	4	4
Rhopalostylis sapida	3	0	1	0	1
Syzygium maire	2	2	5	0	1
Weinmannia	0	0	0	0	0
Ascarina lucida	11	14	12	6	7
Asteraceae	0	0	0	2	0
Coprosma	4	0	4	5	4
Cordyline	1	0	1	0	0
Coriaria	0	0	0	1	0
Dodonaea viscosa	0	2	1	2	1
Epacridaceae	0	1	0	0	0
Fabaceae	0	0	0	0	0
Fuschia	0	0	0	0	0
Ileostylus micranthus	0	1	0	2	2
Leptospermum type	29	77	20	53	15
Malvaceae	0	0	1	0	1
Muehlenbeckia	0	0	0	0	0
Myrsine	0	5	1	1	1
Neomyrtus type	0	1	0	0	0
Pittosporum	4	4	5	6	3
Plagianthus type	0	0	0	0	0
Pomaderris	0	0	0	0	0
Pseudopanax	4	0	2	0	3
Pseudowintera	0	1	0	0	0
Rubus	0	0	0	0	0
Astelia	2	0	0	0	0
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Gunnera	0	0	0	0	0
Poaceae	1	0	0	0	0
Polygonaceae	0	0	0	0	0
Phormium	0	1	0	2	2
Plantago lanceolata	0	0	0	0	0
Rumex	0	0	0	0	0
Taraxacum type	0	0	0	0	0
Cyathea dealbata type	15	6	1	7	4
Dennstaedtiaceae	0	0	0	0	0
Dicksonia	10	1	0	0	1

Depth (m)	**3.15**	**3.25**	**3.35**	**3.45**	**3.55**
Gleichenia	0	1	0	0	0
Histiopteris	0	0	0	0	0
Hymenophyllum	0	0	0	0	1
Hypolepis distans	0	0	0	0	0
Lycopodium	0	0	0	1	0
Monolete fern spores	8	8	1	2	3
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	1	1	1	2	1
Pteridium esculentum	1	0	0	0	0
Pteris	0	0	0	1	0
Cyperaceae	0	5	0	7	0
Haloragaceae	0	0	0	0	0
Haloragis	0	0	0	0	0
Myriophyllum	0	0	0	0	0
Restionaceae	4	1	5	2	7
Typha	0	0	0	0	0
Unknowns	0	2	0	1	0
Charcoal concentration	0.7	3.6	2.2	0.8	2.2

Depth (m)	**3.65**	**3.75**	**3.85**	**3.95**
Lycopodium spike	43	49	23	52
Spike concentration	13911	13911	13911	13911
Agathis australis	9	16	3	3
Alectryon excelsus	0	0	0	0
Cupressus	0	0	0	0
Dacrycarpus dacrydioides	5	5	2	4
Dacrydium cupressinum	18	36	22	28
Dysoxylum spectabile	0	0	0	0
Elaeocarpus	0	0	0	0
Fuscospora	0	0	1	0
Griselinia	5	7	5	7
Hedycarya arborea	0	1	0	0
Knightia excelsa	1	1	1	1
Libocedrus	22	19	28	13
Metrosideros undiff.	5	4	1	3
Nestegis	8	5	8	4
Phyllocladus	11	4	9	4
Pinus	0	0	0	0
Podocarpus type	53	65	35	79
Prumnopitys ferruginea	1	6	3	10
Prumnopitys taxifolia	23	11	20	0
Rhopalostylis sapida	1	0	0	0
Syzygium maire	0	1	0	2
Weinmannia	0	0	0	0
Ascarina lucida	3	1	3	2
Asteraceae	0	0	0	0
Coprosma	9	10	7	10
Cordyline	0	0	0	0
Coriaria	0	0	0	0
Dodonaea viscosa	1	0	0	0
Epacridaceae	0	0	0	0
Fabaceae	0	0	0	0

Depth (m)	**3.65**	**3.75**	**3.85**	**3.95**
Fuschia	0	0	0	0
Ileostylus micranthus	0	1	0	0
Leptospermum type	57	14	47	40
Malvaceae	1	0	0	2
Muehlenbeckia	0	0	0	0
Myrsine	3	0	1	3
Neomyrtus type	1	0	0	0
Pittosporum	2	1	0	0
Plagianthus type	0	0	0	0
Pomaderris	0	0	1	0
Pseudopanax	0	0	0	5
Pseudowintera	0	0	0	1
Rubus	0	0	0	0
Astelia	0	0	0	0
Caryophyllaceae	0	0	0	0
Chenopodiaceae	0	0	0	0
Gunnera	1	0	0	1
Poaceae	0	0	1	0
Polygonaceae	0	0	0	0
Phormium	0	1	2	2
Plantago lanceolata	0	0	0	0
Rumex	0	0	0	0
Taraxacum type	0	0	0	0
Cyathea dealbata type	6	7	2	9
Dennstaedtiaceae	0	0	0	0
Dicksonia	0	0	0	1
Gleichenia	0	0	0	0
Histiopteris	0	0	0	0
Hymenophyllum	1	0	0	2
Hypolepis distans	0	0	1	0
Lycopodium	0	0	0	0
Monolete fern spores	3	4	3	2
Paesia scaberula	0	0	0	0
Phymatosorus diversifolius	1	0	0	0
Pteridium esculentum	0	0	0	0
Pteris	1	0	0	0
Cyperaceae	5	0	9	0
Haloragaceae	0	0	0	0
Haloragis	0	0	0	0
Myriophyllum	0	0	0	0
Restionaceae	0	4	0	10
Typha	0	0	0	0
Unknowns	0	0	0	0
Charcoal concentration	1.9	5.6	7.8	0.8

APPENDIX 3

Lake Tauanui pollen counts:

Depth (m)	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
Lycopodium spike	105	19	95	27	37
Spike Concentration	13911	11300	13911	11300	13911
Agathis australis	2	1	2	2	3
Alectryon excelsus	1	0	0	0	1
Dacrycarpus dacrydioides	2	5	4	8	0
Dacrydium cupressinum	13	13	30	52	24
Dysoxylum spectabile	0	0	0	0	1
Elaeocarpus	4	0	1	3	5
Fuscospora	0	0	0	0	2
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	2	2	0	2	1
Libocedrus	0	0	0	2	10
Manoao colensoi	0	0	0	0	0
Metrosideros undiff.	3	3	8	11	16
Nestegis	0	0	1	1	4
Phyllocladus	2	2	6	6	0
Pinus	6	4	0	0	0
Podocarpus type	15	10	9	13	6
Prumnopitys ferruginea	3	2	1	0	1
Prumnopitys taxifolia	2	4	4	4	4
Syzygium maire	0	0	0	0	0
Weinmannia	0	1	0	0	0
Ascarina lucida	3	0	0	5	3
Asteraceae	6	1	4	1	2
Caldcluvia rosifolia	0	0	0	0	0
Coprosma	13	7	6	4	0
Cordyline	0	0	1	2	1
Coriaria	18	11	15	6	7
Dodonaea viscosa	3	2	1	0	0
Epacridaceae	0	0	0	0	0
Fabaceae	0	0	1	1	0
Griselinia	7	0	2	2	4
Gunnera	0	0	1	0	0
Ixerba brexiodes	0	0	0	0	0
Leptospermum type	1	0	1	0	7
Leucopogon fasciculatus	0	0	0	0	0
Malvaceae	1	0	0	0	0
Melicytus	0	0	0	0	0
Muehlenbeckia	1	1	0	0	0
Myrsine	2	0	0	0	2
Neomyrtus type	0	0	0	0	0
Parsonsia	0	0	0	0	0
Pittosporum	0	1	2	5	0
Pomaderris	0	0	0	0	0
Pseudopanax	0	0	1	4	1
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	0	0	1	1	1
Toronia toru	0	0	0	0	0
Ulex europaeus	2	0	0	0	0
Astelia	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Liliaceae	0	0	0	0	0

Depth (m)	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
Phormium	3	0	0	0	0
Plantago	3	1	0	0	0
Poaceae	39	19	8	14	6
Rumex	0	1	0	0	0
Stellaria	0	0	0	0	0
Taraxacum type	6	3	3	2	4
Adiantum type	0	0	0	0	0
Asplenium	1	2	1	0	0
Cyathea dealbata type	43	73	29	54	43
Dennstaedtiaceae	0	0	0	0	0
Dicksonia squarrosa	0	6	4	2	0
Hymenophyllum	0	1	0	0	0
Hypolepis	0	0	0	3	1
Lycopodium deuterodensum	0	3	0	0	0
Lycopodium ramulosum	0	0	0	0	0
Lycopodium varium	0	0	0	0	0
Lygodium articulatum	0	0	1	0	0
Monolete fern spores	16	17	12	6	12
Paesia scaberula	18	11	22	15	11
Phymatosorus diversifolius	6	12	9	5	5
Polystichum	0	0	0	0	0
Pteridium esculentum	51	64	70	24	22
Pteris	5	0	0	0	0
Cyperaceae	9	6	8	8	8
Haloragis	3	3	4	1	0
Myriophyllum	6	1	5	24	47
Restionaceae	0	1	0	0	0
Typha	4	3	2	3	0
Unknowns	3	1	0	1	0
Charcoal	242	626	437	253	60

Depth (m)	**0.6**	**0.7**	**0.8**	**0.9**	**1**
Lycopodium spike	21	75	101	84	70
Spike Concentration	11300	13911	11300	13911	11300
Agathis australis	9	5	8	8	10
Alectryon excelsus	1	0	0	0	0
Dacrycarpus dacrydioides	4	5	2	1	1
Dacrydium cupressinum	54	55	65	42	45
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	2	0	0	0	0
Fuscospora	0	2	0	0	0
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	2	3	0	0	1
Libocedrus	3	11	0	15	24
Manoao colensoi	0	0	0	0	0
Metrosideros undiff.	7	20	0	14	10
Nestegis	0	5	1	1	2
Phyllocladus	3	2	1	5	2
Pinus	0	0	0	0	0
Podocarpus type	7	9	14	6	5
Prumnopitys ferruginea	2	3	1	0	1
Prumnopitys taxifolia	4	11	0	6	7
Syzygium maire	0	0	0	0	0

Depth (m)	**0.6**	**0.7**	**0.8**	**0.9**	**1**
Weinmannia	0	0	0	0	0
Ascarina lucida	1	4	6	6	5
Asteraceae	0	1	0	0	0
Caldcluvia rosifolia	0	0	0	0	0
Coprosma	0	0	2	1	1
Cordyline	0	0	0	1	0
Coriaria	0	0	0	1	1
Dodonaea viscosa	0	0	0	0	0
Epacridaceae	0	0	0	0	0
Fabaceae	1	0	0	1	0
Griselinia	1	3	4	7	7
Gunnera	0	0	0	0	0
Ixerba brexiodes	0	0	0	0	0
Leptospermum type	1	5	3	2	5
Leucopogon fasciculatus	0	0	0	0	0
Malvaceae	1	0	0	0	0
Melicytus	0	0	0	0	0
Muehlenbeckia	0	0	0	0	0
Myrsine	1	4	0	2	2
Neomyrtus type	0	0	0	0	0
Parsonsia	0	0	0	0	0
Pittosporum	1	1	1	2	1
Pomaderris	0	0	0	0	0
Pseudopanax	1	3	0	0	0
Pseudowintera	0	1	0	0	0
Rhopalostylis sapida	1	2	0	4	1
Toronia toru	0	0	0	0	0
Ulex europaeus	0	0	0	0	0
Astelia	0	1	0	0	0
Chenopodiaceae	0	0	0	1	0
Liliaceae	0	0	0	0	0
Phormium	0	0	0	0	0
Plantago lanceolata	0	0	0	1	0
Poaceae	5	6	2	2	0
Rumex	0	0	0	0	0
Stellaria	0	0	0	0	0
Taraxacum type	1	0	0	0	0
Adiantum type	0	0	0	0	0
Asplenium	0	0	0	0	0
Cyathea dealbata type	65	40	66	71	61
Dennstaedtiaceae	0	0	0	0	0
Dicksonia squarrosa	6	2	0	3	3
Hymenophyllum	1	0	0	0	0
Hypolepis	2	3	0	0	0
Lycopodium deuterodensum	0	1	0	0	1
Lycopodium ramulosum	0	0	0	0	0
Lycopodium varium	0	0	1	1	0
Lygodium articulatum	0	1	0	0	0
Monolete fern spores	9	11	13	7	6
Paesia scaberula	27	36	40	30	46
Phymatosorus diversifolius	0	1	0	0	1
Polystichum	0	0	0	0	0
Pteridium esculentum	11	3	0	4	6
Pteris	0	0	0	0	0

Depth (m)	**0.6**	**0.7**	**0.8**	**0.9**	**1**
Cyperaceae	4	3	0	2	4
Haloragis	0	1	0	0	0
Myriophyllum	8	0	0	0	0
Restionaceae	0	0	0	0	1
Typha	1	0	0	0	0
Unknowns	0	0	0	0	1
Charcoal	179	5	19	10	20

Depth (m)	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**
Lycopodium spike	82	91	118	126	90
Spike Concentration	13911	11300	13911	11300	13911
Agathis australis	8	5	11	11	12
Alectryon excelsus	1	1	0	0	1
Dacrycarpus dacrydioides	0	5	0	0	0
Dacrydium cupressinum	33	43	26	59	65
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	1	0	1	0	0
Fuscospora	1	0	0	0	0
Hedycarya arborea	0	1	0	1	0
Knightia excelsa	0	2	1	0	1
Libocedrus	20	0	20	0	11
Manoao colensoi	0	0	0	0	0
Metrosideros undiff.	21	12	10	21	5
Nestegis	2	0	1	0	0
Phyllocladus	1	6	6	6	2
Pinus	0	0	0	0	0
Podocarpus type	9	9	10	18	6
Prumnopitys ferruginea	1	1	0	5	0
Prumnopitys taxifolia	7	0	12	0	8
Syzygium maire	0	0	1	0	0
Weinmannia	0	0	0	0	1
Ascarina lucida	5	10	3	11	4
Asteraceae	0	0	0	1	0
Caldcluvia rosifolia	0	0	0	0	0
Coprosma	1	7	2	2	1
Cordyline	1	0	2	1	1
Coriaria	3	0	0	0	0
Dodonaea viscosa	0	0	0	1	0
Epacridaceae	1	1	0	0	0
Fabaceae	0	0	0	0	0
Griselinia	7	1	6	0	2
Gunnera	0	0	0	0	0
Ixerba brexiodes	0	0	0	0	0
Leptospermum type	7	7	2	1	1
Leucopogon fasciculatus	1	1	1	0	0
Malvaceae	0	0	0	0	2
Melicytus	0	0	0	0	0
Muehlenbeckia	0	0	0	0	0
Myrsine	3	0	4	0	1
Neomyrtus type	0	0	0	0	0
Parsonsia	0	0	0	0	0
Pittosporum	1	3	3	1	0
Pomaderris	1	0	0	0	0

Depth (m)	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**
Pseudopanax	0	1	1	1	0
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	3	2	2	2	0
Toronia toru	0	0	0	0	0
Ulex europaeus	0	0	0	0	0
Astelia	1	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Liliaceae	0	0	0	0	0
Phormium	0	0	0	0	0
Plantago	0	0	0	0	0
Poaceae	0	3	0	0	0
Rumex	0	0	0	0	0
Stellaria	0	1	0	0	0
Taraxacum type	0	0	0	0	0
Adiantum type	0	0	0	0	0
Asplenium	0	6	0	6	0
Cyathea dealbata type	56	72	76	90	82
Dennstaedtiaceae	0	1	0	0	0
Dicksonia squarrosa	1	7	1	8	0
Hymenophyllum	0	0	0	1	0
Hypolepis	0	0	0	0	2
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium ramulosum	0	0	0	0	0
Lycopodium varium	0	0	0	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	13	13	8	8	3
Paesia scaberula	28	13	9	11	10
Phymatosorus diversifolius	2	0	1	0	3
Polystichum	0	0	0	0	0
Pteridium esculentum	0	0	1	1	0
Pteris	0	0	0	0	0
Cyperaceae	4	6	2	17	0
Haloragis	0	0	0	0	0
Myriophyllum	1	0	0	0	0
Restionaceae	1	0	0	0	0
Typha	0	0	0	0	0
Unknowns	2	1	1	1	0
Charcoal	2	41	3	18	18

Depth (m)	**1.6**	**1.7**	**1.8**	**1.9**	**2**
Lycopodium spike	100	67	86	94	33
Spike Concentration	11300	13911	11300	13911	11300
Agathis australis	11	8	4	13	3
Alectryon excelsus	0	0	0	0	0
Dacrycarpus dacrydioides	0	0	3	4	4
Dacrydium cupressinum	81	44	69	49	58
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	2	0	0	0
Fuscospora	1	0	1	0	0
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	7	2	0	3	2
Libocedrus	12	9	13	13	7

Depth (m)	**1.6**	**1.7**	**1.8**	**1.9**	**2**
Manoao colensoi	0	0	0	0	0
Metrosideros undiff.	26	1	20	4	13
Nestegis	0	2	0	0	0
Phyllocladus	4	2	7	1	4
Pinus	0	0	0	0	0
Podocarpus type	25	2	7	6	19
Prumnopitys ferruginea	4	0	1	0	2
Prumnopitys taxifolia	7	13	0	11	2
Syzygium maire	0	0	12	0	0
Weinmannia	0	0	0	0	0
Ascarina lucida	10	4	8	2	5
Asteraceae	1	0	0	0	0
Caldcluvia rosifolia	0	0	0	0	0
Coprosma	3	2	2	2	4
Cordyline	2	0	0	1	1
Coriaria	0	0	0	0	0
Dodonaea viscosa	1	0	0	1	0
Epacridaceae	0	0	0	0	0
Fabaceae	2	0	3	0	1
Griselinia	0	2	0	3	0
Gunnera	0	0	0	0	0
Ixerba brexiodes	0	0	0	0	0
Leptospermum type	16	0	17	2	6
Leucopogon fasciculatus	0	0	0	0	0
Malvaceae	1	0	0	1	5
Melicytus	0	0	0	0	1
Muehlenbeckia	0	0	0	0	0
Myrsine	0	0	0	2	0
Neomyrtus type	0	0	0	0	0
Parsonsia	0	0	0	0	0
Pittosporum	6	0	5	2	6
Pomaderris	0	0	0	0	0
Pseudopanax	0	0	0	0	1
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	0	1	1	0	0
Toronia toru	0	0	0	0	0
Ulex europaeus	0	0	0	0	0
Astelia	0	0	0	0	2
Chenopodiaceae	0	0	0	0	0
Liliaceae	0	0	0	0	0
Phormium	1	0	0	0	0
Plantago	0	0	0	0	0
Poaceae	1	0	0	0	1
Rumex	0	0	0	0	0
Stellaria	0	0	0	0	0
Taraxacum type	0	0	0	0	0
Adiantum type	0	0	0	0	0
Asplenium	0	0	1	0	1
Cyathea dealbata type	72	110	40	90	55
Dennstaedtiaceae	0	0	0	0	0
Dicksonia squarrosa	1	2	0	2	5
Hymenophyllum	0	0	0	0	0
Hypolepis	5	2	0	1	0
Lycopodium deuterodensum	0	0	0	0	0

Depth (m)	**1.6**	**1.7**	**1.8**	**1.9**	**2**
Lycopodium ramulosum	0	0	0	0	0
Lycopodium varium	0	0	0	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	7	11	3	10	2
Paesia scaberula	13	12	4	4	4
Phymatosorus diversifolius	0	2	0	3	0
Polystichum	3	0	0	0	0
Pteridium esculentum	0	0	3	0	0
Pteris	0	0	0	0	0
Cyperaceae	8	2	8	2	2
Haloragis	0	0	0	0	1
Myriophyllum	0	0	0	0	1
Restionaceae	0	0	0	1	0
Typha	0	0	0	0	0
Unknowns	0	0	0	0	0
Charcoal	16	36	41	1	27

Depth (m)	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**
Lycopodium spike	66	46	111	85	111
Spike Concentration	13911	11300	13911	11300	13911
Agathis australis	8	6	10	8	0
Alectryon excelsus	1	0	0	0	0
Dacrycarpus dacrydioides	2	2	1	0	0
Dacrydium cupressinum	38	59	50	60	57
Dysoxylum spectabile	0	0	0	1	0
Elaeocarpus	0	1	1	0	0
Fuscospora	0	1	0	2	1
Hedycarya arborea	0	0	0	1	0
Knightia excelsa	1	3	3	0	0
Libocedrus	27	7	13	8	21
Manoao colensoi	1	0	0	0	0
Metrosideros undiff.	34	12	7	18	13
Nestegis	3	0	3	0	3
Phyllocladus	3	8	0	5	2
Pinus	0	0	0	0	0
Podocarpus type	17	19	7	15	9
Prumnopitys ferruginea	0	5	0	4	1
Prumnopitys taxifolia	21	0	16	5	20
Syzygium maire	1	0	0	1	0
Weinmannia	1	0	0	0	0
Ascarina lucida	12	9	5	7	7
Asteraceae	0	0	0	0	2
Caldcluvia rosifolia	0	0	0	0	0
Coprosma	2	8	0	0	1
Cordyline	0	0	0	0	1
Coriaria	0	0	1	0	0
Dodonaea viscosa	0	0	0	0	0
Epacridaceae	0	0	0	0	0
Fabaceae	0	0	1	0	0
Griselinia	1	0	1	0	3
Gunnera	0	0	0	0	0
Ixerba brexiodes	0	0	0	0	0
Leptospermum type	12	5	4	4	3

Depth (m)	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**
Leucopogon fasciculatus	0	0	0	0	0
Malvaceae	0	0	0	1	1
Melicytus	0	0	0	1	0
Muehlenbeckia	0	0	0	0	0
Myrsine	3	0	3	0	0
Neomyrtus type	2	0	0	0	1
Parsonsia	0	0	0	0	0
Pittosporum	1	7	2	8	0
Pomaderris	0	0	0	0	6
Pseudopanax	0	0	0	0	0
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	2	0	1	0	0
Toronia toru	0	0	0	0	0
Ulex europaeus	0	0	0	0	0
Astelia	0	1	0	3	0
Chenopodiaceae	0	0	0	0	0
Liliaceae	0	0	0	0	0
Phormium	0	0	0	1	0
Plantago	0	0	0	0	0
Poaceae	1	1	1	0	0
Rumex	0	0	0	0	0
Stellaria	0	0	0	0	0
Taraxacum type	0	0	0	0	0
Adiantum type	0	0	0	0	0
Asplenium	0	2	0	1	0
Cyathea dealbata type	37	52	47	52	71
Dennstaedtiaceae	0	0	0	0	0
Dicksonia squarrosa	1	6	4	1	0
Hymenophyllum	0	2	0	0	0
Hypolepis	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium ramulosum	0	0	1	0	0
Lycopodium varium	0	0	1	0	0
Lygodium articulatum	1	0	0	0	0
Monolete fern spores	5	11	5	1	6
Paesia scaberula	1	11	6	2	5
Phymatosorus diversifolius	1	0	2	0	1
Polystichum	0	0	0	0	0
Pteridium esculentum	2	0	2	0	2
Pteris	0	0	0	0	0
Cyperaceae	4	6	0	5	3
Haloragis	0	0	0	0	0
Myriophyllum	0	1	0	1	0
Restionaceae	0	0	0	1	0
Typha	0	0	0	0	0
Unknowns	1	2	0	0	0
Charcoal	9	27	2	18	1

Depth (m)	**2.6**	**2.7**	**2.8**	**2.9**	**3**	**3.1**
Lycopodium spike	100	59	116	53	44	51
Spike Concentration	11300	13911	11300	13911	11300	13911
Agathis australis	4	5	3	10	5	5
Alectryon excelsus	0	0	0	0	1	0

Depth (m)	**2.6**	**2.7**	**2.8**	**2.9**	**3**	**3.1**
Dacrycarpus dacrydioides	2	2	1	3	3	2
Dacrydium cupressinum	70	47	70	44	57	51
Dysoxylum spectabile	0	0	0	0	1	0
Elaeocarpus	0	0	1	1	0	2
Fuscospora	0	0	0	0	0	1
Hedycarya arborea	0	0	0	0	0	1
Knightia excelsa	1	2	1	1	3	1
Libocedrus	7	22	5	16	9	20
Manoao colensoi	0	0	0	0	0	1
Metrosideros undiff.	7	14	2	21	24	16
Nestegis	0	2	0	5	0	4
Phyllocladus	3	5	2	6	7	6
Pinus	0	0	0	0	0	0
Podocarpus type	13	5	23	18	26	11
Prumnopitys ferruginea	0	1	4	0	1	7
Prumnopitys taxifolia	4	7	5	11	2	7
Syzygium maire	3	0	2	1	0	0
Weinmannia	0	0	0	0	0	0
Ascarina lucida	2	4	3	3	3	4
Asteraceae	0	1	0	0	0	1
Caldcluvia rosifolia	0	0	0	1	0	0
Coprosma	2	2	5	4	4	5
Cordyline	1	0	0	0	1	1
Coriaria	0	1	0	0	0	0
Dodonaea viscosa	2	0	0	0	0	0
Epacridaceae	0	0	0	1	0	0
Fabaceae	1	0	0	0	3	1
Griselinia	0	3	0	3	0	5
Gunnera	0	0	0	0	0	0
Ixerba brexiodes	0	0	0	0	0	1
Leptospermum type	11	4	7	5	10	9
Leucopogon fasciculatus	0	0	0	0	0	0
Malvaceae	3	0	1	0	1	0
Melicytus	0	0	0	1	0	0
Muehlenbeckia	0	0	0	0	0	0
Myrsine	0	3	0	1	0	2
Neomyrtus type	0	0	0	0	0	1
Parsonsia	0	0	1	0	0	0
Pittosporum	3	3	4	0	4	1
Pomaderris	0	1	0	0	0	0
Pseudopanax	0	0	0	0	3	1
Pseudowintera	0	0	0	0	0	0
Rhopalostylis sapida	0	1	0	1	1	2
Toronia toru	0	0	0	0	0	1
Ulex europaeus	0	0	0	0	0	0
Astelia	3	0	2	0	3	0
Chenopodiaceae	0	0	0	0	0	0
Liliaceae	0	0	0	0	0	1
Phormium	1	0	2	0	1	0
Plantago	0	0	0	0	0	0
Poaceae	1	0	0	1	1	1
Rumex	0	0	0	0	0	0
Stellaria	0	0	0	0	0	0
Taraxacum type	0	0	0	0	0	0

Depth (m)	**2.6**	**2.7**	**2.8**	**2.9**	**3**	**3.1**
Adiantum type	0	1	0	0	0	0
Asplenium	2	0	1	0	0	0
Cyathea dealbata type	65	66	67	50	31	38
Dennstaedtiaceae	0	0	0	0	0	0
Dicksonia squarrosa	1	0	2	0	5	0
Hymenophyllum	0	0	0	1	0	0
Hypolepis	0	0	0	1	0	1
Lycopodium deuterodensum	0	1	0	0	0	0
Lycopodium ramulosum	0	0	0	0	0	0
Lycopodium varium	0	0	0	0	0	0
Lygodium articulatum	0	0	0	1	0	0
Monolete fern spores	5	6	0	6	4	5
Paesia scaberula	0	2	3	0	1	0
Phymatosorus diversifolius	0	1	4	2	0	1
Polystichum	0	0	0	0	0	0
Pteridium esculentum	0	0	0	0	0	1
Pteris	0	0	0	0	0	0
Cyperaceae	4	0	6	1	7	2
Haloragis	1	0	0	0	0	0
Myriophyllum	1	1	0	0	0	0
Restionaceae	3	0	0	0	3	0
Typha	0	0	0	0	0	0
Unknowns	0	0	0	0	3	0
Charcoal	11	0	8	0	75	0

Depth (m)	**3.2**	**3.3**	**3.4**	**3.5**	**3.6**	**3.8**
Lycopodium spike	108	67	107	52	90	50
Spike Concentration	11300	13911	11300	13911	11300	11300
Agathis australis	5	4	2	8	1	0
Alectryon excelsus	0	2	0	2	2	0
Dacrycarpus dacrydioides	2	0	0	1	1	0
Dacrydium cupressinum	50	44	36	39	44	8
Dysoxylum spectabile	0	0	0	0	0	0
Elaeocarpus	0	1	0	3	0	0
Fuscospora	0	1	0	0	0	0
Hedycarya arborea	0	0	0	1	0	0
Knightia excelsa	0	5	1	0	3	2
Libocedrus	0	14	2	19	2	0
Manoao colensoi	0	1	0	1	0	0
Metrosideros undiff.	9	0	6	20	6	2
Nestegis	0	0	0	2	0	0
Phyllocladus	5	5	3	3	7	4
Pinus	0	0	0	0	0	0
Podocarpus type	10	10	6	11	10	1
Prumnopitys ferruginea	1	0	3	2	3	0
Prumnopitys taxifolia	14	8	0	9	0	0
Syzygium maire	5	4	6	1	5	6
Weinmannia	0	0	0	0	0	0
Ascarina lucida	0	4	5	10	3	0
Asteraceae	0	0	1	0	0	0
Caldcluvia rosifolia	0	0	0	0	0	0
Coprosma	4	9	5	3	4	0
Cordyline	0	0	1	0	4	0

Depth (m)	**3.2**	**3.3**	**3.4**	**3.5**	**3.6**	**3.8**
Coriaria	0	1	0	0	0	0
Dodonaea viscosa	0	0	1	0	2	0
Epacridaceae	0	1	3	0	0	0
Fabaceae	1	1	1	2	3	1
Griselinia	0	0	0	5	0	0
Gunnera	0	0	0	0	0	0
Ixerba brexiodes	0	0	0	0	0	0
Leptospermum type	2	4	2	8	4	0
Leucopogon fasciculatus	0	0	0	0	0	0
Malvaceae	1	0	0	1	0	0
Melicytus	0	0	0	0	0	0
Muehlenbeckia	0	0	0	0	0	0
Myrsine	0	6	0	0	0	0
Neomyrtus type	0	0	0	0	0	0
Parsonsia	0	0	0	0	0	0
Pittosporum	6	0	6	1	4	0
Pomaderris	0	0	0	0	0	0
Pseudopanax	0	0	0	0	0	0
Pseudowintera	0	0	0	0	0	0
Rhopalostylis sapida	0	1	0	5	5	5
Toronia toru	0	0	0	1	0	0
Ulex europaeus	0	0	0	0	0	0
Astelia	0	0	2	0	1	0
Chenopodiaceae	0	1	0	0	0	0
Liliaceae	0	0	0	3	0	0
Phormium	3	0	6	0	3	14
Plantago	0	0	0	0	0	0
Poaceae	1	1	3	1	8	0
Rumex	0	0	0	0	0	0
Stellaria	0	0	0	0	0	0
Taraxacum type	0	0	0	0	0	0
Adiantum type	0	0	0	0	0	0
Asplenium	5	0	6	0	1	2
Cyathea dealbata type	89	63	92	72	74	243
Dennstaedtiaceae	0	0	0	0	0	0
Dicksonia squarrosa	1	1	0	0	3	1
Hymenophyllum	2	0	1	0	2	0
Hypolepis	0	2	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0	0
Lycopodium ramulosum	0	0	0	0	0	0
Lycopodium varium	0	0	0	0	0	0
Lygodium articulatum	0	0	1	0	0	0
Monolete fern spores	3	6	5	6	1	7
Paesia scaberula	3	1	0	0	0	0
Phymatosorus diversifolius	1	6	0	6	2	6
Polystichum	0	0	0	0	0	0
Pteridium esculentum	0	1	0	0	0	0
Pteris	0	0	0	1	0	0
Cyperaceae	4	0	10	2	0	5
Haloragis	0	0	0	0	0	2
Myriophyllum	1	0	15	4	2	0
Restionaceae	1	0	1	0	2	2
Typha	0	0	0	0	0	0
Unknowns	0	1	0	0	0	1
Charcoal	23	0	11	0	10	80

APPENDIX 4

Wharau Road Swamp pollen counts:

Depth (m)	**0.35**	**0.45**	**0.55**	**0.65**	**0.75**
Lycopodium spike	62	108	162	406	107
Spike Concentration	11300	13911	11300	13911	11300
Agathis australis	0	1	0	2	1
Alectryon excelsus	0	0	0	0	0
Cupressus	2	2	3	0	0
Dacrycarpus dacrydioides	4	2	2	2	2
Dacrydium cupressinum	14	3	15	19	8
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	0	0	2	0
Fuscospora	0	2	0	0	2
Hedycarya arborea	0	2	0	0	0
Knightia excelsa	0	0	0	0	0
Laurelia novae-zelandiae	0	0	0	0	0
Libocedrus	0	0	0	3	0
Manoao colensoi	0	0	0	0	0
Metrosideros undiff.	0	2	0	0	1
Nestegis	0	0	0	0	0
Nothofagus menziesii	0	0	0	0	0
Phyllocladus	0	3	2	4	3
Pinus	4	2	2	0	0
Podocarpus type	8	2	3	4	4
Prumnopitys ferruginea	5	0	2	0	0
Prumnopitys taxifolia	0	7	0	8	0
Syzygium maire	0	0	0	0	0
Vitex lucens	0	0	0	0	0
Weinmannia	0	0	0	0	0
Ascarina lucida	0	0	1	0	2
Asteraceae	0	0	0	1	0
Coprosma	1	1	1	2	4
Cordyline	1	2	1	0	0
Coriaria	0	6	0	2	4
Dodonaea viscosa	1	1	3	0	0
Epacridaceae	0	0	0	0	0
Fabaceae	0	0	0	0	0
Griselinia	0	1	4	7	2
Leucopogon fasciculatus	0	0	0	0	0
Malvaceae	0	0	0	0	0
Myrsine	0	1	0	0	0
Neomyrtus type	0	0	0	0	0
Pittosporum	0	0	0	0	0
Pomaderris	0	0	0	0	0
Pseudopanax	1	0	0	0	0
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	2	2	1	9	2
Schefflera digitata	0	0	0	0	0
Apiaceae	0	0	0	0	0
Astelia	0	0	0	0	0
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	0	2
Epilobium	1	0	0	0	0
Hydrocotyle novae-zelandiae	0	0	0	0	0
Ileostylus micranthus	0	0	0	0	0

Depth (m)	**0.35**	**0.45**	**0.55**	**0.65**	**0.75**
Liliaceae	0	0	0	0	0
Phormium	0	0	0	0	0
Poaceae	28	11	42	7	36
Taraxacum type	1	0	0	0	0
Cyathea dealbata type	24	13	11	27	6
Cyathea smithii type	0	0	1	0	0
Dennstaedtiaceae	0	1	2	0	0
Dicksonia	12	1	0	0	1
Histiopteris	0	0	0	0	0
Hymenophyllaceae	0	4	3	0	0
Hypolepis	0	0	0	0	0
Lycopodium	0	0	0	2	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	16	5	9	20	4
Paesia scaberula	0	2	0	0	0
Phymatosorus diversifolius	0	2	0	2	1
Pteridaceae	0	0	0	0	0
Pteridium esculentum	22	54	35	80	66
Cyperaceae	3	83	7	87	124
Drosera	0	0	0	2	0
Gleichenia	52	37	18	17	0
Haloragaceae	0	0	0	0	0
Haloragis	2	8	1	0	0
Leptospermum type	5	84	6	2	4
Myriophyllum	5	1	0	0	6
Restionaceae	1	2	5	11	28
Typha	3	20	6	8	4
Unknowns	7	7	2	1	0
Charcoal	49	203	82	23	134

Depth (m)	**0.85**	**0.95**	**1.05**	**1.15**	**1.25**
Lycopodium spike	202	218	132	300	154
Spike Concentration	13911	11300	13911	11300	13911
Agathis australis	1	10	9	7	11
Alectryon excelsus	0	0	0	0	0
Cupressus	0	0	0	0	0
Dacrycarpus dacrydioides	0	1	0	2	0
Dacrydium cupressinum	5	25	39	61	35
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	0	1	0	2
Fuscospora	1	2	0	1	0
Hedycarya arborea	0	0	1	1	0
Knightia excelsa	1	0	0	0	0
Laurelia novae-zelandiae	0	0	0	0	0
Libocedrus	1	0	11	0	7
Manoao colensoi	0	0	0	0	0
Metrosideros undiff.	1	0	9	4	3
Nestegis	0	0	5	0	3
Nothofagus menziesii	0	0	0	0	0
Phyllocladus	4	3	18	14	22
Pinus	0	0	0	0	0
Podocarpus type	4	7	5	13	5
Prumnopitys ferruginea	0	3	0	4	4

Depth (m)	**0.85**	**0.95**	**1.05**	**1.15**	**1.25**
Prumnopitys taxifolia	5	1	7	0	2
Syzygium maire	0	0	0	0	0
Vitex lucens	0	0	0	0	0
Weinmannia	0	0	0	0	0
Ascarina lucida	2	0	3	2	7
Asteraceae	0	0	0	0	0
Coprosma	1	3	11	9	34
Cordyline	0	0	0	0	0
Coriaria	2	0	0	0	0
Dodonaea viscosa	0	0	0	0	1
Epacridaceae	0	0	0	0	0
Fabaceae	0	0	0	1	0
Griselinia	0	2	0	0	7
Leucopogon fasciculatus	0	0	0	0	0
Malvaceae	0	0	0	0	0
Myrsine	3	0	2	2	3
Neomyrtus type	0	0	0	0	0
Pittosporum	0	0	0	1	0
Pomaderris	0	0	0	0	0
Pseudopanax	0	0	0	0	0
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	15	2	5	2	0
Schefflera digitata	0	0	0	0	0
Apiaceae	0	0	0	0	0
Astelia	0	0	0	0	0
Caryophyllaceae	0	0	0	1	0
Chenopodiaceae	0	0	0	3	0
Epilobium	0	0	0	0	0
Hydrocotyle novae-zelandiae	0	0	0	0	0
Ileostylus micranthus	0	0	0	0	1
Liliaceae	0	0	0	0	0
Phormium	0	0	0	0	0
Poaceae	2	9	0	5	0
Taraxacum type	1	0	0	0	0
Cyathea dealbata type	7	22	7	15	7
Cyathea smithii type	0	3	0	0	0
Dennstaedtiaceae	0	0	0	0	0
Dicksonia	0	3	0	6	0
Histiopteris	0	0	0	0	0
Hymenophyllaceae	0	1	0	0	0
Hypolepis	0	3	0	0	0
Lycopodium	0	0	0	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	0	2	1	4	0
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	0	0	0	0	0
Pteridaceae	0	0	0	0	0
Pteridium esculentum	119	46	41	8	1
Cyperaceae	152	49	114	5	89
Drosera	2	1	1	1	1
Gleichenia	9	0	14	28	4
Haloragaceae	0	0	0	1	0
Haloragis	2	0	0	0	0
Leptospermum type	21	8	35	14	52

Depth (m)	**0.85**	**0.95**	**1.05**	**1.15**	**1.25**
Myriophyllum	0	2	0	0	0
Restionaceae	21	44	23	30	42
Typha	3	3	0	0	2
Unknowns	0	1	0	0	0
Charcoal	226	50	94	5.4	21

Depth (m)	**1.35**	**1.45**	**1.55**	**1.65**	**1.75**
Lycopodium spike	162	77	333	85	127
Spike Concentration	11300	13911	11300	13911	11300
Agathis australis	10	3	5	5	8
Alectryon excelsus	0	0	0	0	0
Cupressus	0	0	0	0	0
Dacrycarpus dacrydioides	0	0	2	1	0
Dacrydium cupressinum	47	26	55	35	46
Dysoxylum spectabile	0	0	3	0	0
Elaeocarpus	0	3	0	1	0
Fuscospora	0	1	0	0	0
Hedycarya arborea	2	1	0	0	0
Knightia excelsa	1	3	1	0	2
Laurelia novae-zelandiae	0	0	0	0	0
Libocedrus	2	4	0	2	0
Manoao colensoi	0	0	0	0	0
Metrosideros undiff.	9	2	15	6	4
Nestegis	0	5	0	2	0
Nothofagus menziesii	0	0	0	0	0
Phyllocladus	20	37	16	15	6
Pinus	0	0	0	0	0
Podocarpus type	13	10	7	7	15
Prumnopitys ferruginea	0	0	1	0	5
Prumnopitys taxifolia	4	2	3	2	0
Syzygium maire	4	1	4	1	4
Vitex lucens	0	0	0	0	0
Weinmannia	0	0	0	0	0
Ascarina lucida	1	3	4	9	8
Asteraceae	0	0	0	0	0
Coprosma	47	18	19	10	11
Cordyline	0	0	0	0	0
Coriaria	0	0	0	0	0
Dodonaea viscosa	0	0	2	0	0
Epacridaceae	0	0	0	0	0
Fabaceae	3	0	1	0	0
Griselinia	12	7	8	1	6
Leucopogon fasciculatus	0	0	0	0	0
Malvaceae	0	0	0	0	0
Myrsine	0	1	0	3	0
Neomyrtus type	0	0	0	0	0
Pittosporum	2	1	1	1	0
Pomaderris	0	0	0	0	0
Pseudopanax	0	0	0	0	0
Pseudowintera	0	0	0	2	0
Rhopalostylis sapida	0	0	0	1	1
Schefflera digitata	0	0	0	0	0
Apiaceae	0	0	0	0	0

Depth (m)	**1.35**	**1.45**	**1.55**	**1.65**	**1.75**
Astelia	1	0	0	0	0
Caryophyllaceae	0	0	0	0	1
Chenopodiaceae	0	0	0	0	0
Epilobium	0	0	0	0	0
Hydrocotyle novae-zelandiae	0	0	0	0	0
Ileostylus micranthus	0	0	0	0	0
Liliaceae	0	0	0	0	0
Phormium	0	0	1	0	0
Poaceae	4	0	7	0	3
Taraxacum type	0	0	0	0	0
Cyathea dealbata type	10	4	9	6	21
Cyathea smithii type	0	0	0	0	0
Dennstaedtiaceae	0	0	0	0	0
Dicksonia	0	0	0	0	0
Histiopteris	0	0	0	0	0
Hymenophyllaceae	0	0	0	0	0
Hypolepis	0	0	0	0	1
Lycopodium	0	0	0	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	0	1	2	1	1
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	0	0	0	2	0
Pteridaceae	0	0	0	0	0
Pteridium esculentum	0	2	0	0	0
Cyperaceae	8	58	11	88	37
Drosera	1	0	0	0	0
Gleichenia	0	0	0	5	0
Haloragaceae	0	0	0	0	0
Haloragis	0	0	0	0	0
Leptospermum type	21	76	13	136	27
Myriophyllum	0	0	0	0	2
Restionaceae	57	27	34	38	52
Typha	1	0	0	0	0
Unknowns	0	0	2	0	0
Charcoal	2	4	1	1	0

Depth (m)	**1.85**	**1.95**	**2.05**	**2.15**	**2.25**
Lycopodium spike	25	156	543	219	228
Spike Concentration	13911	11300	13911	11300	13911
Agathis australis	3	13	18	29	18
Alectryon excelsus	0	0	1	0	0
Cupressus	0	0	0	0	0
Dacrycarpus dacrydioides	0	1	0	2	0
Dacrydium cupressinum	27	66	61	91	41
Dysoxylum spectabile	0	0	0	3	0
Elaeocarpus	9	0	2	0	1
Fuscospora	0	0	0	2	0
Hedycarya arborea	0	1	0	1	0
Knightia excelsa	1	0	0	0	0
Laurelia novae-zelandiae	0	0	0	0	0
Libocedrus	1	5	5	3	16
Manoao colensoi	0	0	0	0	0
Metrosideros undiff.	9	17	5	2	4

Depth (m)	**1.85**	**1.95**	**2.05**	**2.15**	**2.25**
Nestegis	4	0	1	0	3
Nothofagus menziesii	0	0	1	0	0
Phyllocladus	11	11	5	10	10
Pinus	0	0	0	0	0
Podocarpus type	8	17	8	7	11
Prumnopitys ferruginea	0	1	3	2	1
Prumnopitys taxifolia	2	6	11	6	3
Syzygium maire	2	5	0	1	3
Vitex lucens	0	0	0	0	0
Weinmannia	0	0	0	2	0
Ascarina lucida	4	2	1	3	1
Asteraceae	0	0	1	1	0
Coprosma	14	4	8	4	10
Cordyline	0	1	1	0	2
Coriaria	0	0	0	0	0
Dodonaea viscosa	0	3	0	1	0
Epacridaceae	1	0	0	0	0
Fabaceae	2	4	0	0	0
Griselinia	8	8	2	7	6
Leucopogon fasciculatus	0	0	1	0	1
Malvaceae	0	0	0	0	0
Myrsine	5	0	5	0	1
Neomyrtus type	0	0	0	0	2
Pittosporum	1	0	0	0	2
Pomaderris	0	0	0	0	0
Pseudopanax	0	0	0	0	1
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	1	0	0	0	0
Schefflera digitata	0	0	0	0	0
Apiaceae	0	0	2	0	0
Astelia	0	2	0	0	0
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Epilobium	0	0	0	0	0
Hydrocotyle novae-zelandiae	0	0	0	0	0
Ileostylus micranthus	2	0	0	0	0
Liliaceae	0	0	0	0	0
Phormium	0	0	0	1	0
Poaceae	0	0	1	1	1
Taraxacum type	0	0	0	0	0
Cyathea dealbata type	16	31	12	23	14
Cyathea smithii type	0	0	0	0	0
Dennstaedtiaceae	0	0	0	0	0
Dicksonia	0	0	0	2	0
Histiopteris	0	0	0	0	0
Hymenophyllaceae	0	0	0	2	0
Hypolepis	0	0	0	0	0
Lycopodium	0	0	2	0	0
Lygodium articulatum	0	1	0	0	0
Monolete fern spores	4	5	3	2	1
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	0	0	1	0	0
Pteridaceae	0	0	0	0	0
Pteridium esculentum	0	0	2	0	0

Depth (m)	**1.85**	**1.95**	**2.05**	**2.15**	**2.25**
Cyperaceae	0	13	131	40	214
Drosera	0	1	0	0	0
Gleichenia	8	0	2	0	0
Haloragaceae	0	0	0	0	0
Haloragis	0	0	2	0	0
Leptospermum type	111	22	29	4	48
Myriophyllum	0	0	0	0	0
Restionaceae	65	78	44	58	26
Typha	0	0	1	0	0
Unknowns	0	0	0	0	0
Charcoal	3	0	0	0.5	0

Depth (m)	**2.35**	**2.45**	**2.55**	**2.65**	**2.75**
Lycopodium spike	422	486	187	144	56
Spike Concentration	11300	13911	11300	13911	11300
Agathis australis	15	21	8	7	5
Alectryon excelsus	0	1	0	5	1
Cupressus	0	0	0	0	0
Dacrycarpus dacrydioides	0	3	2	1	2
Dacrydium cupressinum	52	71	53	46	36
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	0	0	1	0
Fuscospora	0	1	0	1	0
Hedycarya arborea	0	0	1	1	1
Knightia excelsa	0	0	2	3	2
Laurelia novae-zelandiae	0	0	0	0	0
Libocedrus	4	3	0	6	0
Manoao colensoi	0	0	0	0	0
Metrosideros undiff.	7	3	13	6	50
Nestegis	0	3	0	11	0
Nothofagus menziesii	0	0	0	0	0
Phyllocladus	9	9	5	7	5
Pinus	0	0	0	0	0
Podocarpus type	12	2	16	3	6
Prumnopitys ferruginea	3	4	0	2	2
Prumnopitys taxifolia	2	10	0	4	0
Syzygium maire	0	0	0	1	3
Vitex lucens	0	0	0	0	0
Weinmannia	1	0	0	0	0
Ascarina lucida	2	2	1	2	7
Asteraceae	0	0	1	0	0
Coprosma	5	4	9	6	8
Cordyline	0	1	0	1	1
Coriaria	0	0	0	0	0
Dodonaea viscosa	1	0	5	1	1
Epacridaceae	0	0	0	1	0
Fabaceae	0	0	0	0	1
Griselinia	7	0	6	1	4
Leucopogon fasciculatus	0	0	0	1	0
Malvaceae	0	0	0	0	0
Myrsine	0	3	0	0	0
Neomyrtus type	0	0	0	4	0
Pittosporum	0	0	0	0	0

Depth (m)	**2.35**	**2.45**	**2.55**	**2.65**	**2.75**
Pomaderris	0	0	1	0	0
Pseudopanax	0	0	0	1	1
Pseudowintera	1	1	2	0	0
Rhopalostylis sapida	0	0	1	1	3
Schefflera digitata	0	0	0	0	0
Apiaceae	0	0	0	2	0
Astelia	0	0	0	0	0
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Epilobium	0	0	0	0	0
Hydrocotyle novae-zelandiae	0	0	0	0	0
Ileostylus micranthus	0	0	0	0	0
Liliaceae	0	0	0	0	0
Phormium	0	0	0	0	0
Poaceae	3	0	21	1	11
Taraxacum type	0	0	0	0	0
Cyathea dealbata type	8	20	4	44	15
Cyathea smithii type	0	0	0	0	0
Dennstaedtiaceae	0	0	0	0	0
Dicksonia	0	0	1	0	2
Histiopteris	0	0	1	0	0
Hymenophyllaceae	0	0	0	0	0
Hypolepis	1	0	0	0	0
Lycopodium	1	0	2	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	3	0	3	8	3
Paesia scaberula	0	0	0	4	0
Phymatosorus diversifolius	0	0	1	1	0
Pteridaceae	0	1	0	0	0
Pteridium esculentum	0	1	0	0	1
Cyperaceae	29	116	48	35	4
Drosera	0	0	0	0	0
Gleichenia	0	0	0	0	0
Haloragaceae	0	0	0	0	0
Haloragis	0	1	2	0	1
Leptospermum type	17	39	18	37	20
Myriophyllum	9	5	391	8	10
Restionaceae	14	12	14	0	0
Typha	0	1	0	1	0
Unknowns	1	1	0	0	0
Charcoal	0.5	0	0.5	0	0

Depth (m)	**2.85**	**2.95**	**3.05**	**3.15**	**3.25**
Lycopodium spike	91	75	57	86	20
Spike Concentration	13911	11300	13911	11300	13911
Agathis australis	6	3	12	12	4
Alectryon excelsus	0	0	1	0	4
Cupressus	0	0	0	0	0
Dacrycarpus dacrydioides	1	2	0	1	1
Dacrydium cupressinum	59	44	65	69	38
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	0	2	0	1
Fuscospora	0	0	1	0	1

Depth (m)	**2.85**	**2.95**	**3.05**	**3.15**	**3.25**
Hedycarya arborea	0	2	0	1	0
Knightia excelsa	2	12	3	0	2
Laurelia novae-zelandiae	0	0	1	0	1
Libocedrus	3	0	2	0	12
Manoao colensoi	1	0	0	0	1
Metrosideros undiff.	5	25	6	3	8
Nestegis	1	0	5	0	5
Nothofagus menziesii	0	0	0	0	0
Phyllocladus	4	3	2	3	10
Pinus	0	0	0	0	0
Podocarpus type	2	4	3	16	5
Prumnopitys ferruginea	1	3	1	0	1
Prumnopitys taxifolia	5	0	3	2	5
Syzygium maire	0	0	0	6	0
Vitex lucens	0	0	0	0	0
Weinmannia	0	0	0	0	0
Ascarina lucida	4	9	10	5	2
Asteraceae	0	0	1	0	0
Coprosma	23	12	11	18	9
Cordyline	0	2	0	0	0
Coriaria	0	0	0	0	0
Dodonaea viscosa	0	2	0	2	0
Epacridaceae	0	0	0	0	1
Fabaceae	0	0	0	1	0
Griselinia	0	3	4	11	3
Leucopogon fasciculatus	1	0	1	0	0
Malvaceae	0	0	0	2	0
Myrsine	0	0	2	1	7
Neomyrtus type	0	0	3	0	4
Pittosporum	1	0	0	0	0
Pomaderris	0	0	0	0	0
Pseudopanax	0	0	0	1	0
Pseudowintera	2	2	1	1	1
Rhopalostylis sapida	0	3	1	2	0
Schefflera digitata	1	0	0	0	1
Apiaceae	0	0	0	0	0
Astelia	0	0	0	1	0
Caryophyllaceae	1	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Epilobium	0	0	0	0	0
Hydrocotyle novae-zelandiae	3	0	0	0	5
Ileostylus micranthus	1	0	0	0	0
Liliaceae	0	0	0	0	0
Phormium	0	0	0	1	0
Poaceae	0	9	0	0	0
Taraxacum type	0	0	0	0	0
Cyathea dealbata type	55	41	60	27	23
Cyathea smithii type	5	7	5	0	2
Dennstaedtiaceae	0	0	0	0	0
Dicksonia	0	2	0	0	0
Histiopteris	0	0	0	0	0
Hymenophyllaceae	0	0	0	1	0
Hypolepis	0	0	0	0	0
Lycopodium	0	0	0	0	1

Depth (m)	**2.85**	**2.95**	**3.05**	**3.15**	**3.25**
Lygodium articulatum	0	0	1	0	0
Monolete fern spores	8	3	4	4	8
Paesia scaberula	1	3	2	0	2
Phymatosorus diversifolius	0	0	1	0	0
Pteridaceae	0	0	0	0	0
Pteridium esculentum	0	2	0	0	1
Cyperaceae	6	9	16	13	27
Drosera	0	0	0	0	0
Gleichenia	0	0	0	0	0
Haloragaceae	0	0	0	0	0
Haloragis	0	0	0	0	0
Leptospermum type	25	5	32	11	53
Myriophyllum	0	11	9	77	69
Restionaceae	0	0	2	14	9
Typha	0	0	2	0	2
Unknowns	0	1	0	0	0
Charcoal	0	0	0	1	0

Depth (m)	**3.35**	**3.45**	**3.5**
Lycopodium spike	56	37	51
Spike Concentration	11300	13911	11300
Agathis australis	2	3	1
Alectryon excelsus	0	1	0
Cupressus	0	0	0
Dacrycarpus dacrydioides	1	2	0
Dacrydium cupressinum	71	30	78
Dysoxylum spectabile	0	0	0
Elaeocarpus	0	2	0
Fuscospora	0	0	1
Hedycarya arborea	1	0	0
Knightia excelsa	2	1	1
Laurelia novae-zelandiae	0	0	0
Libocedrus	1	3	4
Manoao colensoi	0	0	0
Metrosideros undiff.	0	4	0
Nestegis	0	4	0
Nothofagus menziesii	0	0	0
Phyllocladus	3	3	0
Pinus	0	0	0
Podocarpus type	15	6	8
Prumnopitys ferruginea	0	0	0
Prumnopitys taxifolia	3	1	2
Syzygium maire	4	0	1
Vitex lucens	0	1	0
Weinmannia	0	0	0
Ascarina lucida	13	6	6
Asteraceae	0	0	1
Coprosma	3	5	2
Cordyline	1	3	0
Coriaria	0	0	0
Dodonaea viscosa	0	0	0
Epacridaceae	0	0	0
Fabaceae	0	0	2

Depth (m)	**3.35**	**3.45**	**3.5**
Griselinia	0	1	4
Leucopogon fasciculatus	0	0	0
Malvaceae	1	0	0
Myrsine	0	2	1
Neomyrtus type	0	3	0
Pittosporum	0	1	0
Pomaderris	0	0	0
Pseudopanax	0	0	1
Pseudowintera	1	1	7
Rhopalostylis sapida	3	2	4
Schefflera digitata	0	0	0
Apiaceae	0	0	0
Astelia	5	0	0
Caryophyllaceae	0	0	0
Chenopodiaceae	0	0	0
Epilobium	0	0	0
Hydrocotyle novae-zelandiae	0	0	0
Ileostylus micranthus	0	0	0
Liliaceae	0	1	0
Phormium	4	1	3
Poaceae	4	0	3
Taraxacum type	0	0	0
Cyathea dealbata type	63	35	41
Cyathea smithii type	0	3	5
Dennstaedtiaceae	0	0	0
Dicksonia	0	0	0
Histiopteris	0	0	1
Hymenophyllaceae	0	0	0
Hypolepis	0	0	0
Lycopodium	1	0	0
Lygodium articulatum	0	0	0
Monolete fern spores	3	2	2
Paesia scaberula	1	2	5
Phymatosorus diversifolius	0	1	0
Pteridaceae	0	0	0
Pteridium esculentum	0	0	0
Cyperaceae	10	16	1
Drosera	0	0	1
Gleichenia	0	0	0
Haloragaceae	0	0	0
Haloragis	0	0	0
Leptospermum type	7	19	8
Myriophyllum	79	38	20
Restionaceae	17	6	7
Typha	0	0	0
Unknowns	0	0	0
Charcoal	0	0	6

APPENDIX 5

Kaitaia Bog borehole 3 pollen counts:

Depth (m)	**0.05**	**0.15**	**0.25**	**0.35**	**0.45**
Lycopodium spike	205	417	300	316	417
Spike concentration	13911	13911	13911	13911	13911
Fuscospora	1	3	1	2	1
Agathis australis	4	16	5	4	7
Casuarina	0	0	0	0	0
Dacrycarpus dacrydioides	2	2	0	3	4
Dacrydium cupressinum	38	92	75	82	90
Halocarpus	0	0	0	0	0
Libocedrus	1	3	0	1	4
Manoao colensoi	0	0	0	0	0
Phyllocladus	3	7	19	30	18
Podocarpus type	6	11	9	9	16
Prumnopitys ferruginea	1	1	0	0	1
Prumnopitys taxifolia	4	25	16	20	19
Alectryon excelsus	0	0	0	0	0
Beilschmiedia	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	0	0	1	0
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	0	0	1	0	1
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	0	0	6	4	1
Nestegis	0	0	1	4	3
Nothofagus menziesii	0	0	0	0	0
Quintinia	0	0	0	0	0
Syzygium maire	0	0	1	0	1
Vitex lucens	0	0	0	0	0
Weinmannia	0	0	0	0	0
Alseuosmia	0	0	0	0	0
Aristotelia	0	0	0	0	0
Ascarina lucida	0	2	2	5	3
Asteraceae	0	1	1	0	0
Carpodetus serratus	0	0	0	0	0
Coprosma	2	4	4	2	3
Cordyline	0	0	0	1	0
Coriaria	1	0	0	0	0
Dodonaea viscosa	1	4	2	4	0
Fabaceae	0	1	1	1	0
Fuschia	0	0	0	0	0
Griselinia	1	3	0	1	1
Leucopogon fasciculatus	0	0	0	0	0
Macropiper	0	0	0	0	0
Malvaceae	0	0	0	0	0
Myrsine	3	0	0	1	1
Neomyrtus type	10	0	2	2	4
Pittosporum	0	0	0	0	0
Plagianthus type	0	0	0	0	0
Pseudopanax	0	0	0	1	0
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	0	0	0	0	1
Schefflera digitata	0	0	0	0	0
Toronia toru	0	0	0	0	0

Depth (m)	**0.05**	**0.15**	**0.25**	**0.35**	**0.45**
Amaranthaceae	0	1	0	0	0
Astelia	0	0	0	0	0
Caryophyllaceae	1	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Dactylanthus taylorii	0	0	0	0	0
Epilobium	0	0	0	0	0
Freycinetia	0	0	0	0	0
Ileostylus micranthus	0	0	0	0	0
Liliaceae	3	0	0	0	0
Plantago	0	0	0	0	0
Poaceae	19	1	1	0	0
Taraxacum type	1	0	0	0	0
Tupeia antarctica	0	0	0	0	0
Adiantum type	0	0	0	0	0
Cyathea dealbata type	6	4	4	5	7
Cyathea smithii type	0	0	0	0	0
Dicksonia fibrosa	0	0	0	0	0
Dicksonia squarrosa	0	0	0	0	0
Hymenophyllum	0	0	0	0	0
Lycopodium cemuum	0	1	0	0	0
Lycopodium deuterodensum	0	0	1	0	0
Lycopodium laterale	0	0	0	0	0
Lycopodium ramulosum	0	0	0	0	0
Monolete fern spores	1	5	3	1	4
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	0	1	1	0	2
Pteridium esculentum	55	0	0	0	0
Pteris	0	0	0	0	0
Cyperaceae	38	5	4	0	6
Drosera	0	0	0	0	0
Epacridaceae	6	18	24	14	12
Gleichenia	59	160	98	66	217
Haloragis	1	0	0	0	0
Leptospermum type	37	1	3	5	6
Myriophyllum	0	0	0	0	0
Potamageton	0	0	0	0	0
Restionaceae	97	158	122	240	73
Typha	2	0	0	0	0
Unknowns	0	2	1	0	1
Charcoal concentration	32	3	5	2	5

Depth (m)	**0.55**	**0.65**	**0.75**	**0.85**	**0.95**
Lycopodium spike	265	564	264	390	271
Spike concentration	13911	13911	13911	13911	13911
Fuscospora	1	5	3	3	1
Agathis australis	5	12	10	13	3
Casuarina	0	0	0	0	0
Dacrycarpus dacrydioides	4	3	6	4	0
Dacrydium cupressinum	100	84	94	77	47
Halocarpus	0	3	0	1	0
Libocedrus	2	4	1	8	2
Manoao colensoi	0	6	0	4	0
Phyllocladus	10	19	15	15	5

Depth (m)	**0.55**	**0.65**	**0.75**	**0.85**	**0.95**
Podocarpus type	11	7	7	15	4
Prumnopitys ferruginea	2	7	1	6	0
Prumnopitys taxifolia	13	8	26	11	15
Alectryon excelsus	0	0	0	1	0
Beilschmiedia	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	0	0	2	0
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	1	0	0	4	0
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros type	10	6	6	19	0
Nestegis	0	2	0	6	2
Nothofagus menziesii	0	0	0	0	0
Quintinia	0	0	0	0	0
Syzygium maire	0	0	0	0	1
Vitex lucens	0	0	0	0	0
Weinmannia	0	0	0	0	0
Alseuosmia	0	0	0	0	0
Aristotelia	0	0	0	0	0
Ascarina lucida	2	2	3	4	6
Asteraceae	0	0	2	0	0
Carpodetus serratus	0	0	0	0	0
Coprosma	2	4	1	7	0
Cordyline	1	0	0	0	0
Coriaria	0	0	0	0	0
Dodonaea viscosa	0	1	2	2	2
Fabaceae	0	0	0	0	0
Fuschia	0	0	0	0	0
Griselinia	0	4	2	1	2
Leucopogon fasciculatus	0	0	0	0	0
Macropiper	0	0	0	0	0
Malvaceae	0	0	0	0	0
Myrsine	0	1	0	1	1
Neomyrtus type	1	5	0	2	0
Pittosporum	1	0	0	0	0
Plagianthus type	0	0	0	0	0
Pseudopanax	0	1	0	0	1
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	0	1	0	2	0
Schefflera digitata	0	1	0	0	0
Toronia toru	0	0	0	0	0
Amaranthaceae	0	0	0	0	0
Astelia	0	1	0	0	0
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Dactylanthus taylorii	0	0	0	0	0
Epilobium	0	0	0	0	0
Freycinetia	0	1	0	0	0
Ileostylus micranthus	0	0	0	1	0
Liliaceae	0	2	0	1	0
Plantago	0	0	0	0	0
Poaceae	4	0	0	1	0
Taraxacum type	3	1	0	0	0
Tupeia antarctica	0	1	0	1	0

Depth (m)	**0.55**	**0.65**	**0.75**	**0.85**	**0.95**
Adiantum type	0	1	0	1	0
Cyathea dealbata type	3	4	9	5	4
Cyathea smithii type	0	4	0	0	0
Dicksonia fibrosa	0	0	0	0	0
Dicksonia squarrosa	0	1	0	0	0
Hymenophyllum	0	0	0	2	0
Lycopodium cernuum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	0	0	0	0	0
Lycopodium ramulosum	0	0	0	0	0
Monolete fern spores	0	1	2	4	2
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	0	6	1	1	1
Pteridium esculentum	0	1	0	1	0
Pteris	0	1	0	1	0
Cyperaceae	4	1	0	3	1
Drosera	0	0	0	0	0
Epacridaceae	20	16	14	18	10
Gleichenia	131	106	238	71	86
Haloragis	0	0	0	0	0
Leptospermum type	0	2	0	17	0
Myriophyllum	0	0	0	0	0
Potamageton	0	0	0	0	0
Restionaceae	95	96	78	146	58
Typha	0	0	0	0	0
Unknowns	2	0	0	1	0
Charcoal concentration	9	9	0	2	5

Depth (m)	**1.05**	**1.15**	**1.25**	**1.35**	**1.45**
Lycopodium spike	694	487	553	570	386
Spike concentration	13911	13911	13911	13911	13911
Fuscospora	3	2	2	4	3
Agathis australis	11	16	7	11	6
Casuarina	0	1	0	1	0
Dacrycarpus dacrydioides	8	4	3	4	10
Dacrydium cupressinum	94	76	62	77	86
Halocarpus	2	6	7	3	3
Libocedrus	6	6	9	8	10
Manoao colensoi	3	8	3	5	2
Phyllocladus	34	32	15	24	25
Podocarpus type	8	13	5	9	13
Prumnopitys ferruginea	7	4	3	6	4
Prumnopitys taxifolia	15	19	12	13	12
Alectryon excelsus	0	1	0	1	0
Beilschmiedia	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	1
Elaeocarpus	1	0	1	1	2
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	1	0	1	0	1
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros type	8	5	4	10	4
Nestegis	1	3	5	4	2
Nothofagus menziesii	0	0	0	0	0

Depth (m)	**1.05**	**1.15**	**1.25**	**1.35**	**1.45**
Quintinia	0	0	0	0	0
Syzygium maire	0	0	0	0	0
Vitex lucens	0	0	0	0	0
Weinmannia	0	0	0	0	0
Alseuosmia	0	1	0	0	0
Aristotelia	0	0	0	0	0
Ascarina lucida	3	5	2	4	3
Asteraceae	0	0	0	0	0
Carpodetus serratus	0	0	0	0	0
Coprosma	1	3	4	3	12
Cordyline	0	0	0	0	0
Coriaria	0	0	0	0	0
Dodonaea viscosa	1	2	0	2	3
Fabaceae	0	0	0	0	0
Fuschia	0	0	0	0	0
Griselinia	1	4	4	2	1
Leucopogon fasciculatus	0	0	0	0	0
Macropiper	0	0	0	0	0
Malvaceae	0	0	0	0	0
Myrsine	0	0	1	1	1
Neomyrtus type	1	2	1	6	0
Pittosporum	0	0	0	0	0
Plagianthus type	0	0	0	0	0
Pseudopanax	0	0	1	2	0
Pseudowintera	0	0	0	0	1
Rhopalostylis sapida	0	0	0	0	0
Schefflera digitata	0	0	0	0	0
Toronia toru	0	0	0	0	0
Amaranthaceae	0	0	0	0	0
Astelia	0	0	3	1	0
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Dactylanthus taylorii	0	0	0	0	0
Epilobium	0	0	0	0	0
Freycinetia	0	0	0	1	1
Ileostylus micranthus	1	0	0	0	0
Liliaceae	1	0	0	1	0
Plantago	0	0	0	0	0
Poaceae	1	0	0	1	1
Taraxacum type	0	0	0	0	0
Tupeia antarctica	0	0	0	0	0
Adiantum type	0	0	0	0	0
Cyathea dealbata type	9	6	9	3	7
Cyathea smithii type	3	3	1	3	0
Dicksonia fibrosa	0	0	0	0	0
Dicksonia squarrosa	0	0	0	0	2
Hymenophyllum	0	0	0	0	0
Lycopodium cernuum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	0	0	0	0	0
Lycopodium ramulosum	0	0	0	0	0
Monolete fern spores	1	2	4	0	3
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	1	1	0	2	3

Depth (m)	**1.05**	**1.15**	**1.25**	**1.35**	**1.45**
Pteridium esculentum	0	0	0	2	0
Pteris	0	0	0	0	0
Cyperaceae	0	1	3	7	2
Drosera	0	0	0	0	0
Epacridaceae	38	20	17	10	15
Gleichenia	205	250	114	172	263
Haloragis	0	0	0	0	0
Leptospermum type	7	5	21	8	19
Myriophyllum	0	0	0	0	1
Potamageton	0	0	0	0	0
Restionaceae	190	178	168	182	238
Typha	0	0	0	0	0
Unknowns	0	0	0	0	0
Charcoal concentration	9	2	6	10	10

Depth (m)	**1.55**	**1.65**	**1.75**	**1.85**	**1.95**
Lycopodium spike	473	110	142	145	250
Spike concentration	13911	11300	11300	13911	13911
Fuscospora	2	3	2	1	4
Agathis australis	7	5	9	5	10
Casuarina	0	0	0	0	0
Dacrycarpus dacrydioides	6	7	4	10	10
Dacrydium cupressinum	87	72	63	80	59
Halocarpus	3	4	1	6	1
Libocedrus	7	5	4	6	8
Manoao colensoi	6	3	3	6	4
Phyllocladus	20	36	37	28	18
Podocarpus type	8	15	7	5	14
Prumnopitys ferruginea	7	3	3	3	2
Prumnopitys taxifolia	13	14	9	8	4
Alectryon excelsus	0	0	0	0	0
Beilschmiedia	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	2	2	0	3	0
Hedycarya arborea	0	0	0	0	1
Knightia excelsa	0	0	0	0	0
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	3	8	18	7	15
Nestegis	4	5	2	1	5
Nothofagus menziesii	0	0	0	0	0
Quintinia	1	0	1	0	0
Syzygium maire	0	0	0	0	0
Vitex lucens	0	0	0	0	0
Weinmannia	0	0	1	0	0
Alseuosmia	0	0	0	0	0
Aristotelia	0	0	0	0	0
Ascarina lucida	6	4	5	6	3
Asteraceae	0	0	1	0	0
Carpodetus serratus	0	0	0	0	0
Coprosma	0	5	5	1	4
Cordyline	0	0	0	0	2
Coriaria	0	0	0	0	0
Dodonaea viscosa	1	3	1	3	1

Depth (m)	**1.55**	**1.65**	**1.75**	**1.85**	**1.95**
Fabaceae	0	0	0	0	0
Fuschia	0	0	0	0	0
Griselinia	2	3	3	4	6
Leucopogon fasciculatus	1	0	0	0	0
Macropiper	0	0	0	0	0
Malvaceae	0	0	0	1	0
Myrsine	1	1	0	1	0
Neomyrtus type	2	5	18	3	7
Pittosporum	0	1	1	0	0
Plagianthus type	0	0	0	0	0
Pseudopanax	1	1	0	0	2
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	0	1	0	0	1
Schefflera digitata	0	0	0	0	0
Toronia toru	0	0	0	0	0
Amaranthaceae	0	0	0	0	0
Astelia	1	0	3	2	3
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	1	0
Dactylanthus taylorii	0	0	0	0	0
Epilobium	0	0	0	0	0
Freycinetia	1	1	0	1	0
Ileostylus micranthus	0	0	0	0	0
Liliaceae	0	1	1	1	2
Plantago	0	0	0	0	0
Poaceae	1	2	2	1	2
Taraxacum type	0	0	0	0	0
Tupeia antarctica	1	0	0	0	1
Adiantum type	0	6	0	2	1
Cyathea dealbata type	13	10	8	12	3
Cyathea smithii type	3	2	2	0	1
Dicksonia fibrosa	0	0	0	0	0
Dicksonia squarrosa	0	0	0	1	1
Hymenophyllum	0	1	0	0	0
Lycopodium cernuum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	0	0	0	0	0
Lycopodium ramulosum	0	0	0	0	0
Monolete fern spores	0	2	4	1	4
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	1	1	0	1	1
Pteridium esculentum	0	0	0	0	0
Pteris	0	0	0	0	0
Cyperaceae	2	8	3	10	20
Drosera	0	0	0	0	0
Epacridaceae	18	36	50	27	22
Gleichenia	269	350	237	355	174
Haloragis	0	0	0	0	0
Leptospermum type	10	9	42	14	38
Myriophyllum	0	0	0	0	0
Potamageton	0	2	0	0	0
Restionaceae	215	209	222	279	221
Typha	0	0	0	0	0
Unknowns	1	0	0	0	3
Charcoal concentration	10	40	30	16	20

Depth (m)	**2.05**	**2.15**	**2.25**	**2.35**	**2.45**
Lycopodium spike	235	342	205	412	256
Spike concentration	13911	13911	13911	13911	13911
Fuscospora	2	4	2	1	4
Agathis australis	14	4	9	15	16
Casuarina	0	0	0	0	0
Dacrycarpus dacrydioides	6	7	4	3	2
Dacrydium cupressinum	62	71	82	75	68
Halocarpus	4	4	3	2	1
Libocedrus	8	5	11	3	7
Manoao colensoi	1	1	2	2	1
Phyllocladus	28	29	23	10	23
Podocarpus type	13	26	19	14	18
Prumnopitys ferruginea	1	4	2	7	2
Prumnopitys taxifolia	6	5	12	12	8
Alectryon excelsus	0	0	0	1	1
Beilschmiedia	0	0	1	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	3	0	1	0	0
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	1	0	3	0	0
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	13	14	18	19	23
Nestegis	8	11	5	4	7
Nothofagus menziesii	0	0	0	0	0
Quintinia	0	0	0	0	0
Syzygium maire	0	0	0	0	0
Vitex lucens	0	1	0	0	0
Weinmannia	0	0	0	0	0
Alseuosmia	0	0	0	0	0
Aristotelia	0	0	0	0	0
Ascarina lucida	6	5	5	10	7
Asteraceae	0	0	0	0	0
Carpodetus serratus	0	0	0	0	0
Coprosma	2	2	1	6	4
Cordyline	2	2	1	1	1
Coriaria	0	0	0	0	0
Dodonaea viscosa	0	4	1	2	0
Fabaceae	0	0	0	0	0
Fuschia	0	0	0	0	0
Griselinia	4	5	4	2	6
Leucopogon fasciculatus	0	0	0	1	0
Macropiper	0	0	0	0	0
Malvaceae	0	0	0	0	0
Myrsine	0	1	0	3	1
Neomyrtus type	4	3	4	2	5
Pittosporum	0	0	0	0	0
Plagianthus type	0	0	0	0	0
Pseudopanax	1	0	0	2	0
Pseudowintera	0	0	1	0	0
Rhopalostylis sapida	0	1	1	0	1
Schefflera digitata	0	0	0	0	0
Toronia toru	0	0	0	0	0
Amaranthaceae	0	0	0	0	0
Astelia	3	0	1	3	1

Depth (m)	**2.05**	**2.15**	**2.25**	**2.35**	**2.45**
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	1	1
Dactylanthus taylorii	0	0	0	0	0
Epilobium	0	0	0	0	0
Freycinetia	5	3	0	2	2
Ileostylus micranthus	0	0	0	0	0
Liliaceae	5	3	0	4	2
Plantago	0	0	0	0	0
Poaceae	2	0	0	0	0
Taraxacum type	0	0	0	0	0
Tupeia antarctica	1	0	0	0	0
Adiantum type	0	0	0	0	1
Cyathea dealbata type	13	9	14	5	11
Cyathea smithii type	1	3	0	5	0
Dicksonia fibrosa	0	0	0	0	0
Dicksonia squarrosa	2	0	0	0	0
Hymenophyllum	0	0	0	0	0
Lycopodium cemuum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	0	0	0	1	0
Lycopodium ramulosum	0	0	0	0	0
Monolete fern spores	1	7	1	2	2
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	2	1	0	0	0
Pteridium esculentum	0	0	0	1	0
Pteris	0	0	0	0	0
Cyperaceae	5	2	3	7	11
Drosera	0	0	0	0	0
Epacridaceae	18	16	9	18	14
Gleichenia	214	301	202	127	61
Haloragis	0	0	0	0	0
Leptospermum type	34	29	26	33	52
Myriophyllum	0	0	0	0	0
Potamageton	0	0	1	2	0
Restionaceae	263	482	405	371	341
Typha	0	0	0	0	0
Unknowns	1	0	0	0	0
Charcoal concentration	17	5	93	11	13

Depth (m)	**2.55**	**2.65**	**2.75**	**2.85**	**2.95**
Lycopodium spike	222	171	207	117	115
Spike concentration	13911	13911	13911	11300	11300
Fuscospora	6	1	2	5	4
Agathis australis	7	6	7	7	3
Casuarina	0	1	0	0	0
Dacrycarpus dacrydioides	2	2	2	0	3
Dacrydium cupressinum	75	87	79	77	69
Halocarpus	1	2	3	3	0
Libocedrus	5	7	4	6	3
Manoao colensoi	1	4	2	2	3
Phyllocladus	20	17	20	15	19
Podocarpus type	26	17	16	12	12
Prumnopitys ferruginea	5	2	0	3	3

Depth (m)	**2.55**	**2.65**	**2.75**	**2.85**	**2.95**
Prumnopitys taxifolia	7	9	9	11	4
Alectryon excelsus	0	0	0	0	0
Beilschmiedia	0	0	0	0	0
Dysoxylum spectabile	0	1	0	0	0
Elaeocarpus	0	2	2	3	0
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	0	0	1	4	1
Laurelia novae-zelandiae	0	1	0	3	2
Metrosideros undiff.	15	22	15	22	21
Nestegis	7	7	3	10	4
Nothofagus menziesii	0	0	0	0	0
Quintinia	0	0	0	1	0
Syzygium maire	0	0	1	0	0
Vitex lucens	0	0	0	0	0
Weinmannia	0	2	1	0	0
Alseuosmia	0	0	0	0	0
Aristotelia	0	0	0	0	0
Ascarina lucida	3	5	2	5	6
Asteraceae	0	0	0	0	0
Carpodetus serratus	0	0	0	0	0
Coprosma	3	3	2	4	2
Cordyline	1	0	0	1	1
Coriaria	0	0	0	1	0
Dodonaea viscosa	0	1	3	2	1
Fabaceae	0	0	0	0	0
Fuschia	0	0	0	0	1
Griselinia	4	5	3	2	3
Leucopogon fasciculatus	1	1	2	1	1
Macropiper	0	0	0	0	0
Malvaceae	0	0	0	0	0
Myrsine	1	6	5	2	3
Neomyrtus type	3	5	2	9	9
Pittosporum	0	0	0	0	0
Plagianthus type	0	0	0	0	0
Pseudopanax	1	0	0	0	1
Pseudowintera	0	0	0	1	1
Rhopalostylis sapida	1	0	0	0	2
Schefflera digitata	0	0	0	0	0
Toronia toru	0	0	0	0	0
Amaranthaceae	0	0	0	0	0
Astelia	2	2	2	1	5
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Dactylanthus taylorii	0	0	0	0	0
Epilobium	0	0	0	0	0
Freycinetia	2	3	3	2	0
Ileostylus micranthus	1	0	0	0	0
Liliaceae	0	1	2	2	4
Plantago	1	0	0	0	0
Poaceae	1	0	0	2	0
Taraxacum type	0	0	0	0	0
Tupeia antarctica	0	0	0	0	0
Adiantum type	2	0	0	0	0
Cyathea dealbata type	13	16	8	5	14

Depth (m)	**2.55**	**2.65**	**2.75**	**2.85**	**2.95**
Cyathea smithii type	3	2	2	1	0
Dicksonia fibrosa	0	1	0	0	0
Dicksonia squarrosa	0	0	0	0	0
Hymenophyllum	1	0	0	0	0
Lycopodium cernuum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	0	3	1	0	0
Lycopodium ramulosum	0	0	0	0	0
Monolete fern spores	1	7	1	3	4
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	0	1	1	0	3
Pteridium esculentum	0	1	0	1	0
Pteris	0	0	0	0	0
Cyperaceae	1	8	7	11	22
Drosera	0	0	0	0	0
Epacridaceae	6	7	10	16	13
Gleichenia	137	36	57	29	63
Haloragis	0	0	0	0	0
Leptospermum type	10	60	25	14	28
Myriophyllum	0	0	0	0	0
Potamageton	2	0	0	2	3
Restionaceae	407	263	316	244	395
Typha	0	0	0	0	1
Unknowns	0	0	0	0	0
Charcoal concentration	10	43	24	18	70

Depth (m)	**3.05**	**3.15**	**3.25**	**3.35**	**3.45**
Lycopodium spike	108	169	164	163	202
Spike concentration	11300	11300	13911	13911	11300
Fuscospora	3	12	9	19	17
Agathis australis	7	7	7	8	4
Casuarina	0	0	0	0	0
Dacrycarpus dacrydioides	5	7	2	1	2
Dacrydium cupressinum	50	93	63	68	65
Halocarpus	0	2	4	0	1
Libocedrus	12	5	5	4	6
Manoao colensoi	2	3	2	0	4
Phyllocladus	10	11	12	17	9
Podocarpus type	13	12	8	19	15
Prumnopitys ferruginea	1	3	2	2	2
Prumnopitys taxifolia	2	4	5	4	7
Alectryon excelsus	0	0	0	0	1
Beilschmiedia	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	1	0	2	0	0
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	0	0	0	0	1
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	23	24	20	24	18
Nestegis	5	7	9	2	10
Nothofagus menziesii	0	0	0	0	0
Quintinia	0	0	0	0	0
Syzygium maire	1	0	2	1	0

Depth (m)	**3.05**	**3.15**	**3.25**	**3.35**	**3.45**
Vitex lucens	0	0	0	0	0
Weinmannia	0	1	0	0	0
Alseuosmia	0	0	0	0	0
Aristotelia	0	0	0	0	0
Ascarina lucida	3	11	15	12	16
Asteraceae	2	1	0	2	2
Carpodetus serratus	0	0	0	0	0
Coprosma	1	2	2	10	6
Cordyline	0	0	1	0	0
Coriaria	0	0	0	0	0
Dodonaea viscosa	5	1	3	2	0
Fabaceae	0	1	0	0	0
Fuschia	0	0	0	0	0
Griselinia	0	2	5	0	2
Leucopogon fasciculatus	1	0	1	0	0
Macropiper	1	0	0	0	0
Malvaceae	0	1	1	1	0
Myrsine	4	4	5	7	8
Neomyrtus type	5	9	2	11	7
Pittosporum	1	0	0	0	0
Plagianthus type	0	0	1	0	0
Pseudopanax	0	1	1	1	2
Pseudowintera	0	0	0	0	1
Rhopalostylis sapida	0	0	2	0	1
Schefflera digitata	0	0	1	0	0
Toronia toru	0	0	0	0	0
Amaranthaceae	0	0	0	0	0
Astelia	4	0	2	4	1
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	1	0	1	1
Dactylanthus taylorii	0	0	0	0	0
Epilobium	0	0	0	0	0
Freycinetia	0	1	1	4	0
Ileostylus micranthus	0	0	0	0	0
Liliaceae	4	2	3	1	3
Plantago	0	0	1	1	0
Poaceae	1	0	5	5	0
Taraxacum type	0	0	0	0	0
Tupeia antarctica	0	0	0	0	0
Adiantum type	0	0	0	1	0
Cyathea dealbata type	11	11	12	23	22
Cyathea smithii type	2	0	0	2	2
Dicksonia fibrosa	0	0	0	0	0
Dicksonia squarrosa	0	0	0	0	0
Hymenophyllum	0	1	0	0	0
Lycopodium cernuum	0	0	7	17	4
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	0	1	7	5	0
Lycopodium ramulosum	0	2	0	0	0
Monolete fern spores	5	3	1	2	0
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	0	0	2	1	1
Pteridium esculentum	1	0	0	1	1
Pteris	0	0	0	0	0

Depth (m)	**3.05**	**3.15**	**3.25**	**3.35**	**3.45**
Cyperaceae	0	8	11	3	11
Drosera	0	0	0	1	1
Epacridaceae	28	18	11	10	12
Gleichenia	56	44	4	5	3
Haloragis	0	0	0	0	0
Leptospermum type	16	27	29	25	24
Myriophyllum	0	0	0	0	0
Potamageton	0	3	1	2	2
Restionaceae	375	670	522	491	505
Typha	0	1	0	0	0
Unknowns	0	0	0	0	0
Charcoal concentration	19	65	38	36	20

Depth (m)	**3.55**	**3.65**	**3.75**	**3.85**	**3.95**
Lycopodium spike	66	103	128	196	156
Spike concentration	13911	13911	13911	13911	13911
Fuscospora	28	7	36	36	25
Agathis australis	1	1	1	1	3
Casuarina	0	0	0	0	0
Dacrycarpus dacrydioides	3	5	1	4	0
Dacrydium cupressinum	40	29	32	31	37
Halocarpus	0	2	1	1	0
Libocedrus	6	5	10	6	6
Manoao colensoi	4	2	3	7	4
Phyllocladus	11	2	12	12	6
Podocarpus type	12	6	13	10	13
Prumnopitys ferruginea	1	0	0	0	1
Prumnopitys taxifolia	7	8	5	6	6
Alectryon excelsus	0	0	0	0	0
Beilschmiedia	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	2	0	5	0	1
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	1	1	4	1	1
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	47	23	16	17	31
Nestegis	7	2	3	5	10
Nothofagus menziesii	0	0	0	1	0
Quintinia	0	0	0	0	0
Syzygium maire	0	0	0	1	0
Vitex lucens	0	0	0	1	0
Weinmannia	0	0	0	0	0
Alseuosmia	0	0	0	0	0
Aristotelia	0	0	0	0	0
Ascarina lucida	26	3	9	9	10
Asteraceae	1	0	0	1	1
Carpodetus serratus	0	0	0	0	0
Coprosma	1	0	3	2	1
Cordyline	1	1	2	1	0
Coriaria	0	0	0	0	0
Dodonaea viscosa	5	0	0	0	0
Fabaceae	1	0	0	0	0
Fuschia	0	0	0	0	0

Depth (m)	**3.55**	**3.65**	**3.75**	**3.85**	**3.95**
Griselinia	0	1	1	3	1
Leucopogon fasciculatus	0	0	0	0	0
Macropiper	0	0	0	0	0
Malvaceae	0	0	0	0	0
Myrsine	5	6	0	7	6
Neomyrtus type	7	6	5	7	9
Pittosporum	1	0	0	0	0
Plagianthus type	0	0	0	0	0
Pseudopanax	1	0	0	0	0
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	0	2	1	0	1
Schefflera digitata	0	0	0	0	1
Toronia toru	0	1	0	0	0
Amaranthaceae	0	0	0	0	0
Astelia	2	2	3	2	2
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	1	0	3	0
Dactylanthus taylorii	0	0	0	0	0
Epilobium	0	0	0	0	0
Freycinetia	1	2	4	1	3
Ileostylus micranthus	0	0	0	0	0
Liliaceae	3	0	1	0	2
Plantago	0	0	0	0	0
Poaceae	1	3	4	3	2
Taraxacum type	0	0	0	0	0
Tupeia antarctica	0	0	0	0	0
Adiantum type	0	0	0	0	0
Cyathea dealbata type	7	8	11	10	12
Cyathea smithii type	1	0	0	1	3
Dicksonia fibrosa	0	0	0	0	0
Dicksonia squarrosa	0	0	0	0	0
Hymenophyllum	0	0	0	0	0
Lycopodium cernuum	4	5	3	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	0	4	0	0	0
Lycopodium ramulosum	0	0	0	0	0
Monolete fern spores	2	5	10	4	3
Paesia scaberula	0	1	0	0	0
Phymatosorus diversifolius	0	3	0	0	0
Pteridium esculentum	0	0	0	0	0
Pteris	0	0	0	0	0
Cyperaceae	21	10	81	39	40
Drosera	1	1	0	0	0
Epacridaceae	2	6	4	10	7
Gleichenia	4	1	0	0	5
Haloragis	0	0	0	0	0
Leptospermum type	29	12	27	42	59
Myriophyllum	0	0	0	0	0
Potamageton	2	0	1	3	2
Restionaceae	319	154	247	269	289
Typha	1	0	0	0	0
Unknowns	0	8	11	1	0
Charcoal concentration	56	32	33	25	22

Depth (m)	**4.05**	**4.15**	**4.25**	**4.35**	**4.45**
Lycopodium	153	220	95	132	121
Spike concentration	13911	13911	13911	13911	13911
Fuscospora	25	38	40	45	44
Agathis australis	4	6	6	6	2
Casuarina	0	0	0	0	0
Dacrycarpus dacrydioides	2	4	0	2	3
Dacrydium cupressinum	36	33	49	61	51
Halocarpus	0	3	1	1	1
Libocedrus	11	10	3	1	3
Manoao colensoi	5	5	9	5	1
Phyllocladus	8	8	4	5	6
Podocarpus type	15	13	4	19	14
Prumnopitys ferruginea	2	2	3	3	3
Prumnopitys taxifolia	10	5	7	12	10
Alectryon excelsus	0	0	0	0	1
Beilschmiedia	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	2	1	1	4	2
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	2	0	0	0	0
Laurelia novae-zelandiae	0	1	0	0	0
Metrosideros undiff.	29	23	21	18	19
Nestegis	4	8	9	4	3
Nothofagus menziesii	0	0	0	0	0
Quintinia	0	0	0	0	0
Syzygium maire	0	1	0	0	0
Vitex lucens	0	0	0	0	0
Weinmannia	0	0	0	0	0
Alseuosmia	0	0	0	0	0
Aristotelia	0	0	0	0	0
Ascarina lucida	9	9	10	5	4
Asteraceae	0	0	0	0	1
Carpodetus serratus	0	0	0	0	0
Coprosma	1	2	0	3	1
Cordyline	0	3	1	0	1
Coriaria	0	0	0	1	0
Dodonaea viscosa	0	0	0	2	2
Fabaceae	0	0	0	0	0
Fuschia	0	0	0	0	0
Griselinia	3	3	3	1	2
Leucopogon fasciculatus	0	0	0	0	1
Macropiper	0	0	0	0	0
Malvaceae	0	0	0	0	0
Myrsine	1	5	3	5	2
Neomyrtus type	18	7	8	8	17
Pittosporum	0	0	0	0	0
Plagianthus type	0	0	0	0	0
Pseudopanax	0	0	1	0	0
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	0	1	1	2	1
Schefflera digitata	0	0	0	0	0
Toronia toru	0	0	0	0	0
Amaranthaceae	0	0	0	0	0
Astelia	4	3	5	0	3

Depth (m)	**4.05**	**4.15**	**4.25**	**4.35**	**4.45**
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	1	0
Dactylanthus taylorii	1	0	0	0	0
Epilobium	0	0	0	0	0
Freycinetia	0	3	2	14	5
Ileostylus micranthus	1	0	0	0	0
Liliaceae	0	0	4	3	0
Plantago	0	0	0	0	0
Poaceae	0	1	0	3	0
Taraxacum type	0	0	0	0	0
Tupeia antarctica	0	0	0	0	0
Adiantum type	2	2	3	1	0
Cyathea dealbata type	11	4	4	6	6
Cyathea smithii type	0	1	3	1	4
Dicksonia fibrosa	0	3	0	0	1
Dicksonia squarrosa	0	1	0	0	0
Hymenophyllum	0	0	0	0	0
Lycopodium cernuum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	0	1	3	2	11
Lycopodium ramulosum	0	0	0	0	0
Monolete fern spores	5	3	1	1	5
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	0	0	0	0	0
Pteridium esculentum	1	3	0	0	0
Pteris	0	0	0	0	0
Cyperaceae	20	27	8	23	29
Drosera	0	0	0	0	0
Epacridaceae	15	9	26	12	9
Gleichenia	10	34	15	8	10
Haloragis	0	4	0	5	7
Leptospermum type	40	32	51	49	42
Myriophyllum	0	0	0	0	0
Potamageton	1	0	1	1	1
Restionaceae	296	305	389	437	325
Typha	0	0	0	0	0
Unknowns	2	6	0	0	0
Charcoal concentration	20	23	18	26	15

Depth (m)	**4.55**	**4.6**	**4.65**	**4.7**	**4.75**
Lycopodium spike	164	173	227	218	250
Spike concentration	13911	11300	13911	11300	13911
Fuscospora	65	46	47	45	38
Agathis australis	3	4	5	2	4
Casuarina	0	0	0	1	0
Dacrycarpus dacrydioides	3	1	0	3	2
Dacrydium cupressinum	68	53	43	82	51
Halocarpus	1	10	0	4	1
Libocedrus	1	6	1	6	2
Manoao colensoi	2	4	2	7	5
Phyllocladus	6	6	3	3	8
Podocarpus type	26	15	20	14	25
Prumnopitys ferruginea	2	2	2	11	4

Depth (m)	**4.55**	**4.6**	**4.65**	**4.7**	**4.75**
Prumnopitys taxifolia	9	18	9	25	7
Alectryon excelsus	0	0	0	0	0
Beilschmiedia	0	0	0	0	0
Dysoxylum spectabile	0	0	1	0	0
Elaeocarpus	1	1	1	2	1
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	0	0	0	0	0
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	24	6	20	6	18
Nestegis	6	10	9	5	2
Nothofagus menziesii	0	0	0	0	0
Quintinia	0	1	0	0	0
Syzygium maire	2	0	0	0	0
Vitex lucens	0	0	0	0	0
Weinmannia	0	1	0	0	0
Alseuosmia	0	0	0	0	0
Aristotelia	0	0	0	0	0
Ascarina lucida	7	7	9	1	6
Asteraceae	0	0	0	1	0
Carpodetus serratus	0	0	0	0	0
Coprosma	1	4	3	1	1
Cordyline	2	0	0	0	0
Coriaria	0	0	0	0	0
Dodonaea viscosa	2	2	1	1	2
Fabaceae	0	0	0	0	0
Fuschia	0	0	0	0	0
Griselinia	3	3	2	1	4
Leucopogon fasciculatus	0	0	0	0	2
Macropiper	0	0	0	0	0
Malvaceae	0	0	0	0	0
Myrsine	7	0	5	1	4
Neomyrtus type	21	6	14	4	6
Pittosporum	0	2	0	0	0
Plagianthus type	0	0	0	0	0
Pseudopanax	1	0	0	1	0
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	0	0	0	0	0
Schefflera digitata	0	0	0	0	0
Toronia toru	0	0	0	0	0
Amaranthaceae	0	0	0	0	0
Astelia	6	1	3	0	2
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Dactylanthus taylorii	0	0	0	0	0
Epilobium	0	0	0	0	0
Freycinetia	2	0	5	0	6
Ileostylus micranthus	0	0	0	0	0
Liliaceae	4	0	1	3	4
Plantago	0	0	0	0	0
Poaceae	0	0	0	1	0
Taraxacum type	0	0	0	0	0
Tupeia antarctica	0	0	0	0	0
Adiantum type	0	2	0	1	0
Cyathea dealbata type	6	6	4	10	5

Depth (m)	**4.55**	**4.6**	**4.65**	**4.7**	**4.75**
Cyathea smithii type	0	1	2	2	0
Dicksonia fibrosa	0	0	0	0	0
Dicksonia squarrosa	0	0	1	0	0
Hymenophyllum	0	0	0	0	0
Lycopodium cemuum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	7	3	0	8	2
Lycopodium ramulosum	0	0	0	0	0
Monolete fem spores	3	0	4	3	2
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	1	0	0	6	1
Pteridium esculentum	2	0	0	0	2
Pteris	0	0	0	0	2
Cyperaceae	47	23	33	18	31
Drosera	0	0	0	0	0
Epacridaceae	18	19	31	92	26
Gleichenia	5	22	30	177	30
Haloragis	1	0	0	1	14
Leptospermum type	85	73	57	14	40
Myriophyllum	0	0	0	0	0
Potamageton	0	0	0	2	0
Restionaceae	481	594	557	528	389
Typha	0	0	0	0	0
Unknowns	0	0	1	0	1
Charcoal concentration	32	124	9	62	12

Depth (m)	**4.8**	**4.85**	**4.9**	**4.95**	**5.05**
Lycopodium spike	79	128	142	191	145
Spike concentration	11300	13911	11300	13911	13911
Fuscospora	59	64	62	49	61
Agathis australis	2	2	0	3	0
Casuarina	0	0	0	0	0
Dacrycarpus dacrydioides	2	5	5	3	1
Dacrydium cupressinum	56	74	60	28	30
Halocarpus	6	6	3	0	2
Libocedrus	5	3	7	3	2
Manoao colensoi	10	6	12	3	6
Phyllocladus	12	7	3	3	11
Podocarpus type	23	36	26	34	33
Prumnopitys ferruginea	10	3	3	5	3
Prumnopitys taxifolia	12	10	17	13	7
Alectryon excelsus	0	0	0	0	0
Beilschmiedia	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	1	5	4	1	0
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	0	0	1	0	0
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	3	16	5	12	9
Nestegis	4	11	3	8	5
Nothofagus menziesii	0	0	0	0	0
Quintinia	1	0	1	0	0
Syzygium maire	0	0	0	0	0

Depth (m)	**4.8**	**4.85**	**4.9**	**4.95**	**5.05**
Vitex lucens	0	0	0	0	0
Weinmannia	0	0	0	0	0
Alseuosmia	0	0	0	0	0
Aristotelia	0	0	0	1	0
Ascarina lucida	2	4	3	2	1
Asteraceae	1	2	0	1	1
Carpodetus serratus	0	0	0	0	0
Coprosma	4	3	1	0	2
Cordyline	1	2	1	0	0
Coriaria	0	0	0	0	0
Dodonaea viscosa	4	3	1	0	2
Fabaceae	0	0	0	0	0
Fuschia	0	0	0	0	0
Griselinia	3	4	3	5	7
Leucopogon fasciculatus	0	1	1	2	1
Macropiper	0	0	0	0	0
Malvaceae	0	0	0	0	1
Myrsine	1	5	5	2	2
Neomyrtus type	8	8	2	12	8
Pittosporum	0	0	3	0	0
Plagianthus type	0	0	1	0	0
Pseudopanax	0	0	0	0	0
Pseudowintera	0	1	0	0	0
Rhopalostylis sapida	0	0	0	0	0
Schefflera digitata	0	1	0	0	0
Toronia toru	0	0	0	0	0
Amaranthaceae	0	0	0	0	0
Astelia	1	1	0	3	3
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	1	0
Dactylanthus taylorii	0	0	0	0	0
Epilobium	0	0	0	0	0
Freycinetia	1	5	0	2	0
Ileostylus micranthus	1	0	0	0	0
Liliaceae	0	2	2	2	0
Plantago	0	0	0	0	0
Poaceae	2	1	0	0	0
Taraxacum type	0	0	0	0	0
Tupeia antarctica	0	0	0	0	0
Adiantum type	0	3	2	8	2
Cyathea dealbata type	6	10	6	6	7
Cyathea smithii type	0	5	0	0	2
Dicksonia fibrosa	0	0	0	0	0
Dicksonia squarrosa	1	0	0	0	0
Hymenophyllum	0	0	0	0	0
Lycopodium cemuum	0	1	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	8	5	2	5	0
Lycopodium ramulosum	0	0	0	0	0
Monolete fem spores	1	0	5	2	1
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	1	0	0	0	0
Pteridium esculentum	0	2	0	2	0
Pteris	0	1	0	0	0

Depth (m)	**4.8**	**4.85**	**4.9**	**4.95**	**5.05**
Cyperaceae	35	76	45	121	69
Drosera	0	0	1	1	0
Epacridaceae	14	19	27	28	27
Gleichenia	13	23	24	40	43
Haloragis	0	7	2	0	0
Leptospermum type	26	81	23	46	48
Myriophyllum	0	0	0	0	0
Potamageton	0	0	0	0	0
Restionaceae	455	515	507	472	430
Typha	0	0	0	0	0
Unknowns	0	0	0	0	0
Charcoal concentration	78	204	74	69	96

Depth (m)	**5.1**	**5.15**	**5.2**	**5.25**	**5.3**
Lycopodium spike	21	123	6	33	30
Spike concentration	11300	13911	11300	13911	11300
Fuscospora	78	106	80	57	81
Agathis australis	1	6	1	2	1
Casuarina	0	0	0	0	0
Dacrycarpus dacrydioides	3	1	2	2	3
Dacrydium cupressinum	66	81	74	45	44
Halocarpus	11	2	7	0	8
Libocedrus	7	1	9	3	16
Manoao colensoi	5	5	4	11	10
Phyllocladus	4	3	5	2	0
Podocarpus type	17	28	26	21	21
Prumnopitys ferruginea	4	7	4	1	8
Prumnopitys taxifolia	21	17	20	16	27
Alectryon excelsus	0	0	0	0	0
Beilschmiedia	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	2	2	2	1
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	0	0	0	0	0
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	10	13	6	12	0
Nestegis	4	2	5	6	3
Nothofagus menziesii	0	0	0	1	0
Quintinia	0	0	2	0	0
Syzygium maire	0	1	0	0	0
Vitex lucens	0	0	0	0	0
Weinmannia	0	0	0	1	0
Alseuosmia	0	0	0	0	0
Aristotelia	0	0	0	0	0
Ascarina lucida	6	4	3	2	1
Asteraceae	0	0	0	0	1
Carpodetus serratus	0	0	0	0	0
Coprosma	3	2	3	2	3
Cordyline	0	0	0	0	0
Coriaria	0	0	0	0	0
Dodonaea viscosa	1	0	0	0	0
Fabaceae	0	0	0	0	0
Fuschia	0	0	0	0	0

Depth (m)	**5.1**	**5.15**	**5.2**	**5.25**	**5.3**
Griselinia	5	4	5	1	3
Leucopogon fasciculatus	1	0	1	1	0
Macropiper	0	0	0	0	0
Malvaceae	0	0	0	0	0
Myrsine	2	4	2	4	1
Neomyrtus type	4	6	4	1	3
Pittosporum	1	0	1	1	1
Plagianthus type	0	0	1	0	0
Pseudopanax	1	0	0	0	0
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	0	0	0	0	1
Schefflera digitata	0	0	0	0	0
Toronia toru	0	0	0	0	0
Amaranthaceae	0	0	0	0	0
Astelia	3	2	4	0	1
Caryophyllaceae	0	0	0	1	0
Chenopodiaceae	1	0	0	0	0
Dactylanthus taylorii	0	0	0	0	0
Epilobium	0	0	0	0	0
Freycinetia	1	2	0	0	0
Ileostylus micranthus	0	0	1	0	0
Liliaceae	2	0	1	0	2
Plantago	0	0	0	0	0
Poaceae	1	0	2	2	3
Taraxacum type	0	0	0	0	0
Tupeia antarctica	0	0	0	0	1
Adiantum type	0	5	0	0	1
Cyathea dealbata type	13	6	9	7	4
Cyathea smithii type	1	3	0	1	4
Dicksonia fibrosa	0	0	0	0	0
Dicksonia squarrosa	1	0	0	0	1
Hymenophyllum	0	0	0	0	0
Lycopodium cernuum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	0	1	1	4	4
Lycopodium ramulosum	0	0	0	0	0
Monolete fern spores	2	5	4	2	3
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	0	0	1	1	1
Pteridium esculentum	0	0	1	1	0
Pteris	0	0	0	0	0
Cyperaceae	24	55	25	117	61
Drosera	1	0	0	0	2
Epacridaceae	18	11	6	2	2
Gleichenia	12	8	3	0	7
Haloragis	0	0	0	0	0
Leptospermum type	46	71	26	46	3
Myriophyllum	0	0	0	0	0
Potamageton	0	1	0	0	0
Restionaceae	332	433	212	75	43
Typha	0	0	0	0	0
Unknowns	0	0	0	3	0
Charcoal concentration	41	37	867	81	171

Depth (m)	**5.35**	**5.4**	**5.45**	**5.55**	**5.65**
Lycopodium spike	59	290	38	24	13
Spike concentration	13911	11300	13911	13911	13911
Fuscospora	61	54	55	49	28
Agathis australis	1	4	9	6	3
Casuarina	0	0	0	0	0
Dacrycarpus dacrydioides	2	5	13	7	6
Dacrydium cupressinum	32	59	91	170	97
Halocarpus	2	7	4	3	3
Libocedrus	8	13	12	20	9
Manoao colensoi	6	5	2	3	2
Phyllocladus	5	1	7	9	6
Podocarpus type	17	21	29	34	22
Prumnopitys ferruginea	5	9	7	9	6
Prumnopitys taxifolia	13	21	16	13	9
Alectryon excelsus	0	0	0	0	0
Beilschmiedia	0	1	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	1	0	0	4	2
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	0	0	0	0	0
Laurelia novae-zelandiae	0	0	0	1	0
Metrosideros undiff.	18	2	6	6	9
Nestegis	11	3	6	4	1
Nothofagus menziesii	1	0	1	0	0
Quintinia	0	0	0	0	0
Syzygium maire	0	0	2	1	0
Vitex lucens	0	0	0	1	1
Weinmannia	0	0	0	0	0
Alseuosmia	0	0	0	0	0
Aristotelia	0	0	0	0	0
Ascarina lucida	2	1	1	3	4
Asteraceae	2	0	1	0	1
Carpodetus serratus	0	0	0	4	2
Coprosma	4	3	0	6	2
Cordyline	1	3	4	0	0
Coriaria	0	0	0	0	0
Dodonaea viscosa	0	0	0	0	0
Fabaceae	0	0	0	0	0
Fuschia	0	0	0	0	0
Griselinia	2	4	1	0	2
Leucopogon fasciculatus	1	0	0	3	3
Macropiper	0	0	0	0	0
Malvaceae	0	0	1	0	0
Myrsine	8	1	3	3	3
Neomyrtus type	10	0	1	1	0
Pittosporum	0	1	0	0	0
Plagianthus type	0	0	0	0	0
Pseudopanax	0	0	0	1	0
Pseudowintera	0	1	0	3	2
Rhopalostylis sapida	0	0	0	1	1
Schefflera digitata	0	0	0	0	0
Toronia toru	0	0	0	0	0
Amaranthaceae	0	0	0	0	0
Astelia	7	1	1	5	3

Depth (m)	**5.35**	**5.4**	**5.45**	**5.55**	**5.65**
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	4	0	0	0	0
Dactylanthus taylorii	0	0	0	0	0
Epilobium	0	0	0	0	0
Freycinetia	0	2	0	0	2
Ileostylus micranthus	0	0	0	0	0
Liliaceae	0	5	3	0	1
Plantago	0	0	0	0	0
Poaceae	0	0	0	0	1
Taraxacum type	0	0	0	0	0
Tupeia antarctica	0	0	0	0	0
Adiantum type	0	3	5	2	0
Cyathea dealbata type	7	8	22	13	10
Cyathea smithii type	2	3	11	10	4
Dicksonia fibrosa	0	0	0	0	0
Dicksonia squarrosa	0	0	2	0	1
Hymenophyllum	0	0	0	0	1
Lycopodium cernuum	0	0	1	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	1	0	0	3	1
Lycopodium ramulosum	0	0	0	0	0
Monolete fern spores	0	2	8	23	10
Paesia scaberula	0	1	0	0	0
Phymatosorus diversifolius	2	0	1	2	1
Pteridium esculentum	1	0	0	2	4
Pteris	1	0	0	0	0
Cyperaceae	108	176	111	9	7
Drosera	0	0	0	0	0
Epacridaceae	1	11	10	23	8
Gleichenia	12	26	25	82	32
Haloragis	1	0	0	0	0
Leptospermum type	60	3	11	5	9
Myriophyllum	0	1	3	1	0
Potamageton	0	0	0	0	0
Restionaceae	55	91	113	172	122
Typha	0	0	0	0	0
Unknowns	1	1	1	0	0
Charcoal concentration	58	3	14	54	102

Depth (m)	**5.75**	**5.85**	**5.95**
Lycopodium spike	32	16	32
Spike concentration	13911	13911	13911
Fuscospora	47	48	32
Agathis australis	2	1	3
Casuarina	0	0	0
Dacrycarpus dacrydioides	5	8	2
Dacrydium cupressinum	124	106	101
Halocarpus	4	3	2
Libocedrus	9	13	7
Manoao colensoi	2	2	0
Phyllocladus	12	7	6
Podocarpus type	24	11	26
Prumnopitys ferruginea	9	11	10

Depth (m)	**5.75**	**5.85**	**5.95**
Prumnopitys taxifolia	10	11	14
Alectryon excelsus	0	0	0
Beilschmiedia	0	0	0
Dysoxylum spectabile	0	0	0
Elaeocarpus	3	2	2
Hedycarya arborea	0	0	0
Knightia excelsa	0	0	0
Laurelia novae-zelandiae	0	0	1
Metrosideros undiff.	3	11	5
Nestegis	6	3	5
Nothofagus menziesii	1	0	0
Quintinia	0	0	0
Syzygium maire	1	1	1
Vitex lucens	0	0	0
Weinmannia	0	1	1
Alseuosmia	0	0	0
Aristotelia	0	0	0
Ascarina lucida	1	4	0
Asteraceae	0	1	1
Carpodetus serratus	0	0	0
Coprosma	2	6	10
Cordyline	0	0	1
Coriaria	0	0	0
Dodonaea viscosa	0	0	0
Fabaceae	0	0	0
Fuschia	0	0	0
Griselinia	3	0	3
Leucopogon fasciculatus	2	3	1
Macropiper	0	0	0
Malvaceae	1	0	4
Myrsine	7	4	3
Neomyrtus type	3	3	5
Pittosporum	2	0	0
Plagianthus type	0	0	0
Pseudopanax	0	2	3
Pseudowintera	3	1	1
Rhopalostylis sapida	1	0	0
Schefflera digitata	0	0	0
Toronia toru	0	0	0
Amaranthaceae	0	0	0
Astelia	0	2	1
Caryophyllaceae	0	0	0
Chenopodiaceae	0	0	0
Dactylanthus taylorii	0	0	0
Epilobium	1	1	1
Freycinetia baueriana	0	0	1
Ileostylus micranthus	0	0	0
Liliaceae	0	0	4
Plantago	0	0	0
Poaceae	0	0	4
Taraxacum type	0	0	0
Tupeia antarctica	0	0	0
Adiantum type	1	3	0
Cyathea dealbata type	16	11	9

Depth (m)	**5.75**	**5.85**	**5.95**
Cyathea smithii type	7	3	4
Dicksonia fibrosa	0	0	0
Dicksonia squarrosa	1	0	1
Hymenophyllum	0	0	0
Lycopodium cernuum	0	0	0
Lycopodium deuterodensum	0	0	0
Lycopodium laterale	1	0	0
Lycopodium ramulosum	0	0	0
Monolete fern spores	7	7	6
Paesia scaberula	0	0	0
Phymatosorus diversifolius	1	1	3
Pteridium esculentum	2	1	0
Pteris	0	0	0
Cyperaceae	11	13	13
Drosera	0	0	0
Epacridaceae	15	25	10
Gleichenia	37	38	47
Haloragis	0	0	1
Leptospermum type	18	13	7
Myriophyllum	0	0	0
Potamageton	0	0	1
Restionaceae	169	206	139
Typha	0	0	0
Unknowns	0	1	1
Charcoal concentration	66	294	61

APPENDIX 6

Kaitaia Bog borehole 6 pollen counts:

Depth (m)	**0.05**	**0.15**	**0.25**	**0.35**	**0.45**
Lycopodium spike	98	570	301	355	479
Spike concentration	13911	13911	13911	13911	13911
Fuscospora	0	0	2	1	5
Agathis australis	1	18	7	3	5
Casuarina	0	0	0	0	0
Cupressaceae	0	1	0	0	0
Dacrycarpus dacrydioides	1	4	3	0	2
Dacrydium cupressinum	26	67	43	63	69
Halocarpus	0	0	0	0	0
Libocedrus	0	0	0	1	0
Manoao colensoi	0	0	0	0	0
Phyllocladus	9	10	13	9	17
Pinus	0	0	0	0	0
Podocarpus type	3	11	9	19	24
Prumnopitys ferruginea	4	2	5	2	3
Prumnopitys taxifolia	2	16	16	13	12
Alectryon excelsus	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	0	0	0	0
Knightia excelsa	0	0	0	1	0
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	19	1	6	6	10
Nestegis	1	1	1	1	1
Nothofagus menziesii	0	0	0	0	0
Quintinia	0	0	0	0	0
Syzygium maire	5	0	1	0	2
Weinmannia	0	0	0	0	0
Ascarina lucida	1	1	4	2	2
Asteraceae	1	0	0	0	0
Coprosma	1	1	4	1	2
Cordyline	0	1	0	0	0
Coriaria	0	0	0	1	0
Dodonaea viscosa	0	4	2	0	0
Fabaceae	0	0	0	1	1
Geniostoma	0	0	0	0	0
Griselinia	5	0	2	1	0
Leucopogon fasciculatus	0	0	2	1	1
Malvaceae	0	0	0	0	0
Myrsine	1	1	8	1	7
Neomyrtus type	3	0	0	0	0
Pittosporum	0	0	0	0	0
Pseudopanax	0	0	0	0	0
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	0	0	0	1	0
Streblus	0	0	0	0	0
Astelia	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Freycinetia baueriana	0	0	0	0	0
Ileostylus micranthus	0	0	0	0	0
Liliaceae	1	0	0	0	0
Poaceae	2	5	2	0	2
Stellaria	1	0	0	0	0

Depth (m)	0.05	0.15	0.25	0.35	0.45
Taraxacum type	0	1	2	0	0
Adiantum type	0	0	0	0	0
Cyathea dealbata type	2	4	4	4	1
Cyathea smithii type	0	0	0	0	0
Dicksonia squarrosa	0	2	0	0	0
Hymenophyllum	2	0	1	0	0
Lycopodium cernuum	0	0	0	0	0
Lycopodium deuterodensum	1	0	0	0	0
Lycopodium laterale	2	0	4	0	0
Lycopodium volubile	0	1	0	0	0
Lygodium articulatum	1	0	0	0	0
Monolete fern spores	0	1	1	4	3
Paesia scaberula	1	1	0	0	1
Phymatosorus diversifolius	0	0	3	1	1
Pteridium esculentum	3	0	3	1	0
Pteris	0	0	0	0	0
Cyperaceae	30	16	15	16	14
Drosera	0	0	0	0	0
Epacridaceae	2	14	7	6	20
Gleichenia	34	169	96	216	153
Haloragis	0	2	0	0	1
Leptospermum type	83	1	24	5	8
Myriophyllum	0	0	0	0	0
Potamogeton	0	0	0	0	0
Restionaceae	74	143	116	184	270
Typha	0	1	0	0	2
Unknowns	0	1	1	0	0
Charcoal concentration	163	48	48	53	57

Depth (m)	0.55	0.65	0.75	0.85	0.95
Lycopodium spike	303	239	251	315	395
Spike concentration	13911	13911	13911	13911	13911
Fuscospora	0	3	2	2	3
Agathis australis	6	1	4	14	2
Casuarina	0	0	0	0	0
Cupressaceae	0	0	0	0	0
Dacrycarpus dacrydioides	2	4	2	1	1
Dacrydium cupressinum	93	52	61	70	49
Halocarpus	0	0	0	0	0
Libocedrus	0	3	2	3	3
Manoao colensoi	0	0	0	0	0
Phyllocladus	11	19	25	31	37
Pinus	0	0	0	0	0
Podocarpus type	13	11	13	14	22
Prumnopitys ferruginea	0	2	2	7	0
Prumnopitys taxifolia	16	6	4	4	11
Alectryon excelsus	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	0	0	0	0
Knightia excelsa	0	0	0	0	1
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	1	16	9	2	11
Nestegis	0	3	7	3	5

Depth (m)	**0.55**	**0.65**	**0.75**	**0.85**	**0.95**
Nothofagus menziesii	0	0	0	0	0
Quintinia	0	0	0	0	0
Syzygium maire	2	3	2	0	3
Weinmannia	0	0	0	0	0
Ascarina lucida	0	1	3	1	0
Asteraceae	0	1	0	1	1
Coprosma	1	5	2	0	3
Cordyline	0	0	0	0	0
Coriaria	0	0	0	1	0
Dodonaea viscosa	3	1	1	3	0
Fabaceae	0	0	0	0	0
Geniostoma	0	0	0	0	0
Griselinia	4	3	3	3	1
Leucopogon fasciculatus	0	1	0	0	0
Malvaceae	0	0	0	0	0
Myrsine	3	3	1	0	2
Neomyrtus type	0	0	0	2	1
Pittosporum	1	0	3	0	1
Pseudopanax	0	0	0	0	1
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	0	1	0	0	0
Streblus	0	0	0	0	0
Astelia	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Freycinetia baueriana	0	0	0	0	0
Ileostylus micranthus	1	1	0	0	0
Liliaceae	0	0	0	0	0
Poaceae	0	0	1	1	0
Stellaria	0	0	0	0	0
Taraxacum type	0	0	0	0	0
Adiantum type	0	0	0	0	0
Cyathea dealbata type	4	2	4	8	1
Cyathea smithii type	0	0	0	0	0
Dicksonia squarrosa	0	1	0	0	0
Hymenophyllum	0	0	0	0	0
Lycopodium cemuum	0	0	0	0	2
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	0	0	0	0	0
Lycopodium volubile	0	0	0	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	0	0	5	1	1
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	3	0	0	0	0
Pteridium esculentum	0	1	0	1	1
Pteris	0	0	0	0	0
Cyperaceae	9	16	14	61	21
Drosera	0	0	0	0	0
Epacridaceae	33	9	7	6	14
Gleichenia	291	95	137	354	286
Haloragis	0	0	0	9	0
Leptospermum type	6	55	41	25	28
Myriophyllum	0	0	0	0	0
Potamogeton	0	0	0	0	0
Restionaceae	258	151	281	104	227

Depth (m)	**0.55**	**0.65**	**0.75**	**0.85**	**0.95**
Typha	0	0	0	0	0
Unknowns	0	0	0	17	0
Charcoal concentration	66	21	49	352	8

Depth (m)	**1.05**	**1.15**	**1.25**	**1.34**	**1.45**
Lycopodium spike	374	324	448	367	578
Spike concentration	13911	13911	13911	13911	13911
Fuscospora	4	4	6	1	6
Agathis australis	1	21	4	7	4
Casuarina	0	0	0	0	0
Cupressaceae	0	0	0	0	0
Dacrycarpus dacrydioides	1	2	0	1	2
Dacrydium cupressinum	66	83	65	56	57
Halocarpus	0	0	0	0	0
Libocedrus	2	6	1	1	3
Manoao colensoi	0	0	0	0	0
Phyllocladus	16	22	21	27	24
Pinus	0	0	0	0	0
Podocarpus type	12	12	9	12	12
Prumnopitys ferruginea	1	0	0	0	3
Prumnopitys taxifolia	5	12	8	10	7
Alectryon excelsus	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	0	0	0	0
Knightia excelsa	2	1	1	0	3
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	13	4	9	13	18
Nestegis	1	2	8	1	5
Nothofagus menziesii	0	0	1	0	0
Quintinia	0	0	0	0	0
Syzygium maire	0	0	5	7	2
Weinmannia	0	0	0	0	0
Ascarina lucida	1	1	3	2	1
Asteraceae	0	0	0	0	0
Coprosma	2	1	1	0	3
Cordyline	0	0	0	0	0
Coriaria	0	0	0	0	0
Dodonaea viscosa	5	0	3	2	9
Fabaceae	2	0	1	0	1
Geniostoma	0	0	0	0	0
Griselinia	8	1	3	2	3
Leucopogon fasciculatus	1	0	1	1	1
Malvaceae	0	0	1	0	0
Myrsine	6	3	3	4	4
Neomyrtus type	0	0	0	1	0
Pittosporum	0	0	0	0	0
Pseudopanax	0	0	0	0	1
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	0	0	0	0	0
Streblus	0	0	0	0	0
Astelia	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Freycinetia baueriana	0	0	0	0	0

Depth (m)	**1.05**	**1.15**	**1.25**	**1.34**	**1.45**
Ileostylus micranthus	0	0	0	0	0
Liliaceae	0	0	0	0	0
Poaceae	1	0	1	1	0
Stellaria	0	0	0	0	0
Taraxacum type	0	0	0	0	0
Adiantum type	0	0	0	0	0
Cyathea dealbata type	3	10	2	2	4
Cyathea smithii type	0	0	0	0	0
Dicksonia squarrosa	0	0	0	0	0
Hymenophyllum	0	0	0	1	0
Lycopodium cemuum	2	10	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	0	0	0	0	0
Lycopodium volubile	0	0	0	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fem spores	2	2	0	0	4
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	1	0	1	0	0
Pteridium esculentum	0	0	0	0	0
Pteris	1	0	0	0	0
Cyperaceae	7	11	1	9	2
Drosera	0	1	0	0	0
Epacridaceae	8	13	21	19	15
Gleichenia	167	65	30	234	47
Haloragis	1	0	0	1	0
Leptospermum type	35	0	27	37	20
Myriophyllum	0	0	0	0	0
Potamogeton	0	0	0	0	0
Restionaceae	230	142	189	167	186
Typha	0	0	0	0	0
Unknowns	1	0	1	0	0
Charcoal concentration	35	134	36	90	54

Depth (m)	**1.55**	**1.65**	**1.75**	**1.85**	**1.95**
Lycopodium spike	127	746	757	1106	1114
Spike concentration	13911	13911	13911	13911	13911
Fuscospora	1	2	2	1	0
Agathis australis	12	7	6	3	8
Casuarina	0	0	0	0	0
Cupressaceae	0	0	0	0	0
Dacrycarpus dacrydioides	2	3	5	4	3
Dacrydium cupressinum	79	66	89	53	59
Halocarpus	0	0	0	0	0
Libocedrus	1	1	2	1	2
Manoao colensoi	0	0	0	2	0
Phyllocladus	23	31	27	18	11
Pinus	0	0	0	0	0
Podocarpus type	20	11	18	7	7
Prumnopitys ferruginea	1	0	0	0	0
Prumnopitys taxifolia	12	17	26	14	25
Alectryon excelsus	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	0	0	0	0

Depth (m)	**1.55**	**1.65**	**1.75**	**1.85**	**1.95**
Knightia excelsa	0	0	1	1	0
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	7	4	7	2	3
Nestegis	3	2	5	0	1
Nothofagus menziesii	0	0	0	0	0
Quintinia	0	0	0	0	0
Syzygium maire	0	0	2	0	0
Weinmannia	0	0	0	0	0
Ascarina lucida	3	3	0	0	2
Asteraceae	0	0	0	1	0
Coprosma	3	3	2	2	3
Cordyline	0	0	0	0	0
Coriaria	0	0	0	0	0
Dodonaea viscosa	2	2	3	1	1
Fabaceae	1	0	0	0	0
Geniostoma	0	0	0	0	0
Griselinia	4	2	2	1	4
Leucopogon fasciculatus	1	0	0	2	1
Malvaceae	0	0	0	0	0
Myrsine	3	3	1	1	0
Neomyrtus type	0	2	0	0	0
Pittosporum	1	0	0	0	6
Pseudopanax	0	0	0	0	0
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	0	0	0	0	0
Streblus	0	0	0	0	0
Astelia	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Freycinetia baueriana	0	0	0	0	0
Ileostylus micranthus	0	0	0	0	0
Liliaceae	0	0	0	0	0
Poaceae	0	0	0	0	0
Stellaria	0	0	0	0	0
Taraxacum type	0	0	0	0	1
Adiantum type	0	0	0	0	0
Cyathea dealbata type	5	7	5	6	10
Cyathea smithii type	0	0	0	0	0
Dicksonia squarrosa	0	0	0	0	0
Hymenophyllum	0	0	0	0	0
Lycopodium cernuum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	0	0	0	0	0
Lycopodium volubile	0	0	0	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	1	3	3	1	0
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	0	0	0	1	0
Pteridium esculentum	0	0	0	0	0
Pteris	0	0	0	0	0
Cyperaceae	2	2	7	5	6
Drosera	0	0	0	0	1
Epacridaceae	13	11	21	7	28
Gleichenia	251	339	463	132	197
Haloragis	0	0	0	0	0

Depth (m)	**1.55**	**1.65**	**1.75**	**1.85**	**1.95**
Leptospermum type	8	2	0	1	0
Myriophyllum	0	0	0	0	0
Potamogeton	0	0	0	0	0
Restionaceae	146	210	332	175	206
Typha	0	0	0	0	0
Unknowns	0	0	1	70	1
Charcoal concentration	215	22	8	13	10

Depth (m)	**2.05**	**2.15**	**2.25**	**2.35**	**2.45**
Lycopodium spike	304	423	252	397	252
Spike concentration	13911	13911	13911	13911	11300
Fuscospora	1	4	1	3	0
Agathis australis	3	2	5	1	4
Casuarina	0	0	0	0	0
Cupressaceae	0	0	0	0	0
Dacrycarpus dacrydioides	2	3	1	0	4
Dacrydium cupressinum	56	62	33	52	55
Halocarpus	0	0	0	0	4
Libocedrus	12	1	5	4	10
Manoao colensoi	0	0	1	0	3
Phyllocladus	25	37	38	32	37
Pinus	0	0	0	0	0
Podocarpus type	11	7	3	9	9
Prumnopitys ferruginea	0	1	2	2	5
Prumnopitys taxifolia	16	28	9	20	13
Alectryon excelsus	0	0	1	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	0	0	0	2
Knightia excelsa	0	0	0	0	0
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	5	5	13	8	19
Nestegis	5	3	4	3	8
Nothofagus menziesii	0	0	0	0	0
Quintinia	0	0	0	0	0
Syzygium maire	1	0	7	0	1
Weinmannia	0	0	0	0	2
Ascarina lucida	2	1	3	3	11
Asteraceae	2	1	0	1	1
Coprosma	2	2	3	2	3
Cordyline	0	0	1	0	0
Coriaria	1	0	0	0	0
Dodonaea viscosa	2	2	0	3	1
Fabaceae	1	1	1	0	0
Geniostoma	0	0	0	0	1
Griselinia	2	4	1	2	7
Leucopogon fasciculatus	1	0	0	1	6
Malvaceae	0	0	0	0	0
Myrsine	3	0	2	2	4
Neomyrtus type	0	0	4	0	6
Pittosporum	1	1	0	0	0
Pseudopanax	0	0	0	0	1
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	0	0	0	0	0

Depth (m)	**2.05**	**2.15**	**2.25**	**2.35**	**2.45**
Streblus	0	0	0	0	1
Astelia	0	0	0	0	1
Chenopodiaceae	1	0	0	0	2
Freycinetia baueriana	0	0	0	0	0
Ileostylus micranthus	0	0	0	0	1
Liliaceae	0	0	2	0	0
Poaceae	0	0	0	1	0
Stellaria	0	0	0	0	0
Taraxacum type	0	0	0	0	0
Adiantum type	0	0	0	0	1
Cyathea dealbata type	5	9	2	10	8
Cyathea smithii type	0	0	0	0	1
Dicksonia squarrosa	0	0	0	0	0
Hymenophyllum	0	0	0	0	0
Lycopodium cemuum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	0	0	0	0	0
Lycopodium volubile	0	0	0	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	4	1	0	2	1
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	0	0	0	0	0
Pteridium esculentum	0	0	0	0	0
Pteris	0	0	0	0	0
Cyperaceae	19	6	12	6	7
Drosera	0	0	0	0	0
Epacridaceae	8	22	15	18	9
Gleichenia	143	423	105	243	164
Haloragis	0	0	0	0	0
Leptospermum type	37	11	27	22	56
Myriophyllum	0	0	0	0	0
Potamogeton	0	0	0	0	1
Restionaceae	186	138	188	305	497
Typha	0	0	2	0	0
Unknowns	2	1	1	0	0
Charcoal concentration	103	10	11.4	7	4.2

Depth (m)	**2.55**	**2.65**	**2.75**	**2.85**	**2.95**
Lycopodium spike	397	391	700	234	311
Spike concentration	13911	11300	13911	11300	13911
Fuscospora	2	2	0	2	1
Agathis australis	3	6	0	2	0
Casuarina	0	0	0	0	0
Cupressaceae	0	0	0	0	0
Dacrycarpus dacrydioides	7	4	0	2	5
Dacrydium cupressinum	62	65	85	59	58
Halocarpus	0	2	0	1	0
Libocedrus	0	11	0	15	5
Manoao colensoi	0	2	0	4	0
Phyllocladus	19	23	14	28	31
Pinus	0	0	0	0	0
Podocarpus type	9	23	0	14	4
Prumnopitys ferruginea	0	4	0	8	1

Depth (m)	**2.55**	**2.65**	**2.75**	**2.85**	**2.95**
Prumnopitys taxifolia	47	9	31	12	16
Alectryon excelsus	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	1
Elaeocarpus	0	1	0	1	0
Knightia excelsa	0	0	0	0	1
Laurelia novae-zelandiae	0	0	0	1	0
Metrosideros undiff.	0	21	0	17	8
Nestegis	2	7	0	5	7
Nothofagus menziesii	0	0	0	0	0
Quintinia	0	0	0	0	0
Syzygium maire	0	1	0	0	1
Weinmannia	0	0	0	0	0
Ascarina lucida	5	4	0	6	4
Asteraceae	1	0	0	0	2
Coprosma	0	6	0	5	2
Cordyline	0	0	0	1	0
Coriaria	0	1	0	0	0
Dodonaea viscosa	1	3	0	2	3
Fabaceae	0	0	0	0	0
Geniostoma	0	0	0	1	0
Griselinia	1	6	0	4	2
Leucopogon fasciculatus	0	3	0	2	0
Malvaceae	0	0	0	0	0
Myrsine	3	2	0	4	4
Neomyrtus type	0	6	0	11	0
Pittosporum	0	2	0	0	1
Pseudopanax	0	0	0	1	0
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	0	0	0	1	0
Streblus	0	0	0	0	0
Astelia	0	1	0	0	0
Chenopodiaceae	0	0	0	0	0
Freycinetia baueriana	0	0	0	1	0
Ileostylus micranthus	0	0	0	0	0
Liliaceae	0	3	0	1	0
Poaceae	0	1	0	0	0
Stellaria	0	0	0	0	0
Taraxacum type	0	0	0	0	0
Adiantum type	0	3	0	1	0
Cyathea dealbata type	9	3	14	3	12
Cyathea smithii type	0	0	0	1	0
Dicksonia squarrosa	0	0	0	0	0
Hymenophyllum	0	0	0	0	0
Lycopodium cernuum	2	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	0	1	0	0	0
Lycopodium volubile	0	0	0	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	2	1	5	2	1
Paesia scaberula	0	0	0	0	0
Phymatosorus diversifolius	2	1	0	0	0
Pteridium esculentum	0	0	0	2	1
Pteris	0	0	0	0	0
Cyperaceae	7	5	2	55	10

Depth (m)	**2.55**	**2.65**	**2.75**	**2.85**	**2.95**
Drosera	0	0	0	0	0
Epacridaceae	21	13	19	15	10
Gleichenia	465	158	251	133	197
Haloragis	0	0	0	0	0
Leptospermum type	5	57	0	48	18
Myriophyllum	0	1	0	0	2
Potamogeton	0	1	0	0	0
Restionaceae	521	410	454	403	447
Typha	0	0	0	0	2
Unknowns	0	1	0	1	1
Charcoal concentration	147	22.4	206	84.5	147.2

Depth (m)	**3.05**	**3.15**	**3.25**	**3.35**
Lycopodium spike	174	707	82	155
Spike concentration	11300	13911	11300	13911
Fuscospora	0	4	6	11
Agathis australis	6	6	8	4
Casuarina	0	0	0	0
Cupressaceae	0	0	0	0
Dacrycarpus dacrydioides	4	2	4	1
Dacrydium cupressinum	67	65	76	67
Halocarpus	5	0	1	0
Libocedrus	8	4	5	1
Manoao colensoi	4	0	2	0
Phyllocladus	40	20	26	13
Pinus	0	0	0	0
Podocarpus type	16	9	18	6
Prumnopitys ferruginea	6	0	5	0
Prumnopitys taxifolia	8	8	9	8
Alectryon excelsus	0	0	0	0
Dysoxylum spectabile	0	0	0	0
Elaeocarpus	0	0	1	0
Knightia excelsa	0	0	1	1
Laurelia novae-zelandiae	0	0	0	0
Metrosideros undiff.	17	3	13	1
Nestegis	2	0	4	4
Nothofagus menziesii	0	0	0	0
Quintinia	0	0	3	0
Syzygium maire	0	1	1	0
Weinmannia	0	0	0	0
Ascarina lucida	3	2	4	3
Asteraceae	0	0	1	1
Coprosma	3	5	2	1
Cordyline	1	0	1	0
Coriaria	1	0	0	0
Dodonaea viscosa	1	1	0	0
Fabaceae	0	0	0	0
Geniostoma	0	0	0	0
Griselinia	1	1	4	4
Leucopogon fasciculatus	1	0	1	0
Malvaceae	0	0	0	0
Myrsine	1	2	5	4
Neomyrtus type	2	1	2	3

Depth (m)	**3.05**	**3.15**	**3.25**	**3.35**
Pittosporum	0	0	1	1
Pseudopanax	0	0	0	1
Pseudowintera	0	0	0	1
Rhopalostylis sapida	0	1	2	0
Streblus	0	0	0	0
Astelia	1	0	0	0
Chenopodiaceae	1	0	0	0
Freycinetia baueriana	0	0	0	0
Ileostylus micranthus	0	0	0	0
Liliaceae	2	0	5	0
Poaceae	4	1	1	0
Stellaria	0	0	0	0
Taraxacum type	0	0	0	0
Adiantum type	1	0	2	0
Cyathea dealbata type	5	9	18	22
Cyathea smithii type	0	0	2	0
Dicksonia squarrosa	0	0	1	0
Hymenophyllum	0	0	1	0
Lycopodium cernuum	0	0	1	1
Lycopodium deuterodensum	0	0	1	0
Lycopodium laterale	0	2	3	3
Lycopodium volubile	0	0	0	0
Lygodium articulatum	0	0	0	0
Monolete fern spores	0	3	10	3
Paesia scaberula	0	0	0	0
Phymatosorus diversifolius	2	1	0	3
Pteridium esculentum	2	1	0	0
Pteris	0	0	0	0
Cyperaceae	55	51	157	104
Drosera	0	1	0	0
Epacridaceae	11	29	7	7
Gleichenia	50	112	34	42
Haloragis	0	1	0	0
Leptospermum type	43	15	68	28
Myriophyllum	0	0	0	0
Potamogeton	0	0	2	0
Restionaceae	455	554	120	141
Typha	0	2	0	0
Unknowns	0	4	1	2
Charcoal concentration	85.7	16.4	152.1	205.6

APPENDIX 7

Lake Ohia pollen counts:

Depth (m)	**0.05**	**0.15**	**0.25**	**0.35**	**0.45**
Lycopodium spike	66	84	115	69	171
Spike concentration	11300	11300	11300	11300	11300
Total pollen concentration	337	269	183	324	123
Charcoal concentration	2988	2312	2780	4940	1261
Agathis australis	19	16	8	9	15
Dacrycarpus dacrydioides	1	2	6	2	3
Dacrydium cupressinum	76	59	61	66	61
Halocarpus	5	12	3	4	3
Libocedrus	9	6	9	14	14
Manoao colensoi	7	2	1	5	3
Phyllocladus	19	23	20	18	16
Podocarpus type	13	9	18	20	11
Prumnopitys ferruginea	3	1	0	6	5
Prumnopitys taxifolia	15	21	23	10	11
Beilschmiedia	0	0	0	0	0
Corynocarpus laevigatus	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	1
Elaeocarpus	0	3	4	3	1
Fuscospora	5	6	2	1	1
Ixerba brexioides	0	0	0	0	0
Knightia excelsa	0	0	0	0	0
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	7	13	13	11	8
Nestegis	4	4	7	5	1
Nothofagus menziesii	0	0	0	0	0
Quintinia	0	2	0	2	2
Syzygium maire	0	0	0	0	0
Weinmannia	0	0	2	1	7
Ascarina lucida	1	0	0	0	2
Asteraceae	0	1	0	1	1
Coprosma	1	3	2	1	5
Cordyline	2	0	0	0	0
Dodonaea viscosa	0	0	2	1	0
Fabaceae	1	0	0	0	0
Griselinia	5	5	2	4	3
Leucopogon fasciculatus	0	1	0	0	0
Litsea calicaris	0	0	0	0	0
Malvaceae	0	0	0	0	0
Myrsine	4	7	8	4	5
Neomyrtus type	9	6	10	7	7
Pittosporum	0	0	1	0	0
Plagianthus type	1	0	0	0	0
Pseudopanax undiff.	0	0	0	0	0
Pseudowintera	0	1	0	0	0
Rhopalostylis sapida	0	0	0	2	0
Schrophulariaceae	0	0	0	0	0
Toronia toru	0	0	0	0	0
Verbenaceae	0	0	1	0	0
Astelia	2	3	1	0	1
Calystegia	0	0	0	0	0
Chenopodiaceae	0	0	1	1	0
Freycinetia baueriana	0	0	0	0	2

Depth (m)	**0.05**	**0.15**	**0.25**	**0.35**	**0.45**
Ileostylus micranthus	0	0	0	0	0
Liliaceae	7	0	1	1	6
Parsonsia	0	0	1	0	0
Poaceae	1	1	2	1	4
Tupeia antarctica	0	0	1	0	0
Adiantum type	0	0	0	0	1
Cyathea dealbata type	2	4	4	1	3
Cyathea smithii type	0	2	2	3	1
Dicksonia squarrosa	1	0	0	0	0
Hymenophyllum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	0	0	0	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	3	2	3	2	3
Phymatosorus diversifolius	0	0	1	0	0
Pteridium esculentum	1	0	1	6	0
Pteris	0	0	1	0	0
Schizaea	0	0	0	0	0
Cyperaceae	4	18	17	19	41
Epacridaceae	78	83	49	84	107
Gleichenia	72	79	162	110	54
Haloragis	0	0	0	0	0
Leptospermum type	27	26	74	74	43
Potamogeton	0	1	0	0	0
Restionaceae	578	576	406	489	474
Typha	0	0	0	1	0
Unknowns	0	0	0	0	1

Depth (m)	**0.55**	**0.65**	**0.75**	**0.85**	**0.95**
Lycopodium spike	141	55	34	87	86
Spike concentration	11300	11300	11300	11300	11300
Total pollen concentration	130	344	636	197	190
Charcoal concentration	1141	2685	8235	1180	500
Agathis australis	19	20	12	12	22
Dacrycarpus dacrydioides	1	2	2	1	1
Dacrydium cupressinum	43	40	62	52	45
Halocarpus	2	7	5	1	0
Libocedrus	12	6	2	5	7
Manoao colensoi	5	11	14	3	3
Phyllocladus	16	14	8	18	12
Podocarpus type	6	15	16	10	5
Prumnopitys ferruginea	8	15	8	1	2
Prumnopitys taxifolia	16	29	26	7	6
Beilschmiedia	0	0	0	0	0
Corynocarpus laevigatus	0	1	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	10	10	9	6	5
Fuscospora	4	0	4	1	1
Ixerba brexioides	0	0	0	0	0
Knightia excelsa	0	0	0	0	0
Laurelia novae-zelandiae	0	0	0	0	1
Metrosideros undiff.	22	7	15	19	28
Nestegis	5	2	1	9	4

Depth (m)	**0.55**	**0.65**	**0.75**	**0.85**	**0.95**
Nothofagus menziesii	1	0	0	0	0
Quintinia	3	0	4	1	1
Syzygium maire	0	0	0	0	0
Weinmannia	17	22	13	17	6
Ascarina lucida	3	1	2	0	4
Asteraceae	0	0	0	0	0
Coprosma	3	2	3	1	6
Cordyline	0	0	0	1	1
Dodonaea viscosa	0	0	0	0	0
Fabaceae	0	0	0	0	0
Griselinia	1	0	1	4	3
Leucopogon fasciculatus	1	0	0	2	0
Litsea calicaris	0	0	0	0	0
Malvaceae	1	0	0	0	0
Myrsine	1	4	0	5	2
Neomyrtus type	11	7	2	29	28
Pittosporum	2	0	0	0	0
Plagianthus type	0	1	0	0	1
Pseudopanax undiff.	0	0	0	1	1
Pseudowintera	1	0	0	0	0
Rhopalostylis sapida	0	0	0	0	1
Schrophulariaceae	0	0	0	0	0
Toronia toru	0	0	0	0	0
Verbenaceae	0	0	0	0	2
Astelia	0	0	0	4	1
Calystegia	0	0	0	1	0
Chenopodiaceae	0	1	0	1	0
Freycinetia baueriana	0	1	0	0	0
Ileostylus micranthus	0	0	1	0	0
Liliaceae	0	0	0	3	5
Parsonsia	0	0	0	0	0
Poaceae	0	2	0	1	3
Tupeia antarctica	0	0	0	0	0
Adiantum type	0	1	5	1	1
Cyathea dealbata type	3	5	4	5	4
Cyathea smithii type	0	4	2	0	0
Dicksonia squarrosa	0	0	0	0	1
Hymenophyllum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	0	0	0	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	3	1	3	4	4
Phymatosorus diversifolius	3	0	1	0	0
Pteridium esculentum	0	0	0	0	1
Pteris	0	0	0	0	0
Schizaea	0	0	0	0	0
Cyperaceae	23	2	21	18	50
Epacridaceae	94	116	133	54	57
Gleichenia	74	214	258	43	27
Haloragis	0	0	0	0	0
Leptospermum type	67	42	35	204	178
Potamogeton	1	0	0	0	1
Restionaceae	332	231	285	211	190
Typha	0	0	0	0	1
Unknowns	0	0	0	1	0

Depth (m)	**1.05**	**1.15**	**1.25**	**1.35**	**1.45**
Lycopodium spike	2	14	19	39	17
Spike concentration	11300	11300	11300	11300	11300
Total pollen concentration	3221	1285	614	366	484
Charcoal concentration	606	23	25	43	120
Agathis australis	10	23	36	52	32
Dacrycarpus dacrydioides	1	1	2	1	3
Dacrydium cupressinum	122	555	287	401	218
Halocarpus	0	5	2	3	2
Libocedrus	1	4	2	3	1
Manoao colensoi	7	6	4	5	2
Phyllocladus	34	36	18	32	3
Podocarpus type	3	17	3	6	1
Prumnopitys ferruginea	5	6	5	5	4
Prumnopitys taxifolia	7	17	10	6	5
Beilschmiedia	0	0	0	0	0
Corynocarpus laevigatus	0	0	0	0	0
Dysoxylum spectabile	1	0	2	0	0
Elaeocarpus	2	8	6	3	0
Fuscospora	1	3	1	0	0
Ixerba brexioides	1	0	2	1	1
Knightia excelsa	0	1	0	0	0
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	0	3	6	4	4
Nestegis	3	3	1	0	1
Nothofagus menziesii	0	0	0	0	0
Quintinia	5	7	67	17	52
Syzygium maire	0	0	1	0	0
Weinmannia	5	20	11	19	2
Ascarina lucida	1	0	1	0	0
Asteraceae	0	0	0	0	0
Coprosma	1	2	2	1	2
Cordyline	0	1	2	0	0
Dodonaea viscosa	0	0	2	0	0
Fabaceae	1	0	2	0	0
Griselinia	2	5	5	5	2
Leucopogon fasciculatus	1	3	4	2	0
Litsea calicaris	1	0	0	0	0
Malvaceae	0	1	0	0	0
Myrsine	2	4	0	3	0
Neomyrtus type	1	0	1	1	0
Pittosporum	3	4	0	0	0
Plagianthus type	0	0	0	0	0
Pseudopanax undiff.	1	0	1	1	1
Pseudowintera	1	0	1	0	2
Rhopalostylis sapida	0	2	0	0	0
Schrophulariaceae	0	0	0	0	1
Toronia toru	0	0	0	0	0
Verbenaceae	0	0	0	0	0
Astelia	2	1	2	1	0
Calystegia	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Freycinetia baueriana	0	0	0	0	0
Ileostylus micranthus	0	0	0	0	0
Liliaceae	1	0	2	0	0

Depth (m)	**1.05**	**1.15**	**1.25**	**1.35**	**1.45**
Parsonsia	0	0	0	0	0
Poaceae	0	0	0	1	0
Tupeia antarctica	0	0	0	0	0
Adiantum type	4	0	0	0	0
Cyathea dealbata type	1	4	5	5	2
Cyathea smithii type	0	2	1	1	2
Dicksonia squarrosa	0	1	0	1	2
Hymenophyllum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium laterale	0	0	0	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	1	8	0	5	1
Phymatosorus diversifolius	1	0	1	0	0
Pteridium esculentum	0	0	0	1	0
Pteris	0	0	0	0	0
Schizaea	0	0	0	0	0
Cyperaceae	2	0	1	1	0
Epacridaceae	12	22	6	13	3
Gleichenia	1	9	3	11	12
Haloragis	0	0	0	0	0
Leptospermum type	2	1	6	12	0
Potamogeton	0	1	0	0	0
Restionaceae	35	10	1	8	3
Typha	0	0	0	0	0
Unknowns	0	0	1	1	0

Depth (m)	**1.55**	**1.65**	**1.75**	**1.85**	**1.95**
Lycopodium spike	50	87	28	21	53
Spike concentration	11300	11300	11300	11300	11300
Total pollen concentration	233	182	634	466	187
Charcoal concentration	409	1144	2439	179	136
Agathis australis	19	13	6	13	18
Dacrycarpus dacrydioides	2	0	2	2	3
Dacrydium cupressinum	130	86	48	115	128
Halocarpus	3	0	1	3	4
Libocedrus	4	10	2	8	2
Manoao colensoi	5	3	11	7	3
Phyllocladus	20	16	10	70	38
Podocarpus type	5	5	10	4	5
Prumnopitys ferruginea	0	3	20	6	8
Prumnopitys taxifolia	11	9	28	11	9
Beilschmiedia	0	0	0	1	0
Corynocarpus laevigatus	0	0	0	1	0
Dysoxylum spectabile	0	2	0	0	0
Elaeocarpus	8	0	4	2	3
Fuscospora	1	1	2	2	0
Ixerba brexioides	0	0	0	4	9
Knightia excelsa	0	0	0	0	2
Laurelia novae-zelandiae	0	0	0	0	2
Metrosideros undiff.	4	12	10	15	19
Nestegis	0	5	1	1	3
Nothofagus menziesii	0	0	0	0	0
Quintinia	33	3	2	16	24

Depth (m)	**1.55**	**1.65**	**1.75**	**1.85**	**1.95**
Syzygium maire	0	0	1	0	1
Weinmannia	8	4	28	11	9
Ascarina lucida	0	2	0	6	4
Asteraceae	0	1	0	0	0
Coprosma	1	5	0	3	2
Cordyline	0	0	0	0	0
Dodonaea viscosa	0	0	0	0	0
Fabaceae	0	0	0	0	0
Griselinia	1	3	2	0	5
Leucopogon fasciculatus	1	0	0	6	5
Litsea calicaris	0	0	0	0	0
Malvaceae	1	0	0	0	0
Myrsine	3	2	1	3	2
Neomyrtus type	6	11	8	0	2
Pittosporum	0	1	0	1	4
Plagianthus type	0	0	0	0	0
Pseudopanax undiff.	1	0	0	0	0
Pseudowintera	4	0	0	1	0
Rhopalostylis sapida	2	0	0	3	1
Schrophulariaceae	0	0	0	0	0
Toronia toru	0	0	0	0	2
Verbenaceae	0	0	0	0	0
Astelia	2	2	1	5	2
Calystegia	0	0	0	0	2
Chenopodiaceae	0	0	0	0	0
Freycinetia baueriana	0	0	0	0	0
Ileostylus micranthus	0	0	0	0	0
Liliaceae	1	2	1	1	0
Parsonsia	0	0	0	0	0
Poaceae	0	0	0	0	0
Tupeia antarctica	0	0	0	0	0
Adiantum type	1	1	1	0	2
Cyathea dealbata type	3	2	5	4	3
Cyathea smithii type	0	1	1	8	5
Dicksonia squarrosa	2	1	0	1	4
Hymenophyllum	1	0	0	1	1
Lycopodium deuterodensum	0	0	0	0	1
Lycopodium laterale	0	0	1	0	0
Lygodium articulatum	0	0	0	1	0
Monolete fern spores	14	1	1	8	3
Phymatosorus diversifolius	0	0	0	1	3
Pteridium esculentum	0	0	0	0	1
Pteris	0	0	0	0	0
Schizaea	0	0	0	1	0
Cyperaceae	28	17	5	2	0
Epacridaceae	19	77	82	24	33
Gleichenia	51	87	236	47	43
Haloragis	0	0	0	0	0
Leptospermum type	9	87	29	4	5
Potamogeton	0	0	2	0	0
Restionaceae	111	224	223	10	12
Typha	0	0	0	0	0
Unknowns	0	0	0	0	2

Depth (m)	**2.05**	**2.15**	**2.25**	**2.35**	**2.45**	**2.55**
Lycopodium spike	16	43	67	14	49	189
Spike concentration	11300	11300	11300	11300	11300	11300
Total pollen concentration	370	159	99	416	122	35
Charcoal concentration	147	79	8	206	5	0
Agathis australis	6	30	35	24	52	35
Dacrycarpus dacrydioides	1	3	1	1	2	2
Dacrydium cupressinum	66	69	45	54	47	62
Halocarpus	9	5	3	3	2	7
Libocedrus	6	3	5	3	4	1
Manoao colensoi	3	6	3	4	3	6
Phyllocladus	18	21	44	35	36	43
Podocarpus type	7	4	4	3	2	4
Prumnopitys ferruginea	3	1	0	6	3	3
Prumnopitys taxifolia	4	7	5	7	8	9
Beilschmiedia	1	0	0	1	1	2
Corynocarpus laevigatus	0	0	0	0	0	0
Dysoxylum spectabile	1	1	0	1	0	0
Elaeocarpus	5	5	1	2	1	5
Fuscospora	0	0	0	0	0	0
Ixerba brexioides	3	1	1	2	0	3
Knightia excelsa	1	0	0	0	0	1
Laurelia novae-zelandiae	2	0	0	0	0	0
Metrosideros undiff.	11	25	28	20	26	12
Nestegis	4	2	5	5	1	2
Nothofagus menziesii	0	0	1	0	0	0
Quintinia	13	26	22	10	20	8
Syzygium maire	2	2	2	0	0	0
Weinmannia	8	10	4	7	1	1
Ascarina lucida	2	8	13	2	6	6
Asteraceae	0	1	0	0	0	1
Coprosma	1	6	4	2	6	4
Cordyline	1	0	0	1	2	1
Dodonaea viscosa	1	1	0	0	0	0
Fabaceae	1	3	2	0	0	1
Griselinia	2	2	2	1	4	3
Leucopogon fasciculatus	0	0	1	0	1	3
Litsea calicaris	0	0	1	0	0	0
Malvaceae	0	0	1	0	0	0
Myrsine	3	9	11	4	5	7
Neomyrtus type	6	7	8	3	6	7
Pittosporum	2	1	1	1	3	0
Plagianthus type	0	2	0	0	0	1
Pseudopanax undiff.	0	0	0	0	0	0
Pseudowintera	0	0	1	1	0	1
Rhopalostylis sapida	0	0	0	0	1	1
Schrophulariaceae	0	0	0	0	0	0
Toronia toru	1	0	0	0	0	0
Verbenaceae	0	0	0	0	0	0
Astelia	4	5	7	3	1	2
Calystegia	0	0	0	0	0	0
Chenopodiaceae	0	0	0	1	0	0
Freycinetia baueriana	3	1	4	0	1	1
Ileostylus micranthus	0	0	0	0	0	0
Liliaceae	0	0	2	2	1	0

Depth (m)	**2.05**	**2.15**	**2.25**	**2.35**	**2.45**	**2.55**
Parsonsia	0	0	0	0	0	0
Poaceae	3	5	1	2	0	1
Tupeia antarctica	0	0	1	2	5	3
Adiantum type	1	1	0	0	0	1
Cyathea dealbata type	5	2	2	2	1	4
Cyathea smithii type	5	0	1	0	1	0
Dicksonia squarrosa	1	1	0	0	0	0
Hymenophyllum	1	0	0	0	0	2
Lycopodium deuterodensum	0	0	0	0	0	0
Lycopodium laterale	0	0	0	0	0	1
Lygodium articulatum	0	0	2	0	0	0
Monolete fern spores	1	1	1	3	0	3
Phymatosorus diversifolius	1	0	0	0	0	0
Pteridium esculentum	0	0	0	0	0	0
Pteris	0	0	0	0	0	0
Schizaea	0	0	0	0	0	0
Cyperaceae	1	1	4	3	2	4
Epacridaceae	11	10	2	7	1	7
Gleichenia	18	8	2	9	2	9
Haloragis	0	0	0	1	0	0
Leptospermum type	6	5	11	9	6	5
Potamogeton	0	0	0	0	0	0
Restionaceae	7	1	0	11	0	5
Typha	0	0	0	0	0	0
Unknowns	0	0	0	0	0	0

APPENDIX 8

Lake Tangonge pollen counts:

Depth (m)	**0.25**	**0.35**	**0.45**	**0.55**	**0.65**
Lycopodium spike	32	73	46	38	52
Spike concentration	11300	11300	11300	11300	11300
Total pollen concentration	55	24	29	31	23
Charcoal concentration	86	38	6	3	4
Fuscospora	1	2	1	1	4
Agathis australis	3	7	4	11	7
Dacrycarpus dacrydioides	17	20	27	31	23
Dacrydium cupressinum	102	81	87	102	75
Halocarpus	3	2	4	2	2
Libocedrus	2	1	5	2	4
Manoao colensoi	5	3	3	2	3
Phyllocladus	15	13	13	13	11
Podocarpus type	6	7	4	7	6
Prumnopitys ferruginea	5	4	5	4	4
Prumnopitys taxifolia	11	8	13	9	3
Alectryon excelsus	0	0	0	0	0
Beilschmiedia	0	0	0	0	0
Casuarina	0	1	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	3	3	2	2	2
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	1	1	3	2	1
Laurelia novae-zelandiae	0	0	2	0	3
Metrosideros undiff.	25	27	25	28	20
Nestegis	2	6	5	4	1
Nothofagus menziesii	0	0	0	0	0
Quintinia	3	0	2	2	1
Syzygium maire	5	4	1	5	1
Vitex lucens	1	0	0	0	1
Weinmannia	2	0	2	1	5
Ascarina lucida	9	3	3	8	13
Asteraceae	1	0	0	0	0
Carpodetus	0	0	0	0	0
Cordyline	2	3	1	2	5
Coriaria	0	0	0	1	1
Dodonaea viscosa	2	0	0	1	1
Fabaceae	0	0	0	0	0
Fuschia	0	0	0	0	0
Griselinia	10	13	5	12	6
Ixerba brexioides	0	0	0	0	0
Leucopogon fasciculatus	4	0	2	0	1
Malvaceae	0	0	0	0	0
Myrsine	2	6	3	0	0
Neomyrtus type	5	18	12	4	11
Pittosporum	4	4	2	4	1
Plagianthus type	0	0	0	0	0
Pseudopanax	2	2	0	2	1
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	1	0	1	0	3
Schefflera digitata	2	2	1	1	0
Apiaceae	0	0	0	0	0
Astelia	1	0	2	2	5

Depth (m)	**0.25**	**0.35**	**0.45**	**0.55**	**0.65**
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Dactylanthus taylorii	0	0	0	0	0
Freycinetia baueriana	0	0	0	0	1
Hydrocotyle novae-zelandiae	0	0	0	0	0
Ileostylus micranthus	1	1	0	0	1
Liliaceae	1	2	2	2	4
Parsonsia	0	0	0	0	0
Phormium	1	0	1	0	0
Poaceae	1	1	1	1	2
Pteridium esculentum	4	1	1	1	4
Tupeia antarctica	0	0	0	0	0
Adiantum type	0	3	1	0	2
Cyathea dealbata type	4	3	6	13	9
Cyathea smithii type	1	1	4	2	4
Dicksonia fibrosa	0	0	0	0	0
Dicksonia squarrosa	0	0	0	1	0
Hymenophyllum	1	0	1	0	2
Lycopodium cernuum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium fastigiatum	0	0	0	0	0
Lycopodium laterale	0	0	0	0	0
Lycopodium varium	0	0	0	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	2	16	15	26	36
Paesia scaberula	0	0	0	0	0
Phylloglossum drummondii	0	0	0	0	0
Phymatosorus	6	9	15	6	20
Pteris	0	0	0	0	0
Coprosma	92	111	163	101	115
Cyperaceae	19	48	34	18	15
Drosera	0	0	0	0	0
Epacridaceae	2	3	1	3	4
Gleichenia	174	70	14	10	12
Haloragis	0	0	0	0	0
Leptospermum type	193	270	70	63	43
Myriophyllum	1	0	0	0	1
Potamogeton	0	0	0	1	1
Restionaceae	20	10	14	9	18
Typha	0	0	2	0	2
Unknowns	2	0	0	0	0

Depth (m)	**0.75**	**0.85**	**0.95**	**1.05**	**1.1**
Lycopodium spike	57	43	103	187	107
Spike concentration	11300	11300	11300	11300	11300
Total pollen concentration	20	29	12	6	13
Charcoal concentration	5	6	36	3	40
Fuscospora	9	4	6	4	10
Agathis australis	8	7	5	6	5
Dacrycarpus dacrydioides	26	17	13	29	15
Dacrydium cupressinum	91	78	85	38	31
Halocarpus	1	2	4	0	0
Libocedrus	4	6	5	3	12

Depth (m)	**0.75**	**0.85**	**0.95**	**1.05**	**1.1**
Manoao colensoi	1	0	1	4	0
Phyllocladus	8	8	10	3	5
Podocarpus type	5	4	5	3	5
Prumnopitys ferruginea	1	1	2	1	2
Prumnopitys taxifolia	6	4	2	3	6
Alectryon excelsus	0	0	0	0	0
Beilschmiedia	0	1	0	0	0
Casuarina	0	1	0	0	0
Dysoxylum spectabile	0	1	0	1	0
Elaeocarpus	2	1	1	2	0
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	0	1	2	1	2
Laurelia novae-zelandiae	1	1	2	1	1
Metrosideros undiff.	46	40	30	32	44
Nestegis	2	3	2	1	2
Nothofagus menziesii	0	0	0	0	0
Quintinia	3	3	3	3	3
Syzygium maire	1	4	1	3	0
Vitex lucens	0	1	1	0	0
Weinmannia	1	0	0	0	0
Ascarina lucida	12	13	10	38	19
Asteraceae	2	0	2	1	5
Carpodetus	0	0	0	0	0
Cordyline	3	1	4	0	1
Coriaria	1	0	1	0	0
Dodonaea viscosa	0	1	0	0	0
Fabaceae	0	0	0	1	0
Fuschia	0	0	0	0	0
Griselinia	6	7	4	1	2
Ixerba brexioides	0	0	0	0	0
Leucopogon fasciculatus	0	0	0	0	0
Malvaceae	0	0	0	0	0
Myrsine	0	0	0	2	1
Neomyrtus type	5	10	7	4	12
Pittosporum	3	3	0	0	1
Plagianthus type	0	0	0	0	0
Pseudopanax	2	1	0	1	0
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	0	2	3	3	3
Schefflera digitata	0	0	0	0	0
Apiaceae	0	0	0	0	0
Astelia	2	0	2	0	1
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	1	0	0	0
Dactylanthus taylorii	1	0	0	0	0
Freycinetia baueriana	0	0	1	1	11
Hydrocotyle novae-zelandiae	0	0	0	0	0
Ileostylus micranthus	0	1	1	0	0
Liliaceae	3	2	1	3	3
Parsonsia	0	0	0	0	0
Phormium	0	1	0	0	3
Poaceae	3	4	6	4	0
Pteridium esculentum	6	2	6	6	6
Tupeia antarctica	0	0	0	1	1

Depth (m)	**0.75**	**0.85**	**0.95**	**1.05**	**1.1**
Adiantum type	0	0	1	3	2
Cyathea dealbata type	12	16	23	18	17
Cyathea smithii type	6	6	11	2	1
Dicksonia fibrosa	0	0	1	2	2
Dicksonia squarrosa	2	2	8	4	6
Hymenophyllum	0	1	0	3	0
Lycopodium cernuum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium fastigiatum	0	0	0	0	0
Lycopodium laterale	0	0	0	0	0
Lycopodium varium	0	0	0	0	2
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	33	55	78	109	155
Paesia scaberula	0	0	0	0	0
Phylloglossum drummondii	0	0	0	0	0
Phymatosorus	12	17	28	62	34
Pteris	0	0	0	0	0
Coprosma	83	111	17	1	7
Cyperaceae	15	18	34	7	69
Drosera	0	0	0	0	0
Epacridaceae	7	4	1	5	8
Gleichenia	20	24	33	17	19
Haloragis	0	0	0	0	0
Leptospermum type	28	37	9	4	0
Myriophyllum	0	2	0	0	0
Potamogeton	4	4	8	6	7
Restionaceae	25	26	55	15	80
Typha	1	1	1	0	0
Unknowns	0	0	1	1	0

Depth (m)	**1.15**	**1.2**	**1.25**	**1.3**	**1.35**
Lycopodium spike	168	117	118	127	694
Spike concentration	11300	11300	11300	11300	11300
Total pollen concentration	11	20	16	20	2
Charcoal concentration	62	579	250	146	30
Fuscospora	13	28	35	61	30
Agathis australis	5	4	2	2	7
Dacrycarpus dacrydioides	12	4	3	1	3
Dacrydium cupressinum	35	57	43	45	31
Halocarpus	1	0	0	2	1
Libocedrus	7	4	11	4	7
Manoao colensoi	3	3	2	5	3
Phyllocladus	3	7	5	6	1
Podocarpus type	6	11	15	11	13
Prumnopitys ferruginea	4	2	6	5	5
Prumnopitys taxifolia	7	15	8	20	9
Alectryon excelsus	0	0	0	0	0
Beilschmiedia	0	0	0	0	0
Casuarina	0	0	0	1	0
Dysoxylum spectabile	0	0	1	0	0
Elaeocarpus	0	0	0	1	2

Depth (m)	**1.15**	**1.2**	**1.25**	**1.3**	**1.35**
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	0	0	0	0	0
Laurelia novae-zelandiae	2	0	2	0	1
Metrosideros undiff.	28	27	14	11	25
Nestegis	4	7	9	7	5
Nothofagus menziesii	0	0	0	0	0
Quintinia	1	3	3	3	1
Syzygium maire	1	1	0	1	0
Vitex lucens	0	0	0	0	0
Weinmannia	0	0	2	1	0
Ascarina lucida	9	7	3	8	5
Asteraceae	3	10	12	13	5
Carpodetus	0	0	0	0	0
Cordyline	5	4	7	4	1
Coriaria	0	0	0	0	0
Dodonaea viscosa	0	2	0	1	0
Fabaceae	1	0	0	0	0
Fuschia	0	0	0	0	0
Griselinia	3	1	5	1	3
Ixerba brexioides	0	0	0	0	0
Leucopogon fasciculatus	0	0	0	1	0
Malvaceae	0	0	0	0	0
Myrsine	0	2	1	0	0
Neomyrtus type	4	10	12	10	17
Pittosporum	2	1	2	0	3
Plagianthus type	0	0	0	0	0
Pseudopanax	0	0	0	0	1
Pseudowintera	0	0	0	1	0
Rhopalostylis sapida	4	0	0	0	1
Schefflera digitata	0	0	0	0	0
Apiaceae	0	0	0	0	0
Astelia	4	0	5	4	2
Caryophyllaceae	0	0	0	0	1
Chenopodiaceae	0	1	0	0	0
Dactylanthus taylorii	0	0	0	0	0
Freycinetia baueriana	1	3	0	0	1
Hydrocotyle novae-zelandiae	0	0	0	0	0
Ileostylus micranthus	0	0	1	0	0
Liliaceae	6	4	6	1	1
Parsonsia	0	0	0	1	0
Phormium	0	0	0	1	0
Poaceae	13	1	6	2	2
Pteridium esculentum	0	1	2	0	4
Tupeia antarctica	1	1	2	0	0
Adiantum type	3	2	2	6	2
Cyathea dealbata type	26	9	4	6	6
Cyathea smithii type	2	1	4	3	1
Dicksonia fibrosa	3	0	1	0	0
Dicksonia squarrosa	14	0	2	0	3
Hymenophyllum	0	0	1	0	0
Lycopodium cernuum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	1	0
Lycopodium fastigiatum	0	0	0	0	0
Lycopodium laterale	0	0	0	0	0

Depth (m)	**1.15**	**1.2**	**1.25**	**1.3**	**1.35**
Lycopodium varium	0	0	0	0	0
Lygodium articulatum	1	0	0	0	0
Monolete fern spores	114	13	24	9	13
Paesia scaberula	1	0	0	0	0
Phylloglossum drummondii	0	0	0	0	0
Phymatosorus	26	1	8	1	1
Pteris	3	0	0	0	0
Coprosma	17	12	32	15	2
Cyperaceae	134	260	224	278	146
Drosera	0	0	0	0	0
Epacridaceae	5	11	15	9	7
Gleichenia	75	106	31	172	36
Haloragis	0	0	0	0	0
Leptospermum type	32	145	118	170	59
Myriophyllum	0	0	0	0	0
Potamogeton	16	0	4	1	0
Restionaceae	156	255	142	189	93
Typha	1	0	0	0	0
Unknowns	0	0	1	3	5

Depth (m)	**1.4**	**1.45**	**1.5**	**1.55**	**1.65**
Lycopodium spike	866	347	64	142	125
Spike concentration	11300	11300	11300	11300	11300
Total pollen concentration	2	4	21	10	9
Charcoal concentration	18	27	32	38	93
Fuscospora	36	49	70	46	51
Agathis australis	0	3	2	2	0
Dacrycarpus dacrydioides	8	1	5	2	3
Dacrydium cupressinum	52	49	55	59	59
Halocarpus	0	2	3	1	3
Libocedrus	7	4	13	5	0
Manoao colensoi	0	2	8	30	3
Phyllocladus	5	2	6	0	1
Podocarpus type	22	19	26	30	31
Prumnopitys ferruginea	17	7	7	6	4
Prumnopitys taxifolia	38	29	35	28	34
Alectryon excelsus	0	0	0	0	1
Beilschmiedia	0	0	0	0	0
Casuarina	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	1	0	2	2
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	0	1	0	1	0
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	6	9	6	5	8
Nestegis	0	2	5	5	4
Nothofagus menziesii	0	0	0	0	0
Quintinia	1	1	1	0	1
Syzygium maire	0	0	0	0	0
Vitex lucens	0	0	0	0	0
Weinmannia	0	0	1	0	0

Depth (m)	**1.4**	**1.45**	**1.5**	**1.55**	**1.65**
Ascarina lucida	1	3	4	2	5
Asteraceae	3	1	0	0	0
Carpodetus	0	0	0	0	0
Cordyline	1	0	1	1	0
Coriaria	0	0	0	0	0
Dodonaea viscosa	0	0	0	0	0
Fabaceae	0	0	0	0	0
Fuschia	0	0	0	0	0
Griselinia	2	1	1	3	3
Ixerba brexioides	0	0	0	0	0
Leucopogon fasciculatus	0	2	0	0	1
Malvaceae	0	1	0	0	0
Myrsine	1	2	2	3	4
Neomyrtus type	1	2	8	4	0
Pittosporum	0	0	0	0	1
Plagianthus type	0	0	1	1	0
Pseudopanax	1	1	0	1	0
Pseudowintera	0	0	0	0	0
Rhopalostylis sapida	1	0	0	0	0
Schefflera digitata	0	0	0	0	0
Apiaceae	0	0	0	0	0
Astelia	1	1	1	1	1
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Dactylanthus taylorii	0	0	0	0	0
Freycinetia baueriana	3	0	1	0	0
Hydrocotyle novae-zelandiae	0	0	0	0	0
Ileostylus micranthus	0	0	0	0	0
Liliaceae	0	0	2	2	0
Parsonsia	0	0	0	0	0
Phormium	0	0	0	0	0
Poaceae	0	3	5	0	1
Pteridium esculentum	1	1	0	2	1
Tupeia antarctica	0	1	0	1	0
Adiantum type	3	1	2	1	1
Cyathea dealbata type	8	7	5	6	4
Cyathea smithii type	1	4	1	4	2
Dicksonia fibrosa	0	0	0	0	0
Dicksonia squarrosa	1	0	0	0	0
Hymenophyllum	0	0	0	0	0
Lycopodium cernuum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium fastigiatum	0	0	1	0	0
Lycopodium laterale	0	0	0	0	0
Lycopodium varium	0	0	0	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	24	7	5	5	1
Paesia scaberula	0	0	0	0	0
Phylloglossum drummondii	0	0	0	0	0
Phymatosorus	7	2	1	1	1
Pteris	0	0	0	0	0
Coprosma	6	4	4	2	5
Cyperaceae	221	147	252	175	179
Drosera	0	0	0	1	0

Depth (m)	**1.4**	**1.45**	**1.5**	**1.55**	**1.65**
Epacridaceae	2	2	0	2	0
Gleichenia	61	25	19	22	19
Haloragis	0	0	1	0	0
Leptospermum type	6	47	15	121	30
Myriophyllum	0	0	1	0	0
Potamogeton	1	0	2	0	0
Restionaceae	145	106	28	19	18
Typha	0	0	0	0	0
Unknowns	2	2	0	0	0

Depth (m)	**1.75**	**1.85**	**1.95**	**2.05**	**2.15**
Lycopodium spike	156	62	327	661	323
Spike concentration	11300	11300	11300	11300	11300
Total pollen concentration	6	20	5	3	6
Charcoal concentration	33	36	2	3	16
Fuscospora	54	41	4	1	4
Agathis australis	7	13	22	19	20
Dacrycarpus dacrydioides	1	6	2	4	3
Dacrydium cupressinum	72	72	71	69	63
Halocarpus	3	5	0	0	2
Libocedrus	9	11	13	21	14
Manoao colensoi	4	4	4	6	1
Phyllocladus	5	1	19	13	9
Podocarpus type	33	16	10	14	2
Prumnopitys ferruginea	10	3	10	3	4
Prumnopitys taxifolia	19	15	15	8	10
Alectryon excelsus	0	0	0	0	0
Beilschmiedia	0	0	0	0	0
Casuarina	0	0	2	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	1	2	1	5
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	0	0	0	0	0
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	4	8	17	22	29
Nestegis	3	6	3	3	1
Nothofagus menziesii	0	0	0	0	0
Quintinia	0	1	1	2	2
Syzygium maire	0	0	1	2	4
Vitex lucens	0	0	0	0	0
Weinmannia	0	0	1	8	13
Ascarina lucida	3	4	1	1	0
Asteraceae	1	0	1	1	2
Carpodetus	0	1	0	0	0
Cordyline	0	1	0	0	0
Coriaria	0	0	1	0	0
Dodonaea viscosa	0	0	0	0	0
Fabaceae	0	0	0	0	0
Fuschia	0	0	1	0	0
Griselinia	2	0	1	2	5
Ixerba brexioides	0	0	1	0	0
Leucopogon fasciculatus	0	0	1	1	1
Malvaceae	0	0	0	0	0

Depth (m)	**1.75**	**1.85**	**1.95**	**2.05**	**2.15**
Myrsine	3	1	2	1	2
Neomyrtus type	0	1	2	7	8
Pittosporum	2	3	0	3	2
Plagianthus type	0	0	0	0	0
Pseudopanax	0	1	0	0	1
Pseudowintera	0	0	0	1	0
Rhopalostylis sapida	0	0	0	0	0
Schefflera digitata	0	0	0	0	0
Apiaceae	0	1	0	0	0
Astelia	0	3	1	1	2
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Dactylanthus taylorii	0	0	0	0	0
Freycinetia baueriana	0	0	0	0	1
Hydrocotyle novae-zelandiae	0	0	0	0	0
Ileostylus micranthus	0	1	0	0	0
Liliaceae	1	2	1	1	0
Parsonsia	0	0	1	0	0
Phormium	0	0	0	0	0
Poaceae	0	4	1	1	2
Pteridium esculentum	2	3	1	2	1
Tupeia antarctica	1	0	0	0	0
Adiantum type	0	2	0	2	3
Cyathea dealbata type	9	6	10	6	9
Cyathea smithii type	4	4	2	0	4
Dicksonia fibrosa	0	0	0	0	0
Dicksonia squarrosa	0	0	0	0	0
Hymenophyllum	0	0	0	2	2
Lycopodium cernuum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium fastigiatum	0	0	0	0	0
Lycopodium laterale	0	3	0	0	0
Lycopodium varium	0	0	0	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	3	8	36	114	163
Paesia scaberula	0	0	0	0	0
Phylloglossum drummondii	0	0	0	0	0
Phymatosorus	0	2	3	23	31
Pteris	0	0	0	0	0
Coprosma	1	7	5	16	29
Cyperaceae	75	181	252	335	293
Drosera	0	0	0	0	0
Epacridaceae	3	5	1	1	1
Gleichenia	11	59	35	22	4
Haloragis	0	0	0	1	4
Leptospermum type	28	24	136	65	29
Myriophyllum	0	0	0	0	0
Potamogeton	0	0	0	1	0
Restionaceae	22	24	4	8	5
Typha	0	0	0	0	1
Unknowns	1	0	1	4	0

Depth (m)	**2.25**	**2.35**	**2.45**	**2.55**	**2.65**
Lycopodium spike	118	155	74	18	53
Spike concentration	11300	11300	11300	11300	11300
Total pollen concentration	17	14	15	49	15
Charcoal concentration	0	14	0	2	1
Fuscospora	4	12	1	1	2
Agathis australis	22	13	18	9	13
Dacrycarpus dacrydioides	6	7	75	83	44
Dacrydium cupressinum	45	69	37	32	36
Halocarpus	0	3	0	3	1
Libocedrus	7	6	2	5	6
Manoao colensoi	1	1	0	0	1
Phyllocladus	7	4	3	5	3
Podocarpus type	10	14	5	1	1
Prumnopitys ferruginea	5	9	5	0	3
Prumnopitys taxifolia	9	12	8	1	3
Alectryon excelsus	0	0	0	1	2
Beilschmiedia	0	0	0	0	0
Casuarina	0	0	1	0	0
Dysoxylum spectabile	2	1	0	0	0
Elaeocarpus	3	1	3	3	2
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	0	0	0	0	1
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	27	20	38	38	37
Nestegis	2	7	4	6	4
Nothofagus menziesii	0	0	0	0	0
Quintinia	2	1	2	5	3
Syzygium maire	1	0	5	6	6
Vitex lucens	0	0	0	0	0
Weinmannia	23	6	1	2	2
Ascarina lucida	1	2	1	0	3
Asteraceae	0	0	0	0	0
Carpodetus	0	0	0	0	0
Cordyline	0	3	1	3	1
Coriaria	0	2	0	0	0
Dodonaea viscosa	0	1	0	0	0
Fabaceae	0	0	0	0	0
Fuschia	0	0	0	0	0
Griselinia	4	3	18	20	25
Ixerba brexioides	0	0	0	1	0
Leucopogon fasciculatus	1	1	0	1	0
Malvaceae	0	0	0	0	0
Myrsine	2	2	5	6	8
Neomyrtus type	29	91	73	22	32
Pittosporum	3	1	6	5	4
Plagianthus type	0	0	0	0	0
Pseudopanax	1	2	4	8	4
Pseudowintera	0	0	0	1	0
Rhopalostylis sapida	0	0	1	0	1
Schefflera digitata	0	0	0	0	0
Apiaceae	0	0	0	0	0
Astelia	4	0	2	2	5
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0

Depth (m)	**2.25**	**2.35**	**2.45**	**2.55**	**2.65**
Dactylanthus taylorii	0	0	0	0	0
Freycinetia baueriana	0	2	10	8	10
Hydrocotyle novae-zelandiae	0	0	0	0	0
Ileostylus micranthus	0	0	0	1	0
Liliaceae	1	1	0	0	0
Parsonsia	0	0	0	0	0
Phormium	0	0	0	0	0
Poaceae	0	0	2	0	0
Pteridium esculentum	1	1	0	0	0
Tupeia antarctica	0	0	1	0	0
Adiantum type	0	1	1	0	1
Cyathea dealbata type	6	7	7	6	1
Cyathea smithii type	2	3	0	1	1
Dicksonia fibrosa	0	0	0	0	0
Dicksonia squarrosa	0	1	2	1	1
Hymenophyllum	3	0	0	0	0
Lycopodium cernuum	0	1	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium fastigiatum	0	0	0	0	0
Lycopodium laterale	0	0	0	0	0
Lycopodium varium	0	0	0	0	0
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	341	422	106	53	58
Paesia scaberula	1	0	0	0	0
Phylloglossum drummondii	0	0	0	0	0
Phymatosorus	27	23	18	33	20
Pteris	0	0	0	0	0
Coprosma	11	20	2	3	3
Cyperaceae	237	46	2	1	6
Drosera	0	0	0	0	0
Epacridaceae	1	3	2	8	3
Gleichenia	0	23	0	0	0
Haloragis	28	57	1	0	0
Leptospermum type	11	37	4	1	4
Myriophyllum	0	1	0	0	0
Potamogeton	0	0	0	0	0
Restionaceae	1	11	0	2	1
Typha	0	0	0	0	0
Unknowns	0	0	0	0	0

Depth (m)	**2.75**	**2.85**	**2.95**	**3.05**	**3.15**
Lycopodium spike	15	10	14	13	24
Spike concentration	11300	11300	11300	11300	11300
Total pollen concentration	56	83	54	59	32
Charcoal concentration	1	3	5	1	0
Fuscospora	1	2	1	0	2
Agathis australis	7	4	7	5	5
Dacrycarpus dacrydioides	34	31	39	45	54
Dacrydium cupressinum	60	54	53	44	47
Halocarpus	0	1	0	0	0
Libocedrus	0	4	7	5	4

Depth (m)	**2.75**	**2.85**	**2.95**	**3.05**	**3.15**
Manoao colensoi	1	1	0	0	1
Phyllocladus	5	4	5	3	3
Podocarpus type	4	10	6	7	3
Prumnopitys ferruginea	4	5	2	1	1
Prumnopitys taxifolia	4	4	4	2	2
Alectryon excelsus	0	0	0	0	0
Beilschmiedia	0	0	0	0	0
Casuarina	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	2	2	2	1	3
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	2	0	1	0	1
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	64	42	44	36	39
Nestegis	1	3	4	11	7
Nothofagus menziesii	0	0	0	0	0
Quintinia	7	9	9	2	7
Syzygium maire	5	4	1	2	3
Vitex lucens	0	0	0	1	0
Weinmannia	2	1	1	1	0
Ascarina lucida	5	4	10	7	1
Asteraceae	0	0	0	0	0
Carpodetus	0	0	0	0	0
Cordyline	1	0	0	2	0
Coriaria	0	0	2	0	0
Dodonaea viscosa	1	0	0	0	0
Fabaceae	0	0	0	0	0
Fuschia	0	0	0	0	0
Griselinia	13	24	10	15	19
Ixerba brexioides	0	0	1	0	0
Leucopogon fasciculatus	0	0	0	1	0
Malvaceae	0	0	0	0	0
Myrsine	6	6	4	7	10
Neomyrtus type	21	11	9	10	10
Pittosporum	2	4	7	8	8
Plagianthus type	0	0	0	0	0
Pseudopanax	8	14	7	7	6
Pseudowintera	0	0	1	0	0
Rhopalostylis sapida	1	2	4	1	0
Schefflera digitata	0	0	0	0	1
Apiaceae	0	0	0	0	0
Astelia	3	0	1	2	2
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Dactylanthus taylorii	1	0	0	0	0
Freycinetia baueriana	2	5	6	16	15
Hydrocotyle novae-zelandiae	0	0	0	0	0
Ileostylus micranthus	0	0	1	1	3
Liliaceae	0	0	0	0	1
Parsonsia	0	0	0	0	0
Phormium	0	1	0	0	0
Poaceae	4	0	0	0	0
Pteridium esculentum	0	0	0	0	0
Tupeia antarctica	0	0	0	0	0

Depth (m)	**2.75**	**2.85**	**2.95**	**3.05**	**3.15**
Adiantum type	0	0	0	0	0
Cyathea dealbata type	6	7	5	4	2
Cyathea smithii type	1	2	3	0	2
Dicksonia fibrosa	0	0	0	1	0
Dicksonia squarrosa	1	0	0	0	0
Hymenophyllum	3	1	0	3	2
Lycopodium cernuum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium fastigiatum	0	0	1	0	0
Lycopodium laterale	0	0	0	0	0
Lycopodium varium	0	1	0	0	1
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	56	68	43	53	54
Paesia scaberula	0	0	0	0	0
Phylloglossum drummondii	0	0	0	0	0
Phymatosorus	24	25	20	20	16
Pteris	0	0	0	0	0
Coprosma	1	5	1	1	2
Cyperaceae	0	3	1	0	0
Drosera	0	0	0	0	0
Epacridaceae	1	2	1	6	3
Gleichenia	2	1	3	0	1
Haloragis	0	0	0	0	0
Leptospermum type	2	0	0	2	1
Myriophyllum	2	0	0	0	0
Potamogeton	1	1	2	0	0
Restionaceae	0	0	0	3	1
Typha	0	0	0	0	0
Unknowns	0	0	3	5	0

Depth (m)	**3.25**	**3.35**	**3.45**	**3.55**	**3.65**
Lycopodium spike	45	25	36	57	176
Spike concentration	11300	11300	11300	11300	11300
Total pollen concentration	21	32	23	17	5
Charcoal concentration	2	2	1	4	2
Fuscospora	0	1	1	1	3
Agathis australis	4	5	8	5	9
Dacrycarpus dacrydioides	58	63	11	19	37
Dacrydium cupressinum	78	77	95	94	60
Halocarpus	4	1	1	2	2
Libocedrus	4	1	8	6	3
Manoao colensoi	2	3	2	5	1
Phyllocladus	7	10	8	4	10
Podocarpus type	9	8	12	19	7
Prumnopitys ferruginea	3	3	7	10	4
Prumnopitys taxifolia	10	13	12	14	9
Alectryon excelsus	0	0	0	0	0
Beilschmiedia	0	0	0	0	0
Casuarina	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	3	3	3	2

Depth (m)	**3.25**	**3.35**	**3.45**	**3.55**	**3.65**
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	4	1	0	1	0
Laurelia novae-zelandiae	0	0	1	0	0
Metrosideros undiff.	18	12	26	38	48
Nestegis	12	8	5	2	9
Nothofagus menziesii	0	0	0	0	0
Quintinia	2	6	5	1	6
Syzygium maire	2	0	1	3	1
Vitex lucens	0	0	1	0	0
Weinmannia	0	0	0	0	4
Ascarina lucida	13	12	10	8	4
Asteraceae	0	0	0	0	0
Carpodetus	0	0	0	0	0
Cordyline	0	2	1	2	0
Coriaria	0	0	0	0	0
Dodonaea viscosa	0	0	0	0	1
Fabaceae	0	0	0	1	0
Fuschia	0	0	0	0	0
Griselinia	9	10	13	5	4
Ixerba brexioides	0	0	0	0	0
Leucopogon fasciculatus	0	0	1	1	0
Malvaceae	0	0	0	0	0
Myrsine	1	4	4	6	7
Neomyrtus type	8	5	4	14	27
Pittosporum	2	3	0	3	3
Plagianthus type	0	0	0	0	0
Pseudopanax	1	5	4	2	1
Pseudowintera	1	0	1	0	1
Rhopalostylis sapida	0	0	0	0	0
Schefflera digitata	0	0	0	3	0
Apiaceae	0	0	0	0	0
Astelia	7	0	0	1	2
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Dactylanthus taylorii	0	0	0	0	0
Freycinetia baueriana	4	4	2	5	5
Hydrocotyle novae-zelandiae	0	0	1	1	0
Ileostylus micranthus	0	0	1	1	0
Liliaceae	0	0	0	0	0
Parsonsia	1	0	0	0	0
Phormium	2	1	3	1	2
Poaceae	1	0	0	0	0
Pteridium esculentum	2	1	0	0	0
Tupeia antarctica	0	0	0	0	0
Adiantum type	0	0	1	1	1
Cyathea dealbata type	1	5	9	4	5
Cyathea smithii type	3	1	3	0	2
Dicksonia fibrosa	0	0	0	0	0
Dicksonia squarrosa	0	0	0	0	1
Hymenophyllum	0	0	0	0	0
Lycopodium cernuum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium fastigiatum	1	0	0	1	0
Lycopodium laterale	0	0	0	0	0

Depth (m)	**3.25**	**3.35**	**3.45**	**3.55**	**3.65**
Lycopodium varium	4	1	2	1	2
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	74	46	42	41	35
Paesia scaberula	0	0	0	0	0
Phylloglossum drummondii	1	0	0	0	0
Phymatosorus	57	25	19	18	20
Pteris	0	0	0	0	0
Coprosma	1	3	2	7	11
Cyperaceae	0	0	5	23	29
Drosera	0	0	0	0	0
Epacridaceae	1	2	5	0	5
Gleichenia	7	4	26	40	9
Haloragis	0	0	0	1	0
Leptospermum type	0	1	3	10	22
Myriophyllum	0	0	0	0	0
Potamogeton	1	0	0	1	1
Restionaceae	0	1	3	4	5
Typha	0	0	0	0	0
Unknowns	0	0	0	0	4

Depth (m)	**3.75**	**3.85**	**3.95**	**4.05**	**4.15**
Lycopodium spike	31	23	39	14	24
Spike concentration	11300	11300	11300	11300	11300
Total pollen concentration	31	29	25	59	38
Charcoal concentration	0	2	2	1	8
Fuscospora	2	0	0	0	0
Agathis australis	5	3	3	3	4
Dacrycarpus dacrydioides	28	37	45	19	17
Dacrydium cupressinum	91	117	202	172	210
Halocarpus	0	3	5	2	2
Libocedrus	3	5	4	5	3
Manoao colensoi	5	2	4	2	3
Phyllocladus	10	9	7	4	10
Podocarpus type	11	7	13	4	10
Prumnopitys ferruginea	13	10	10	13	8
Prumnopitys taxifolia	14	9	12	6	10
Alectryon excelsus	0	0	0	0	0
Beilschmiedia	0	0	0	0	0
Casuarina	0	0	0	0	0
Dysoxylum spectabile	0	0	0	0	0
Elaeocarpus	0	0	0	1	0
Hedycarya arborea	0	0	0	0	0
Knightia excelsa	2	2	3	3	4
Laurelia novae-zelandiae	0	0	0	0	0
Metrosideros undiff.	25	18	19	17	25
Nestegis	9	2	4	2	2
Nothofagus menziesii	0	0	0	1	0
Quintinia	1	0	0	0	2
Syzygium maire	0	2	0	0	0
Vitex lucens	0	0	0	0	0
Weinmannia	3	4	3	2	1

Depth (m)	**3.75**	**3.85**	**3.95**	**4.05**	**4.15**
Ascarina lucida	0	0	0	0	1
Asteraceae	0	0	0	0	0
Carpodetus	0	0	0	0	0
Cordyline	1	0	0	0	0
Coriaria	0	0	0	0	0
Dodonaea viscosa	0	0	0	0	1
Fabaceae	0	0	0	0	0
Fuschia	0	0	0	0	0
Griselinia	3	0	0	2	0
Ixerba brexioides	0	0	0	0	0
Leucopogon fasciculatus	6	3	1	1	4
Malvaceae	0	0	0	0	0
Myrsine	2	2	1	0	0
Neomyrtus type	26	18	6	1	3
Pittosporum	5	0	3	5	1
Plagianthus type	0	0	2	0	0
Pseudopanax	1	0	0	1	0
Pseudowintera	2	3	8	16	11
Rhopalostylis sapida	0	0	0	0	0
Schefflera digitata	0	0	0	0	0
Apiaceae	0	0	0	0	0
Astelia	3	2	3	4	2
Caryophyllaceae	0	0	0	0	0
Chenopodiaceae	0	0	0	0	0
Dactylanthus taylorii	0	0	0	0	0
Freycinetia baueriana	1	0	1	1	0
Hydrocotyle novae-zelandiae	0	0	0	0	0
Ileostylus micranthus	0	0	0	0	0
Liliaceae	0	0	0	0	0
Parsonsia	0	0	0	0	0
Phormium	0	1	1	0	1
Poaceae	1	0	0	0	1
Pteridium esculentum	0	0	0	0	1
Tupeia antarctica	0	1	2	5	3
Adiantum type	2	0	1	1	1
Cyathea dealbata type	1	1	6	8	8
Cyathea smithii type	2	0	1	0	3
Dicksonia fibrosa	0	0	0	0	0
Dicksonia squarrosa	0	1	1	4	2
Hymenophyllum	1	1	0	1	1
Lycopodium cernuum	0	0	0	0	0
Lycopodium deuterodensum	0	0	0	0	0
Lycopodium fastigiatum	0	0	2	0	1
Lycopodium laterale	0	0	0	0	0
Lycopodium varium	1	0	0	0	2
Lygodium articulatum	0	0	0	0	0
Monolete fern spores	7	14	24	38	27
Paesia scaberula	0	0	0	0	0
Phylloglossum drummondii	0	0	0	0	0
Phymatosorus	2	1	7	5	5
Pteris	0	0	0	0	0
Coprosma	34	11	21	17	10
Cyperaceae	7	3	0	0	1
Drosera	0	0	0	0	0

Depth (m)	**3.75**	**3.85**	**3.95**	**4.05**	**4.15**
Epacridaceae	1	0	0	0	0
Gleichenia	48	0	0	0	0
Haloragis	1	1	0	0	0
Leptospermum type	39	6	3	2	0
Myriophyllum	0	0	2	0	0
Potamogeton	0	0	1	0	0
Restionaceae	1	0	1	0	0
Typha	0	0	0	0	0
Unknowns	0	0	0	0	0

Depth (m)	**4.25**	**4.35**	**4.45**
Lycopodium spike	29	18	34
Spike concentration	11300	11300	11300
Total pollen concentration	38	53	29
Charcoal concentration	2	2	0
Fuscospora	0	1	0
Agathis australis	6	3	3
Dacrycarpus dacrydioides	23	11	13
Dacrydium cupressinum	266	186	201
Halocarpus	0	2	0
Libocedrus	8	7	4
Manoao colensoi	2	1	2
Phyllocladus	7	3	3
Podocarpus type	10	14	9
Prumnopitys ferruginea	4	5	5
Prumnopitys taxifolia	4	5	11
Alectryon excelsus	0	0	0
Beilschmiedia	0	0	0
Casuarina	0	0	0
Dysoxylum spectabile	0	0	0
Elaeocarpus	0	1	1
Hedycarya arborea	1	0	1
Knightia excelsa	7	7	7
Laurelia novae-zelandiae	0	0	0
Metrosideros undiff.	35	32	24
Nestegis	5	2	9
Nothofagus menziesii	0	0	0
Quintinia	1	2	2
Syzygium maire	1	3	0
Vitex lucens	0	0	0
Weinmannia	2	3	1
Ascarina lucida	1	0	1
Asteraceae	0	0	0
Carpodetus	0	0	0
Cordyline	0	2	1
Coriaria	0	0	0
Dodonaea viscosa	0	0	1
Fabaceae	0	0	1
Fuschia	0	0	0
Griselinia	1	4	0
Ixerba brexioides	0	1	0

Depth (m)	**4.25**	**4.35**	**4.45**
Leucopogon fasciculatus	0	1	3
Malvaceae	0	0	0
Myrsine	0	0	0
Neomyrtus type	2	27	24
Pittosporum	3	4	6
Plagianthus type	0	0	0
Pseudopanax	0	0	0
Pseudowintera	8	6	5
Rhopalostylis sapida	0	0	0
Schefflera digitata	0	0	0
Apiaceae	0	0	0
Astelia	2	10	7
Caryophyllaceae	0	0	0
Chenopodiaceae	0	0	0
Dactylanthus taylorii	1	0	0
Freycinetia baueriana	1	1	0
Hydrocotyle novae-zelandiae	0	0	0
Ileostylus micranthus	0	0	0
Liliaceae	0	4	1
Parsonsia	0	0	0
Phormium	0	0	0
Poaceae	5	4	2
Pteridium esculentum	2	0	2
Tupeia antarctica	1	3	2
Adiantum type	2	2	3
Cyathea dealbata type	11	10	9
Cyathea smithii type	0	1	0
Dicksonia fibrosa	0	0	0
Dicksonia squarrosa	0	1	0
Hymenophyllum	1	0	1
Lycopodium cemuum	0	0	0
Lycopodium deuterodensum	0	0	0
Lycopodium fastigiatum	1	1	1
Lycopodium laterale	0	0	0
Lycopodium varium	1	1	0
Lygodium articulatum	0	0	0
Monolete fern spores	42	23	31
Paesia scaberula .	0	0	0
Phylloglossum drummondii	0	0	0
Phymatosorus	4	0	4
Pteris	0	0	0
Coprosma	17	18	16
Cyperaceae	0	1	3
Drosera	0	0	0
Epacridaceae	0	1	0
Gleichenia	1	1	0
Haloragis	0	0	0
Leptospermum type	0	7	4
Myriophyllum	0	0	0
Potamogeton	0	0	1
Restionaceae	1	0	0
Typha	0	0	0
Unknowns	0	3	4

The end.